REGULATORY OBSERVATION Resolution Plan	
RO Unique No.:	RO-UKHPR1000-0026
RO Title:	Demonstration that radioactivity has been reduced So Far As Is Reasonably Practicable (SFAIRP)
Technical Area(s)	Reactor Chemistry
Revision:	1
Overall RO Closure Date (Planned):	2021-06-30
Linked RQ(s)	RQ-UKHPR1000-0390
Linked RO(s)	RO-UKHPR1000-0015
Related Technical Area(s)	
Other Related Documentation	
Scope of Work	

Background

The radionuclides and associated radioactivity levels present in a Pressurised Water Reactor (PWR), notably in the primary circuit and other systems connected to it, are important contributors to Operator Radiation Exposure (ORE), routine radioactive wastes production, impacts on the environment and the public and act as a potential source term during accident scenarios. The designers and the operator of a PWR can influence the concentrations and behaviour of radionuclides by the choices made during plant design and operations, e.g. by appropriate material selection, by exercising adequate controls, by optimising the operating chemistry or by minimising impurity levels.

For the Generic Design Assessment (GDA) of UK HPR1000, the Requesting Party (RP) has recognised the importance of preventing, minimising and controlling radioactivity levels on nuclear safety and environment protection, and provided claims, arguments and evidence across multiple topics to this effect. Technical submissions made throughout the past GDA steps and planned to be made in Step 4 support this approach. A number of topic reports related to Source Term, Reactor Chemistry, Mechanical Engineer, Fuel and Core, Radwaste Management, etc., that cover various aspects of radioactivity levels prevention, minimisation, unavoidable production and control/management, recognise the need to justify that radioactivity levels have been reduced So Far As Is Reasonably Practicable (SFAIRP) throughout the plant. Among these documents, ONR has continued to receive and assess the RP's suite of supporting documentation, including that which defines and justifies the radiological source term(s) for UK HPR1000.

However, to date, it has not been made fully clear what the comprehensive set of evidence is that the RP will provide to support the claims and arguments relevant to reduction of radioactivity levels SFAIRP. While the RP plans to address this gap in future documentation, the scope of what is proposed or the timescales for doing so remain to be clarified and confirmed. Similarly, it has not been made clear how the safety case will be integrated to ensure that a holistic justification is provided in terms of demonstrating that radioactivity levels have been reduced SFAIRP, including how radioactivity is generated and transported in UK HPR1000 and information on the nature and quantity of all radiochemical species.

ONR have already raised RO-UKHPR1000-0015, Demonstration that Risks Associated with Fuel Deposits are Reduced so far as is Reasonably Practicable (SFAIRP), Reference [1], which is closely related to this RO but deals exclusively with the safety impacts of fuel deposits which can be wider than the generation of radionuclides*.*

This Regulatory Observation (RO) has therefore been raised to:

- *Explain ONR's regulatory expectations;*
- *Ensure the RP provides a suitable safety case for the risks presented by the radioactivity expected to be present in the primary circuit and other connected systems of the UK HPR1000;*
- *Obtain confidence that adequate evidence will be provided by the RP to support the claims and arguments made in the UK HPR1000 generic safety case; and*
- *Assist ONR's judgement of whether a robust demonstration that radioactivity* levels *within UK HPR1000 will be reduced SFAIRP.*

Regulatory Expectations

Overall, ONR expect the claims and arguments presented in the PCSR and supporting references to be adequately substantiated by suitable and sufficient evidence. ONR would therefore expect the safety case for UK HPR1000 to:

- *Quantify (estimate) and characterise (i.e. chemical/physical characteristics) of all radioactive species present in the primary circuit and other connected systems of the UKHPR1000, during normal operational states.*
- *Adequately justify the estimates for* relevant radionuclides *in UK HPR1000. The information provided should include a suitable amount of robust supporting evidence and be demonstrated to be appropriate for the UK HPR1000 design and consistent with the extant generic safety case.*
- *Substantiate the systems, controls and measures that will be used to minimise and remove the radionuclides identified, including identifying appropriate limits and conditions necessary in the interests of safety.*
- *Demonstrate that all reasonably practicable measures have been taken to reduce radioactivity* levels *in UK HPR1000 SFAIRP.*
- Provide an adequate quantitative estimate, via calculation or other equivalent and suitable means, of

the inventory and associated activities of corrosion products expected to be generated and transported in the primary circuit of the UK HPR1000. The estimate should take account of all relevant plant specific design features and anticipated operations. The estimate should cover all phases of normal, at power operations, from start-up to shutdown.

- Estimate the quantities of activated corrosion products present in all relevant systems connected to the primary circuit, including the:
  - o Spent Fuel Pool;
  - o Chemical and Volume Control System (CVCS); and
  - o In-containment Reactor Water Storage Tank (IRWST).
- Compare and contrast the quantitative estimate with the extant source term derived for activated corrosion products in the primary circuit and all relevant systems for UK HPR1000.

Therefore in responding to this RO, ONR expects the RP to:

- *Demonstrate how the safety case will cover those aspects described above;*
- *Provide an explicit demonstration that radioactivity* levels *in UK HPR1000 will be reduced SFAIRP;*
- *Identify any associated controls, limits and conditions necessary to ensure this is achieved; and*
- *Substantiate that the plant design and engineering is adequate to reduce radioactivity* levels *SFAIRP.*

Scope of work

The present resolution plan describes the current plan to address this RO. It contains the strategy, the planned activities, deliverables, milestones and timescales.

The proposed scope of work will cover prevention/minimisation and control/management of radionuclide generation and transport throughout the plant and of radioactivity levels so as to notably prevent/minimise/manage operator radiation exposure, routine waste generation and impacts on the environment and the public. The approach taken for UK HPR1000 is to prevent/minimise/optimise generation, transport and accumulation of radionuclides and radioactivity levels throughout the plant and over its lifetime, focussing on (but is not limited to) the following aspects:

- optimising the chemistry regime and SSCs design,
- minimising and controlling impurities,
- making appropriate materials choices,
- optimising operating practices.

The response to this RO is focussed on outlining the work that has already been started and/or completed, as well as the planned work that will be undertaken in Step 4 to demonstrate that radionuclides and radioactivity levels present in the UK HPR1000 have been minimised SFAIRP. Reports related to radioactivity levels minimisation from all relevant technical areas/disciplines, such as Source Term, Reactor Chemistry, Mechanical Engineering, Fuel and Core, Radwaste Management will be integrated.

The work to be undertaken as part of this resolution plan focusses on bringing together the information that supports the minimisation of radionuclides generation and radioactivity levels SFAIRP, so that the case can be clearly overviewed and understood. This information provides demonstration that the UK HPR1000 design and operation have been and are being developed to ensure that radionuclides generation and transport and radioactivity levels in the UK HPR1000 have been minimised SFAIRP. Part of the information has already been submitted during Steps 2 and 3, some of which will be updated to reflect progress made since then. Additional information is also planned to be submitted during Step 4 to complement the current case. Gaps may be identified as the work progresses in the related technical areas and will be managed and closed where relevant as part of the resolution of this RO, in accordance with the project procedures.

Deliverable Description

RO-UKHPR1000-0026.A1 – Produce a safety case route map for radioactivity in the UK HPR1000 design

In response to this Action the RP should:

- *Provide a route map which identifies where information relating to the production, quantities, characterisation, distribution, behaviour and removal or clean-up of radioactivity in the UK HPR1000 safety case is documented.*
- *ONR expect this route map to explain how the safety case meets the regulatory expecations described in this RO, and any other matters considered relevent by the RP.*
- *The response should explain how the different technical topics interface and where the linkages, and differences may exist. In particular the on-going work in relation to defining the "source terms" for UK HPR1000 and resolving RO-UKHPR1000-0015 need to be considered in the response.*
- *The response should explain how and where any specific aspects of the UK HPR1000 design and operations which can impact on radioactivity are justified in the safety case, including:*
    - *The use of enriched boric acid and associated recycling*
    - *The design of the primary circuit hydrogen dosing system*
    - *The use of inerting applied to tanks and ullages*
    - *The operating chemistry regime, including the approach to start-up and shutdown chemistry*
    - *Material choices and treatments*
    - *The use of secondary neutron sources*
    - *Fuel cleanliness criteria*
    - *The dosing and clean-up systems and process*
- *Demonstrate that claims and arguments in the generic safety case are consistent between technical topics and with the underlying supporting evidence.*
- *Where in producing this route map the RP identifies gaps in the information presented as part of the safety case, additional information should be identified and a plan and timescales for its production and submission to ONR presented.*

RO-UKHPR1000-0026.A2 – Demonstrate that radioactivity in UK HPR1000 has been reduced SFAIRP

The overall intent for this Action is that the RP should identify the relevent nuclear safety risks associated with radioactivity in UK HPR1000 and provide a suitable and sufficient justification that they have been reduced so far as is reasonably practicable (SFAIRP).

In response to this Action the RP should:

- *Identify the range of measures in place which eliminate, reduce and/or control the generation and accumulation of radiochemical species for UK HPR1000. An appropriate balance needs to be achieved and demonstrated. Information provided in response to this ROA should therefore include:*
  - *Evidence that operating practices which are necessary, expected, or can be applied for UK HPR1000 have been optimised in terms of reducing the generation and accumulation of radioactivity SFAIRP.*
  - *Evidence that the primary circuit operating chemistry for UK HPR1000 has been optimised to reduce the generation and accumulation of radioactivity SFAIRP.*
  - *Evidence those key materials choices and their surface treatments; have been considered from the perspective of reducing the generation and accumulation of radioactivity SFAIRP.*
- *Identify operational parameters and/or controls that may signifcantly impact the generation, transport and accumulation of radiochemical species in UK HPR1000 and explain the sensitivity to these.*
- *ONR recognise that some of the evidence and justification requested under this Action may exist in other parts of the generic safety case; in those instances the RP should clearly indicate this, including demonstrating its applicability to this Action, in particular the demonstration that it reduces risks SFAIRP.*

RO-UKHPR1000-0026.A3 – Demonstrate that the UK HPR1000 design is capable of minimising radioactivity in the primary circuit and connected systems

In response to this Action the RP should:

- *Based on the response to A2, provide sufficient supporting evidence to demonstrate that the clean-up systems present in the UK HPR1000 have adequate capacity and capability to manage the levels of radioactivity predicted to be present in the plant.*
- *Identify the underpinning asumptions regarding the clean-up efficiencies of UK HPR1000 systems which are claimed to reduce, minimise, or eliminate radiochemical species, including a proportionate justifcation for these.*
- *The response should consider all operational states, as appropriate.*
- *The response should consider the primary circuit of UK HPR1000, but also other connected systems where radioactivity may be present, including:*
  - *CVCS and boron recycle equipment*
  - *Spent fuel pool*
  - *In-containment reactor water storage tank*
  - *Residual heat removal system*

– *ONR recognise that some of the evidence and justification requested under this Action may exist in other parts of the generic safety case; in those instances the RP should clearly indicate this, including demonstrating its applicability to this Action.*

Resolution Plan for ROA1, ROA2 and ROA3

– **Scope**

The scope associated with radionuclide generation and transport and ensuring that radioactivity levels have been minimised SFAIRP is wide-ranging. It requires consideration of several aspects, including:

- the plant lifecycle
  The design, construction, commissioning, operation and decommissioning of the plant need to be considered when assessing how to prevent/minimise radionuclide generation and transport, and associated radioactivity levels;
- the operating states of the plant
  All operating states should be considered, including maintenance and testing periods;
- the related technical areas, including Fuel and Core, Mechanical Engineering, Radiological Protection, Radioactive Waste, Decommissioning and Spent Fuel Management, Structural Integrity, Environment and Reactor Chemistry, and how they interface and are integrated with respect to preventing/minimising radionuclide generation and transport, and associated radioactivity levels;
- the key SSCs
  All SSCs that come into contact with primary coolant or that are susceptible to be activated need to be considered in addition to those that may become contaminated, including through leakage. The key ones (including the RCP [RCS] and auxiliary and waste management systems, RPV, SGs, PZR, Reactor Coolant Pumps, tanks, valves, filters, heat exchangers, demineralisers) need to be considered proportionately to their relevance and impact on radionuclide generation and transport and on radioactivity levels, in terms of how they are designed and operated.

– **Methodology to develop the case**

Each of the above mentioned aspects have been considered in developing the case. The key steps in the methodology applied when developing the case for the UK HPR1000 are summarised as follows and together, comprehensively respond to **ROA2** and **ROA3**:

1. identify the sources of radionuclides, the key radionuclides of interest and the main influencing factors;
2. identify the transport mechanisms and the main SSCs and factors influencing those;
3. quantify (estimate) and characterise (i.e. chemical/physical characteristics) all relevant radioactive species (i.e. determine the source terms);
4. identify the measures that ensure radionuclides generation and transport and radioactivity levels are prevented/minimised/optimised/managed/controlled from source to disposal,
5. demonstrate all relevant measures have been considered and implemented for the UK HPR1000, with due consideration for proportionality. Propose and implement modifications, if necessary;

6. summarise information from Steps 4 and 5 into the ALARP / BAT demonstration in relevant areas, notably Radiological Protection, Radwaste management and Environment;
7. update as relevant the source term (i.e. if any change is made that influences the source term) and, if the source term is changed, reiterate the process from Steps 4 and/or 5.

These steps are detailed below.

- Step1: Identification of the sources of radionuclides, the key radionuclides of interest and main influencing factors

Before measures are taken to reduce radionuclide generation and transport, and associated radioactivity levels, the sources of radionuclides and the key radionuclides need to be identified together with the main influencing factors.

During power operation, nuclear reactions (i.e. fission and activation) occur in the reactor core and the surrounding area. Therefore, all the SSCs as well as primary coolant in the core area may become the source of radionuclides, these sources may include:

- Fuel: fuel, tramp uranium, cladding material constituents;
- Primary Coolant: water constituents, including impurities and chemical additions;
- Non-fuel core components: control rods, secondary neutron sources, etc.;
- Primary circuit: material constituents;
- Air surrounding the core area.

These sources will generate different radionuclides, which are grouped according to their production mechanisms, i.e. Corrosion products (CP), Fission products (FP), Actinides (ActP) and Activation Products (AP).

The key radionuclides of each group need to be further identified together with the major factors which affect the reduction/prevention of their production and the radioactivity levels. A number of criteria should be considered during the selection process of the key radionuclides, e.g. UK HPR1000 characteristics (design, chemistry, material, etc.), information from representative and adequate OPEX, and the radionuclides characteristics (decay mode, half-lives, the energy strength of the emitting ray, DCFs, etc.).

Among the criteria mentioned above, some cannot be changed or influenced (e.g. radionuclide characteristics), while others can be influenced through design and/or operating decisions. These design and operating parameters represent the factors that can influence the reduction/prevention of radionuclide generation and radioactivity levels.

More information, including the selection criteria, the selection methodology, the final list of radionuclides as well as the main influencing factors, can be found in the *Report of Radionuclide Selection during Normal Operation*, which constitutes one of the source term documents that will be included in the document map that will be produced in response to **ROA1** (discussed in more detail later in this resolution plan).

- Step 2: Identification of the radionuclides transport mechanisms and the main SSCs and factors influencing those

Once in the primary coolant, radionuclides will be transported from the primary circuit to the various connected systems, mainly as a result of:

a) Water movements needed to notably adjust primary coolant chemistry / radiochemistry or for shutdown needs. The RCP[RCS], RIS/RA [RHRS], RCV [CVCS], TEP [CSTS], REA [RBWMS], PTR [FPCTS], TEG [GWTS] and other relevant systems are involved in such movements.

b) Unavoidable leaks or drainage. The RPE [VDS], SRE [SRS], TEU [LWTS], APG [SGBS], HVAC, TES [SWTS] and other relevant systems are involved in the management of with such leaks/drainage.

Finally, a small proportion will be discharged into the environment and a greater part will be disposed of to relevant waste infrastructures.

In terms of transport inside the components of these systems, radionuclides can be:

a) Present in the fluid (gas/steam phase and/or liquid phase) passing through or stored in the various components of the systems;

b) Trapped in the accumulation units of the systems;

c) Deposited on the inner surface of the components of the systems.

With the understanding of the radionuclides' whole-cycle transport path, the SSCs and factors that significantly influence the behaviour and the distribution of the radionuclides can be identified.

For example,

- In order to reduce the quantity of radionuclides in the fluid (so as to reduce the discharges to the environment), type and efficiency of the purification units, e.g. filters or demineralisers, are considered as two influencing factors related to the radioactivity levels in the fluid and in the accumulation units;
- In terms of deposition (in order to reduce the ORE) design measures and/or manufacturing and/or layout will influence the deposits quantity.

More information about the radionuclides transport mechanisms, the identification of factors influencing radionuclides transport and distribution and radioactivity levels as well as the estimation of the source term in the radioactive systems are described in the *Normal Operation Source Term General Report* and *Derived Source Term Supporting Report,* which constitute two of the source term documents that will be included in the document map that will be produced in response to **ROA1** (discussed in more detail later in this resolution plan).

- Step 3: Quantification (estimate) and characterisation (i.e. chemical/physical characteristics) of all relevant radioactive species

a) The following process has been carried out:

- Establish the source term strategy (i.e. identification of radioactivity, scope and categories of source term, establish source term documents map, inputs & assumptions consideration, methodologies, justifications) to guide the whole-cycle development of source term,
- Identify the users of the source term for the UK HPR1000 safety and environment case,
- Based on the understanding of the source term users, determine the scope of the source term:
  - All physical and chemical forms of radionuclides (including FP, CP, AP, ActP);
  - Radionuclides from generation, transport to discharges/disposal
  - On-site (All main radioactive systems) and off-site (environment)
  - Covering all the operating mode (Steady-state, transient, shutdown, Outage)
  - Operation and decommissioning
- Define the source terms:

  Seven source terms for normal operation have been defined:
  - Primary Coolant Source Term;
  - Secondary Coolant Source Term;
  - Derived Source Term;
  - Airborne Activity;
  - Gaseous and Liquid Discharges;
  - Spent Fuel Assembly Source Term;
  - Activated Structures Source Term.
- Establish the source term documents map,
- Quantify/estimate all the identified source terms based on recognised methods (i.e. OPEX based, Theoretical, Combined)
- Justify the methodologies, inputs & assumptions and the source term values.

b) The documents associated with this step are as follows:

- Source term strategy, as well as general reports, are established to guide the source terms estimation/quantification task:
  - Normal Operation Source Term Strategy Report
  - Report of Radionuclide Selection during Normal Operation
  - Normal Operation Source Term General Report
- Reports associated with the various source terms constitute the main contents of the source term documentation. These reports provide the whole development process of each of the seven source terms, including methodologies, inputs and assumptions, the source term values and all relevant justifications. They also present information on the influencing factors (which

are part of the inputs or assumptions).

- Source term technical user reports are also produced to guide the source term application for the following areas:
  - Radiological Protection;
  - Environmental Discharges and Dose Impact Assessment;
  - Decommissioning;
  - Radioactive Waste and Spent Fuel Management

The source term documents described above will be included in the document map that will be produced in response to **ROA1** (discussed in more detail later in this resolution plan).

- Step 4: Measures that contribute to ensuring radionuclide generation and transport and radioactivity levels are prevented/minimised/optimised/managed/controlled from source to disposal
- Step 5: Demonstrate all relevant measures have been considered and implemented for the UK HPR1000, with due consideration for proportionality. Propose and implement modifications, if necessary

As part of the response to **ROA2** and **ROA3**, the following work will be done through these two steps, generally carried out together.

Based on the information stated in the 3 previous steps, the UK HPR1000 measures for preventing/minimising/optimising/managing/controlling radionuclides generation and transport and radioactivity levels can be identified.

All the key SSCs and factors that will be identified as contributing to the prevention/minimisation/optimisation/management/control of radionuclides production and transport and of radioactivity levels from source to disposal, need to be analysed and demonstrated that they have been optimised or be optimised if not already (i.e. if gaps are identified), as relevant. In some cases, the optimisation will be the result of a balance between conflicting factors as the optimisation needs to consider prevention or minimisation of the radiation exposure of workers, radioactive waste generation and impacts on the environment and the public.

A number of procedures and processes set out how an activity is to be undertaken during GDA. These are mandatory and are part of the overall strategy and project arrangements for GDA. The most relevant ones for demonstrating that radionuclide generation and transport, and associated radioactivity levels have been minimised SFAIRP, are the following ones, which are followed consistently in all technical areas for UK HPR1000 design and safety case development:

- UK HPR1000 Safety Case Development Manual (HPR-GDA-REPO-0110), Reference [2].
- ALARP Methodology (GHX00100051DOZJ03GN), Reference [3].
- ALARP Demonstration Instruction (GHX00100119DOZJ03GN), Reference [4].

- BAT Methodology (GHX00100055DOHB03GN) and BAT Application Work Instruction for GDA Project (GH-30E-010), Reference [5] and [6].
- Optioneering procedure - Provisions on Optioneering process for UK HPR1000 Generic Design Assessment (GDA) Project (GH-40M-018), Reference [7].
- Decision-making procedure - Provisions on Technical Decision-making Systems for UK HPR1000 Generic Design Assessment (GDA) Project (GH-40M-007), Reference [8].
- Modifications related procedures.

Through the process described above, integration and an overall balanced design are expected to be achieved.
Examples of the work carried out up to now are provided below:

– For the prevention/minimisation of generation at source

In Steps 1 to 3, the sources of radionuclides are identified for the four categories of radionuclides and the source terms have been determined based on the design information.

In order to find out all the key measures that can prevent/minimise the radionuclides generation effectively, factors identified are analysed category by category (FP, CP, AP, ActP), with due consideration to the source term values (proportionally).

Based on work carried out up to now, the measures to minimise/prevent the generation of radionuclides and reduce radioactivity levels fall under Fuel and Core, Reactor Chemistry, Structural Integrity and Mechanical Engineering areas and are developed, analysed and optimised as part of the overall work undertaken within the relevant area, in an integrated manner within the area itself (considering all relevant requirements from the area) and between related areas (considering requirements from other areas as relevant).

For FP for example, measures identified and analysed for existing and potential further optimisation are as follows:

- For Fuel and Core, fuel design (notably material selection and anti-debris device design) and manufacture (e.g. tight fuel cleanliness limits to limit tramp uranium) are required to be optimised as much as possible to minimise fuel failure, as well as to minimise fissionable material contamination on the surface of the fuel cladding. Fuel management (e.g. core dimension, fuel type, fuel distribution and cycle length, fuel failure detection) is also required to be optimised to get the right balance between the radioactivity inventory and the other factors (e.g. safety and costs);
- For Reactor Chemistry, chemistry regime will influence the integrity of fuel cladding (and therefore FP generation) and therefore need to be optimised to ensure fuel integrity and at the same time fulfil other requirements such as prevention/minimisation of AP and CP generation, reactivity control, etc.;
- For Structural Integrity, there are no measures that have been identified as influencing effectively FPs production;

- For Mechanical Engineering, process parameters, e.g. the flow rate or temperature of primary coolant, can affect fuel failure, but they are not considered as key factors (for normal operation) and therefore not analysed as part of the radionuclides production prevention/minimisation.

– For the prevention/minimisation/optimisation of radionuclides transport

Based on Step 2 outcomes, four main aspects are identified for radionuclides transport and behaviour throughout the plant:

- Deposition on the inner surface of components and pipes;
- Accumulation on purification/treatment units;
- Fluid stream according to the established process/routes;
- Leakage.

Measures are identified for each aspect and analysed for existing and potential further optimisation, in an integrated manned (as relevant) to establish the right balance and reach an overall optimisation. Measures identified fall under different technical areas and are analysed as part of the overall work undertaken within the relevant area, in an integrated manner within the area itself (considering all relevant requirements from the area) and between related areas (considering requirements from other areas as relevant).

Examples of measures identified (per technical area) are given below for illustrative purposes:

- For Structural Integrity, design (including material selection) and manufacture of components can influence radioactivity levels in SSCs and is to be demonstrated to be optimised, e.g. smoothness improvement of the inner surface of the components, leak tightness, optimised design of the components/pipes to avoid/minimise dead ends, sharp bends, low points, etc.

- For Mechanical Engineering, the design of SSCs and their operating parameters (e.g. flow rate, etc.) can affect the deposition or the efficiency of the treatment units or the fluid stream and therefore influence the radioactivity levels in the different systems. Key measures need to be demonstrated to be optimised or be optimised if not already.

- For Reactor Chemistry, operating chemistry can influence the deposition in the circuits, the efficiency of the treatment units or the fluid stream (e.g. in case chemical pollution for example the fluid cannot be recycled and need to be managed as waste). As such, the chemistry regime needs to be demonstrated to be optimised and be optimised if not already.

- For Waste management, SSCs design (e.g. treatment technology selection, segregation, etc.) and operation (e.g. end of treatment criteria, use of a particular treatment) can influence the activity levels in the fluid stream and in the accumulation units and subsequent waste. These need to be demonstrated to be optimised and be optimised if not already.

For the prevention/minimisation/optimisation of discharges/disposal

As part of this RO, focus will be given to the optimisation of the treatment process of the waste abatement systems so as to prevent/minimise/optimise the discharges to environment, the production of solid radwaste and the disposability of all waste produced. This is linked to RO-UKHPR1000-0005 related to the *Demonstration that the UK HPR1000 Design reduces the risks associated with radioactive waste management, so far as is reasonably practicable*.

The measures identified in the above point on radionuclide transport are also relevant here. The measures to prevent/minimise/optimise the discharges/disposal are considered under two aspects:

- one is the optimisation of disposal route selection: gaseous vs. liquid vs. solid (linked to previous point);
- the other is the individual optimisation for treatment of solid, liquid and gaseous respectively.

- <u>Step 6: Summarise information from Step 4 and 5 into ALARP /BAT demonstration in relevant areas</u>

The work conducted as part of this step consists in summarising the outcomes from previous Steps 4 and 5 in the ALARP/BAT demonstration of the relevant technical areas and responds to **ROA3 and ROA2**.

- <u>Step 7: Update as relevant the source terms and reiterate the process from step 4/5</u>

This step consists of reflecting, where relevant, any changes made to the design that affect the source terms so as to ensure the source terms are consistent with the design and its intended operation and are ALARP/BAT.
In case of updates of the source terms, the process needs to be reiterated from Step 4 or 5 (depending on the changes made to the design and the source terms) until the analysis yields no further optimisations.

– **Summary of how radionuclides generation and transport and radioactivity levels have been minimised SFAIRP**

To meet the expectations of **ROA1**, **ROA2** and **ROA3**, a route map document that gives a holistic view of how radionuclides generation and transport and radioactivity levels have been minimised SFAIRP in the UK HPR1000 will be produced, titled "*Minimisation of Radioactivity Route Map Report*". In response to **ROA1**, the report will contain a traditional document map, identifying which documents in the safety case contain information relating to the production, quantification, characterisation, behaviour and clean-up of radioactivity in the UK HPR1000, and in response to **ROA2** and **ROA3,** it will include an overview that explains holistically how radionuclide generation and transport, and associated radioactivity levels have been minimised SFAIRP, focussing on the key aspects of the demonstration.

<u>Document map (ROA1)</u>

The overall documentation that provides the justification that the UK HPR1000 design and operation minimises radioactivity levels SFAIRP and optimises radionuclide generation and transport, and associated radioactivity levels, will be consolidated and presented in the form of a document map in the route map report. This will take the form of tables or a flowchart. The document map will guide the reader through the case and identify where in the case the detailed information on each relevant aspects of the demonstration is contained.

Since part of the documentation that will support the demonstration that radionuclide generation and transport and radioactivity levels have been reduced SFAIRP is still being developed or updated, gaps in the case may be identified and additional justification/evidence may be required and will be provided in new documents or in updates to existing reports (as relevant). Such gaps will be managed in accordance with the project procedures and closed out during GDA if relevant or identified as FAPs on the future licensee and handed over to the future licensee as part of the transition from GDA to the site-specific stage. Examples of areas where justification is to be provided during Step 4 and where gaps may be identified when these justifications are developed are:

- *Justification of the enrichment level of boric acid*

  Enriched lithium hydroxide and enriched boric acid are proposed in the UK HPR1000 to ensure that the pH is optimised and appropriately controlled which notably contributes to minimising corrosion in the primary circuit, thus minimising the generation of activated corrosion products and ensuring structural integrity of components. Currently, the justification of the level of enrichment of boric acid and its benefits and the associated evidence has not fully been provided. The “Selection of Enriched Boric Acid” report will provide this justification and associated evidence and is planned for submission by the 30th June 2020.

- *Adequately justifying material selection and surface treatments*

  Currently the Topic Report on Application of Cobalt Based Alloy in SSCs demonstrates that the use of cobalt containing alloys has been minimised SFAIRP. Evidence of the minimisation of use of silver have been provided in source term related documents and in RQ-0482 response but need to be incorporated into the safety case documentation. Evidence of the minimisation of other corrosion products also have to be provided, in a proportionate manner to ensure relevant considerations have been given to preventing/minimising the production of CP SFAIRP. In addition to material selection, surface treatments and their role and impact on corrosion product generation and deposition have been analysed and considered for UK HPR1000. Justification for the surface treatments proposed for the UK HPR1000 will be provided in Step 4 in the “Topic Report on Surface Treatment of SSCs” which is planned for submission by the 13th August 2020.

<u>Holistic Summary (ROA2 and ROA3)</u>

Based on the methodology presented above, the route map report will contain a summary of how radionuclide generation and transport, and associated radioactivity levels have been minimised SFAIRP in the UK HPR1000, focusing on the main factors and measures (e.g. operating chemistry, material selection, SSCs design and operating practices), through application of the proportionality principle. This summary will also refer out to the relevant documentation where detailed information is provided.

The relevant areas/disciplines that contribute to the case will be included, such as Source Term, Reactor Chemistry, Mechanical Engineering Fuel and Core, Radwaste Management, Structural Integrity and Environment. The output of the ALARP/BAT demonstration reports for each of the relevant technical areas will be used as the basis for the summary.

Prevention and minimisation of radionuclide generation and transport, and radioactivity levels are often the result of a balance between various competing factors/requirements from different technical areas, e.g. mechanical resistance vs prevention/minimisation of CP in relation to the use of cobalt containing alloys, reactivity control vs prevention/minimisation of tritium production in relation to the use of boric acid, elimination/minimisation of H_2 explosion risk vs minimisation of carbon-14 production in relation to the use of nitrogen as a cover gas for the VCT and other tanks and vessels. In the holistic summary, such balances will be presented and the decision making explained.

Timescales

The first version of the "*Minimisation of Radioactivity Route Map Report*" will be submitted on the 30th of April 2020. This will include the document map and the holistic summary (which may not be complete at that time as all the documents to produce this summary will not be available), including all of the documents that form part of the case and how they inter-relate, ultimately providing a view of how radionuclide generation and transport and radioactivity levels have been minimised SFAIRP. The second version of the report will be submitted on the 30th October 2020 and will reflect the progress made between the first and second version and will provide the full holistic summary, and take account of the holistic design review planned for September 2020. It will also reflect the outcome of ONR assessment (if any).

RO-UKHPR1000-0026.A4 – Identify any controls necessary to ensure radioactivity in UK HPR1000 will be minimised

In response to this Action the RP should:

- *Based on the responses to A2 and A3, identify the controls, including any limits and conditions, which are necessary to ensure radioactivity is reduced SFAIRP. Such controls need to be demonstrated to be consistent with the design, intended operations and generic safety case claims for UK HPR1000.*

Resolution Plan for ROA4

Based on the responses to ROA2 and ROA3, the controls, including the limits and conditions for radionuclides generation and transport and radioactivity levels minimisation will be identified commensurately to GDA scope and stage. Where controls, LCOs, assumptions and/or commitments are identified in the work undertaken as part of the response to ROA2 and ROA3, these will be captured and transferred to the future licensee in-line with the process proposed in response to Action 4 of RO-UKHPR1000-0004, Reference [9].

RO-UKHPR1000-0026.A5 – Provide adequate quantitative activity estimate of corrosion products in the primary circuit and the relevant systems.

Resolution Plan for ROA5

(1) *Provide adequate quantitative activity estimate of corrosion products in the primary circuit.*

A quantitative estimate of UK HPR1000 corrosion product activity in the primary circuit, for all normal operation conditions, has been made, primarily based on OPEX data from CPR units, and justified by comparison with OPEX data from EDF units and CPR units (independent set of data to that used for estimating UK HPR1000 corrosion product activity), and is currently provided in the *Primary Coolant Source Term Calculation Report*. While these estimated and justified activity values are considered appropriate for use at GDA, the RP will provide a theoretical quantitative estimate of UK HPR1000 corrosion product activity in the primary circuit calculated using CAMPSIS code or semi-analytical calculations to address this ROA requirement. CAMPSIS is a crud behaviour analysis code developed by CGN to assess the fuel crud and the distribution of activated corrosion products in the primary circuits in a PWR. CAMPSIS code has been verified and validated using CGN OPEX from CPR units, lab test data and international PWR measured data.

- The calculations will encompass all relevant plant specific design features and anticipated operations for the UK HPR1000. A number of factors are associated with corrosion products generation and transport mechanisms; however, only those significantly affecting these mechanisms will be considered, as far as reasonably practicable, for the theoretical estimation, including the pH in the primary coolant, elemental constituents in the structural materials of relevant SSCs (sources), purification of the primary coolant and zinc injection.

- The corrosion products that will be considered are those identified in the Report of *Radionuclide Selection during Normal Operation*, i.e. Co-60, Co-58, Fe-59, Mn-54, Cr-51, Ag-110m, Sb-122 and Sb-124. In addition, Zn-65 will be considered since zinc injection which is one of the modifications that has been made in the UK HPR1000 is a potential source of Zn-65.

- The estimation method for these corrosion products in the primary circuit of the UK HPR1000 is as follow:
  - ✓ **First group of radionuclides: Co-60, Co-58, Fe-59, Mn-54, Cr-51, Zn-65**

    The generation and behavior of Co-60, Co-58, Fe-59, Mn-54, Cr-51 and Zn-65 in the primary coolant at different chemistry regimes at steady condition are considered in CAMPSIS code, so the quantitative estimation of volumetric activity and deposited activity for the first group of corrosion products in the primary circuit will be performed using CAMPSIS code (it is noted that the deposition of Zn-65 isn't considered in the CAMPSIS code due to the low injection concentration, such that deposited activity will not be assessed for Zn-65).

    However, CAMPSIS code is not capable of modeling the transient phases because the corrosion products generation and transport mechanisms during such phases is much more complicated than those during steady power operation. In order to quantitatively assess the corrosion product activity in the primary circuit during transients, the ratios of extant corrosion products source term values (from CPR1000 OPEX) between steady power operation and transient phase will be calculated and then applied to the corrosion products activity for steady power operation calculated with CAMPSIS code.

- ✓ **Second group of radionuclides: Ag-110m, Sb-122, Sb-124**

  CAMPSIS code does not cover these radionuclides due to their complex origins and behaviors. Semi-theoretical analysis will be undertaken based on the comparisons between CGN units and the UK HPR1000, e.g. material composition and the contact area with the primary coolant. The source term for the second group during steady conditions can be calculated based on the quantified reduction/increase expected from the differences between UK HPR1000 and OPEX units and the CGN OPEX. The deposited source term for these corrosion products will be assessed using a similar approach.

  In order to quantitatively assess the corrosion product activity in the primary circuit during transients, the ratios of extant corrosion products source term values (from CPR1000 OPEX) between steady power operation and transient phase will be calculated and then applied to the corrosion products activity for steady power operation calculated by the semi-theoretical analysis.

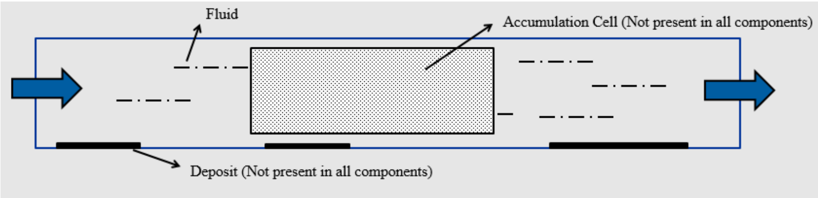
(2) Estimate the quantities of activated corrosion products present in all relevant systems connected to the primary circuit, including SFP, CVCS and IRWST.

Radionuclides including activated corrosion products are generated in core area. Once generated, they will be transported with the primary coolant to the various connected systems and may deposit on the inner surface of the components. The radionuclides in the various systems can be:

a) Present in the fluid passing through or stored in the various components of the systems. This is defined as the fluid Source Term (ST);

b) Trapped in the accumulation units of the systems, e.g. filters. This is defined as the accumulation ST;

c) Deposited on the inner surface of the components of the systems. This is defined as the deposit ST.



They are collectively referred to as the derived ST.

For the fluid ST and accumulation ST, normally there is not enough OPEX (in terms of breadth and depth) as only some specific radionuclides that are indicators of plant safety and environment performance are routinely monitored in these systems. Therefore, they are obtained theoretically. The following calculation model is commonly applied worldwide, including in the French fleet and in American units.

$$\frac{dA_i}{dt} = \sum_k B_k(A_i) - \sum_j C_j(A_i)$$

Where:

A_i — The activity of radionuclide i in a designated system;

$B_k(A_i)$ — Increment items that contribute to the increase of A_i;

$C_j(A_i)$ — Reduction items that contribute to the reduction of A_i.

For the deposit ST, it is obtained by statistical analysis based on OPEX data of CGN units.

When quantifying the activated corrosion products present in relevant systems connected to the primary circuit, the UK HPR1000 specific design parameters are considered. The derived ST methodology, input and assumptions and values are provided in the *Derived Source Term Supporting Report*.

(3) Compare and contrast the quantitative estimate with the extant source term derived for activated corrosion products in the primary circuit and all relevant systems for UK HPR1000.

Primary coolant extant and newly calculated corrosion products ST values will be compared and contrasted (magnitude of the ST values, significant radionuclides) and conclusions will be drawn where relevant.

The derived ST values for corrosion products will be explained/interpreted for the systems in scope of the ROA (i.e. systems connected to primary circuit including SFP, IRWST, CVCS). For each system, the main mechanisms of corrosion products transfer from primary coolant to the system will be explained, the key corrosion products in the system will be identified and the key challenges/risks they represent for the safety case will be explained.

Recap for ROA5:

The information and the detailed analysis presented above for points (1) and (3) will be presented in the newly planned report *The Corrosion Product Source Term Analysis with the UK HPR1000 Specific Design.*

The information and the detailed analysis presented above for point (2) are presented in the report D*erived Source Term Supporting Report,* Reference [12].

Impact on the GDA Submissions

The impacted GDA submissions will include two new documents (stated below) and other existing and planned documents in the source term, reactor chemistry and materials selection areas. As part of work delivery, a better understanding will be gained of the full impact that this resolution plan will have on other GDA submissions. These submissions will be updated appropriately with relevant information produced as a result of the work identified in this plan.

New document:

No.	Title	Revision	Planned Submission Date

1	Minimisation of Radioactivity Route Map Report	A	30th April 2020
2	Minimisation of Radioactivity Route Map Report	C	30th October 2020
3	The Corrosion Product Source Term Analysis with UK HPR1000 Specific Design	A	28th February 2021

Timetable and Milestone Programme Leading to the Deliverables

Timetable for all related deliverables is described in attached Gantt Chart in APPENDIX A.

Reference

[1] RO-UKHPR1000-0015, Demonstration that Risks Associated with Fuel Deposits are Reduced so far as is Reasonably Practicable (SFAIRP).

[2] UK HPR1000 Safety Case Development Manual, HPR-GDA-REPO-0110.

[3] ALARP Methodology, GHX00100051DOZJ03GN.

[4] ALARP Demonstration Instruction, GHX00100119DOZJ03GN.

[5] BAT Methodology, GHX00100055DOHB03GN.

[6] BAT Application Work Instruction for GDA Project, GH-30E-010.

[7] Optioneering procedure, Provisions on Optioneering process for UK HPR1000 Generic Design Assessment (GDA) Project, GH-40M-018.

[8] Decision-making procedure, Provisions on Technical Decision-making Systems for UK HPR1000 Generic Design Assessment (GDA) Project, GH-40M-007.

[9] RO-UKHPR1000-0004, Development of a Suitable and Sufficient Safety Case.

[10] Primary Coolant Source Term Calculation Report, GHX00800006DRDG03GN, Rev. D.

[11] Primary Coolant Source Term Methodology Report, GHX00800002DRDG03GN, Rev. E.

[12] Derived Source Term Supporting Report, GHX00530001DNFP03GN, Rev. C.

APPENDIX A RO-UKHPR1000-0026 Gantt Chart

Tasks	**Steps**	**2020**												**2021**					
		Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
Preparation of Submission and Closure of RO Action																			
Minimisation of Radioactivity Route Map Report Rev. A	Development	■	■	■	■														
	Submission				▲														
Minimisation of Radioactivity Route Map Report Rev. B	Development					■	■	■	■	■	■								
	Submission										▲								
The Corrosion Product Source Term Analysis with UK HPR1000 Specific Design, Rev. A	Development								■	■	■	■	■	■	■				
	Submission														▲				
Assessment																			
Regulators assessment		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Target RO closure Date																			▲