Environment Agency

Generic design assessment of new nuclear power plants

Best available techniques for the UK HPR1000 design - AR03

Detailed assessment – final report

10 January 2022

Version 1

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Executive summary

This report covers our detailed assessment of the Requesting Party’s (RP's) submission on best available techniques (BAT) for the United Kingdom Hualong Pressurised Water Reactor design (UK HPR1000). This report covers the requirements in Table 1, Items 2, 4 and 5 of our Process and Information Document (P&ID) (Environment Agency, 2016).

Our assessment has considered the RP’s submission in relation to relevant UK policy, legislation and guidance, including the Environment Agency’s Radioactive Substances Regulation (RSR) Environmental Principles (REPs) (Environment Agency, 2010a). The most relevant principles include:

- Radioactive Substance Management Developed Principle 3 (RSMDP3): Use of BAT to minimise waste
- RSMDP4: Processes for identifying BAT
- RSMDP7: BAT to minimise environmental risk and impact
- Engineering Developed Principle 2 (ENDP2): Avoidance and minimisation of impacts
- ENDP4: Environment protection functions and measures

Our conclusion is that the RP has made an adequate demonstration of BAT in relation to radioactive substances for the UK HPR1000, based on the defined scope for Generic Design Assessment (GDA) (GNSL, 2019a). This has been demonstrated to a sufficient level in line with our expectations for GDA. Our assessment of BAT for monitoring is provided in the monitoring assessment report (Environment Agency, 2022a). Operational aspects of BAT will be assessed if we receive a site-specific permit application.

We have identified a number of Assessment Findings that we will expect a future operator to address. These are:

- **Assessment Finding 3: A future operator shall develop arrangements for managing environment protection measures. This should include specification, procurement, manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.**
- **Assessment Finding 4: A future operator shall consider the potential high efficiency particulate air (HEPA) filter sealing performance technique improvements being considered for nuclear new builds including Hinkley Point C to ensure application of good practice.**
- **Assessment Finding 5: A future operator shall have arrangements to periodically review the practicability of techniques for abating carbon-14.**
- **Assessment Finding 6: A future operator shall periodically review the possibility to remove secondary neutron sources or to optimise their design at the earliest opportunity.**
- **Assessment Finding 7: A future operator shall demonstrate that the UK HPR1000 will be operated in a way that represents best available techniques**

for the selection and change strategy of demineraliser resins and filters for liquid waste management systems.

- **Assessment Finding 8: A future operator shall address the BAT relevant post-GDA commitments the Requesting Party identified in the Post-GDA Commitment List, GHX00100084KPGB03GN.**
- **Assessment Finding 9: A future operator shall assess the impact of its proposed operating fuel cycle on the radioactive waste generation and disposal before implementing any changes.**
- **Assessment Finding 10: A future operator shall specify procedures to detect failed fuel and act to minimise discharges to the environment.**
- **Assessment Finding 11: A future operator shall periodically review and continue to optimise water chemistry regimes presented during GDA to reduce waste generation.**
- **Assessment Finding 12: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.**
- **Assessment Finding 13: A future operator shall define a procedure to follow in the event of leakage to the secondary circuit that demonstrates the discharge of activity to the environment is minimised.**
- **Assessment Finding 14: A future operator shall periodically review and continue to optimise the balance between gaseous, liquid and solid phase disposals of carbon-14.**
- **Assessment Finding 15: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to help inform future dose assessments.**

Contents

1. Introduction

This report provides our detailed assessment of the RP's submission in relation to demonstrating its use of BAT in the UK HPR1000 design for GDA purposes. This report is based on the final consolidated set of GDA submissions.

We use a 2-stage process to carry out GDA: initial assessment, followed by detailed assessment. The findings from our initial assessment are set out in the Initial assessment: Statement of findings published in November 2018. From our initial assessment, the items raised for further information at detailed assessment were specifically to:

- provide detailed information on proposed radioactive waste management systems
- define a systematic approach for demonstrating BAT
- demonstrate that BAT is influencing the reference design (HPR1000) for deployment in the UK (UK HPR1000)
- demonstrate that the priorities for improvements are related to public dose impact or non-human species dose rate impact
- identify and present the necessary evidence to support the BAT claims and arguments
- consider both technique and the implementation of the selected technique

This detailed assessment has built on that initial assessment and is based on additional submissions and ongoing technical engagement with the RP. The assessment method, findings and conclusions are presented in the following sections.

BAT is defined as the latest stage of development of processes, facilities or methods of operation that indicate the practical suitability of a particular measure for limiting discharges, emissions and waste. In determining whether a set of processes, facilities and methods of operation constitute BAT in general or individual cases, special consideration shall be given to:

- comparable processes, facilities or methods of operation which have recently been successfully tried out
- technological advances and changes in scientific knowledge and understanding
- the economic feasibility of such techniques
- time limits for installing both new and existing plants
- the nature and volume of the discharges and emissions concerned

Operators, when disposing of radioactive waste, need to ensure that the radiological impacts on people are kept as low as reasonably achievable (ALARA), taking into account economic and social factors. This is the 'optimisation requirement'. We expect operators to achieve this by using BAT to manage the generation, processing and disposal of radioactive waste (Environment Agency, 2010b).

Identifying BAT is the result of a process of 'optimisation', where the Requesting Party (RP) selects options that minimise the generation and discharge of radioactive waste, considering all relevant factors, including economic considerations (Environment Agency, 2010b). The results of this process lead to a design that meets high environmental standards, where the costs are not excessive in relation to the environmental protection they provide; in other words, not grossly disproportionate.

The Environmental Permitting Regulations 2016 (as amended, UK Parliament, 2016) provide the legal framework for regulating activities involving the use of radioactive substances, the generation of radioactive wastes and the release of those radioactive wastes into the environment. The regulations include a requirement that we carry out our work to ensure that all exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable (ALARA), economic and social factors being taken into account. We do this by requiring designers and operators to use BAT, including to minimise the creation of wastes, discharges into the environment and their impact.

Our assessment covers the techniques used to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment, and minimise the impact of those discharges. This assessment report is linked to other assessment reports listed here:

- the assessment of BAT for monitoring is provided in the monitoring assessment report (Environment Agency, 2022a)
- the assessment of solid and non-aqueous waste is provided in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b)
- the assessment of the gaseous and liquid discharges and proposed limits is provided in the discharges assessment report (Environment Agency, 2022c)
- the assessment of the radiological impact is provided in the impacts assessment report (Environment Agency, 2022d)
- the assessment of strategic considerations for radioactive waste management report (Environment Agency, 2022e)
- the assessment of new nuclear power plant: Preliminary detailed assessment of generic site description and assessment of dose to the public and to wildlife (Environment Agency, 2022f)

2. Assessment

2.1. Assessment method

The basis of our assessment was to:

- review the appropriate sections of the Pre-Construction Environmental Report (PCER) and its supporting documents (Appendix 2) against our regulatory expectations
- hold technical meetings with the RP to clarify our understanding of the information presented and explain any concerns we had with that information

- raise Regulatory Queries (RQs) to clarify our understanding of the information presented
- raise Regulatory Issues (RIs) or Regulatory Observations (ROs) where we believed the RP did not provide enough information, the details of which are in Appendix 1
- assess the techniques the RP proposed to prevent and minimise the creation of radioactive waste, minimise the discharges of gaseous and aqueous radioactive waste to the environment and minimise the impact of those discharges, the details of which are in Appendix 3
- decide on any potential GDA Issues or Assessment Findings to carry forward from GDA

2.2. Assessment objectives

The assessment considered whether:

- the significant radionuclides in each waste stream have been identified. These are those radionuclides that contribute significantly to the amount of activity in waste disposals or to the potential dose to members of the public
- BAT can be demonstrated to prevent and minimise the creation of radioactive waste (solid, liquid and gaseous), minimise the discharges of gaseous and aqueous radioactive waste to the environment and minimise the impact of those discharges
- the BAT method described the approach used to review the design and to develop the case that supports the demonstration that the design and operation of the UK HPR1000 are BAT
- the options chosen can be demonstrated to be BAT
- the design has been challenged to look for potential improvements
- the option selection process gives sufficient importance to environmental protection
- suitably qualified and experienced person (SQEP) personnel are involved in the option selection process

2.3. Assessment scope

The scope of our BAT assessment within the GDA process is the nuclear island and those buildings, processes and functions which are related to managing radioactive waste and discharges of gaseous and aqueous radioactive waste to the environment. The nature of the solid wastes that will arise in the UK HPR1000 and our view on the proposed processing of these is limited in this assessment report, as it is provided in more detail in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b).

The buildings that are within the detailed design scope of GDA and which are identified with the potential to generate gaseous and aqueous radioactive waste due to the inventories and processes within them include the:

- reactor building (BRX)
- nuclear auxiliary building (BNX)

- safeguard building A (BSA)
- safeguard building B (BSB)
- safeguard building C (BSC)
- radioactive waste treatment building (BWX)
- fuel building (BFX)

Further buildings outside the 'nuclear island' and not subject to detailed design in GDA include the conceptual radioactive waste stores, which are also likely to generate small quantities of gaseous and aqueous radioactive waste (Gaseous and aqueous waste from conceptual radioactive waste stores is not included within the scope of GDA) (GNSL, 2019a).

The aim of GDA is to carry out a meaningful assessment of a nuclear power plant design without ruling out options for a future operator. GDA provides the opportunity for the RP to optimise the design and operation of a nuclear power plant by applying BAT. The designer cannot make operator decisions and therefore these cannot be assessed at GDA. Operational aspects are addressed at the permitting stage following GDA. What represents BAT may vary over the life cycle of the nuclear power plant and therefore BAT would be reviewed regularly as part of ongoing regulation.

2.4. Process for identifying best available techniques

The main procedures for identifying BAT are set out in the BAT Methodology submission (GNSL, 2018a) and the Requirements on Optioneering and Decision-Making submission (GNSL, 2018b). The BAT Methodology (GNSL, 2018a) describes the approach used to review the design and to develop the case that supports the demonstration that the design and operation of the UK HPR1000 are BAT. The Requirements on Optioneering and Decision-Making submission (GNSL, 2018b) describes the approach used to apply both BAT and as low as reasonably practicable (ALARP) to making potential design modifications. Claims generated as part of this optimisation process are presented along with their accompanying arguments and evidence in the Demonstration of BAT submission (GNSL, 2021a).

The RP has suitably recognised the relevant principles of optimisation and sought to apply these in presenting the GDA BAT case. The approach has been guided by considering standard environmental permit conditions and P&ID requirements relating to optimisation (Environment Agency, 2016). The RP has also carried out several optioneering exercises to identify optimal approaches to the UK HPR1000 for GDA purposes (see section 2.11).

The RP's approach has been to set out claims, develop arguments in support of these, and to provide the relevant supporting evidence, where possible. The approach recognises that the UK HPR1000 is an evolution of earlier pressurised water reactor (PWR) technology and reflects on design improvements that are relevant to the BAT claims (as the RP described against specific BAT arguments, see appendix 3). We consider this to be a sensible approach and a suitable method by which to convey the 'BAT case' for generic design assessment of the UK HPR1000.

The RP has provided extensive evidence and this is reflected in more than 100 references that support its Demonstration of BAT submission (GNSL, 2021a). We have sampled these references as part of our assessment. The regulators have raised several RQs and ROs in relation to BAT aspects (Appendix 1). The RP has responded to the RQs and ROs and has developed its BAT case based on discussions held around such RQs and ROs and the outcomes.

The RP's approach has also included identifying aspects relating to BAT that a future operator will need to action at the detailed design and permitting stage. These aspects have been identified as forward action plans (FAPs) (section 2.14). We consider this to be a useful approach and recognise the value of these FAPs. The FAPs are unlikely to be an exhaustive list of the additional work a future operator will be expected to consider at site-specific permitting.

Overall, our conclusions are that the RP has followed an appropriate process for identifying BAT in the design of the UK HPR1000.

2.5. Optioneering

The RP's approach to optioneering for the UK HPR1000 is aimed at generating and evaluating options to address potential enhancements to the design in accordance with the legal requirements relating to BAT, which we regulate. It also aims to reduce risks so far as is reasonably practicable (SFAIRP), which is regulated by the Office for Nuclear Regulation (ONR) for nuclear installations. Regulators require the RP to consider a sufficiently wide range of process and management options to ensure the best option is implemented. Options should be available, reliable and reasonably robust within the required timeframe for a solution.

The Requirements on Optioneering and Decision-Making submission (GNSL, 2018b) sets out the requirements for the optioneering and decision-making procedures. The RP developed a procedure to provide guidance on how to generate and evaluate options to address the potential enhancements of the design in Guidance for Optioneering (GNSL, 2019b) and a procedure to set out a framework for managing the potential enhancements in Provisions on Optioneering Process (GNSL, 2019c).

We assessed the following as examples of optioneering exercises the RP carried out in support of the BAT case for the UK HPR1000:

- Optioneering Report of the HEPA Filters Types (GNSL, 2021c), which identifies a preferred type of high efficiency particulate air (HEPA) filter for the UK HPR1000.
- Optioneering Report for Gaseous Radioactive Waste Processing Techniques (GNSL, 2020a), which supports the demonstration that the UK HPR1000 gaseous waste treatment system (GWTS) processing techniques selected represent BAT.
- Optioneering Report for Liquid Radioactive Waste Processing Techniques (GNSL, 2020b), which supports the demonstration that the UK HPR1000 liquid waste treatment system (LWTS) processing techniques selected represent BAT.

- Optioneering Report for Operational Solid Waste Processing Techniques (GNSL, 2020c), which identifies a range of alternative technologies for managing solid and non-aqueous liquid waste and selects the optimised options for each waste stream.

We raised an RQ concerning the optioneering process used for radioactive waste processing techniques (RQ-UKHPR1000-0434). The response to the RQ clarified that the optioneering reports for the selection of gaseous and liquid waste treatment techniques were not produced as a result of a gap identified in the UK HPR1000 design, but to provide evidence as part of the BAT and ALARP demonstrations and, therefore, did not strictly accord with GNSL, 2019c. However, the operational solid waste treatment techniques submission was produced because of identified gaps, and, therefore, as part of the process to solve gaps, it is in accordance with GNSL, 2019c. The responses to the RQs improved our understanding of the application of the optioneering process and resulted in revised gaseous and liquid optioneering reports (GNSL, 2020a).

The RP's optioneering method and process have varied in terms of the specific approaches to scoring and sensitivity analysis. We recognise that different approaches are possible and consider that the approach the RP adopted has been appropriately scoped and is consistent with our expectations for GDA. Overall, our conclusions are that The RP has used optioneering approaches where appropriate, targeting those aspects that are relevant to the UK design and, where prompted, in response to specific regulatory considerations, for example, to justify specific design option selection. Some of these optioneering aspects are discussed below in relation to our assessment of the relevant BAT arguments as presented by the RP (GNSL, 2021a).

2.6. The claims, arguments and evidence approach

The claims, arguments and evidence (CAE) approach the RP used is detailed in its BAT Methodology submission (GNSL, 2018a) and is commonly used for nuclear new build projects, including previous GDAs to demonstrate the application of BAT. Our full systematic assessment of the RP's CAE in relation to best available techniques is detailed in Appendix 3.

2.7. Summary of the generation, minimisation and management of radioactive waste in the UK HPR1000

Most radionuclides in the reactor core are retained within the fuel pin and in the activated structures. However, a small amount of radioactivity can transfer from the fuel or structure into the primary coolant through leaks, diffusion, tramp uranium or corrosion. A small proportion of those radionuclides in the primary coolant can then transfer to the secondary coolant system (in case of steam generator (SG) tube leaks and diffusion) and removed by the waste management systems. We have illustrated the sources and flow paths for radioactive wastes within the UK HPR1000 in Figure 1 (a simplified diagram adapted from figures in Demonstration of BAT GNSL, 2021a).

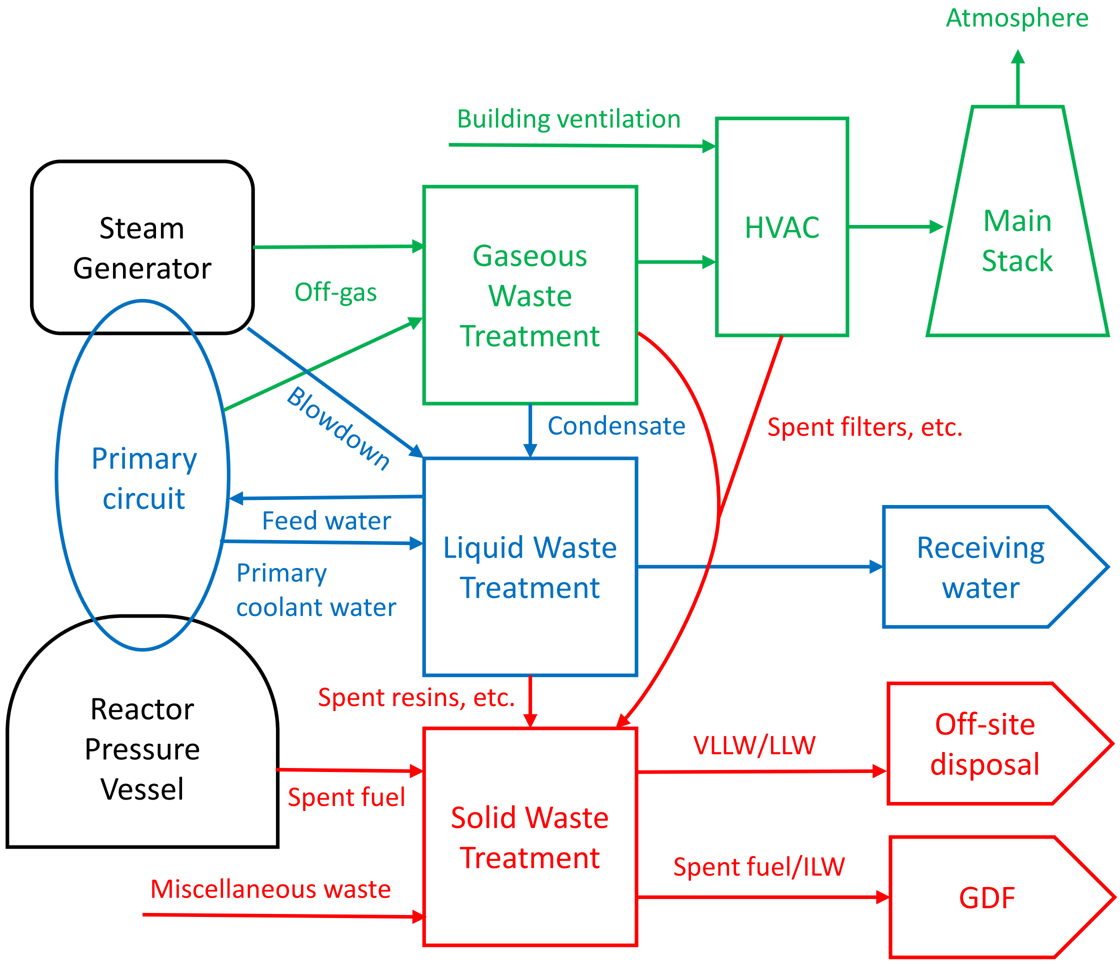

Figure 1: The gaseous, liquid and solid wastes routes

To minimise the levels of radioactivity, the RP has outlined how the UK HPR1000 design prevents, minimises, controls and manages radionuclides generated and transported throughout the plant (GNSL, 2021b). The origins of radioactivity within the UK HPR1000 and the most important measures for minimising radionuclides generated are as follows:

- Fission products and actinides leakage from the fuel are minimised through optimised fuel and core design, fuel manufacturing, chemistry regime in the primary circuit and fuel operating management.
- Activation products from materials of structures, systems and components (SSCs) in contact with the primary coolant are minimised by using materials in which impurity elements have been minimised and controlled by implementing an optimised chemistry water quality control.
- Activation of dissolved substances within the primary coolant are also minimised by implementing an optimised chemistry water quality control. For example, tritium production is minimised by using boron (used to control reactivity) enriched in boron-10 and lithium hydroxide (used to adjust pH) enriched in lithium-7.
- Corrosion products from materials generated and suspended in the primary coolant are minimised by improved corrosion performance of selected materials and implementing an optimised chemistry regime.

2.8. Summary of the Requesting Party's claims to minimise radioactive waste in the UK HPR1000

The RP claims that the UK HPR1000 design prevents and minimises the generation of radioactive waste. CAE in support of this are provided as part of the Demonstration of BAT submission (GNSL, 2021a). The BAT related arguments the RP presented and our associated conclusions are summarised in the sections below and more detail is provided in Appendix 3.

The RP claims that the following aspects of the UK HPR1000 design help to prevent and minimise the generation of radioactive waste in the core and primary circuit:

- design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products from the fuel into the primary circuit
- management of core design and cycle length to minimise spent fuel during operation
- optimised design, an appropriate chemical water control and material selection to minimise the radioactivity of activated structures, the generation of corrosion products and activated products

The RP claims that the following aspects of the UK HPR1000 design help to minimise the radioactive waste disposed to the environment:

- a gaseous waste treatment system that includes processes to reduce radioactivity of short-lived fission products in the gaseous phase before being discharged into the environment
- a heating, ventilation and air conditioning (HVAC) system that prevents the fugitive emissions of radioactive substances
- treatment techniques for liquid waste that minimise the discharge of radioactivity into the environment
- segregation and decay storage to minimise the radioactivity associated with wastes that require disposal

The RP claims that the following aspects of the UK HPR1000 design help to minimise the volume of radioactive waste requiring disposal at other premises:

- optimised design to minimise the volume of operational and decommissioning waste
- a number of features will allow future operators to adopt an operating philosophy that will minimise the quantity of solid radioactive waste associated with routine operations and maintenance
- facilities with selected waste processing techniques for managing, treatment and storing solid radioactive waste
- availability of a range of decontamination techniques for use during decommissioning

Evidence to support the above claims are summarised in the Demonstration of BAT submission (GNSL, 2021a) and detailed in the supporting documents, a number of which we have reviewed during our assessment (Appendix 2). Our full systematic assessment of the RP's CAE in relation to BAT is detailed in Appendix 3 and summarised in the following sections.

2.9. Assessment of the minimisation of the generation of waste in the UK HPR1000

The demonstration of BAT for minimising and managing radioactive waste in the UK HPR1000 is presented in the Demonstration of BAT submission (GNSL, 2021a) and the supporting documentation. This section summarises the assessment of the CAE related to minimising the generation of waste in the UK HPR1000, and more detail is in Appendix 3. The RP has identified the radionuclides that will contribute significantly to the amount of activity in waste disposals and will result in doses to members of the public. The RP has presented, for the normal operation source term, the mechanisms that generate radionuclides in the reactor core and the primary circuit, the methodology for selecting radionuclides and a list of the selected radionuclides (GNSL, 2021d). The RP also quantified the radionuclides distribution in the radioactive systems under normal operation conditions (GNSL, 2021e).

The regulators queried what list of documents form the safety case for the source term (RQ-UKHPR1000-0390), a demonstration that radioactivity will be reduced SFAIRP (RO-UKHPR1000-0026) and the generation, transport and behaviour of tritium (RO-UKHPR1000-0049). ONR raised these RQs and ROs but they were also relevant to our assessment. The response to the RQ included a list of the documents that form the BAT case for source term and how the source term is demonstrated to be BAT, which was useful for our assessment.

The resolution of RO-UKHPR1000-0026 included the production of the Minimisation of Radioactivity Route Map Report (GNSL, 2021b). This document acts as a summary and a route map to justify how the design of the UK HPR1000 minimises radioactivity. The Route Map (GNSL, 2021b) refers to largely the same set of supporting documents as Demonstration of BAT submission (GNSL, 2021a). The Route Map (GNSL, 2021b) contained useful evidence for decay storage and conditioning of waste that supplemented the information in, and has been added to, the Demonstration of BAT submission (GNSL, 2021a) for the minimisation of waste in the UK HPR1000.

The resolution of RO-UKHPR1000-0049 principally concerned an adequate justification that the risks due to tritium have been reduced SFAIRP. However, a few submissions concerning radioactive waste arisings were revised in line with RO-UKHPR1000-0049. The revision of the Minimisation of the Discharge and Environment Impact of Tritium (GNSL, 2020d) submission included additional information on the management of the spent fuel pond (SFP) to minimise the production of gaseous tritium. The SFP is the main source of gaseous tritium, and both the temperature in the building and the temperature of the water have a significant impact on evaporation rates. The RP's demonstration that the design of the SFP has been optimised as BAT is assessed in Argument 2f in Appendix 3.

2.10. Assessment of the radioactive waste processing in the UK HPR1000

The RP has described how radioactive substances will be processed in the UK HPR1000 to ensure that waste is appropriately managed for disposal, considering the application of the waste hierarchy and ALARA/BAT principles. The solid radioactive waste management arrangements for the UK HPR1000 have been changed significantly from the reference design (Fangchenggang 3 [FCG3]) to comply with UK radioactive waste policies and practices. We summarise the design features of the UK HPR1000 used for processing gaseous, liquid and solid wastes in the next sections. Our assessment report on solid waste, spent fuel and disposability provides a summary for solid wastes (Environment Agency, 2022b).

We note that detailed operational aspects of relevance to the BAT case cannot be provided in the RP's documentation at this time, although broad operational aspects are discussed. This is appropriate for the GDA stage, as a future operator would decide how the plant is operated. We would expect further details on how the plant will be operated to ensure that BAT is implemented in the site permitting phase. Limits and conditions relevant to the BAT case are the limits on plant operating parameters necessary for environmental safety. These are included in operating rules, technical specifications and main environmental safety management requirements. Operational aspects of specific relevance to the BAT case are required to be developed by a future operator in an Assessment Finding in Appendix 3 and as follows:

Assessment Finding 3: A future operator shall develop arrangements for managing environment protection measures. This should include specification, procurement, manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.

2.10.1. Processing gaseous wastes

This section summarises the assessment of the CAE related to gaseous wastes, and more detail is in Appendix 3. The processing of gaseous waste in the UK HPR1000 design is conducted by the GWTS, the HVAC, and the condenser vacuum system (CVS). Figure 2 shows a diagram of the radioactive gaseous radioactive waste handling systems that the RP provided (GNSL, 2021a).

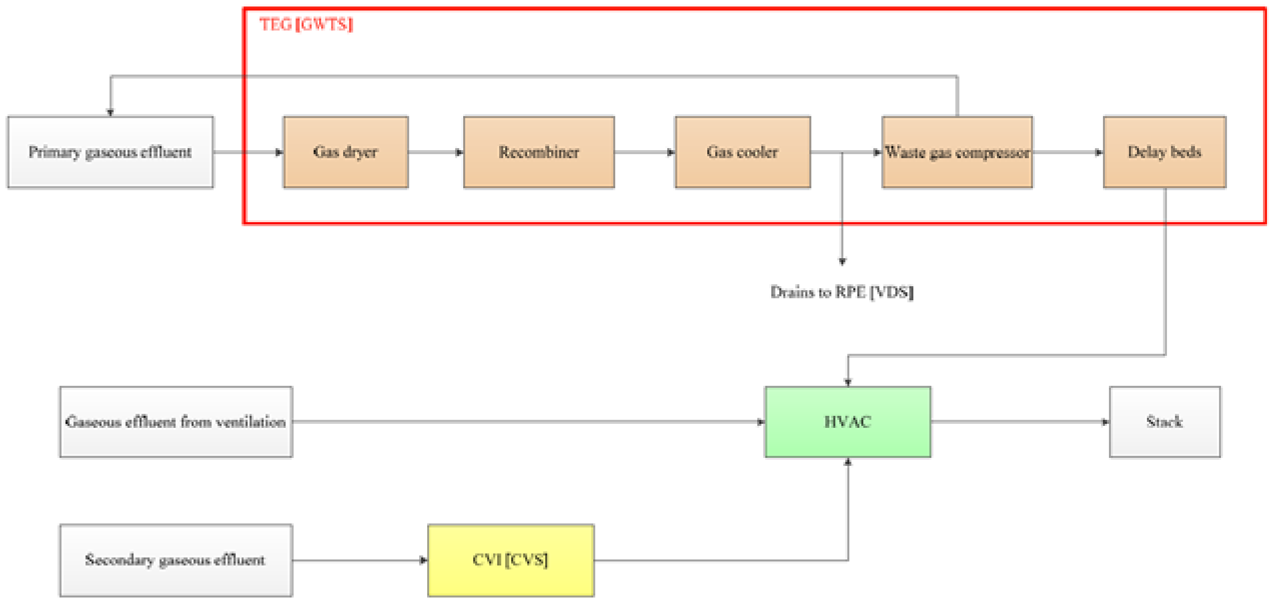

Figure 2: Radioactive gaseous effluent streams (GNSL, 2021a)

The GWTS is designed to collect and treat the process gaseous radioactive waste produced from the vessels, tanks and other equipment, which contain reactor coolant during normal operations. It continuously flushes nitrogen through the gas space of these vessels and tanks to control the hydrogen/oxygen concentration under the flammability limits. The GWTS includes delays beds, which are used to slow radioactive noble gases to allow time for the radioactive gases to decay to lower activity levels before leaving the system. The CVS removes non-condensable gases collected from within the steam condenser. The gaseous effluent from the GWTS and CVS are routed to the nuclear auxiliary building ventilation system (NABVS) where it is filtered by HEPA filters and iodine adsorbers, if needed (automatically put into operation when elevated concentrations of radioactivity are detected).

Gaseous effluent from building ventilation is managed by the HVAC system, which provides treatment for the radioactive aerosols and radioactive gases (including radioactive isotopes of iodine) in the gaseous effluent using HEPA filters to remove particulate matter and iodine adsorbers to remove radioactive isotopes of iodine. The RP claims that design features of the UK HPR1000 ensure that the impacts of gaseous discharges are minimised. Relevant aspects are outlined in the Demonstration of BAT submission (GNSL, 2021a).

The UK HPR1000 design aims to avoid and reduce gaseous waste arisings, limit the concentration of radionuclides in gaseous wastes by using delay beds, and remove particulate material from gaseous waste using HEPA filtration. The main features of the design relevant to minimising the production of gaseous wastes are as follows:

- the design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products from the fuel into the primary circuit
- the prompt detection and in core management of failed fuel

- the GWTS system that includes processes to reduce radioactivity in the gaseous phase before being discharged into the environment
- delay beds within the GWTS to allow the decay of short-lived fission products
- an HVAC system that prevents the fugitive emissions of radioactive substances, which includes HEPA filters and iodine adsorbers, the latter are not all permanently in-line and will be automatically put into operation if elevated concentrations of radioactivity are detected

In summary of our assessment of relevant CAE (Appendix 3), we observe the following:

- Using a modern and well-established fuel design and further measures to reduce fuel failure rates will help to minimise gaseous waste arisings by limiting releases from fuel failure. Measures to detect and manage fuel failure within the core should also prove effective in this regard. The regulators will ensure that a future operator develops suitable arrangements to ensure that gaseous discharges are minimised by appropriate fuel management. We have raised an Assessment Finding in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b) for this purpose. We discuss the management of spent fuel further in our related assessment report (Environment Agency, 2022b).
- Using delay bed technology is effective at reducing discharges of noble gases and consistent with approaches adopted in other PWRs. Delay beds are also expected to have some effects on reducing the concentration of short-lived iodine radionuclides.
- Using HEPA filters is effective at abating radioactive particulates. Going into our public consultation we cited a potential GDA Issue that required the RP to demonstrate how BAT is applied for the choice of HEPA filter design. The concerns we had have been resolved and further discussion of the optioneering study is provided for Argument 2c in Appendix 3. We expect a future operator to consider the improvements to sealing performance techniques that are being considered for Hinkley Point C (HPC) and have raised an associated Assessment Finding:

Assessment Finding 4: A future operator shall consider the potential high efficiency particulate air (HEPA) filter sealing performance technique improvements being considered for nuclear new builds including Hinkley Point C to ensure application of good practice.

- The UK HPR1000 design aims to discharge gases and particulates at height via a main stack and this will help to minimise the impacts of those discharges by adequate dispersion in the environment. The height and location of the stack are a site-specific matter for the detailed design stage as the optimal stack height will be dependent on local dispersion characteristics.
- We believe the design facilitates the minimisation of discharges to the environment, subject to assessment of operational choices to be considered at the site-specific stage.
- We agree with the RP that no abatement of tritium or carbon-14 is practicable currently (GNSL, 2021a)) and this is in line with all other PWRs (International

Atomic Energy Agency (IAEA), 2004). The RP demonstrates that commercially available tritium and carbon-14 abatement processes are not feasible for the low concentrations present in aqueous and gaseous discharges from a PWR. The cost and energy required to install and run the currently available abatement processes are disproportionate to the abatement benefits (GNSL, 2021a). We expect a future operator to continue to review the progress of worldwide new techniques that can be used to abate carbon-14 prior to discharge. We have raised an Assessment Finding to this effect:

Assessment Finding 5: A future operator shall have arrangements to periodically review the practicability of techniques for abating carbon-14.

- We agree with the RP that a future operator should review the need for secondary neutron sources (SNS) to reduce the production of tritium, provided it can make a safety case to do this. We have raised the following Assessment Finding:

Assessment Finding 6: A future operator shall periodically review the possibility to remove secondary neutron sources or to optimise their design at the earliest opportunity.

Assessment of the quantity of gaseous discharges to the environment is provided in our related assessment report (Environment Agency, 2022c).

2.10.2. Processing liquid wastes

This section summarises the assessment of the CAE related to liquid wastes, and more detail is in Appendix 3. The liquid radioactive waste management system (LRWMS) is designed to collect, temporarily store, monitor and treat liquid radioactive waste before it is discharged. Figure 3 shows a diagram of the liquid radioactive waste processing systems and LRWMS that the RP provided (GNSL, 2021a). The LRWMS includes 2 drainage systems:

- the nuclear island vent and drain system (VDS) which collects the drainage from BRX, BNX, BSA, BSB, BSC and BFX
- the sewage recovery system (SRS) which collects drainage from buildings including BWX.

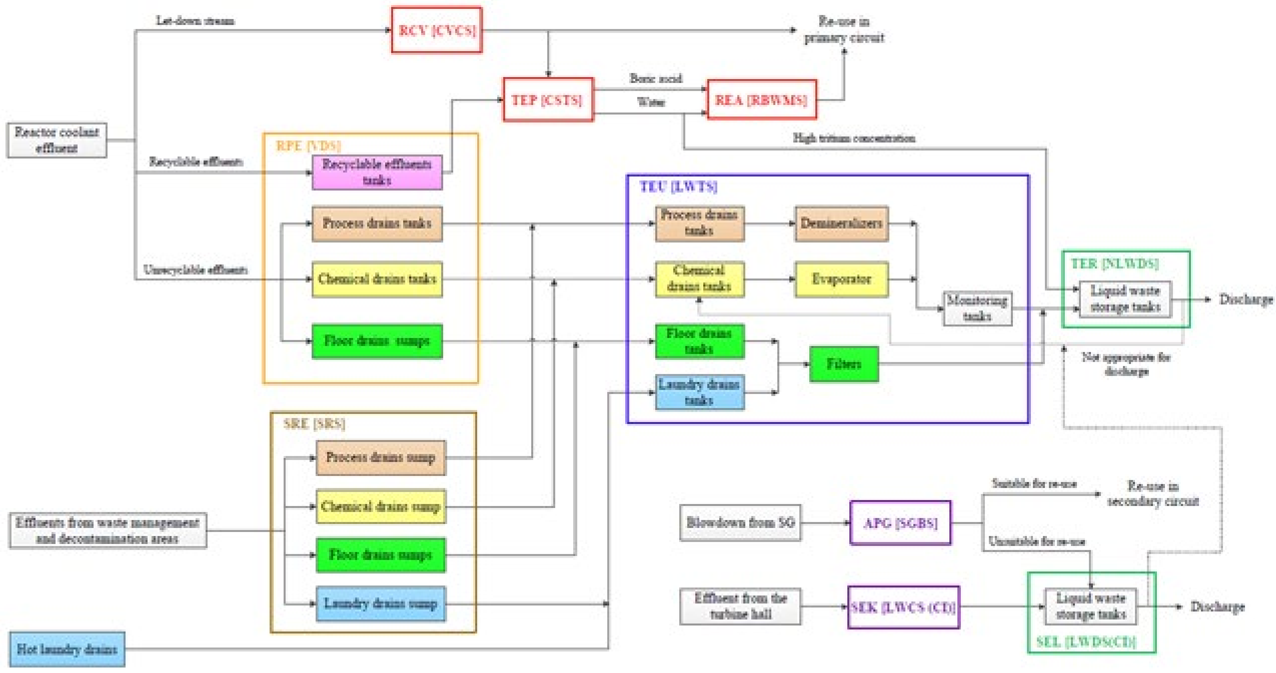

Figure 3: Liquid effluent streams and LRWMS (GNSL, 2021a)

The final discharge line receives aqueous disposals from 2 systems downstream of the liquid waste treatment sub-systems. These are the nuclear island liquid waste discharge system (NLWDS) and conventional island liquid waste discharge system (LWDS [CI]). Each of these systems contains 3 storage tanks. The NLWDS principally receives liquid waste from the coolant storage and treatment system (CSTS) and from the LWTS, which contains tanks for process, chemical, floor and laundry drains, and treatment systems, including demineralisers, evaporators and filters. The LWDS (CI) receives liquid waste from the steam generator blowdown system (SGBS) and the waste fluid collection system for conventional island (WFCSCI).

The CSTS stores the primary effluents discharged by the chemical and volume control system (CVCS) and collected by the VDS. Most of the primary effluents will be recycled, with a small amount discharged. To minimise the radioactivity of discharged primary effluents, the solids and soluble impurities in the reactor coolant are removed using filters and demineralisers before they are treated in the CSTS evaporator.

The systems can detect abnormal conditions and will have alarms and clear operational procedures to protect against accidental discharge of liquid effluent. System components such as tanks, processing equipment, pumps, valves, and instruments that may contain radioactivity are arranged in appropriate containment to prevent or minimise release to the environment.

During operation, the LRWMS will generate solid wastes that include waste called ‘concentrate’ and ‘sludge’, spent filters and spent ion exchange resins. The solid wastes will be treated and disposed of via the solid radioactive waste management system.

During decommissioning, the water within the reactor and fuel pool systems will be treated and discharged using the systems identified above as far as practicable, including aqueous effluents arising from decontamination and dismantling activities. This approach will be reviewed periodically and defined by the operator as the plant approaches decommissioning. Redundant items of plant and equipment will be managed according to the solid radioactive waste management system.

The RP claims that design features of the UK HPR1000 ensure that the impacts of aqueous discharges are minimised. Relevant aspects are outlined in the Demonstration of BAT submission (GNSL, 2021a). The UK HPR1000 design aims to:

- avoid and reduce aqueous waste arisings
- ensure appropriate segregation, treatment and reuse of liquids
- enable optimised use of filter and demineraliser technology
- use evaporators for liquids that require this treatment

The main features of the design relevant to minimising aqueous discharges are as follows:

- the design, manufacture and management of nuclear fuel to minimise the potential for a release of fission products from the fuel into the primary circuit
- the prompt detection and management of failed fuel
- treatment techniques within the LRWMS that allow liquid to be reused within the plant and help to minimise the discharge of radioactivity to the environment. These technologies comprise filtration of solids, and use of ion exchange (demineraliser) resins to remove ionic species and evaporators
- the elimination or reduction of materials that are susceptible to activation at all stages of commissioning and operation. This prevents activation products forming that could contribute to waste

In summary of our assessment of relevant CAE (Appendix 3), we observe the following:

- Using a modern and well-established fuel design, and further measures to reduce fuel failure rates should help to minimise liquid waste by limiting fission product releases from failed fuel. Measures to detect and manage fuel failure should also prove effective in this regard. The regulators will ensure that a future operator develops suitable arrangements to ensure that liquid discharges are minimised by appropriate fuel management and have raised an Assessment Finding in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b).
- The UK HPR1000 design enables clean-up and reuse of liquids within the plant, therefore avoiding unnecessary discharges. The design also provides a future operator with the flexibility to transfer liquid radioactive waste between systems in the LRWMS (that is, from the NLWDS to the LWTS for further treatment if required).
- We agree the design facilitates the minimisation of discharges to the environment, subject to assessment of operational choices to be considered at the site-specific stage.
- The UK HPR1000 uses filters, demineraliser and evaporator technology to remove radioactivity from liquids which are standard equipment in nuclear power plants. We

agree with the RP that the use of these technologies is appropriately targeted at segregated liquids within the plant systems (GNSL, 2021a). These technologies concentrate and contain radioactivity in accordance with our regulatory expectations. A future operator will need to demonstrate that the selection of resin and resin change strategy used in demineralisers is optimised and can be demonstrated to be BAT. We have raised the following Assessment Finding:

Assessment Finding 7: A future operator shall demonstrate that the UK HPR1000 will be operated in a way that represents best available techniques for the selection and change strategy of demineraliser resins and filters for liquid waste management systems.

- No abatement of liquid tritium is practicable as although some tritium abatement technologies exist, none have been successfully used on a PWR to separate the low concentrations of tritium present in aqueous wastes. We agree it would be disproportionate to use techniques at this time to avoid liquid disposals of tritium, given the small dose impact (Environment Agency, 2022d).

Assessment of quantities of liquid discharges to the environment is provided in our related assessment report (Environment Agency, 2022c).

2.10.3. Processing solid wastes

This section summarises the assessment of the CAE related to solid wastes, and more detail is in Appendix 3. Solid radioactive wastes are produced during the operational and decommissioning phases of a power station's life cycle. The UK HPR1000 design has a waste management strategy and system based on available treatment technologies and current and planned future disposal facilities. Our assessment of the waste management strategy is provided in the strategic considerations for radioactive waste management assessment report (Environment Agency, 2022e).

The solid waste treatment system (SWTS) is designed to collect, segregate, treat, condition, package and store various types of operational solid radioactive wastes, which are categorised as high level waste (HLW), intermediate level waste (ILW), low level waste (LLW) and very low level waste (VLLW) before being transported offsite for disposal. The RP provided a good description of how solid wastes and spent fuel arisings will be minimised at source. We recognise that decay storage can reduce the activity of waste that need disposing of, and we support plans for early waste treatment and conditioning. The information the RP provided gives confidence that the sampling of the solid wastes will be feasible for the UK HPR1000.

The nature of the solid wastes that will arise in the UK HPR1000, and details of our view on the proposed processing of these, is described further in our assessment report on solid radioactive waste (Environment Agency, 2022b).

2.11. Consideration of BAT and ALARP in optimisation

Demonstrating that BAT has been applied to the design and operation of the UK HPR1000 means relevant factors, including safety aspects must be balanced against all other needs. Therefore, optimisation must be based on an approach that considers both BAT and, for ONR, the reduction of relevant risks, SFAIRP (sometimes referred to as reducing risks to ALARP), where appropriate. ALARA is a legal duty placed on the Environment Agency's regulation, which we then place on operators directly and indirectly through the permit and its conditions. Both ALARA and SFAIRP are legal requirements through their respective regulations. ALARA is the international term used in standards, including the Basic Safety Standards Directive (BSSD) (Euratom, 1996) and is a duty placed on the Environment Agency through Environmental Permitting Regulations 2016 (as amended, UK Parliament, 2016). SFAIRP is the legal term in the Health and Safety at Work Act 1974 (UK Parliament, 1974) and is regulated by ONR for nuclear installations. The concept of SFAIRP is normally expressed in terms of reducing risks to ALARP, the terms SFAIRP and ALARP being synonymous. Radiation doses meet ALARA when they have been reduced to a level that represents a balance between dose and other factors, including economics. BAT are the means (for example, plant and processes) the operator uses to control disposals of radioactive waste into the environment. BAT is within the control of the operator and is how the operator seeks to demonstrate that doses to the public are kept to ALARA. For relevant risks to be judged reduced SFAIRP, it is necessary to demonstrate that the cost of reducing the risk further would be grossly disproportionate to the benefit gained.

At the time of writing our consultation document (January 2021), our preliminary conclusions were that the RP has demonstrated the UK HPR1000 to be consistent with our expectations on BAT in so far as this has been demonstrated and to a level in line with our expectations for GDA. However, we could not make our final conclusion as ALARP aspects of the design were yet to be fully demonstrated to and accepted by ONR, and a few relevant ROs remained open. We concluded that BAT was adequately addressed in the RP's design development processes and therefore anticipated that any design changes that may result from ongoing ALARP considerations would be appropriately assessed in terms of BAT. However, pending appropriate outcomes, we raised a potential GDA Issue that required the RP to demonstrate that appropriate consideration has been given to both environmental and safety aspects, to achieve an optimised design.

ONR had raised a number of ROs for plant systems where BAT is also relevant (such as radioactive waste management systems). Of relevance are RO-UKHPR1000-0005, Demonstration that the UK HPR1000 design reduces the risks associated with radioactive waste management, so far as is reasonably practicable and RO-UKHPR1000-0026, Demonstration that radioactivity has been reduced so far as is reasonably practicable.

These ROs have now been closed to the regulators' satisfaction. Closure has not resulted in any significant design changes or impacts on the CAE that the RP has made in the demonstration of BAT document. We are therefore content that the UK HPR1000 design has been demonstrated to be consistent with our expectations on BAT by the RP and suitably optimised in line with our expectations for GDA, resulting in the potential GDA Issue being resolved.

2.12. Requirements management

Requirements management at GDA concerns the transfer of requirements and assumptions from the environment case documentation from GDA to the site-specific stage and a future operator. The RP's approach to requirements management (GNSL, 2021f) includes the development of environmental requirements. We queried the transfer of environmental operational specifications from GDA to a future operator (RQ-UKHPR1000-0726). The conclusion from the RQ included providing environment input into a transition plan for handover of GDA documentation and knowledge transfer.

RQ-UKHPR1000-0929 was also raised for clarity on how the requirements management process will facilitate clear and effective transfer into a future operator's arrangements. The response to the RQ included a revision of the Requirements Management Summary Report (GNSL, 2021f) to describe the transition arrangements which are in place to ensure that important information is transferred.

The RP's approach to requirements management (GNSL, 2021f) includes identifying systems that provide an environment protection function (EPF). We requested a list of SSCs and engineered controls that contribute to the application of BAT (RQ-UKHPR1000-0498). We queried how the RP would ensure that a future operator would adequately maintain the equipment identified as providing an EPF for the design (RQ-UKHPR1000-0536). This illustrates how the examination, maintenance, inspection and testing (EMIT) arrangements are being developed and how the requirements are transferred to the operator.

We welcome the inclusion of a site-specific stage FAP to further develop EPFs and measures and associated requirements (a FAP is detailed in section 2.14). The demonstration of the adequacy of EMIT of SSCs that provide an EPF was the topic of RO-UKHPR1000-0051, which detailed our expectation that the environment case includes a demonstration that the EPF of SSCs can be maintained at all times under normal operations. The response to RO-UKHPR1000-0051 included the revision of the EMIT Strategy and Periodic Test Design Methodology submissions (GNSL, 2021g and 2021h) and the creation of a Gap Analysis submission (GNSL, 2021i) to benefit the demonstration of BAT.

Assessment of the revised EMIT Strategy (GNSL, 2021g) noted 3 examples in an appendix providing detail on the EPF of the SSC and the EMIT activity and frequency, including the preventative maintenance, inspection, and periodic test requirements based on the experience of the RP. The level of detail in each example provides sufficient information to provide confidence that the SSC can be maintained, inspected and tested in line with the application of BAT. The choice of examples was beneficial to the demonstration of BAT as the selection included SSCs that are passive, automatic and/or manual in operation. The revised Periodic Test Design Methodology (GNSL, 2021h) was assessed and found to be updated to include EPFs alongside safety functions, which was an efficient and effective update.

The Gap Analysis (GNSL, 2021i) is important as it underpins the whole EPF identification process and it is valuable to understand the underlying process and assumptions. It is part of the safety case and will be available to a future operator. The Gap Analysis provides details of the review of the relevant GDA submissions against the environmental requirements and operating experience (OPEX), and the updates needed to the submissions to close the identified gaps. The Gap Analysis is clear that during GDA the focus is on ensuring the methodologies will enable the operational management arrangements to be developed at the site-specific stage. The outcome of the Gap Analysis included identifying a lack of a methodology for determining the EMIT regime and arrangements relevant to environment protection, which resulted in updates to the EMIT Strategy (GNSL, 2021g) and Periodic Test Design Methodology (GNSL, 2021h) as mentioned in the previous paragraph.

The Demonstration of BAT submission (GNSL, 2021a) contains a list of post-GDA FAPs that covers those aspects that are not considered within the scope of GDA, and will need to be addressed by the future operator. The FAPs include the commitment to further develop the EMIT work for EPFs and associated requirements at the site-specific stage and this is listed in the Post-GDA Commitment List (GNSL, 2021j) with all post-GDA commitments. The use of a FAP to capture a commitment is appropriate to highlight where a future operator needs to expand on the BAT case submitted during GDA.

The RP provided sufficient information to meet the intent of RO-UKHPR1000-0051 and has addressed the issues which led to it being raised. We have identified an Assessment Finding to ensure a future operator develops arrangements for managing environment protection measures. This should include manufacturing, commissioning and operation, including examination, maintenance, inspection, and testing requirements.

Assessment Finding 3: A future operator shall develop arrangements for managing environment protection measures. This should include This should include specification, procurement, manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.

The Generic Limits and Condition for Normal Operation submission (GNSL, 2021k) mentions that the arrangements relevant to operating limits and conditions comprise 7 categories. These include environmental technical specifications (ETS), which consist of the limits and conditions for environment protection functions. The submission states that the ETS will be developed in the nuclear site licensing phase. We requested some further clarification on this process (RQ-UKHPR1000-1655), including how environmental requirements will be used to shape the Limiting Conditions for Operation (LCO). The Generic Limits and Condition for Normal Operation submission (GNSL, 2021k) was updated to capture environmental requirements on LCOs, the main principles of the method for transferring EPF requirements into LCOs at GDA stage and to identify main environmental LCOs for GDA.

2.13. Decommissioning

Decommissioning will take place following the operational lifetime of the facility. For GDA, a demonstration of BAT should ensure the design minimises the volumes of decommissioning waste. The RP has provided details of the decommissioning strategy, plans and how the design facilitates decommissioning (GNSL, 2021l) with accompanying documents. This evidence supports the BAT demonstration that the UK HPR1000 design has been developed considering requirements to facilitate decommissioning, relevant OPEX has been incorporated into the design, and there are suitable plans and proposals (GNSL, 2021m and 2021n). Our assessment of the decommissioning strategy is provided in the strategic considerations for radioactive waste management assessment report (Environment Agency, 2022e).

The initial supporting documents were assessed and found to have omitted opportunities for BAT demonstration (RQ-UKHPR1000-0618). The documents were subsequently updated to provide additional evidence and demonstration that BAT has been included in the design.

Providing a robust BAT/ALARP demonstration for the regulators for decommissioning the UK HPR1000 was the topic of RO-UKHPR1000-0042. The RO noted that the overall justification that relevant risks relating to decommissioning will be reduced to ALARA/ALARP should balance health, safety and environmental aspects in an optimised way. The RO was resolved following the RP's response, including updates to several decommissioning submissions to enhance the demonstration that UK HPR1000 can be decommissioned using existing techniques, safely and with minimal impacts on the environment. The Decommissioning Waste Management Proposal (GNSL, 2021n) was revised and supplements to the submission included providing evidence for assumed contaminated depth of concrete and steel that will need to be removed during decommissioning.

2.14. BAT matters for future operator

The areas that the RP considers a future operator will need to follow up, either during site-specific design or during commissioning and operations, are detailed in Appendix 4. We have raised an Assessment Finding to capture the identified BAT post-GDA commitments:

Assessment Finding 8: A future operator shall address the BAT relevant post-GDA commitments the Requesting Party identified in the Post-GDA Commitment List, GHX00100084KPGB03GN.

3. Compliance with Environment Agency requirements

The requirements set out in our P&ID and REPs (Environment Agency, 2016 and 2010a) are shown below along with compliance provision the RP provided in its GDA submissions:

- P&ID Item 2: A description of the Requesting Party's management arrangements and responsibilities for: – Include: 'establishing the methodology for identifying the 'best available techniques' (BAT) …. And ensuring their use in the design'. The RP provided the method for identifying BAT in the BAT Methodology and Requirements on Optioneering and Decision-Making documents (GNSL, 2018a and b).
- P&ID Item 4: A detailed description of the radioactive waste management arrangements: You should describe your optimisation process and identify and justify the techniques you are proposing as BAT. The RP provided the details of the radioactive waste management arrangements in the Radioactive Waste Management Arrangements submission (GNSL, 2021o) and our associated strategic considerations for radioactive waste management assessment report (Environment Agency, 2022e). The RP provided the demonstration of BAT in the Demonstration of BAT submission (GNSL, 2021a).
- P&ID Item 5: Quantification of radioactive waste disposals: 'infrequent but necessary aspects of operation, for example, plant wash-out; and the foreseeable, undesired deviations from planned operation (based on a fault analysis) consistent with the use of BAT, for example, occasional fuel pin failures'. The RP provided the details of the discharges and disposals from normal operations in the Quantification of Discharges and Limits submission (GNSL, 2021p) and the demonstration of BAT in the Demonstration of BAT submission (GNSL, 2021a).
- RSMDP3 – Use of BAT to minimise waste (The best available techniques should be used to ensure that production of radioactive waste is prevented and, where that is not practicable, minimised with regard to activity and quantity). The RP provided the BAT arguments to show that the design of the UK HPR1000 will ensure that the production and disposal of radioactive substances will be minimised. The RP's primary procedures are the BAT Methodology and Requirements on Optioneering and Decision-Making submissions (GNSL, 2018a and b), with the results shown in the Demonstration of BAT submission (GNSL, 2021a).
- RSMDP4 – Processes for identifying BAT (The best available techniques should be identified by a methodology that is timely, transparent, inclusive, based on good quality data, and properly documented). The RP provided the method for identifying BAT in the BAT Methodology and Requirements on Optioneering and Decision-Making submissions (GNSL, 2018a and b).
- RSMDP7 – BAT to minimise environmental risk and impact (When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised). The RP's decision-making regarding the management of radioactive substances for the UK HPR1000 will comply with the RP's primary procedures outlined in the BAT Methodology and Requirements on Optioneering and Decision-Making submissions (GNSL, 2018a and b) to ensure that any resulting environmental risk and impact are minimised, with the results provided in the Demonstration of BAT submission (GNSL, 2021a).
- ENDP2 – Avoidance and minimisation of impacts (Radiological impacts to people and the environment should be avoided and, where that is not practicable, minimised in line with the operations being carried out). The RP's BAT arguments

are presented to show that the design of the UK HPR1000 avoids and, where this is not practicable, minimises radiological impacts to people and the environment, including the Minimisation of Radioactivity Route Map Report (GNSL, 2021b) submission with the results shown in the Demonstration of BAT submission (GNSL, 2021a).

- ENDP4 – Environment protection functions and measures (Environment protection functions under normal and fault conditions should be identified, and it should be demonstrated that adequate environment protection measures are in place to carry out these functions). The RP's consideration of EPFs is provided in the design and associated processes in the Requirement Management Summary Report (GNSL, 2021f), including the development of a List of SSCs and Engineered Controls that Contribute to the Application of BAT (GNSL, 2019d) and detail on the EPF of the SSC and the EMIT activity and frequency, including the preventative maintenance, inspection, and periodic test requirements based on the experience of the RP in the EMIT Strategy (GNSL, 2021g).

4. Public comments

4.1. General Nuclear System Limited's public comments process

General Nuclear System Limited (GNSL) received 5 public comments up to 17 September 2021 concerned directly with BAT:

On 19 Feb 2018, GNSL received a comment on its choice of materials (ANON-1XYX-8W7U-N) concerning the use of 690 alloys in the steam generator tubes and the use of Stellite™ in contact with primary circuit coolant. GNSL responded by providing reasons for selecting 690 alloys, including meeting the material selection requirements for resistance to primary and secondary circuit corrosion, worldwide use and international good practice, and OPEX from China's PWR fleet. It provided evidence showing that 690 alloys heat transfer tubes, together with strict water chemistry control of primary circuit coolant, can effectively avoid corrosion of the tubes (GNSL, 2020e). We consider selecting Alloy 690 demonstrates BAT as it is a widely used material for steam generators in the worldwide PWRs due to its high corrosion resistance, heat transfer performance and comprehensive mechanical properties. The RP has also systematically reviewed the design for further opportunities to reduce corrosion, including the surface treatment of SSCs (GNSL, 2021q). Our assessment notes that the design minimises the application of cobalt based alloys, and, therefore, the use of Stellite™, and is limited to some wear resisting parts and some valves. Regular inspections of cobalt based alloy valves will be carried out and zinc injection technology adopted in the UK HPR1000. The injection of zinc into reactor coolant leads to the incorporation of zinc into the oxide films on surfaces. The zinc conditioned oxide is protective, minimising corrosion and deposition of corrosion products.

(The use of Stellite™ also received a comment on 8 Aug 2018 [ANON-1XYX-8W7W-Q], with a similar response from GNSL).

On 28 August 2018, GNSL received a comment on the development of BAT for the radioactive waste system (ANON-1XYX-8W76-P) concerning BAT for FCG3. GNSL responded by stating that the Chinese nuclear regulatory regime does include the application of BAT, but does not require the demonstration of BAT. Our assessment notes how the BAT demonstration for the UK HPR1000 has been developed in the UK context during GDA.

On 29 May 2020, GNSL received a comment on its Demonstration of BAT submission (ANON-1XYX-8WSA-W) concerning the SG tubes as a source of corrosion products and the use of nickel containing materials. GNSL responded by summarising the analysis of steam generator tube material and the material selection optioneering process, which we have included in our assessment and consider to be suitably demonstrated.

On 18 July 2020, GNSL received a follow-up comment to ANON-1XYX-8WSA-W concerning SG tube material optioneering (ANON-1XYX-8WSD-Z). GNSL responded by confirming that the use of Alloy 690TT (thermal treatment) is considered to provide the best solution for the HPR1000 when all factors are considered. The choice of SG tube material is discussed further for public consultation response UK HPR1000-035 below and has been assessed as detailed in Appendix 3 for Argument 1f.

On 14 August 2020, GNSL received a comment on the use of a containment ventilation filtration system (ANON-1XYX-8WSF-2). GNSL responded by confirming that the design has two systems to filter the containment if required. The first system operates during normal plant operation and the second is available to operate during accident conditions. We assessed the technologies use in the containment filtration ventilation systems including delay beds, HEPA filters and iodine adsorbers and concluded that the RP has demonstrated that the containment ventilation filtration system technologies in the UK HPR1000 design represent BAT.

4.2. Environment Agency public consultation

We held a public consultation on our preliminary GDA Assessment Findings (Environment Agency, 2021 a and b), which ran for 12 weeks, from 11 January to 4 April 2021. We received several consultation responses relevant to BAT, which have been published (https://consult.environment-agency.gov.uk/nuclear/assessing-new-nuclear-power-station-ukhpr1000). Our replies to each point raised are presented within our decision document (Environment Agency, 2022g). However, specific comments relevant to the BAT assessment are discussed below.

We received responses (UK HPR1000-018 and UK HPR1000-027) concerning our interest in the RP's choice of HEPA filter. The choice of HEPA filtration is important to ensure the concentration of particulate matter within the gaseous radioactive waste stream is minimised during normal and accident conditions. We are content that the revised option selection report now demonstrates clearly that the RP has fully considered environmental factors during its HEPA option selection process. Further information on this can be found in Appendix 3 for Argument 2c.

We received a response (UK HPR1000-033) concerning the layout and the treatment technologies selected for the LRWMS. The layout and treatment technologies for the LRWMS have been assessed and the choices have been selected following the optioneering process mentioned in section 2.11. An Assessment Finding has been raised in section 2.8 for a future operator to demonstrate that the UK HPR1000 will be operated in a way that represents BAT for the selection and change strategy of demineraliser resins for liquid waste management systems. The process drain stream uses filters and demineralisers to remove suspended and dissolved radioactivity. The diagram in section 2.8 is a simplified version of the RP’s process diagrams. The floor drains contain suspended solids and therefore the stream uses filters and the dissolved radioactivity is expected to be low. The floor drains stream can be routed via the evaporator to concentrate and contain radioactivity. The treatment technologies are established technologies and are still effective. Continuous improvements in efficiency are being made to commercially available filters and ion exchange media, so the media and the technologies are considered to be BAT.

We received a response (UK HPR1000-035) concerning SG tube material selection, which is linked to public comments (ANON-1XYX-8WSA-W and ANON-1XYX-8WSD-Z) received by the RP, mentioned previously. The SG tube material selection has been assessed as detailed in Appendix 3 for Argument 1f. SG tubes are the most significant source of corrosion products as they have the largest surface area in contact with the primary coolant. Alloy 690TT is used in PWRs worldwide and was selected for the UK HPR1000 SG tubes following the material selection methodology (GNSL, 2019e) assessed against relevant good practice (RGP) and OPEX. Nickel-based alloys are used because of their corrosion resistance, high temperature strength and thermal expansion properties. Alloy 690TT has been developed and used without reported failure during operation following the observation of stress corrosion cracking (SCC) on earlier stainless steel and alloy SG tube materials (GNSL, 2020e). Other SG tube materials include titanium stabilised austenitic stainless steels are not widely used in the worldwide PWRs (GNSL, 2019e). Waste implications are only one factor of many that need to be considered, and we are content that the process of materials selection is appropriate and has duly considered radioactive waste minimisation. The SG tube material selection is predominantly linked to safety and structural integrity, which ONR has assessed. (https://www.onr.org.uk/new-reactors/uk-hpr1000/reports.htm).

We received a response (UK HPR1000-035) concerning the consideration of cost during the demonstration of BAT. The Environment Act 1995 (UK Parliament, 1995) requires us to take cost into account when exercising our powers, for example, granting a permit. Cost is also a component of ‘reasonable’ in ALARA. So, we would expect an operator to use cost as one of the criteria within a BAT (optimisation) assessment. The RP has considered cost in the optioneering process, where it is a significant factor, notably in considering HEPA filter choice. The reduction in dose impact between the 2 options was low, but the cost of implementing one option was high (Argument 2c in Appendix 3) where the cost of building redesign to accommodate cylindrical filters was considered. The RP has demonstrated that H-3 and C-14 abatement is grossly disproportionate as discussed in section 2.7.

After careful consideration there have been no comments received that impact, or change, our preliminary conclusions. The aspects raised had been or were considered as a part of our normal assessment process.

5. Conclusion

Our conclusion is that the RP has followed an appropriate process for identifying BAT in the design of the UK HPR1000, and also that BAT has been demonstrated in the design of the UK HPR1000 to a level that is in line with the expectations of GDA (noting that BAT aspects relating to operator choices will be assessed at the site-specific permitting stage).

We reach this conclusion based on our assessment of the design and the supporting CAE that the RP has provided (Appendix 3).

We have identified several Assessment Findings in relation to this assessment area. These are as follows:

- **Assessment Finding 3: A future operator shall develop arrangements for managing environment protection measures. This should include specification, procurement, manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.**
- **Assessment Finding 4: A future operator shall consider the potential high efficiency particulate air (HEPA) filter sealing performance technique improvements being considered for nuclear new builds including Hinkley Point C to ensure application of good practice.**
- **Assessment Finding 5: A future operator shall have arrangements to periodically review the practicability of techniques for abating carbon-14.**
- **Assessment Finding 6: A future operator shall periodically review the possibility to remove secondary neutron sources or to optimise their design at the earliest opportunity.**
- **Assessment Finding 7: A future operator shall demonstrate that the UK HPR1000 will be operated in a way that represents best available techniques for the selection and change strategy of demineraliser resins and filters for liquid waste management systems.**
- **Assessment Finding 8: A future operator shall address the BAT relevant post-GDA commitments the Requesting Party identified in the Post-GDA Commitment List, GHX00100084KPGB03GN.**
- **Assessment Finding 9: A future operator shall assess the impact of its proposed operating fuel cycle on the radioactive waste generation and disposal before implementing any changes.**
- **Assessment Finding 10: A future operator shall specify procedures to detect failed fuel and act to minimise discharges to the environment.**
- **Assessment Finding 11: A future operator shall periodically review and continue to optimise water chemistry regimes presented during GDA to reduce waste generation.**

- **Assessment Finding 12: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.**
- **Assessment Finding 13: A future operator shall define a procedure to follow in the event of leakage to the secondary circuit that demonstrates the discharge of activity to the environment is minimised.**
- **Assessment Finding 14: A future operator shall periodically review and continue to optimise the balance between gaseous, liquid and solid phase disposals of carbon-14.**
- **Assessment Finding 15: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to help inform future dose assessments.**

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Provisions on Optioneering Process for UK HPR1000 Generic Design Assessment (GDA) Project, GH-40M-018, Revision A, June 2019.

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List of SSCs and Engineered Controls that Contribute to the Application of BAT, GHX00100012DOHB00GN, Revision A, December 2019.

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Optioneering Report for Gaseous Radioactive Waste Processing Techniques, GHX00100038DNFF03GN, Revision F, April 2020.

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Optioneering Report for Liquid Radioactive Waste Processing Techniques, GHX00100042DNFF03GN, Revision F, April 2020.

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Optioneering Report for Operational Solid Waste Processing Techniques, GHX00100056DNFF03GN, Revision D, June 2020.

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Minimisation of the Discharge and Environment Impact of Tritium, GHX00100004DOHB00GN, Revision D, July 2020.

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Material Selection Report of SG, GHX00100034DPCH03GN, Revision C, October 2020.

GNSL, 2020f.

Optioneering Report for Secondary Neutron Source, GHX00100001DRRL03TR, Revision A, August 2020.

GNSL, 2020g.

Topic Report on Hydrogen Dosing Technical Analysis for the Primary Circuit, GHX00100008DCHS03GN, Revision G, October 2020.

GNSL, 2020h.

Topic Report on Startup on Shutdown Chemistry, GHX00100105DCHS03GN, Revision D, November 2020.

GNSL, 2020i.

Topic Report on Commissioning Chemistry, GHX00100102DCHS03GN, Revision D, November 2020.

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Compliance Analysis of RGPs for sample of HVAC systems, GHX00800001DCNT02GN, Revision A, May 2020.

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Holistic Design Review Strategy, HPR-GDA-REPO-0143, Revision 000, April 2020.

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Pre-Construction Environmental Report Chapter 3 – Demonstration of BAT, HPR/GDA/PCER/0003, Revision 002, October 2021.

GNSL, 2021b.

Minimisation of Radioactivity Route Map Report, GHX00100002DNHS03GN, Revision E, February 2021.

GNSL, 2021c.

Optioneering Report of the HEPA Filters Types, GHX08000003DCNT03TR, Revision E, June 2021.

GNSL, 2021d.

Report of Radionuclide Selection during Normal Operation, GHX00800001DRDG03GN, Revision E, January 2021.

GNSL, 2021e.

Derived Source Term Supporting Report, GHX00530001DNFP03GN, Revision E, July 2021.

GNSL, 2021f.

Requirement Management Summary Report, GHX00100127DOZJ03GN, Revision D, July 2021.

GNSL, 2021g.

Examination, Maintenance, Inspection and Testing (EMIT) Strategy, GHX42EMT001DOYX45GN, Revision D, March 2021.

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Periodic Test Design Methodology, NE15BW-X-YX-0000-000021, Revision C, January 2021.

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Operational Management during GDA – Gap Analysis against Environment Requirements, HPR-GDA-REPO-0191, Revision 000, May 2021.

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Post-GDA Commitment List, GHX00100084KPGB03GN, Revision C, August 2021.

GNSL, 2021k.

Generic Limits and Conditions for Normal Operation, GHX37OTS001DOYX45GN, Revision B, May 2021.

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Consistency Evaluation for Design of Facilitating Decommissioning, GHX71500005DNFF03GN, Revision E, March 2021.

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Decommissioning Waste Management Proposal, GHX71500009DNFF03GN, Revision G, July 2021.

GNSL, 2021o.

Pre-Construction Environmental Report, Chapter 4 Radioactive Waste Management Arrangements, HPR/GDA/PCER/0004, Revision 002, October 2021.

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Pre-Construction Environmental Report, Chapter 6 Quantification of Discharges and Limits, HPR/GDA/PCER/0006, Revision 002, October 2021.

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Topic Report on Surface Treatment of SSCs, GHX00100122DPCH03GN, Revision C, May 2021.

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Topic Report of pH Control in the Primary Circuit of UK HPR1000, GHX00100007DCHS03GN, Revision I, July 2021.

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Topic Report on Impurity Control for the Operation, GHX00100103DCHS03GN, Revision G, January 2021.

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Topic Report on Zinc Injection in the Primary Circuit of UK HPR1000, GHX00100010DCHS03GN, Revision F, April 2021.

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Topic Report on Application of Cobalt in SSCs, GHX00100048DPCH03GN, Revision E, March 2021.

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Minimisation of the Discharge and Environment Impact of Carbon-14, GHX00100005DOHB00GN, Revision D, May 2021.

GNSL, 2021w.

Expected Event List for UK HPR1000, GHX00500001DNFP02GN, Revision E, April 2021.

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Pre-Construction Environmental Report, Chapter 7 Radiological Assessment, HPR/GDA/PCER/0007, Revision 002, October 2021.

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Conceptual Proposal of ILW Interim Storage Facility, GHX00100063DNFF03GN, Revision E, March 2021.

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Management Proposal of Waste Non-fuel Core Components, GHX00100064DNFF03GN, Revision F, January 2021.

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Waste Inventory for Operational Solid Radioactive Waste, GHX00100069DNFF03GN, Revision E, April 2021.

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UK PARLIAMENT, 1995.

The Environment Act 1995.

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The Environmental Permitting (England and Wales) Regulations 2016 as amended May 2018.

List of abbreviations

ALARA	As low as reasonably achievable
ALARP	As low as reasonably practicable
BAT	Best available techniques
BFX	Fuel building
BNX	Nuclear auxiliary building
BQZ	ILW interim storage facility
BRX	Reactor building
BSA	Safeguard building a
BSB	Safeguard building b
BSC	Safeguard building c
BWX	Radioactive waste treatment building
CAE	Claims, arguments and evidence
CSBVS (EBA)[1]	Containment sweeping and blowdown ventilation system
CSTS (or TEP)	Coolant storage and treatment system
CVCS (or RCV)	Chemical and volume control system
CVS (or CVI)	Condensate vacuum system
DF	Decontamination factor
DPUR	Dose per unit release
EDF	Électricité de France
EMIT	Examination, maintenance, inspection and testing
ENDP	Engineering developed principle

[1] The UK HPR1000 systems have trigram acronyms in the submission documents which are three letter versions of the system acronyms as used for the European Pressurised Reactor (EPR)

EPF	Environmental protection function
EPR	European Pressurised Reactor
ETS	Environmental technical specification
FAC	Flow-accelerated corrosion
FAP	Forward action plan
FCG3	Fangchenggang 3
GDA	Generic design assessment
GNSL	General Nuclear System Limited
GTRF	Grid to rod fretting
GWTS (or TES)	Gaseous waste treatment system
HAW	Higher activity waste
HEPA	High efficiency particulate air filter
HFT	Hot functional test
HLW	High level waste
HPC	Hinkley Point C
HTO	Tritiated water
HVAC	Heating, ventilation and air-conditioning system
IAEA	International Atomic Energy Agency
ICIA	In-core instrument assembly
ILW	Intermediate level waste
LCO	Limiting conditions for operation
LLW	Low level waste
LLWR Ltd	Low Level Waste Repository Ltd (UK)
LMS (or KIL)	Leakage monitoring system
LRWMS	Liquid radioactive waste management systems
LWDS (CI) (or SEL)	Conventional island liquid waste discharge systems

LWTS (or TEU)	Liquid waste treatment system
MFFCS (or ARE)	Main feedwater flow control system
MSS (or VVP)	Main steam system
NABVS (or DWN)	Nuclear auxiliary building ventilation system
NLWDS (or TER)	Nuclear island liquid waste discharge system
NSS (or REN)	Nuclear sampling system
OECD	Organisation for Economic Co-operation and Development
ONR	Office for Nuclear Regulation
OPEX	Operating experience
PCER	Pre-Construction Environmental Report
PCSR	Pre-Construction Safety Report
P&ID	Process and Information Document
PRMS (or KRT)	Plant radiation monitoring system
PWR	Pressurised water reactor
REPs	RSR Environmental Principles
RGP	Relevant good practice
RCCA	Rod cluster control assembly
RI	Regulatory Issue
RO	Regulatory Observation
RQ	Regulatory Query
RSMDP	Radioactive Substance Management Developed Principle
RSR	Radioactive Substances Regulation
RWM	Radioactive Waste Management Ltd (UK)
SCC	Stress corrosion cracking
SCCA	Stationary core component assembly
SFAIRP	So far as is reasonably practicable

SFEN	Société Francaise d'Energie Nucléaire
SFP	Spent fuel pool
SG	Steam generator
SGBS (or APG)	Steam generator blowdown system
SNS	Secondary neutron source
SQEP	Suitably qualified and experienced person
SRS (or SRE)	Sewage recovery system
SSC	Structures, systems and components
SWTS (or TES)	Solid waste treatment system
TT	Thermal treatment
UK HPR1000	UK version of the Hualong Pressurised Reactor
VDS (or RPE)	Nuclear island vent and drain system
VLLW	Very low level waste
WFCSCI (or SEK)	Waste Fluid Collection System for Conventional Island

Glossary

Assumptions

Considerations that, together with requirements, are necessary to define the scope of the safety case.

Commitments

Additional pieces of work that come from the GDA process that the Requesting Party (or Site Licensing Company) need to complete to produce an adequate safety case.

Environment protection function

A function that is necessary to a facility to avoid and/or minimise radiological impacts to people and the environment.

Deflagration

An explosion in which the speed of burning is lower than the speed of sound in the surroundings.

Hazardous substances

Substances or groups of substances that are toxic, persistent and liable to bioaccumulate, and other substances or groups of substances which give rise to an equivalent level of concern.

Non-hazardous pollutant

Any substance that is not a hazardous substance but is liable to cause pollution in significant quantities.

Nuclear island

The parts of the plant where the reactor and its main supported systems which enable it to operate are located.

Requirements

Standards, expectations and conditions that the plant as built, operated and decommissioned will need to meet, and against which the safety case has been developed.

Sacrificial

Designed to be used up in fulfilling a purpose or function.

The regulators

Environment Agency and the Office for Nuclear Regulation.

Tramp uranium

Uranium contamination of the primary circuit

Appendix 1: Regulatory Queries and Observations relating to BAT

RQs and ROs that are most relevant to the application of BAT for the UK HPR1000 (There are no Regulatory Issues [RIs] raised during this GDA) are shown below. The Demonstration of BAT, Revision 002 (GNSL, 2021a) submission and supporting documents have been updated to include the responses made to all RQs and ROs. ROs are published on the ONR website, along with resolution plans. RQ information is not published, but all RQs relevant to BAT are summarised below. Progress against each has been discussed at technical level meetings with the RP.

Regulatory Queries:

- RQ-UKHPR1000-0194 (6 February 2019): Management of the aerial filtration systems. The regulators requested further information on the type of HEPA filter selected, conditioning of supply air and management of condensate in the HVAC system.
- RQ-UKHPR1000-0374 (19 July 2019): Hydrogen concentration in the primary circuit. The regulators requested further information on the proposed limits and conditions for hydrogen concentration in the UK HPR1000, together with details of the relevant optioneering.
- RQ-UKHPR1000-0375 (19 July 2019): Primary circuit pH and reactivity control through Li:B coordination. The regulators requested further information on the limiting values for lithium concentration in all relevant plant states and optioneering for the target pH value of 7.2.
- RQ-UKHPR1000-0427 (13 August 2019): Spent fuel pool tritium production. The regulators requested further information on the control and optimisation of the SFP water temperature and HVAC flow rate and air temperature to minimise tritium production.
- RQ-UKHPR1000-0428 13 August 2019): Aerial back migration. The regulators requested further information on the design of the containment sweeping and blowndown ventilation system (CSBVS) system to prevent the back migration of process air and potential unplanned discharge.
- RQ-UKHPR1000-0429 (13 August 2019): Carbon delay beds for gaseous wastes. The regulators requested further information on the optimisation of the delay bed parameters, management of the delay beds, and prevention of suspended activated particles from the delay beds.
- RQ-UKHPR1000-0430 (13 August 2019): Charcoal waste. The regulators requested further information on confirmation of the radioactive waste category of the charcoal waste and the expected activity levels, and the management of charcoal waste and the implication of failed fuel pins.
- RQ-UKHPR1000-0431 (13 August 2019): Control of carbon-14 production. The regulators requested further information on the choice of cover gas and controls in place to prevent/minimise entrainment of cover gas into the coolant.

- RQ-UKHPR1000-0434 (13 August 2019): Radioactive waste processing techniques optioneering. The regulators requested further information on how the optioneering processes applied in the reports meet the expectations of the RP's procedure and involvement of the technical committee.
- RQ-UKHPR1000-0487 (9 October 2019): Primary circuit pH and reactivity control through Li:B coordination. The regulators requested further information on optioneering for the target pH value of 7.2 in relation to the design choices and materials of the UK HPR1000.
- RQ-UKHPR1000-0490 (9 October 2019): Impurity control. The regulators requested further information on evidence for the proposed impurity controls levels.
- RQ-UKHPR1000-0498 (17 October 2019): BAT systems document request. The regulators requested the following additional documents for assessment: a list of BAT relevant main systems and components, the BAT Demonstration Checklist Guidance and an example Design or design-change BAT analysis record sheet.
- RQ-UKHPR1000-0536 (13 November 2019): Qualification of equipment for its intended environmental protection function. The regulators requested further information on the general method of equipment qualification for equipment or instrumentation that provides an environmental protection function - to include how a piece of equipment or instrument is shown to be fit for the intended purpose and kept in a state of maintenance and calibration consistent with its use.
- RQ-UKHPR1000-0537 (13 November 2019): Gaseous radioactive waste processing techniques optioneering. The regulators requested further information on the optioneering of processing techniques for radioactive particles, and clarification on the optioneering process used and the next steps following the optioneering.
- RQ-UKHPR1000-0538 (13 November 2019): HVAC iodine adsorbers. The regulators requested further information on the management of the HVAC iodine adsorbers.
- RQ-UKHPR1000-0540 (13 November 2019): Liquid radioactive waste processing techniques optioneering. The regulators requested further information on the use of ‘concentrate and contain’ of radioactive waste over ‘dilute and disperse’ to reduce environmental pollution and the use of OPEX to optimise the selected techniques, as well as clarification on the optioneering process used and the next steps following the optioneering.
- RQ-UKHPR1000-0618 (27 January 2020): Decommissioning missed opportunities for BAT demonstration. The regulators requested further information on volumes/weights of waste to provide a balanced demonstration of BAT and clarification that temporary treatment facilities will be demonstrated to be BAT.
- RQ-UKHPR1000-0633 (12 February 2020): Sampling and monitoring - general queries. The regulators requested further information on the arrangements for monitoring and sampling before disposal and to assess whether the waste packages meet the requirements for disposal.
- RQ-UKHPR1000-0709 (30 March2020): Topic report on start-up and shutdown chemistry Rev. C. The regulators requested further information on queries, including how the hydrazine addition volumes are calculated.

- RQ-UKHPR1000-0725 (3 April 2020): Demineraliser decontamination factors. The regulators requested further information on expected decontamination factors (DFs) for each demineraliser system and how the design is optimised to maximise abatement efficiency and radionuclide retention.
- RQ-UKHPR1000-0726 (3 April 2020): Operator guidance relating to BAT. The regulators requested further information on what guidance for operators will be provided to ensure operation is BAT.
- RQ-UKHPR1000-0745 (23 April 2020): Underground and embedded liquid containment systems. The regulators requested further information on a demonstration of BAT for avoiding and minimising underground and embedded liquid containment systems and managing these systems when they cannot avoid being used.
- RQ-UKHPR1000-1204 (20 October 2020): HEPA filter optioneering additional questions. The regulators requested further information in the HEPA filter optioneering report to resolve RO-UKHPR1000-0036.
- RQ-UKHPR1000-1255 (10 November 2020): Provision of leak detection and monitoring capabilities to facilitate decommissioning. The regulators requested further information on the leak detection and collection systems.
- RQ-UKHPR1000-1604 (18 March 2021): Steam Generator Material Selection and Ageing and Degradation mechanisms. The regulators requested clarification and further evidence to support the statements made within the SG reports.
- RQ-UKHPR1000-1655 (23 March 2021): Environment Limiting Conditions for Operation. The regulators requested information on environmental LCOs, including how environmental requirements will be used to shape the LCOs.

Regulatory Observations:

- RO-UKHPR1000-0004 (3 September 2018): Development of a suitable and sufficient safety case. The regulators requested evidence to demonstrate that the RP has adequate processes and controls in place to ensure that a suitable and sufficient safety case for UK HPR1000 will be produced and developed throughout GDA. This is fundamentally linked to the environment case and the demonstration of BAT.
- RO-UKHPR1000-0005 (26 October 2018): Demonstration that the UK HPR1000 design reduces the risks associated with radioactive waste management, so far as is reasonably practicable. The regulators requested a demonstration that risks relevant to radioactive waste management are reduced, *so far as is reasonably practicable*.
- RO-UKHPR1000-0012 (30 July 2019): Identification and application of relevant good practice applicable to mechanical engineering for the UK HPR1000 design. The regulators requested a demonstration that the design reduces relevant risks to ALARP. The RP’s strategy is to identify RGP and carry out a mechanical engineering gap analysis of the design against it.
- RO-UKHPR1000-0015 (13 September 2019): Demonstration that risks associated with fuel deposits are reduced so far as is reasonably practicable (SFAIRP). The

regulators requested details of the quantity and characterisation of the fuel deposits expected for UK HPR1000.

- RO-UKHPR1000-0021 (23 September 2019): Demonstration of the adequacy of examination, maintenance, inspection and testing (EMIT) of structures, systems and components important to safety. The regulators requested the strategy and approach to EMIT, the EMIT requirements and assumptions proposed for the generic UK HPR1000 design, and whether the design and safety case is consistent with UK legal requirements and regulatory expectations.
- RO-UKHPR1000-0026 (10 December 2019): Demonstration that radioactivity has been reduced so far as is reasonably practicable (SFAIRP). The regulators requested a demonstration that all reasonably practicable measures have been taken to reduce radioactivity in the UK HPR1000 SFAIRP.
- RO-UKHPR1000-0036 (26 March 2020): HEPA filter type. The regulators requested a demonstration that the optioneering study and justification of the choice of HEPA filter comprehensively considers the minimisation of fugitive discharges, energy use and the production and disposal of radioactive waste.
- RO-UKHPR1000-0037 (3 April 2020): In-core instrument assemblies radioactive waste safety case. The regulators requested a demonstrate that risks relevant to the radioactive waste management of in-core instrument assemblies (ICIAs) are reduced to ALARP.
- RO-UKHPR1000-0039 (7 April 2020): Performance analysis of UK HPR1000 heating ventilation and air conditioning systems. The regulators requested an HVAC environmental modelling and analysis strategy, to model and analyse the HVAC system, and carry out an ALARP analysis for the HVAC system.
- RO-UKHPR1000-0040 (15 April 2020): Providing an adequate safety case for the interim storage of intermediate level waste (ILW). The regulators requested a suitable and sufficient safety case for the interim storage of all ILW arising from the operation and decommissioning of the UK HPR1000.
- RO-UKHPR1000-0041 (24 April 2020): Disposability of higher activity waste from the UK HPR1000. The regulators requested an update on the Disposability Submission, a draft Disposability Assessment Report or a Disposability Summary Report to meet with the Environment Agency's public consultation timescales, provide the final Disposability Assessment report, main supporting documentation and a FAP, and update on Progress of the Disposability Assessment.
- RO-UKHPR1000-0042 (29 April 2020): Robust demonstration of ALARP for decommissioning the UK HPR1000. The regulators requested evidence of implementing the method for assessing design requirements for facilitating decommissioning.
- RO-UKHPR1000-0049 (14 August 2020): Generation, Transport and Behaviour of Tritium during Normal Operations. The regulators requested a demonstration that the behaviour of tritium in the UK HPR1000, during normal operations, is adequately understood and controlled.
- RO-UKHPR1000-0051 (2 October 2020): Demonstration of BAT for the Examination, Maintenance, Inspection and Testing (EMIT) of Systems, Structures and Components (SSCs) that provide an Environmental Protection Function (EPF).

The regulators requested a demonstration that EPF of SSCs can be maintained at all times under normal operations, commensurate to GDA stage and scope.

Appendix 2: The Requesting Party's documentation assessed

We referred to the following documents to produce this report and details of the most recent version of the documents are provided in the References section:

- Pre-Construction Environmental Report, Chapter 3 - Demonstration of BAT (HPR/GDA/PCER/0003).
- Pre-Construction Environmental Report Chapter 4 - Radioactive Waste Management Arrangements (GX00510004KPGB02GN).
- Pre-Construction Safety Report V1 Amendment Report for Environment Agency Public Consultation (HX00100122DPCH03GN).
- Pre-Construction Safety Report Chapter 10 - Auxiliary Systems (HPR/GDA/PCSR/0010).
- Pre-Construction Safety Report Chapter 21 - Reactor Chemistry (HPR/GDA/PCSR/0021).
- Pre-Construction Safety Report Chapter 23 - Radioactive Waste Management (HPR/GDA/PCSR/0023).
- Pre-Construction Safety Report Chapter 24 – Decommissioning (HPR/GDA/PCSR/0024).
- Pre-Construction Safety Report Chapter 28 - Fuel Route and Storage (HPR/GDA/PCSR/0028).
- Pre-Construction Safety Report - Chapter 29 Interim Storage of Spent Fuel (HPR/GDA/PCSR/0029).
- Minimisation of Radioactivity Route Map Report (GHX00100002DNHS03GN).
- BAT Methodology (GHX00100055DOHB03GN).
- Requirements on Optioneering and Decision-Making (HPR-GDA-PROC-0012).
- Provisions on Optioneering Process for UK HPR1000 Generic Design Assessment (GDA) Project (GH-40M-018).
- Guidance for Optioneering (HPR/GDA/REPO/0080).
- Optioneering Report of the HEPA Filters Types (GHX08000003DCNT03TR).
- Optioneering Report for Gaseous Radioactive Waste Processing Techniques (GHX00100038DNFF03GN).
- Optioneering Report for Liquid Radioactive Waste Processing Techniques (GHX00100042DNFF03GN).
- Optioneering Report for Operational Solid Waste Processing Techniques (GHX00100056DNFF03GN).
- Report of Radionuclide Selection during Normal Operation (GHX00800001DRDG03GN).
- Derived Source Term Supporting Report (GHX00530001DNFP03GN).
- Requirement Management Summary Report (GHX00100127DOZJ03GN).
- Examination, Maintenance, Inspection and Testing (EMIT) Strategy (GHX42EMT001DOYX45GN).

- Operational Management during GDA - Gap Analysis against Environment Requirements (HPR-GDA-REPO-0191).
- List of SSCs and Engineered Controls that Contribute to the Application of BAT (GHX00100012DOHB00GN).
- Consistency Evaluation for Design of Facilitating Decommissioning (GHX71500005DNFF03GN).
- Decommissioning Waste Management Proposal (GHX71500009DNFF03GN).
- Supportive Report of BAT on Nuclear Design (GHX00800007DRDG03GN).
- Topic Report of pH Control in the Primary Circuit of UK HPR1000 (GHX00100007DCHS03GN).
- Topic Report on Hydrogen Dosing Technical Analysis for the Primary Circuit (GHX08RCV001DNHX03GN).
- Topic Report on Startup on Shutdown Chemistry (GHX00100105DCHS03GN).
- Topic Report on Impurity Control for the Operation (GHX00100103DCHS03GN).
- Topic Report on Zinc Injection in the Primary Circuit of UK HPR1000 (GHX00100010DCHS03GN).
- Topic Report on Power Operation Chemistry (GHX00100104DCHS03GN).
- Topic Report on Commissioning Chemistry (GHX00100102DCHS03GN).
- Topic Report on Application of Cobalt in SSCs (GHX00100048DPCH03GN).
- Minimisation of the Discharge and Environment Impact of Carbon-14 (GHX00100005DOHB00GN).
- Minimisation of the Discharge and Environment Impact of Tritium (GHX00100004DOHB00GN).
- Material Selection Report of SG (GHX00100034DPCH03GN).
- Material Selection Methodology (GHX00100006DPCH03GN).

Appendix 3: Assessment of the Requesting Party's claims, arguments and evidence in relation to best available techniques

This appendix includes a summary of the RP's CAE in relation to best available techniques and our assessment of the CAE. The Demonstration of BAT submission (GNSL, 2021a) includes 5 claims (noted as sub-claims in the submission) and 24 arguments with associated evidence. We have assessed these and sampled the supporting evidence to reach our conclusions.

Our assessment of each claim is provided, in turn, below.

We note that at the outset the RP has identified several aspects a future operator will need to consider. These are termed FAPs and are defined in section 2.14. We agree that these are appropriate actions for future operators to address and have included an Assessment Finding to prompt future operator actions:

Assessment Finding 8: A future operator shall address the BAT relevant post-GDA commitments the Requesting Party identified in the Post-GDA Commitment List, GHX00100084KPGB03GN.

Claim 1: Prevent and minimise the creation of radioactive waste and spent fuel

This claim is supported by 7 arguments (1a-1g) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 1a: Minimise the concentration of fission products in the primary coolant by the design, manufacture and management of fuel

A summary of evidence the RP presented in support of Argument 1a in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Causes of fuel failure - provides evidence of the primary causes of fuel rod failure from IAEA reports.
- Minimising grid to rod fretting fuel failures - details the GTRF performance improvements in the UK HPR1000 fuel design.
- Minimising debris related fuel failures - provides evidence for the use of anti-debris devices and cleaning of fuel rods.
- Preventing manufacturing defects - provides evidence of the tests, inspections and manufacturing controls.
- Increasing the corrosion resistance of the cladding tube - details the corrosion resistance of the zirconium alloy fuel cladding.

- Minimising the risk of pellet-cladding interaction (PCI) related fuel failures - provides details of the shape of the fuel pellets to minimise PCI fuel failures.
- Minimising the presence of fissionable material on external fuel cladding surfaces - provides evidence of the measures taken during manufacture of the fuel assemblies.
- Fuel handling and storage system - provides evidence of the design measures to minimise dropping and collision of fuel assemblies.

The RP recognises that it is important to prevent fission products from leaking out of the fuel into the primary coolant and, in turn, to minimise the radioactive waste production from the treatment of the primary coolant. The RP highlights the causes of fuel failure identified by IAEA reports and discusses the likelihood of the causes of fuel failure, for example, grid to rod fretting (GTRF) has historically been the dominant cause of fuel failure in PWRs worldwide. The UK HPR1000 fuel adopts features that minimise GTRF used in other PWRs worldwide, including increased contact area and low relaxation spring design.

The type of fuel assembly specified in GDA (AFA 3G™ AA fuel assembly) is an established fuel design and is used worldwide with substantial OPEX (Société Francaise d' Énergie Nucléaire [SFEN], 1999). The AFA 3G™ AA fuel assembly is equipped with an anti-debris device. This consists of a mesh that is efficient in preventing debris in the primary coolant from passing through the nozzle and damaging the fuel. The fuel cladding is a zirconium alloy developed by Framatome and is recognised for minimising the risk of fuel failure resulting from corrosion confirmed by oxide film measurement on fuel rods (Framatome, 2020).

Our conclusions are that the fuel assembly includes the features that should minimise the frequency and severity of fuel failures that should minimise the concentration of fission products in the primary coolant. We also welcome the provision of operational specifications to a future operator that should help to minimise the likelihood of fuel failure (a FAP is detailed in section 2.14).

Argument 1b: Minimise the concentration of fission products in the primary coolant by detection and management of failed fuel

A summary of evidence the RP presented in support of Argument 1b in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- In-process sampling and monitoring to detect fuel failures - details the systems that sample and monitor to detect in core fuel failure and the associated response.
- Detection of failed fuel during unloading - provides evidence for the function of the online and offline sipping facilities.

The RP provides evidence that the design of the UK HPR1000 enables the detection and management of failed fuel assemblies to help prevent or minimise fission products from entering the primary coolant.

The nuclear sampling system (NSS) and the plant radiation monitoring system (PRMS) provide in-process sampling and monitoring respectively to detect fuel failure during normal operations, including details of the operator response to the 2 alarm levels which will be determined at the site-specific stage (A FAP is detailed in section 2.14).

Evidence is provided for the functions of the online and offline sipping facilities, including the details of the operator response to the gamma activity concentration exceeding the defined threshold (GNSL, 2021a).

Our conclusions are that these systems and facilities should provide an effective process to detect and manage failed fuel in the UK HPR1000 and welcome a FAP identified by the RP in section 2.14.

Argument 1c: Minimise the quantity of spent fuel by core dimension design and cycle length selection

A summary of evidence the RP presented in support of Argument 1c in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Core dimension - provides evidence that the larger core dimensions used in the evolved UK HPR1000 design require fewer fresh fuel assemblies to produce the same amount of energy.
- Cycle length - provides evidence that the selected 18-month fuel cycle produces less spent fuel than 12 or 24-month fuel cycles.

The RP acknowledges that optimising the efficiency of the UK HPR1000 to reduce the amount of spent fuel generated minimises the amount of spent fuel that will need managing and disposing of. The evolution of the UK HPR1000 has resulted in an increase in the core dimensions, which will subsequently result in using more spent fuel assemblies, but improving the thermal energy production per fuel assembly. The widely used 18-month fuel cycle length has been selected, which produces less spent fuel than 12 and 24-month fuel cycles (GNSL, 2021o). A future operator has the flexibility to choose a refuelling programme, so we have raised an Assessment Finding:

Assessment Finding 9: A future operator shall assess the impact of its proposed operating fuel cycle on the radioactive waste generation and disposal before implementing any changes.

Argument 1d: Minimise the generation of tritium in the primary coolant

A summary of evidence the RP presented in support of Argument 1d in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Use of zirconium alloy cladding for fuel rods - provides evidence that the selected fuel assembly has a very low failure rate to minimise tritium generation.
- Optimised boron concentration - details that boric acid with enriched 35% boron-10 is applied to reduce tritium production from boron-11.

- Use of lithium-7 enriched lithium hydroxide - details that lithium hydroxide with enriched 99.9% lithium-7 is applied to significantly minimise tritium production.
- Optimisation of design and use of secondary neutron sources - discusses the source of tritium from beryllium and the preliminary feasibility assessment of not using SNS assemblies.

The RP has defined tritium as a significant radionuclide because of the quantity of radioactivity that will be discharged from the UK HPR1000, although the dose to the public and impact on the environment from tritium discharges is low. The RP recognises that tritium is produced by the fission of heavy nuclei, the neutron activation of primary coolant constituents, such as boron, lithium, deuterium and the neutron activation of specific material constituents, for example, beryllium contained in the SNS.

The fuel assembly selected for the UK HPR1000 is a widely-used fuel assembly design (SFEN, 1999). The RP argues that the large amount of tritium inventory from ternary fission reactions in the fuel is a potential source of tritium in the primary coolant, but the fuel cladding failure of the selected fuel assembly has been significantly minimised, resulting in the low failure rate of the assembly. The NSS and PRMS provide in-process sampling and monitoring respectively to detect fuel failure during normal operations, as discussed in Argument 1b. We expect a future operator to ensure that its procedures on discovering a failed fuel pin will minimise discharges to the environment and have raised an Assessment Finding:

Assessment Finding 10: A future operator shall specify procedures to detect failed fuel and act to minimise discharges to the environment.

Boric acid is widely used to control reactivity in PWRs, and boric acid enriched with boron-10 is used in the UK HPR1000. This reduces the total amount of boric acid (less boron-11) and consequently reduces the amount of lithium hydroxide required for pH control.

The RP acknowledges that lithium hydroxide injected into the primary circuit to adjust the pH of the coolant contributes to tritium production and argues that tritium production is minimised by using lithium hydroxide with enriched 99.9% lithium-7 (GNSL, 2021r).

The RP states that SNS assemblies are used in the UK HPR1000 design to ensure sufficient neutron count for ex-core neutron detectors to monitor the state of the core and ensure criticality control. The SNS assemblies contain beryllium which is a significant source of tritium under neutron radiation. We think it is beneficial to remove them, provided the safety case can be made to do so, as has been done for other PWR designs in operation. The RP discusses the SNS options that could reduce or eliminate tritium production from SNS in an optioneering submission (GNSL, 2020f) and states that a future operator will need to continue to review the option for removing SNS assemblies for continued operational use. We have identified an Assessment Finding for an evaluation of the environmental impact of removing SNS.

Assessment Finding 6: A future operator shall periodically review the possibility to remove secondary neutron sources or to optimise their design at the earliest opportunity.

The RP has provided evidence for minimising the generation of tritium in the primary circuit within the scope of GDA, including proposed controls and limits on the sources of tritium production.

Argument 1e: Minimise the radioactivity level of waste by optimising the water chemistry in the primary coolant

A summary of evidence the RP presented in support of Argument 1e in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Primary coolant pH control - describes how primary coolant pH strongly influences the corrosion processes, which can affect the materials in the primary circuit and also the integrity of the fuel cladding.
- Hydrogen dosing - describes how the hydrogen concentration in the primary coolant is managed to reduce material corrosion.
- Hydrated hydrazine dosing - describes how hydrated hydrazine dosing during start-up reduces the generation of corrosion products.
- Control of impurities - provides evidence of how impurities in the primary circuit are minimised by UK HPR1000 systems.
- Optimisation of the chemistry regime - describes how zinc injection has been adopted as a design modification in the UK HPR1000 to minimise corrosion.

The RP recognises that primary circuit water chemistry has an important role in protecting equipment and generating radioactive waste during operation and can influence the waste classifications at decommissioning.

The primary coolant pH is selected to minimise solubility of corrosion products. The regulators queried the use of the coordinated boron-lithium regime to provide a target pH value of 7.2 for most of the cycle (Including RQ-UKHPR1000-0375 and 0487). The responses to the RQs provided additional OPEX and evidence that the target pH of 7.2 is balanced with the lithium concentration to minimise corrosion and resulted in updates to the Topic Report of pH Control in the Primary Circuit of UK HPR1000 (GNSL, 2021r).

Hydrogen is added in the primary coolant to maintain a reducing environment, which helps to suppress the radiolytic decomposition of water (oxygen source), and dissolved hydrogen concentration control is important in the development of the chemistry programme. The regulators queried the optioneering for the proposed hydrogen concentration and the evidence for choices for developing the chemistry programme (Including RQ-UKHPR1000-0374). The response to the RQ provided further information on how the hydrogen concentration is sustained to maintain a reducing environment and, therefore, minimise corrosion. This resulted in updates to the Topic Report on Hydrogen Dosing Technical Analysis for the Primary Circuit (GNSL, 2020g).

Hydrated hydrazine dosing during plant start-up creates a reducing environment that minimises the generation of corrosion products (GNSL, 2020h). Hydrazine injection produces a negligible amount of carbon-14 and this is minor compared to other sources of carbon-14 (Argument 1g). The regulators queried the management of the hydrazine injection (Including RQ-UKHPR1000-0709). The response to the RQ provided further information, including that the CVCS demineralisers are bypassed when hydrazine is injected to save damaging the resin from the ammonia that is formed and, therefore, reduce radioactive waste.

Low levels of impurities in the primary circuit are maintained by a number of systems that supply the primary coolant makeup water and purify the coolant of the primary circuit, so corrosion is minimised. The regulators queried the evidence provided for the justification of the proposed impurity controls levels to minimise corrosion (Including RQ-UKHPR1000-0490). The responses to the RQs discussed the corrosion mechanisms with additional evidence of the controls, and resulted in updates to the Topic Report on Impurity Control for the Operation (GNSL, 2021s).

The RP argues that adopting zinc injection is an example of optimising the chemistry regime as it minimises corrosion and subsequent deposition of any corrosion products that are produced (GNSL, 2021t). The benefits of adopting zinc injection are reducing the worker dose and for activity levels during maintenance and decommissioning. Zinc injection can produce carbon-14 in the coolant, but this is negligible compared to other sources of carbon-14 (Argument 1g). Zinc injection is regarded as good practice, contributes to minimisation of solid waste and is adopted as a design modification in the UK HPR1000.

Corrosion products present in the primary coolant deposited on fuel cladding surfaces can cause fuel failures and, in turn, an increase in spent fuel arisings and discharges. The fuel deposits are also known as crud. The regulators raised RO-UKHPR1000-0015 to ask to be provided with details of the quantity and characterisation of the fuel deposits expected for UK HPR1000. The RO was resolved with sufficient evidence that the primary circuit operating chemistry has been optimised to reduce the generation and accumulation of fuel deposits, during at-power, normal operations.

We recognise that the development of the primary circuit chemistry regime is a significant aspect of the design and operation of the UK HPR1000, and that the design appears to offer flexibility in terms of water chemistry control. We will expect a future operator to ensure optimised water chemistry regimes are consistent with the relevant GDA submissions or review and improve them, (if possible) as this is an important aspect in terms of reducing waste generation. We identify this as an Assessment Finding:

Assessment Finding 11: A future operator shall periodically review and continue to optimise water chemistry regimes presented during GDA to reduce waste generation.

Argument 1f: Minimise corrosion products generation and activation of structure and component through material selection

A summary of evidence the RP presented in support of Argument 1f in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Minimise or substitute elements susceptible to activation in SSCs material - provides evidence for the controls on the amounts of elements (cobalt, silver, antimony and nickel) that are easily activated and significantly contribute to waste generation.
- Application of corrosion-resistant material - provides evidence that the main materials of the primary circuit are corrosion resistant.
- Minimise material corrosion through passivation during hot functional test - briefly describes the factors affecting the passivation film to minimise corrosion of the material.

The RP recognises that material selection of SSCs is an important aspect for demonstrating BAT as corrosion and activation of SSCs form radionuclides and consequently contribute to radioactive waste and discharges. The RP argues that material selection for the UK HPR1000 considers OPEX from the life cycle of worldwide PWRs. It is argued that the amounts of elements which could easily be activated and significantly contribute to waste generation are strictly controlled (GNSL, 2021u).

Austenitic stainless steel and Alloy 690 are the main materials used in the primary circuit. These materials have corrosion resistance to the primary coolant and the surface finishing will be optimised to decrease corrosion rates and minimise the production of corrosion products. Austenitic stainless steel and Alloy 690 are widely used worldwide for primary circuit materials.

SG tubes are the most significant source of corrosion products as they have the largest surface area in contact with the primary coolant. The RP proposes using Alloy 690TT for SG tubes of UK HPR1000 in the material selection report of SG submission (GNSL, 2020e). Alloy 690TT is used in worldwide PWRs and was selected for the SG tubes based on RGP and OPEX, and as a result of an optioneering process following the material selection methodology (GNSL, 2019e). The regulators queried the relative corrosion resistance between Alloy 690TT and 800NG (RQ-UKHPR1000-1640) and the RQ response noted that Alloy 690TT performed better in terms of SSC resistance, SSC failure and corrosion resistance under deteriorated secondary side crevices chemistry condition (for example, accumulated alkaline sulphate concentration).

Alloy 690 is a nickel-based alloy and therefore a source of Co-58 via the activation of Ni-58. Co-58 production is minimised by optimising the surface treatment as well as controlling the water chemistry in the primary coolant (GNSL, 2021b). Nickel-based alloys are used because of their corrosion resistance, high temperature strength and thermal expansion properties. Alloy 690 has been developed and used without reported failure during operation following the observation of SCC on earlier stainless steel and alloy SG tube materials (GNSL, 2020e). Other SG tube materials include titanium stabilised austenitic stainless steels, although they are not widely used in the worldwide PWRs, so the OPEX was not applicable for the UK HPR1000 (GNSL, 2019e).

The chemistry regime during hot functional test (HFT) is optimised for important passivation processes to minimise corrosion of the material in the primary circuit. The passivation processes create a protective oxide film (GNSL, 2020i) which is beneficial in minimising waste. Passivation during hot functional testing is standard practice during commissioning of a nuclear power plant (IAEA, 2014).

We recognise minimising the use of certain elements and materials is beneficial in reducing waste, and we will expect a future operator to demonstrate that it has selected and procured appropriate materials, including cobalt based and nickel containing alloys, at the detailed design stage. Our expectation is that the minimisation of waste is considered, but there are other fundamental factors that influence material selection decisions, such as structural integrity and safety, which ONR has assessed (https://www.onr.org.uk/new-reactors/uk-hpr1000/reports.htm).

Argument 1g: Minimise the production of carbon-14 in the primary coolant

A summary of evidence the RP presented in support of Argument 1g in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Generation of carbon-14 - provides a summary for the sources and annual production of carbon-14.
- Optimising the generation of carbon-14 - provides evidence of reviews on minimising the production of carbon-14.
- Assessment of cover and flushing gas - provides a summary of an optioneering assessment, including associated OPEX and the conclusion that nitrogen is the preferred option.
- Optimisation of the generation of carbon-14 resulting from the use of nitrogen as a cover and flushing gas - provides evidence of an assessment of techniques with benefit and detriment discussions to reduce the nitrogen dissolved in the coolant.

The RP recognises that carbon-14 is one of the significant radionuclides in terms of its contribution to dose of the most exposed person and discharge activity. The RP carried out assessments to explore opportunities to minimise the generation of carbon-14. The assessments appropriately focused on generation of carbon-14 from the cover and flushing gas.

The carbon-14 minimisation submission (GNSL, 2021v) asserts that nitrogen is the next best choice after hydrogen as a cover gas. Nitrogen is chemically stable, does not react with water, is non-toxic and non-corrosive, making it a suitable cover gas. Nitrogen does however dissolve in the coolant and nitrogen-14 can be activated to form carbon-14. However, oxygen-17 is the main source of carbon-14 as it contributes to about 88% of the carbon-14 production. This is because the UK HPR1000 uses water as coolant, in which oxygen-17 is naturally present as one of the isotopes of oxygen, and its natural concentration in the coolant is constant. Nitrogen-14 in the primary coolant is the second source of carbon-14 as it contributes about 12% of the carbon-14 production. Nitrogen is used as a cover gas in existing nuclear power plants. Carbon-14 can be further reduced by using technologies, including floating barriers in tanks to minimise nitrogen entrainment.

The regulators queried the control of carbon-14 production (RQ-UKHPR1000-0431) and the RQ response prompted an update to the Minimisation of the Discharge and Environment Impact of Carbon-14 (GNSL, 2021v) submission. The updated minimisation submission provided a balanced benefit and detriment review to conclude that using nitrogen will generate more carbon-14. However, this was outweighed by the safety benefit of eliminating this source of hydrogen, and the associated risks of a hydrogen deflagration that would need to be managed using complex safety-related control systems.

Our conclusions are that a demonstration of BAT has been provided for the UK HPR1000 to minimise production of carbon-14. We have raised the following Assessment Finding.

Assessment Finding 12: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.

Claim 2: Minimise the radioactivity of gaseous and aqueous radioactive wastes discharged into the environment

This claim is supported by 7 arguments (2a-2g) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 2a: Minimise leaks of radioactive process fluids from containment systems

A summary of evidence the RP presented in support of Argument 2a in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Codes and standards - summarises the use of international codes and standards to develop and review the design.
- Welded connections - provides evidence for the preferential use of welded connections.
- Reliable isolation - provides evidence for the preferential use of double isolations in the containment systems.
- Hydraulic pressure testing - summarises the hydraulic pressure testing that will be designed at the site-specific stage to confirm the leak tightness of the containment systems and its components.
- Monitoring - provides evidence of radiation monitoring by the plant radiation monitoring system (PRMS) and leakage monitoring by the leakage monitoring system (LMS) and the associated response from a future operator (including carrying out coolant inventory procedures and potentially shutting down the reactor to examine the leak source and terminate the leak).

- Optimisation of embedded pipes and components - provides evidence that embedded pipes and components are minimised.
- Leaks collection by RPE [VDS] and SRE [SRS] - provides evidence of the function of the VDS and SRS and the measures taken to prevent leaks.
- Spent fuel pool containment and leak detection systems - provides evidence of leak detection between the concrete secondary containment and the steel liner and the reuse of any leakage in the VDS.
- Containment structure - provides evidence that the containment structure will be leak tight provided by the internal containment.

The design of the UK HPR1000 includes a range of provisions to help ensure that radioactive process fluids that are unavoidably created during operations are contained within the associated containment systems designated facilities. Relevant measures to ensure leak tightness, as described by the RP, include the preferential use of welded connections and double isolations, pressure testing, leak detection and collection systems.

The regulators queried the demonstration of BAT for avoiding and minimising underground and embedded liquid containment systems (RQ-UKHPR1000-0745). The response to the RQ confirmed that underground and embedded liquid containment systems are only included in the design where necessary. Embedded pipework adopts the design of double-layer casing where the outer pipe is in direct contact with concrete and the inner pipe transports the liquid. If the inner pipe leaks, it flows towards a sump, which can be visually inspected and is monitored.

The regulators queried the provision of leak detection and collection systems that contribute to minimise the leakage of radioactive liquid (RQ-UKHPR1000-1255). The response to the RQ provided details of the systems and associated responses to detected leaks. Although the RQ did not provide additional information, it did highlight that the detailed information is in the associated system design manuals. We will expect a future operator to demonstrate at the site-specific stage that the design of the containment systems includes leak detection and collection systems for the leakage of radioactive waste outside the primary containment boundary. The ONR have raised Assessment Finding AF-UKHPR1000-0178 (Ref. ONR, 2022) to request the evidence from a future operator.

Our conclusions are that a demonstration of BAT has been provided for the UK HPR1000 for measures for ensuring leak tightness at the GDA stage.

Argument 2b: Minimise the transfer of radioactivity into the secondary circuit

A summary of evidence the RP presented in support of Argument 2b in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Secondary circuit process description - summarises the function of the secondary circuit and the 3 steam generators (SGs).

- The design, manufacture and management of the steam generator - provides evidence that leaks are minimised by applying robust equipment design, commissioning and maintenance processes.
- Secondary circuit water chemistry - provides evidence of the techniques to avoid corrosion (particularly the SG tubes), heat transfer degradation and flow-accelerated corrosion (FAC).
- In-process monitoring to detect steam generators' leaks - provides evidence of the 4 in-process radioactive monitoring techniques provided by the PRMS.
- Management of potential radioactive gaseous and aqueous waste from the secondary circuit - summarises the treatment routes for gaseous and aqueous waste from the secondary circuit.

The RP recognises that the structural integrity of the SG is important in minimising the spread of radioactive contamination into the secondary circuit where it has the potential to contaminate downstream SSCs (GNSL, 2020e). The RP also argues that leak tightness from the SG primary side to the secondary side is assured by the design and in-service inspection. The RP has provided evidence that the material surfaces in contact with the primary and secondary coolants have been selected to ensure structural integrity and minimise the generation of corrosion productions during the design lifetime. Also, the RP has provided evidence of the optimisation of the primary and secondary circuit chemistry to minimise corrosion.

We note that the design includes 4 in-process radioactive monitoring techniques provided by the PRMS, including noble gases in the main steam line of the main steam system (MSS), nitrogen-16 in the main steam line of the MSS, radioactivity levels in the SG blowdown water via the sampling circuit, and radioactivity levels of non-condensable gas extracted from the CVS, which can detect and alert operators to an issue with the SGs, including a leak from the primary circuit into the secondary circuit. A small leak from the primary circuit into the secondary circuit is included in the list of expected events (GNSL, 2021w), with a minor impact on noble gases discharges. In the event of a steam generator tube rupture, the main feedwater flow control system (MFFCS) performs SG isolation and main feedwater isolation to avoid SG overfilling and prevent the radioactive fluid from releasing into the secondary circuit.

We endorse that the RP recommends placing a requirement on a future operator to carry out inspections of the SG during commissioning and at regular intervals throughout its operational lifetime (A FAP is detailed in section 2.14). Periodic SG inspection is normal practice at PWRs. We will expect a future operator to be able to demonstrate that a discharge of activity to the environment is minimised in the event of a leak from the primary circuit into the secondary circuit. We identify this as an Assessment Finding:

Assessment Finding 13: A future operator shall define a procedure to follow in the event of leakage to the secondary circuit that demonstrates the discharge of activity to the environment is minimised.

Our conclusions are that a demonstration of BAT has been provided for the UK HPR1000 for minimising the transfer of radioactivity into the secondary circuit at GDA.

Argument 2c: Minimise the radioactivity of gaseous radioactive waste discharges by optimising the HVAC system

A summary of evidence the RP presented in support of Argument 2c in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Configuration of HVAC systems - provides a summary of the HVAC.
- Designing HVAC systems to maintain negative pressure - summarises how the design maintains a building environment below atmospheric pressure to prevent the spread of contamination.
- Abatement of gaseous radioactive waste using HEPA filters and iodine adsorbers - summarises the provision and configuration of the HEPA filters and iodine adsorbers.
- Demonstration of performance of HEPA filters and iodine adsorbers - provides evidence of in-process monitoring and periodic testing to maintain the expected performance.

The RP argues that the HVAC system is designed and configured to abate radioactive particulates using HEPA filters and to abate radioactive isotopes of iodine using iodine adsorbers when iodine is detected to minimise the radioactivity of the gaseous radioactive waste before being discharged to the environment. The HVAC system for the UK HPR1000 is segregated into sub-systems according to the main areas. The regulators queried the management of the HVAC systems to prevent back migration of contamination (RQ-UKHPR1000-0428). The response to the RQ provided evidence that depressions are maintained to provide a sufficient extract pressure, and the velocity through the containment barrier is maintained greater than 0.5m/s to prevent back flow of air.

The regulators issued RO-UKHPR1000-0012 and RO-UKHPR1000-0039 with potential implications for the design of the HVAC system. The resolution of the ROs included writing the Compliance Analysis of RGPs for sample of HVAC systems submission (GNSL, 2020j), which noted some non-compliances with HVAC standards that were captured by RO-UKHPR1000-0036 as discussed in the following paragraphs.

HEPA filtration within the HVAC systems aims to ensure that the concentration of particulate matter within the gaseous radioactive waste stream is minimised during normal and accident conditions. The extent of filtration, in terms of the number of filter banks, has been designed to ensure appropriate efficiency based on demands from the plant areas. The regulators queried the management of the aerial filtration systems, including the choice of HEPA filter type (RQ-UKHPR1000-0194 and RO-UKHPR1000-0036). The response to the RQ provided evidence for the management of condensate that drains into the LRWMS and supply air centralised treatment in the BNX.

Going into our public consultation we cited a potential GDA Issue that required the RP to demonstrate how BAT is applied for the choice of high efficiency particulate air filter design. Based on the submissions the RP made, the regulators judged there were potential regulatory shortfalls associated with the following aspects as noted in RO-UKHPR1000-0036:

- the evaluation of the choices of HEPA filter type (rectangular versus cylindrical)
- demonstration that the selection of HEPA filter has considered the prevention of fugitive discharges by optimisation of the sealing efficiency
- the assessment of the impact the choice of HEPA filter has on the volume and disposability of the radioactive waste over the operational lifetime of a UK HPR1000 reactor
- demonstration of BAT for the choice of HEPA filter

The response to RO-UKHPR1000-0036 the RP presented consisted exclusively in the revision of Optioneering Report of the HEPA Filters Types (GNSL, 2021c). The HEPA optioneering report was updated twice to include clarification on some points in the RO (RQ-UKHPR1000-1204). The updates for the evaluation of the choices of HEPA filter type included an improved assessment of the options against the safety, environmental, technical and economic criteria. The supporting OPEX was expanded from 5 to 25 years, including OPEX from Yangjiang and Daya Bay, with the addition of OPEX statements from Électricité de France's (EDF's) French fleet and Sizewell B adding useful historical support to the Chinese OPEX. The RP ensured the relevant disciplines' SQEP participated in the optioneering and decision-making workshop.

The assessment of the environmental impact of fugitive discharges was expanded in the revised HEPA optioneering report (GNSL, 2021c), which took account of the response to RQ-UKHPR1000-1204. The HEPA optioneering report highlighted that the aerosol dose accounts for 0.1% of the total dose from gaseous discharges, indicating that fugitive discharges would be negligible and failed filters are included in expected events (which have been considered by the Environment Agency when assessing potential discharge limits). The negligible dose from fugitive discharges indicates that a small reduction in sealing performance for a filter choice will not be detrimental to the demonstration of BAT. The sealing performance and improvement measures section of the HEPA optioneering report was also expanded to include the improvements to techniques that are being considered for HPC and these improvements can be considered by a future operator at the site-specific stage. We have raised the following Assessment Finding.

Assessment Finding 4: A future operator shall consider the potential high efficiency particulate air (HEPA) filter sealing performance technique improvements being considered for nuclear new builds including Hinkley Point C to ensure application of good practice.

The generation of waste from the 2 filter options was demonstrated to be the same, with some reasonable assumptions made where information was not readily available. The HEPA optioneering report (GNSL, 2021c) indicated that for disposal the rectangular HEPA filters will be dented from both sides before super-compaction to fit the 210 litre drum and the super-compactor. In response to RQ-UKPR1000-1204, the HEPA optioneering report included an additional section on secondary waste. The management of rectangular filters for disposal was presented more clearly and indicated that the preparation for super-compaction would be undertaken by Low Level Waste Repository Ltd (LLWR Ltd).

In response to RQ-UKPR1000-1204, the HEPA optioneering report (GNSL, 2021c) noted that the advantages of cylindrical filters for facilities with higher levels of radioactivity are not applicable to a PWR with low levels of activity, which strengthened the demonstration of BAT. The RP noted that the holistic design review (GNSL, 2020k) did not impact the HEPA filter optioneering, and the other regulatory questions on ventilation are independent of the type of HEPA filters and therefore do not impact the HEPA filter optioneering. The RP submitted the information committed to in its resolution plan, which was sufficient to meet the intent of RO-UKHPR1000-0036. It has addressed the issues which led to it being raised, resulting in the RO being resolved.

The iodine adsorbers are bypassed under normal operations and they are brought into operation to reduce radioactive iodine if the PRMS system detects elevated concentrations of radioactivity. The regulators queried the management of the iodine adsorbers (RQ-UKHPR1000-0538) to determine if the design allows the HVAC iodine adsorbers to be operated in line for normal operations that are expected to produce radioactivity or only if the PRMS system detects elevated concentrations of radioactivity. The response to the RQ confirmed that the iodine adsorbers can be brought in line manually by a future operator if operations with potential to produce iodine are planned to be carried out. The RP has demonstrated that the HVAC technologies in the UK HPR1000 design represent BAT.

Argument 2d: Minimise the radioactivity of gaseous radioactive waste discharges by installing and optimising the gaseous waste treatment system (TEG [GWTS])

A summary of evidence the RP presented in support of Argument 2d in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Description of the TEG [GWTS] - provides a summary of the GWTS.
- Selection of the treatment techniques for noble gases - provides evidence for the choice of treatment technique for noble gases.
- Sizing of delay beds to support abatement of xenon and krypton - provides evidence that the number of delay beds and quantity of charcoal within them provides the necessary delay time.
- In-process sampling and monitoring to support demonstrating the application of BAT - provides evidence for the in-process sampling and monitoring carried out to ensure that the GWTS is operating as expected.

The RP argues that the GWTS manages gaseous radionuclides that are unavoidably generated during the operation of the UK HPR1000. The radionuclides present in the primary gaseous radioactive waste are mainly noble gases, carbon-14, tritium, iodine isotopes and other minor radionuclides (such as cobalt and caesium). The treatment techniques in the GWTS are selected for treating gaseous and particulate radionuclides present in the gaseous effluent. The RP submitted an optioneering report to support the demonstration of BAT for the selected treatment techniques in the GWTS (GNSL, 2020a). The regulators queried the optioneering process (RQ-UKHPR1000-0537) and the response to the RQ prompted an update to the optioneering report, which improved the demonstration of BAT. The update presented a more detailed BAT demonstration for the processing of noble gases (delay beds sizing), controls to optimise performance (humidity, pressure) and to map out information on radioactive iodines and particulates.

The RP argues that the activated charcoal delay beds technique for processing noble gases is deemed to be the best option for the UK HPR1000. This demonstrates BAT as it is a passive system requiring less maintenance and is used in other facilities in the UK. The regulators queried the management of the delay beds and the discharge of secondary waste (RQ-UKHPR1000-0429), and the management of the charcoal waste from the GWTS delay beds and HVAC iodine adsorbers (RQ-UKHPR1000-0430). The responses to the RQs confirmed that the charcoal in the GWTS delay beds is designed to last for the lifetime of the facility and is expected to be VLLW, and the HVAC iodine adsorbers waste is anticipated to be LLW. The RQ responses also provided evidence of how a future operator can optimise performance of the delay beds by managing parameters, including choice of charcoal media, and how temperature, pressure, humidity and flow rate are monitored. Filters are installed upstream and downstream of the delay beds to retain particles generated from the charcoal and, therefore, minimise the discharge of activity.

The RP argues that sampling and monitoring is carried out to ensure that the GWTS is operating as expected. Our assessment of the demonstration of BAT for the in-process sampling and monitoring is in a separate report (Environment Agency, 2022a).

The RP has demonstrated that using delay bed technology in the UK HPR1000 design and the size of the delay beds represents BAT.

Argument 2e: Minimise the radioactivity of aqueous discharges by optimising the liquid radioactive waste management system

A summary of evidence the RP presented in support of Argument 2e in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Configuration of the liquid waste management system - provides a summary of the design policies the LRWMS is based on and a summary of the systems in the LRWMS.
- Minimise the radioactivity of aqueous discharges by coolant storage and treatment system TEP [CSTS] - provides a summary of the treatment techniques in the CSTS and evidence that most of the primary effluent is reused.
- Description of liquid wastes - provides a summary of the liquid wastes via the associated drains.
- LRWMS tank sizing - provides evidence for the capacity of each tank in the LRWMS.
- LRWMS treatment techniques - provides evidence of the optioneering process for treatment techniques and the optimisation of the LRWMS.
- In-process sampling and monitoring for demonstrating performance - provides a summary of the in-process monitoring and sampling techniques used for the LRWMS.

The RP argues that liquid radioactive waste will only be discharged to the environment after appropriate treatment, and monitoring and sampling has demonstrated that concentrations of radioactive substances are appropriate for discharge. The RP submitted an optioneering report to support the demonstration of BAT for the selected treatment techniques in the LRWMS (GNSL, 2020b). The regulators queried the optioneering process (RQ-UKHPR1000-0540) and the response to the RQ prompted an update to the optioneering report, which improved the demonstration of BAT. The update provided an enhanced optioneering of the treatment techniques and details of the decision-making workshop attended by environmental leads.

The techniques in the LRWMS include using filters, demineralisers and evaporators as shown in Figure 3 in section 2.8. The filters remove insoluble particles and fibres, the demineralisers remove soluble radionuclides, and the evaporators reduce liquid waste volumes and keep impurities in the concentrate. The demineralisers contain ion exchange resin and the regulators queried the validity of expected DFs and how the DFs are optimised (RQ-UKHPR1000-0725). The response to the RQ confirmed that the expected DFs are determined from OPEX and demonstrated that the abatement efficiency is optimised by considering factors, including resin volume, equipment design parameters and other measures to maximise the efficiency (such as monitoring and sampling, and pH and impurity control). The choice of which ion exchange resin to use is for a future operator to make, therefore a future operator will need to demonstrate that the selection of resin and resin change strategy used in demineralisers is optimised and can be demonstrated to be BAT. We have raised an Assessment Finding to this effect.

Assessment Finding 7: A future operator shall demonstrate that the UK HPR1000 will be operated in a way that represents best available techniques for the selection and change strategy of demineraliser resins and filters for liquid waste management systems.

The RP argues that in-process monitoring and discharge sampling and monitoring enables a future operator to appropriately manage the process to minimise waste in the LRWMS. Our assessment of the in-process and discharge sampling and monitoring is in a separate assessment report (Environment Agency, 2022a).

The UK HPR1000 design benefits from inherent features that allow liquid to be reused, and this is helped by applying appropriate techniques to concentrate and contain waste, where practicable. The RP has demonstrated that the design of the UK HPR1000 liquid radioactive waste management system represents BAT.

Argument 2f: Minimise the discharge of tritium

A summary of evidence the RP presented in support of Argument 2f in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- The spent fuel pool cooling and environmental conditions - provides evidence of a detailed analysis of the factors affecting the production of tritium.

- Assessment of alternative options for tritium treatment - provides evidence that there are no available technologies for tritium abatement at low concentrations.

The RP recognises that the primary sources of gaseous tritium are evaporation from the SFP and the reactor pool (used during refuelling). The regulators queried the design of the SFP and HVAC system in terms of minimising tritium production as optimisation of the SFP temperature and HVAC flow rate are important factors in minimising the discharge of tritium (RQ-UKHPR1000-0427). The response to the RQ resulted in an update to the Demonstration of BAT (GNSL, 2021a) and additional detailed analysis in the Minimisation of the Discharge and Environment Impact of Tritium (GNSL, 2020d). We agree with the conclusions from the analysis that there were low environmental benefits from further developing the factors affecting the evaporation from SFP and the reactor pool as it is a small proportion of the total dose impact, and it would be disproportionate to change the design.

The RP argues that following an assessment of techniques for the abatement of tritium, including consideration of the IAEA review and the Organisation for Economic Co-operation and Development's (OECD) technical reports, there are no currently viable technologies for tritium abatement at low concentrations, and we support this view. Minimising tritium production at source is detailed in Argument 1d.

Argument 2g: Minimise the discharge of carbon-14

A summary of evidence the RP presented in support of Argument 2g in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Assessment of alternative options for carbon-14 treatment - provides evidence that it is not practicable to abate gaseous carbon-14.

The RP argues that following a technology assessment, including considering the IAEA review and OECD technical reports, there are no commercially viable abatement techniques for gaseous carbon-14 that have been successfully used on a PWR. We agree with the RP's view. However, given carbon-14 is the main contributor to dose, we will require a future operator to review the practicability of techniques for abating carbon-14 at the site-specific permitting stage and periodically thereafter. We have raised an Assessment Finding to this effect.

Assessment Finding 5: A future operator shall have arrangements to periodically review the practicability of techniques for abating carbon-14.

Claim 3: Minimise the impact of discharges on people and non-human biota

This claim is supported by 4 arguments (3a-3d) and extensive evidence. We summarise each argument below and provide our conclusions.

Argument 3a: Partitioning of radionuclides has been optimised to minimise the impact on members of the public and the environment

A summary of evidence the RP presented in support of Argument 3a in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- DPUR for annual discharges - provides evidence for the calculation of DPUR values. The conclusion is that, for tritium, the DPUR is higher if discharged in the gaseous phase for all considered cases. For carbon-14, the DPUR to individuals of the public is higher in the liquid phase and higher in the gaseous phase for the UK and world population collective dose.
- Expected quantity and distribution of phases and chemical forms of tritium and carbon-14 in the annual discharges - provides detail of how the different forms of tritium and carbon-14 behave in the environment in the liquid and gaseous phase.
- Radiological impact mechanism of carbon-14 - briefly summarises the radiological assessment method and the results detailed in PCER Chapter 7 Radiological Assessment (GNSL, 2021x).

The RP argues that the design optimises the phase of tritium to the liquid phase to minimise the impact on members of the public and the environment. We agree that the measures taken in the design will enable the majority of tritium to be discharged in the liquid phase. The RP also argues that the design will not dictate the phase for carbon-14 as the dose per unit release (DPUR) values for the liquid and gaseous phase are higher and lower for different DPUR cases.

We agree that the chemical form of tritium is controlled by the design as tritiated water (HTO) and discharging tritium in the liquid phase is preferable to discharging tritium in the gaseous phase. This is because the total DPUR for the annual tritium discharge into the receiving water environment is lower than that for the annual tritium discharge into the atmosphere. The DPUR for carbon-14 is lower to individuals but there is a higher collective dose to the UK and the world population if discharged in the gaseous phase and vice versa. Therefore, the RP's approach to allow a future operator to define the balance between the gaseous and liquid phase of annual discharges and solid waste of carbon-14 is acceptable and we have raised the following Assessment Finding:

Assessment Finding 14: A future operator shall periodically review and continue to optimise the balance between gaseous, liquid and solid phase disposals of carbon-14.

The radiological assessment models used during GDA for the assessment of dose do not distinguish the chemical forms of carbon-14. Therefore, the contribution of the chemical forms of carbon-14 present in annual discharge has not been quantified, so we have raised the following Assessment Finding:

Assessment Finding 15: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to help inform future dose assessments.

Our assessment of dose to members of the public and the environment is provided in the generic site description and assessment of dose to the public and to wildlife assessment report (Environment Agency, 2022f).

Argument 3b: Eliminate solids, gases and non-aqueous liquids entrained within aqueous radioactive waste

A summary of evidence the RP presented in support of Argument 3b in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Removal of entrained gases by TEP [CSTS] - provides evidence for the degassing process carried out in the CSTS

The RP argues that the techniques implemented in the LRWMS for eliminating solids, gases and non-aqueous liquids will minimise entrained radioactive waste before being discharged into the environment. The RP recognises that a future operator will need to develop a management strategy during commissioning to ensure any non-aqueous liquid waste is separated from aqueous wastes before being discharged. A future operator will also need to develop management controls during the site-specific stage to further minimise the potential to contaminate aqueous waste with non-aqueous liquids (A FAP is detailed in section 2.14).

Argument 3c: Optimisation of the discharge stack height

A summary of evidence the RP presented in support of Argument 3c in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Impact of gaseous radioactive discharges on members of the public and non-human biota - briefly summarises the radiological assessment carried out in PCER Chapter 7 - Radiological Assessment (GNSL, 2021x).

The RP argues that the height of gaseous discharges from the main stack will help to minimise the dose to members of the public and the environment. The RP has carried out a dose assessment based on an assumed stack height of 70 metres. This indicated that the total dose is below the dose constraint (300μSv/y) and screening value (10μGy/h), which is adequate for the GDA stage of assessment.

The RP recognises that determining the stack height will be a site-specific activity for a future operator and captured this as a FAP. Determining the stack height involves complex modelling requiring detailed site-specific parameters. An Assessment Finding has been raised in the monitoring assessment report (Environment Agency, 2022a).

Argument 3d: Optimisation of the location and timing of liquid discharge

A summary of evidence the RP presented in support of Argument 3d in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Impact of liquid radioactive discharges on members of the public and non-human biota - briefly summarises the radiological assessment carried out in PCER Chapter 7 - Radiological Assessment (GNSL, 2021x).

The design of the UK HPR1000's liquid effluent management system allows the timing and location of effluent discharges to be controlled. The RP has carried out a dose assessment based on the generic site. This indicated that the total dose is below the human dose constraint (300µSv/y) and wildlife screening value (10µGy/h), which is adequate for the GDA stage of assessment.

The timing and location of effluent discharges should be progressed with a future operator at the site-specific design stage. We also note that design features enabling controlled discharges and suitable characterisation of liquid effluents are consistent with the demonstration of BAT (BAT demonstration assessment in Environment Agency, 2022a).

Claim 4: Minimise the mass/volume of solid and non-aqueous liquid radioactive wastes and spent fuel

This claim is supported by 3 arguments (4a-4c) and extensive evidence. We summarise each argument below and provide our conclusions. Further assessment of the solid and non-aqueous liquid radioactive wastes and spent fuel can be found in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b).

Argument 4a: Minimise the volume of structures, systems and components that will become radioactive waste

A summary of evidence the RP presented in support of Argument 4a in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Reduce the volume of solid radioactive waste by optimising the system configuration - provides examples of systems that have been optimised while maintaining the systems' safety and operational functions.
- Minimise the volume of solid radioactive waste by radiation zoning and contamination zoning - the use of undesignated and designated areas is described in relation to minimising the volume of solid radioactive waste.
- Minimise the volume of solid radioactive waste by optimising the building layout - buildings are located in close proximity to minimise the length of pipes and concrete for construction.

The management, treatment and disposal considerations considered during the design of the UK HPR1000 help to minimise the generation of solid radioactive waste. Several SSCs have been removed, while maintaining the system's safety and operational functions, including 39 manual valves removed along with relevant piping systems for the reactor coolant system. This will reduce the volume of solid radioactive waste produced during plant maintenance and decommissioning. Items of plant equipment have also been removed as the design has evolved, including a non-regenerative heat exchanger, which will reduce radioactive waste at decommissioning.

The RP states that the UK HPR1000 contamination and access control approach is based on the international RGP and is the same as the UK philosophy. The approach includes separating active and non-active work in controlled and supervised areas to limit the spread of contamination and, therefore, reduce the secondary waste.

The buildings in the nuclear island that are in GDA scope are within close proximity of each other, which is beneficial for the systems that transfer radioactive waste for abatement. Buildings outside the nuclear island and not subject to detailed design in GDA include the conceptual radioactive waste stores. These will benefit from being close to the nuclear island to ensure waste packages are not transferred over long distances and pipe length is minimised to prevent leakage.

Our conclusion is that the evolution of the design has removed several SSCs that would otherwise become radioactive waste. The zoning approach is based on international RGP and buildings in the nuclear island are close to each other.

Argument 4b: Minimise the volume of solid radioactive waste by extending the design life of SSC and reusing maintenance equipment and tools

A summary of evidence the RP presented in support of Argument 4b in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Extending the design life of equipment - provides examples of components and equipment that have, where possible, been designed with a design life of 60 years.
- Optimising the design of filters and demineralisers to extend the equipment service life - presents details on design improvements to extend the life of filters and demineraliser resins.
- Controlling operational parameters to maintain the performance of filters and demineralisers - describes the measures adopted to maintain the operational performance as well as to protect the components.
- Minimise the volume of solid radioactive waste by reusing maintenance equipment and tools located in the controlled area - provides details on the provision of space within the controlled area to enable a future operator to store and reuse maintenance equipment, including tools.

The UK HPR1000 has been designed with a minimum design life of 60 years. The replacement of some SSCs with a limited operational life is unavoidable and the RP has considered replacing them less often to minimise the volume of solid radioactive waste.

The size and operating conditions of the filters, demineralisers and evaporators have been optimised so they do not need replacing as often and, therefore, create less solid radioactive waste. The regulators queried the configuration and management of demineralisers to optimise the treatment and flexibly balance liquid discharges versus production of solid waste (RQ-UKHPR1000-0783). The response to the RQ provided evidence of the flexible configuration of the demineralisers, which gives a future operator choice. For example, the design of the demineraliser unit of the LWTS allows a future operator to use the 3 resins beds in series, as 2 in series or only one on its own to optimise the abatement and liquid discharges versus the production of solid waste. A future operator will need to demonstrate that the selection of resin and resin change strategy used in demineralisers is optimised and can be demonstrated to be BAT. We have raised the following Assessment Finding:

Assessment Finding 7: A future operator shall demonstrate that the UK HPR1000 will be operated in a way that represents best available techniques for the selection and change strategy of demineraliser resins and filters for liquid waste management systems.

The regulators queried the use of the first delay bed as a guard bed and how the delay beds parameters (humidity and pressure) will be optimised to minimise discharges and extend the life of the delay beds (RQ-UKHPR1000-0429). The RQ response confirmed that the first delay bed is not sacrificial and can be bypassed without impacting the ability of the delay bed system. The flexible system allows the bypassed delay bed to be maintained and returned to service. The RP also confirmed that the temperature, humidity, pressure and flow rate are monitored to optimise the operation of the delay beds, and the waste from the delay beds is expected to be LLW during decommissioning (RQ-UKHPR1000-0430).

The measures the RP detailed contribute to reducing the volume of solid radioactive waste that will be produced and collectively demonstrate BAT. The RP's resolution of the HEPA filter choice RO (RO-UKHPR1000-0036), see Argument 2c, has provided a demonstration that the choice of HEPA filter represents BAT.

Argument 4c: Reducing the volume of solid waste and non-aqueous liquid waste requiring disposal by adopting efficient segregation, treatment techniques and container selection.

A summary of evidence the RP presented in support of Argument 4c in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Segregation of waste - describes how solid radioactive wastes and spent fuel are segregated and collected based on their waste category, and how they are stored, transferred and treated independently of each other, to prevent mixing and cross-contamination.
- Best use of off-site LLW treatment services to minimise the volume of LAW - provides information on the optioneering studies carried out and use of LLW treatment services.
- Waste treatment technology and container selection for HAW to minimise the volume of HAW - provides information on the optioneering studies carried out for managing and minimising HAW.

- Minimising the volume and radioactivity of solid radioactive wastes by decay storage - presents details on the decay storage of boundary wastes.

The RP recognises that the solid and non-aqueous liquid radioactive wastes generated by the UK HPR1000 will place demands on the capacity of current and planned disposal routes in the UK. The RP argues that the design includes a number of techniques and facilities that will allow a future operator to reduce the volume of solid and non-aqueous liquid radioactive wastes requiring disposal.

The RP carried out optioneering studies to determine the preferred options of solid radioactive waste processing techniques and packaging, considering the principles of BAT. The selected techniques provide a demonstration that the volume of solid and non-aqueous liquid radioactive wastes will be minimised.

The RP observes that decay storage is a recognised practice in the nuclear industry and is particularly useful for managing boundary waste (including ILW that decays to LLW). The RP argues that the UK HPR1000 has sufficient storage capacity for decay storage. The regulators queried the design and management of the ILW interim storage facility (BQZ) and the selected 2-phased approach (RO-UKHPR1000-0040). The 2-phased approach can provide knowledge from the construction and operator of the first store, which can be incorporated into the second store. The resolution of the RO included the revision of the Conceptual Proposal of ILW Interim Storage Facility submission (GNSL, 2021y) to include additional information on OPEX and EMIT of SSCs which improved the demonstration of BAT.

We recognise that decay storage can reduce the activity of waste that needs disposing of, and that this is a particularly useful approach for radionuclides with short half-lives. We also support plans for early waste treatment and conditioning, where appropriate, as de-watering and immobilisation helps to ensure containment and reduce future burdens where it is shown that robust and disposable products can be produced, as long as options are not ruled out for a future operator.

Claim 5: Select the optimal disposal routes for wastes

This claim is supported by 3 arguments (5a-5c) and extensive evidence. We summarise each argument below and provide our conclusions. Further assessment of the disposal routes for wastes can be found in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b).

Argument 5a: The provision of waste management facilities with sufficient space and services to allow a future operator to install a range of waste management processes

A summary of evidence the RP presented in support of Argument 5a in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Waste characterisation and assessment facilities - provides evidence to support the conclusion that providing enough space in the design will allow a future operator to characterise waste.
- Segregation and sorting facilities - provides evidence to support the conclusion that providing enough space in the design will allow a future operator to segregate and sort waste.
- Waste treatment facilities - provides details of the ILW and LLW treatment facilities, including summaries of the wastes.
- Waste storage capacity - provides evidence to support the conclusion that enough space has been provided for a future operator to optimise storage of LLW, ILW and spent fuel.

The design of the UK HPR1000 waste treatment facilities include the space and services that are required to install the equipment necessary to characterise, treat and store waste. This, it is argued, will allow a future operator to implement the optimal waste disposal route for radioactive solid waste. Therefore, for GDA, the RP has aimed to demonstrate that waste could be disposed of to appropriate routes based on currently established practice and national plans. Future site operators would need to select the actual disposal routes and demonstrate that they are BAT.

Characterisation, sorting, treatment and storage provisions will allow consignment to appropriately permitted routes, including those currently provided by waste management service providers. The regulators queried the arrangements for monitoring and sampling before disposal and whether the waste packages meet the requirements for disposal (RQ-UKHPR1000-0633). The response to the RQ provided an example approach for HLW/ILW boundary waste, which included:

- gamma spectrometry at source and/or before packaging
- calculation of the expected decay time
- transfer to the relevant storage area
- monitoring/inspection during the storage period
- retrieval from the storage area once the package has decayed to the lower category
- monitoring to confirm it can be disposed of or transferred to another building

As the characterisation strategy for solid and non-aqueous liquid waste has only been developed at a concept level during GDA we have raised an Assessment Finding in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b). The information provided by the RP provides confidence that the sampling of the solid wastes will be feasible for the UK HPR1000. Our Assessment Finding concerns a future operator further developing a characterisation strategy and sampling approach for solid wastes, within the detailed design stage, to ensure that the approach will be BAT.

Overall, we recognise that the design does not constrain future operators, and our conclusions are that the RP has provided a sufficient case in this respect for GDA.

Argument 5b: All solid and non-aqueous liquid lower activity wastes have been demonstrated to be compatible with waste treatment and disposal services available in the UK by obtaining ‘agreements in principle’ from service providers

A summary of evidence the RP presented in support of Argument 5b in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Agreement in principle - provides justification for the assumption that LLWR Ltd will provide all waste services via a waste service contract.

The RP has engaged with the suppliers of waste management services for solid and non-aqueous radioactive waste in the UK. Agreement in principle has been obtained for LAW arisings from the UK HPR1000 with LLWR Ltd. The regulators challenged the RP to find out if there will be non-radioactive hazardous substances associated with the LLW wastes arising from the UK HPR1000 (RQ-UKHPR1000-0636). The RP's response to the RQ showed there were no hazardous substances, but there were a number of non-hazardous pollutants. We are satisfied that the RP has assessed the inventory for hazardous materials and non-hazardous pollutants, for this stage of GDA.

We consider this ‘agreement in principle’ with LLWR Ltd suitably demonstrates waste compatibility with current disposal routes based on high level descriptions of waste inventory and characteristics. A future operator would be expected to confirm future compatibility by further detailed assessment against waste acceptance criteria at that time.

Argument 5c: Disposability assessments have been undertaken to demonstrate that all solid HAW are compatible with disposability concepts prepared by Radioactive Waste Management Ltd for the UK’s proposed GDF

A summary of evidence the RP presented in support of Argument 5c in the Demonstration of BAT submission (GNSL, 2021a) is as follows:

- Disposability assessment – spent fuel and HLW - provides a summary of the considerations of the disposability assessment for spent fuel and HLW, including RCCA, SCCA and ICIA.
- Disposability assessment – intermediate level waste - provides a brief summary of the current assessment of compatibility of the proposed waste packaging options with anticipated long-term waste management requirements.

The RP has explored the requirements for the disposability assessments and has obtained disposability advice from Radioactive Waste Management Limited (RWM). The regulators queried the production of the disposability assessment (RO-UKHPR1000-0041), including seeking assurance that the RP’s and RWM’s plans are aligned and can be completed within GDA timescales. Details of the resolution of RO-UKHPR1000-0041 are discussed in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2022b).

The regulators queried the management of the ICIAs (RO-UKHPR1000-0037), including seeking justification for the decay storage. The resolution of the RO included the revision of submissions including the Management Proposal of Waste Non-fuel Core Components (GNSL, 2021z) and Waste Inventory for Operational Solid Radioactive Waste (GNSL, 2021ab) submissions. The updates to the submissions included information on the waste minimisation of ICIAs, decay storage of HLW ICIAs in the SFIS facility and presented information and justification of the classification and segregation of the ICIAs into LLW, ILW and/or HLW.

Appendix 4: Forward action plans identified by the Requesting Party

The following list of FAPs is from the Demonstration of BAT (GNSL, 2021a) submission and shows the areas that the RP considers a future operator will need to follow up, either during site-specific design or during commissioning and operations. The list of FAPs is included in the Post-GDA Commitment List (GNSL, 2021j) submission along with other BAT relevant commitments from sources including RQs and technical meetings. We have raised an Assessment Finding to capture the identified BAT commitments in the Post-GDA Commitment List (GNSL, 2021j) submission:

Assessment Finding 8: A future operator shall address the BAT relevant post-GDA commitments the Requesting Party identified in the Post-GDA Commitment List, GHX00100084KPGB03GN.

Forward action plans the RP identified in the Demonstration of BAT (GNSL, 2021a) are as follows:

- Future operator will develop management controls that will include QA requirements to minimise external debris within the primary circuit.
- Introduction of increasingly robust pre-commissioning inspection regimes to identify and remove external debris.
- Provide the future operator with operating technical specifications.
- Placing a requirement on the future operator to undertake inspections of the SG during commissioning and at regular intervals throughout its operational lifetime.
- The future operator will also develop management controls that will further minimise the potential to contaminate aqueous waste with non-aqueous liquids.
- Design of the main discharge stack use BAT and the parameters including the effective discharge height should be optimised considering process needs, feasibility, safety aspect and environmental aspect.
- Design of the liquid waste discharge point should use BAT to minimised environmental impact taking into account the dispersion characteristics of the receiving water environment.
- The future operator will document any requirements for liquid waste discharge control (frequency, concentration, flowrate) within appropriate management arrangements which satisfy relevant discharge limits.
- The future operator will present proposals for managing waste prior to operations commencing and provide a demonstration that such proposals represent BAT.
- The future operator will determine the final disposal routes for LAW and demonstrate that such proposals represent BAT.
- The future operator will determine the final disposal routes for HAW and demonstrate that such proposals represent BAT.
- Alarm values of relevant KRT [PRMS] monitoring channels will be determined at site-specific stage.

- The action which should be taken when the level of fuel failure indicator is exceeded will be defined at site-specific stage.
- Carry out hydraulic water pressure test design for fluid system: this design activity is integrated in the commissioning tests design of the system and is not covered by the GDA Scope.
- The future operator will decide when necessary to adopt a mobile unit for separating the non-aqueous liquid wastes from aqueous radioactive wastes generated from nuclear island prior to discharge.
- Appropriate arrangements, methodologies and processes will be further developed for the development of environment protection functions and associated requirements, notably in terms of manufacturing, commissioning and operation, including examination, maintenance, inspection and testing (EMIT) requirements.
- The management strategy of failed fuel will be finalised at site-specific stage.
- Engage with relevant supplier to discuss other SNS design options, undertake detailed optioneering for SNS and make decision the final SNS design.

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