Preliminary detailed assessment of best available techniques (BAT) for General Nuclear System Limited’s UK HPR1000 design - AR03

Version 1, 11 January 2021

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Executive summary

This report covers our Generic Design Assessment (GDA) of General Nuclear System Limited's (GNSL's) submission on best available techniques (BAT) for the United Kingdom Hualong Pressurised Water Reactor design (UK HPR1000) as required in Table 1, Items 2, 4 and 5 of our Process and Information Document (P&ID) (Environment Agency, 2016).

Our assessment has considered GNSL's submission in relation to relevant UK policy, legislation and guidance, including Environment Agency's Radioactive Substances Regulation (RSR) Environmental Principles (REPs) (Environment Agency, 2010), the main ones being:

- 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 preliminary conclusion at this stage is that the Requesting Party (RP) has made an adequate demonstration of BAT in relation to radioactive substances for the UK HPR1000. This has been demonstrated to a sufficient level in line with our expectations for GDA. Our assessment continues, and we note that GNSL is responding to a number of Regulatory Observations (ROs) that could impact the BAT case. Our assessment of BAT for monitoring is provided in the monitoring assessment report (Environment Agency, 2021a).

We have identified 2 potential GDA Issues and, if these are not resolved by the end of GDA, they will become GDA Issues:

- **Potential GDA Issue 2: GNSL has not yet provided a demonstration that selected options are optimised with respect to environmental protection and safety. We require GNSL to demonstrate that it has considered environmental aspects, alongside safety aspects, in order to achieve a design optimised for both.**
- **Potential GDA Issue 3: GNSL has provided environmental justification for the choice of high efficiency particulate air filter design. However, further justification must be provided to demonstrate how best available techniques is applied.**

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 manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.**
- **Assessment Finding 4: A future operator shall keep under review the possibility to remove secondary neutron sources or to optimise their design at the earliest occasion.**
- **Assessment Finding 5: 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 for liquid waste management systems.**

- **Assessment Finding 6: A future operator shall review and optimise water chemistry regimes presented during GDA to reduce waste generation.**
- **Assessment Finding 7: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.**
- **Assessment Finding 8: A future operator shall review the practicability of techniques for abating carbon-14.**
- **Assessment Finding 9: A future operator shall optimise the balance between gaseous, liquid and solid phase of carbon-14.**
- **Assessment Finding 10: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to inform future dose assessments.**
- **Assessment Finding 11: 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 12: A future operator shall address the post-GDA forward action plans identified by GNSL in the 'Demonstration of BAT' submission, HPR/GDA/PCER/0003, Revision 001-1, October 2020 (GNSL, 2020b).**

We will continue to review these conclusions as GNSL's design for the UK HPR1000 develops and our assessment progresses.

Contents

1. Introduction

This report provides our detailed assessment of GNSL's submission in relation to demonstrating its use of BAT in the UK HPR1000 design for GDA purposes.

This report is based on information received at the time of writing in October 2020. Any subsequent or updated information will be assessed alongside the responses to our consultation. Our final assessment results will be published in our Decision Document at the end of GDA. We are targeting completing GDA in early 2022.

We set up an agreement with GNSL to carry out GDA of the UK HPR1000 design, which came into effect in January 2017. Revision 000-1 of the 'Pre-Construction Environmental Report (PCER) Chapter 3 Demonstration of BAT' submission was submitted in November 2018 (GNSL, 2018a) and assessment of this submission and the supporting documents generated a number of Regulatory Queries (RQs) and ROs. A table summarising these and later RQs and ROs is provided in Appendix 1. Subsequent responses to these RQs and ROs and discussions at meetings with the RP have been incorporated into the later revisions of the 'Demonstration of BAT' submission (GNSL, 2020a and b) and supporting submissions. It is recognised there are certain areas that a future operator needs to finalise, for example, the height of the main stack, so BAT can be applied at the time.

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 GNSL (the Requesting Party (RP)). The assessment method, findings and preliminary conclusions are presented in the following sections.

Identifying BAT is the result of a process of 'optimisation', where minimising the generation and discharge of radioactive waste is balanced against costs and other relevant impacts. 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.

The Environmental Permitting Regulations 2016 (GB 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 to minimise creation of wastes, discharges into the environment and their impact.

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

It therefore follows that what is 'best available techniques' for a particular process will change with time in the light of technological advances, economic and social factors, as well as changes in scientific knowledge and understanding. If the reduction of discharges and emissions resulting from using BAT does not lead to environmentally acceptable results, additional measures have to be applied. 'Techniques' include both the technology used and the way in which the installation is designed, built, maintained, operated and dismantled.

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:

- the assessment of BAT for monitoring is provided in the monitoring assessment report (Environment Agency, 2021a)
- the assessment of solid and non-aqueous waste is provided in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2021b)
- the assessment of the gaseous and liquid discharges and proposed limits is provided in the discharges assessment report (Environment Agency, 2021c)
- the assessment of the radiological impact is provided in the impacts assessment report (Environment Agency, 2021d)

2. Assessment

2.1. Assessment method

The basis of our assessment was to:

- review the appropriate sections of the PCER and its supporting documents against our regulatory expectations, the details of which are in Appendix 2
- hold technical meetings with GNSL to clarify our understanding of the information presented and explain any concerns we had with that information
- raise RQs to clarify information supplied to us and ROs where we believed information from GNSL was insufficient, the details of which are in Appendix 1
- assess the techniques GNSL 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 doses to members of the public
- the best available techniques 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

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, 2021b).

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) and 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).

The scope 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. It is important that BAT is applied when the most benefits can be realised. The design and operation of the nuclear power plant needs to be optimised at all stages of the project life cycle from design to decommissioning.

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

The majority of radionuclides in the reactor core are retained within the fuel cladding 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 or corrosion. A small proportion of those radionuclides in the primary coolant can then transfer to secondary coolant system (in case of steam generator (SG) tube leaks and diffusion), auxiliary systems and 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, 2020b).

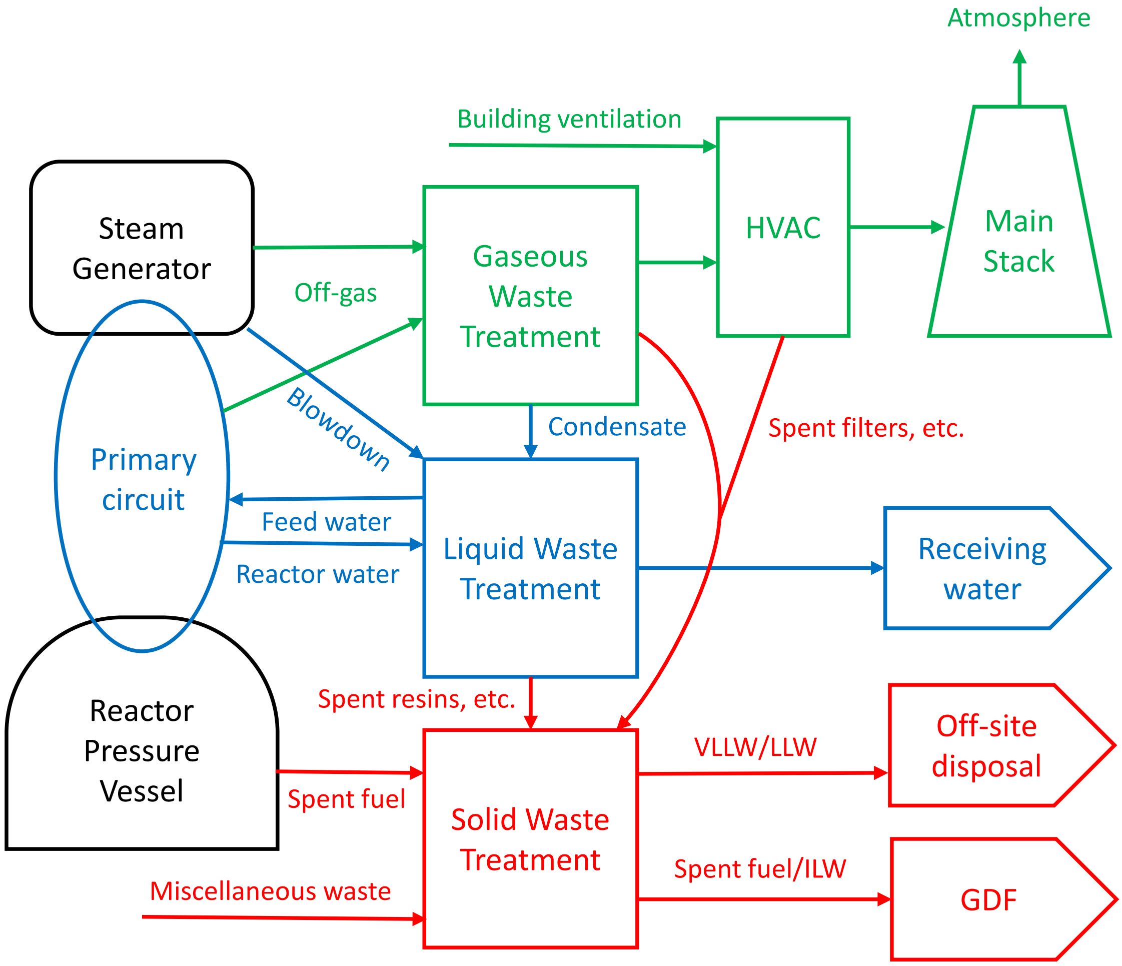

Figure 1: The gaseous, liquid and solid wastes routes.

2.4.1. Minimisation of activity in the UK HPR1000

To minimise the levels of radioactivity, GNSL has outlined how the UK HPR1000 design best prevents and minimises, and controls and manages radionuclides generated and transported throughout the plant (GNSL, 2020c). The origins of radioactivity within the UK HPR1000 and the measures for minimising radionuclides generated are mainly as follows:

- fission products and actinides leakage and generation 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 and 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

2.4.2. Minimisation 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, 2020b) and the supporting documentation. GNSL has broadly 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 regulators queried what forms the source term for the UK HPR1000 (RQ-UKHPR1000-0390), a demonstration that radioactivity will be reduced so far as is reasonably practicable (SFAIRP) (RO-UKHPR1000-0026) and the generation, transport and behaviour of tritium (RO-UKHPR1000-0049). The response to the RQ provided 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 ROs remains open at this time and the resolution of the ROs includes developing a minimisation of radioactivity route map for the generation and transport of radionuclides. The further submissions are unlikely to influence the BAT demonstration and we will review our preliminary conclusions following the closure of the ROs.

2.5. Minimising waste in the UK HPR1000

GNSL claims that the UK HPR1000 design prevents and minimises the generation of radioactive waste. Claims, arguments and evidence in support of this are provided as part of the ‘Demonstration of BAT’ submission (GNSL, 2020b). The BAT related arguments GNSL presented and our associated conclusions are summarised in the sections below.

GNSL 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

GNSL 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 uncontrolled discharge 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

GNSL 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, treating 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, 2020b) and detailed in the supporting documents, a number of which have been reviewed during our assessment (Appendix 2).

2.6. An overview of radioactive waste processing in the UK HPR1000

GNSL 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 waste hierarchy and as low as reasonably practicable (ALARP)/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, 2021b).

We note that detailed operational aspects of relevance to the BAT case are not provided in the GNSL documentation at this time, although broad operational aspects are discussed. This is appropriate for the GDA stage as a future operator will decide how the reactor is operated. We will 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 identified as 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 manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.

2.7. Processing gaseous wastes

The processing of gaseous waste in the UK HPR1000 design is conducted by the gaseous waste treatment system (GWTS), the heating, ventilation and air conditioning system (HVAC), and the condenser vacuum system (CVS). Figure 2 shows a diagrammatic representation of the radioactive gaseous effluent streams GNSL provided (GNSL, 2020b).

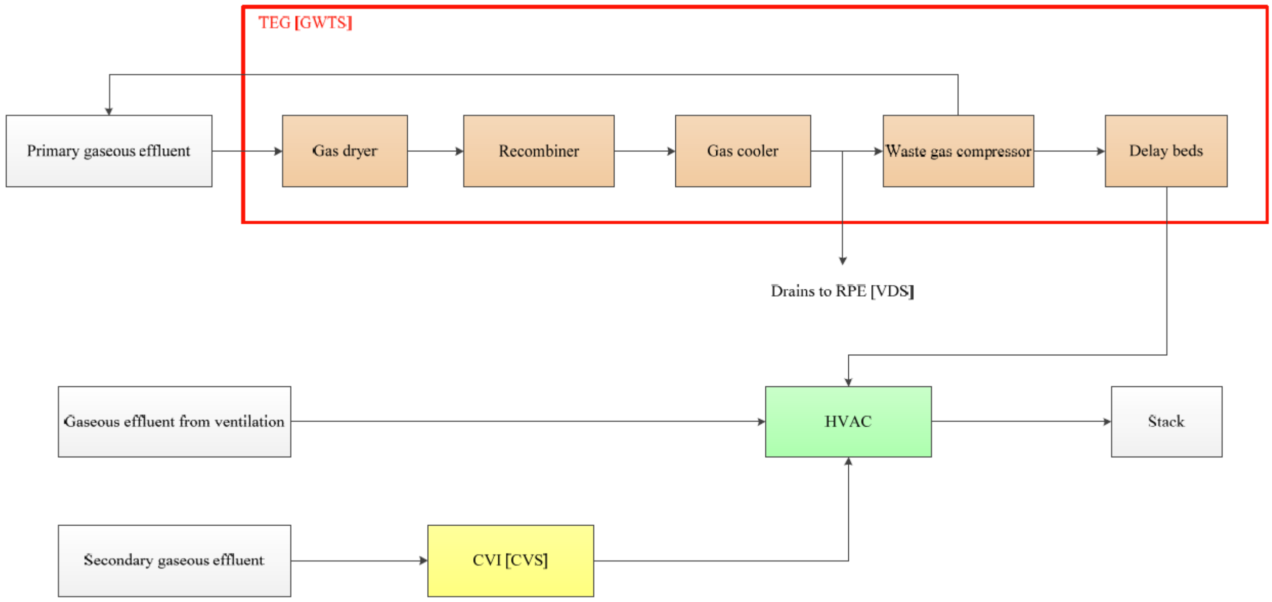

Figure 2: Radioactive gaseous effluent streams (GNSL, 2020b)

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 CVS is not included within the scope of the GDA). 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 traps 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 if needed.

GNSL 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, 2020b).

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 to remove particulate material from gaseous waste using HEPA filtration. It is worth noting that discharges of tritium and carbon-14 are directly proportional to power production. 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 abate short lived fission products

- an HVAC system that prevents the uncontrolled discharge of radioactive substances, which includes HEPA filters and iodine adsorbers, the later are not all permanently in-line and will be automatically put into operation if elevated concentrations of radioactivity are detected

We observe the following at this stage:

- Using a modern and well-established fuel design and further measures to reduce fuel failure rates will help 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, and we have raised an Assessment Finding in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2021b). We discuss the management of spent fuel further in our related assessment report (Environment Agency, 2021b).
- Using delay bed technology is effective at reducing discharges of noble gases and consistent with approaches adopted in other light water reactors. Delay beds are also expected to have some effects to reducing the concentration of short-lived iodine radionuclides. Our preliminary conclusion is that GNSL has demonstrated that the quantity of charcoal to enable delay and the management of the delay beds has been optimised in the UK HPR1000 design. However, aspects of the GWTS design are currently subject to further, specific consideration by the regulators and we will need to revisit this preliminary conclusion if any design changes were to adversely affect the efficiency of the abatement.
- The optioneering for the choice of HEPA filter for the UK HPR1000 design is currently the attention of an RO (RO-UKHPR1000-0036). The RO details the regulatory expectations. This includes our expectation that the optioneering study and HEPA filter choice comprehensively consider minimising gaseous radioactive discharges and solid radioactive waste arisings. They also need to consider energy use and the production and disposal of radioactive waste.
- 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.
- We agree with GNSL that no abatement of tritium or carbon-14 is practicable at this time (International Atomic Energy Agency (IAEA), 2004). Commercially available tritium and carbon-14 abatement processes are not feasible for the low concentrations present in aqueous and gaseous discharges from a pressurised water reactor (PWR). The cost and energy required to install and run the abatement processes are disproportionate to the abatement benefits. We expect a future operator to continue to review the progress of worldwide new techniques that can be used to reduce the production of carbon-14 and to abate carbon-14 prior to discharge. We have raised an Assessment Finding to this effect:

  Assessment Finding 8: A future operator shall review the practicability of techniques for abating carbon-14.
- We agree with GNSL that a future operator should review the need for secondary neutron sources (SNS) so as 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 4: A future operator shall keep under review the possibility to remove secondary neutron sources or to optimise their design at the earliest occasion.

Assessment of the quantity of gaseous discharges to the environment is provided in our related assessment report (Environment Agency, 2021c).

2.8. Processing liquid wastes

The liquid radioactive waste management system (LRWMS) is designed to collect, temporarily store, monitor and treat liquid radioactive waste before it is discharged. The LRWMS includes 2 drainage systems; the nuclear island vent and drain system (VDS) and the sewage recovery system (SRS). The VDS collects the drainage from BRX, BNX, BSA, BSB, BSC and BFX and the SRS collects drainage from buildings including BWX. Figure 3 shows a diagrammatic representation of the liquid effluent streams and LRWMS GNSL provided (GNSL, 2020b).

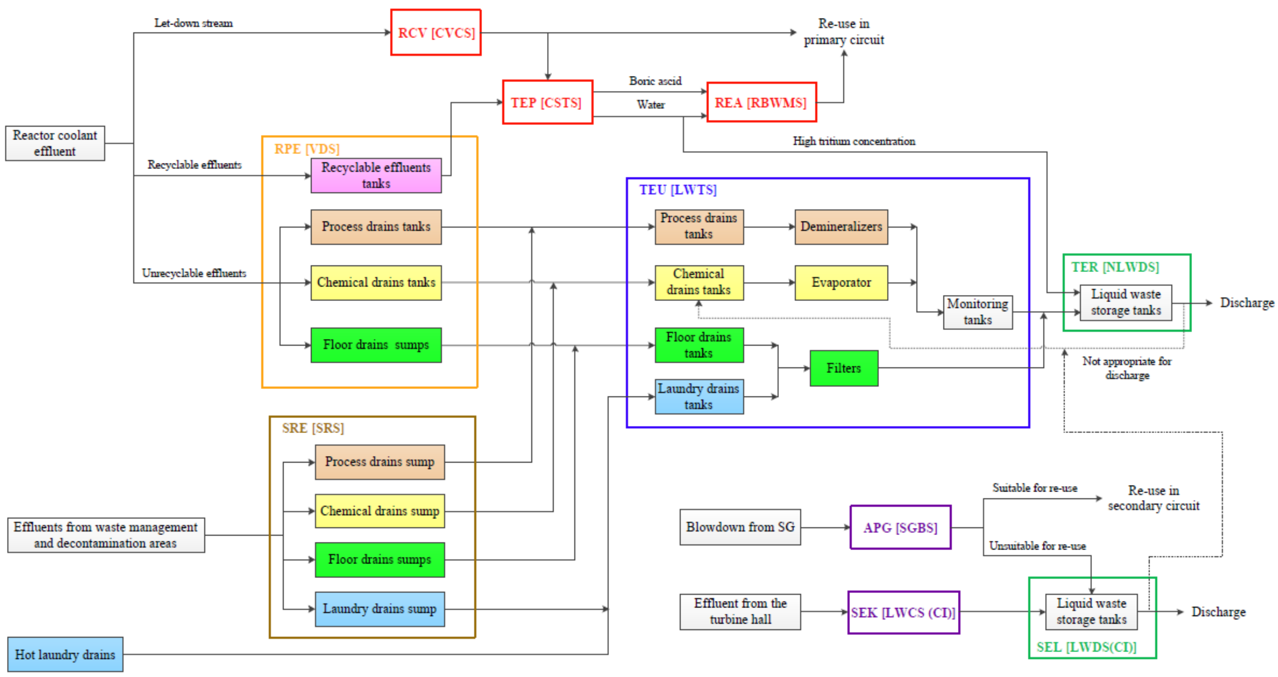

Figure 3: Liquid effluent streams and LRWMS (GNSL, 2020b)

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]) and 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 liquid waste treatment system (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 reused, 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 it is treated in the CSTS evaporator.

Detecting abnormal conditions and subsequent alarms, as well as operational procedures, protects against accidental discharge. 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.

At 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 (to be reviewed periodically and defined as the plant approaches decommissioning). Redundant items of plant and equipment will be managed according to the solid radioactive waste management system.

GNSL 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, 2020b). 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, 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 liquid waste, or arise as components of solid waste

We observe the following at this stage:

- Using a modern and well-established fuel design, and further measures to reduce fuel failure rates (including minimising grid to rod fretting [GTRF], anti-debris devices and cleaning of fuel rods), will help minimise liquid waste by limiting fission product releases from failed fuel. Measures to detect and manage fuel failure (including monitoring systems and on-line and off-line sipping facilities) should also prove effective in this regard. We will seek to 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, 2021b).
- 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).

- The UK HPR1000 uses filters, demineraliser and evaporator technology to remove radioactivity from liquids which are standard equipment in nuclear power plants. In our view, use of these technologies is appropriately targeted at segregated liquids within the plant systems. This transfers the radioactivity to solid waste, consistent with a 'concentrate and contain' approach. 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 5: 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 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. It would be grossly disproportionate to use techniques at this time to avoid liquid disposals of tritium, given the small dose impact (Environment Agency, 2021d).

Assessment of quantities of liquid discharges to the environment is provided in our related assessment report (Environment Agency, 2021c).

2.9. Processing solid wastes

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 assumed future disposal facilities. Our assessment of the waste management strategy is provided in the strategic considerations for radioactive waste management assessment report (Environment Agency, 2021e).

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.

The nature of the solid wastes that will arise in the UK HPR1000 and our view on the proposed processing of these, is described further in our assessment report on solid radioactive waste (Environment Agency, 2021b).

2.10. Process for identifying best available techniques

The main procedures for identifying BAT are the 'BAT Methodology' report (GNSL, 2018b) and the 'Requirements on Optioneering and Decision-Making' report (GNSL, 2018c). The 'BAT Methodology' (GNSL, 2018b) 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' report (GNSL, 2018c) describes the approach used to apply both BAT and ALARP to making potential enhancements. Claims generated as part of this optimisation process are presented along with their accompanying arguments and evidence in the 'Demonstration of BAT' submission (GNSL, 2020a).

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

GNSL'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 PWR technology and reflects on design improvements that are relevant to the BAT claims (as described by GNSL against specific BAT arguments, see below). 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.

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

GNSL'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' (section 2.16). We consider this to be a useful approach and recognise the value of these forward action plans. The 'forward action plans' 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 preliminary conclusions are that GNSL has followed an appropriate process for identifying BAT in the design of the UK HPR1000.

2.11. Optioneering

GNSL'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, and to reduce risks SFAIRP, which is regulated by 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 & Decision-Making' submission (GNSL, 2018c) sets out the requirements for the optioneering and decision-making procedures. GNSL developed a procedure to provide guidance on how to generate and evaluate options to address the potential enhancements of the design 'Guidance for Optioneering' (GNSL, 2019a) and a procedure to set out a framework for managing the potential enhancements 'Optioneering Process for UK HPR1000 Generic Design Assessment (GDA) Project' (GNSL, 2019b).

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

- Optioneering Report of the HEPA Filters Types (GNSL, 2020d), which identifies a preferred type of HEPA filter for the UK HPR1000
- Optioneering Report for Gaseous Radioactive Waste Processing Techniques (GNSL, 2020e), which supports the demonstration that the UK HPR1000 GWTS processing techniques selected represent BAT

- Optioneering Report for Liquid Radioactive Waste Processing Techniques (GNSL, 2020f), which supports the demonstration that the UK HPR1000 LWTS processing techniques selected represent BAT
- Optioneering Report for Operational Solid Waste Processing Techniques (GNSL, 2020g), which identifies a range of alternative technologies for managing solid and non-aqueous liquid waste, and selects the optimised options for each waste stream

The regulators issued an RQ concerning the optioneering process used for the radioactive waste processing techniques optioneering (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, 2019b. However, the operational solid waste treatment techniques report was produced as a result of identified gaps, and, therefore, as part of the process to solve gaps, it is in accordance with GNSL, 2019b. The responses to the RQs improved our understanding of the optioneering process and resulted in revised gaseous and liquid optioneering reports (GNSL, 2020e and 2020f).

GNSL'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 GNSL adopted has been appropriately scoped and is consistent with our expectations for GDA. Overall, our preliminary conclusions are that GNSL 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 GNSL (GNSL, 2020b).

2.12. 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. 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 an environmental objective and SFAIRP is a legal requirement derived from UK health and safety legislation. Radiation doses meet ALARA when they have been reduced to a level that represents a balance between dose and other factors (including economics). 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.

ONR has raised a number of ROs relating to SFAIRP considerations for plant systems where BAT is also relevant, which remain open and are yet to be resolved. The open ROs include 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'.

As detailed in this assessment report, our preliminary conclusions are that the UK HPR1000 design is consistent with BAT in so far as this has been demonstrated and to a level in line with our expectations for GDA. We will come to our final decision after the SFAIRP aspects of the design are demonstrated to ONR, as reflected in outstanding ROs. In addition, limits and conditions of operation are yet to be fully defined for plant that has an environmental protection function.

There remains a possibility, therefore, that design changes in response to ongoing SFAIRP considerations may impact on the design of plant and how it is to be operated. This may ultimately impact on the BAT case for the UK HPR1000. Until SFAIRP has been demonstrated there is a risk that the BAT case cannot be considered to be finalised. However, we think the risk of significant changes to the claims, argument and evidence made for BAT is small.

It is anticipated that any design changes that may result from ongoing SFAIRP considerations will be appropriately assessed in terms of BAT. We will need to revisit our current preliminary conclusion pending any design changes to the UK HPR1000 to ensure SFAIRP and once any operational limits and conditions are defined. We will continue to liaise with ONR on this as part of the ongoing assessment, and this work will inform our final decision document.

Our preliminary conclusion is subject to the following potential GDA Issue:

Potential GDA Issue 2: GNSL has not yet provided a demonstration that selected options are optimised with respect to environmental protection and safety. We require GNSL to demonstrate that it has considered environmental aspects, alongside safety aspects, in order to achieve a design optimised for both.

2.13. 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. GNSL's approach to requirements management (GNSL, 2020h) includes the development of environmental requirements. The regulators queried the transfer of environmental operational specifications from GDA to a future operator (RQ-UKHPR1000-00726). The conclusion from the RQ response was the development of a transition plan for handover of GDA documentation and knowledge transfer.

GNSL's approach to requirements management (GNSL, 2020h) includes identifying systems that provide an environmental protection function (EPF). The regulators requested a list of SSCs and engineered controls that contribute to the application of BAT (RQ-UKHPR1000-0498). This provided a useful insight into how these are being developed at the GDA stage. The regulators 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 necessary 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 forward action plan to further develop EPFs and measures and associated requirements (A follow-up action is detailed in section 2.16). The demonstration of the adequacy of EMIT of SSCs is also a topic of enquiry (RO-UKHPR1000-0021), together with the need to ensure a suitable and sufficient safety case RO (RO-UKHPR1000-0004). Both these ROs remain open at this time and the outputs of these could influence the BAT demonstration. We have identified an Assessment Finding for the development of EPFs and associated requirements.

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

2.14. Decommissioning

Decommissioning will take place following the operational lifetime of the facility. Including BAT during GDA is important to ensure the design minimises the volumes of decommissioning waste. GNSL has provided details of the decommissioning strategy, plans and how the design facilitates decommissioning (GNSL, 2020i) with accompanying documents. This evidence supports the BAT demonstration that the UK HPR1000 design has been developed taking into account requirements to facilitate decommissioning, relevant operating experience (OPEX) has been incorporated into the design and there are suitable plans and proposals (GNSL, 2020j and 2020k). Our assessment of the decommissioning strategy is provided in the strategic considerations for radioactive waste management assessment report (Environment Agency, 2021e).

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 ALARP demonstration for the regulators for decommissioning the UK HPR1000 is the topic of an RO (RO-UKHPR1000-0042) which remains open at this time. The outputs are unlikely to influence the BAT demonstration and we will review our preliminary conclusions following the closure of the RO.

2.15. The claims, arguments and evidence approach

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

2.16. BAT matters for future operator

The following table adapted from the ‘Demonstration of BAT’ (GNSL, 2020b) submission shows the areas that GNSL considers a future operator will need to follow up, either during site-specific design or during commissioning and operations. We have raised an Assessment Finding to capture the identified forward action plans.

Assessment Finding 12: A future operator shall address the post-GDA forward action plans identified by GNSL in the 'Demonstration of BAT' submission, HPR/GDA/PCER/0003, Revision 1.1, October 2020 (GNSL, 2020b).

Follow-up actions identified by GNSL
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

Follow-up actions identified by GNSL
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

3. Compliance with Environment Agency requirements for GDA

The requirements set out in our P&ID and REPs (Environment Agency, 2016a and 2010) are shown in the following table:

Requirement from P&ID and REPs	Comments
P&ID Item 2: A description of the requesting party's management arrangements and responsibilities for: – Include: 'establishing the methodology	The method for identifying BAT is provided in the 'BAT Methodology' and 'Requirements on Optioneering and

Requirement from P&ID and REPs	Comments
for identifying the 'best available techniques' (BAT) …. and ensuring their use in the design'.	Decision-Making' documents (GNSL, 2018b and c).
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 details of the radioactive waste management arrangements are in the 'Radioactive Waste Management Arrangements' submission (GNSL, 2020l) and our associated strategic considerations for radioactive waste management assessment report (Environment Agency, 2021e). The demonstration of BAT is provided in the 'Demonstration of BAT' submission (GNSL, 2020b).
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 details of the discharges and disposals from normal operations are in the 'Quantification of Discharges and Limits' submission (GNSL, 2020m) and the demonstration of BAT is provided in the 'Demonstration of BAT' submission (GNSL, 2020b).
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.**	BAT arguments are presented 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, 2018b and c) with the results shown in the 'Demonstration of BAT' submission (GNSL, 2020b).
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 method for identifying BAT is provided in the 'BAT Methodology' and 'Requirements on Optioneering and Decision-Making' submissions (GNSL, 2018b and c).
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**	All 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, 2018b and c) to ensure that any resulting environmental

Requirement from P&ID and REPs	Comments
environmental risk and impact are minimised.	risk and impact are minimised, with the results provided in the 'Demonstration of BAT' submission (GNSL, 2020b).
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.**	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, 2020c) submission with the results shown in the 'Demonstration of BAT' submission (GNSL, 2020b).
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 deliver these functions.**	Consideration is given to environmental protection functions in the design and associated processes in the 'Requirement Management Summary Report' (GNSL, 2020h), including the development of a 'List of SSCs and Engineered Controls that Contribute to the Application of BAT' (GNSL, 2019c).

4. Public comments

GNSL received 4 public comments up to 30 June 2020 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, 2020n Material Selection Report). We consider selecting 690 alloys 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. GNSL has also systematically reviewed the design for further opportunities to reduce corrosion, including the surface treatment of SSCs (GNSL, 2020o). 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 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 BAT does not form part of the Chinese nuclear regulatory

regime. 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 steam generator 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.

5. Conclusion

Our preliminary conclusion at this stage is that GNSL 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.

We reach this preliminary conclusion, at this time, based on our assessment of the design and the supporting claims, arguments and evidence that GNSL has provided. A number of ROs that may have implications in relation to the BAT demonstration remain open (Appendix 1). We are unaware of any significant impact on the claims, arguments and evidence that GNSL has made in its demonstration of BAT submission to date. However, the observations remain open and are yet to be resolved. We will continue to liaise with ONR on this as part of the ongoing assessment, and this work will inform our final decision document. Our preliminary conclusion at this time is subject to the following potential GDA Issue:

- **Potential GDA Issue 2: GNSL has not yet provided a demonstration that selected options are optimised with respect to environmental protection and safety. We require GNSL to demonstrate that it has considered environmental aspects, alongside safety aspects, in order to achieve a design optimised for both.**

Our HEPA filter type RO also remains open (RO-UKHPR1000-0036) and we expect the resolution to include the provision of a robust optioneering study and justification for the choice of HEPA filter type. As this work continues, we have identified the following potential GDA Issue:

- **Potential GDA Issue 3: GNSL has provided environmental justification for the choice of high efficiency particulate air filter design. However, further justification must be provided to demonstrate how best available techniques is applied.**

At this stage, we have identified a number of 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 manufacturing, commissioning and operation, including examination, maintenance, inspection and testing requirements.**
- **Assessment Finding 4: A future operator shall keep under review the possibility to remove secondary neutron sources or to optimise their design at the earliest occasion.**
- **Assessment Finding 5: 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 for liquid waste management systems.

- **Assessment Finding 6: A future operator shall review and optimise water chemistry regimes presented during GDA to reduce waste generation.**
- **Assessment Finding 7: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.**
- **Assessment Finding 8: A future operator shall review the practicability of techniques for abating carbon-14.**
- **Assessment Finding 9: A future operator shall optimise the balance between gaseous, liquid and solid phase of carbon-14.**
- **Assessment Finding 10: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to inform future dose assessments.**
- **Assessment Finding 11: 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 12: A future operator shall address the post-GDA forward action plans identified by GNSL in the 'Demonstration of BAT' submission, HPR/GDA/PCER/0003, Revision 001-1, October 2020 (GNSL, 2020b).**

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Environment Agency. 2021d	'Generic design assessment of new nuclear power plant: Preliminary detailed assessment of radiological impacts for General Nuclear System Limited UK HPR1000 design, AR07' January 2021
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GNSL. 2018b	‘BAT Methodology’ GHX00100055DOHB03GN, Revision C, July 2018
GNSL. 2018c	‘Requirements on Optioneering and Decision-Making’ HPR-GDA-PROC-0012, Revision 0, May 2018
GNSL. 2019a	‘Guidance for Optioneering’ HPR/GDA/REPO/0080, Revision 000, December 2019
GNSL. 2019b	‘Provisions on Optioneering Process for UK HPR1000 Generic Design Assessment (GDA) Project’ GH-40M-018, Revision A, June 2019
GNSL. 2019c	‘List of SSCs and Engineered Controls that Contribute to the Application of BAT’ GHX00100012DOHB00GN, Revision A, December 2019
GNSL. 2019d	‘Minimisation of the Discharge and Environment Impact of Carbon-14’ GHX00100005DOHB00GN, Revision C, December 2019
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GNSL. 2020u	‘Topic Report on Impurity Control for the Operation’ GHX00100103DCSH03GN, Revision E, June 2020

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GNSL. 2020w	‘Topic Report on Application of Cobalt in SSCs’ GHX00100048DPCH03GN, Revision C, June 2020
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Abbreviations

Acronym	*Meaning*
AF	Assessment Finding
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
CGN	China General Nuclear Power Corporation
CSBVS (EBA)	Containment sweeping and blowndown 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
EMIT	Examination maintenance inspection and testing
ENDP	Engineering developed principle

Acronym	*Meaning*
FAC	Flow-accelerated corrosion
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
HTO	Tritiated water
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
ICIA	In-core instrument assembly
ILW	Intermediate level waste
JPO	Joint Programme Office
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

Acronym	*Meaning*
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
PCI	Pellet-cladding interaction
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
RP	Requesting Party
RQ	Regulatory Query
RSMDP	Radioactive Substance Management Developed Principle

Acronym	*Meaning*
RSR	Radioactive Substances Regulation
RWM	Radioactive Waste Management Ltd (UK)
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
SRS (or SRE)	Sewage recovery system
SSC	Structures, systems and components
SWTS (or TES)	Solid waste treatment system
UK HPR1000	UK version of the Hua-long 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

Word/Phrase	*Meaning*
Deflagration	An explosion in which the speed of burning is lower than the speed of sound in the surroundings.
Nuclear island	A collection of site buildings containing radioactivity.
Sacrificial	Designed to be used up or destroyed in fulfilling a purpose or function.
The regulators	Environment Agency and the Office for Nuclear Regulation.

Appendix 1: Regulatory Queries and Observations relating to BAT

The following table summarises the RQs and ROs that are most relevant to the application of BAT for the UK HPR1000 (There are no Regulatory Issues [RIs] relevant to BAT).

Revision 1.1 of the 'Demonstration of BAT' submission and supporting documents is intended to address the results of resolving any RQs and ROs at that time. The 'Pre-Construction Safety Report V1 Amendment Report for Environment Agency Public Consultation' (GNSL, 2020p) details the amendments made to the Pre-Construction Safety Report (PCSR) V1 chapters that contain important environment-related information as part of the production of the interim environment case for public consultation.

ROs and RIs are published on the ONR website, along with resolution plans. RQ information is not routinely published, but all RQs and subsequent responses are available to the regulators through the Joint Programme Office (JPO). Progress against each has been discussed at technical level meetings with the RP.

RQ/RO/RI	Date issued	Title and summary
Regulatory Queries		
RQ-UKHPR1000-0194	06-Feb-2019	Management of the aerial filtration systems GNSL was requested to provide 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-Jul-2019	Hydrogen concentration in the primary circuit GNSL was requested to provide 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-Jul-2019	Primary circuit pH and reactivity control through Li:B coordination GNSL was requested to provide further information on the: • limiting values for lithium concentration in all relevant plant states • optioneering for the target pH value of 7.2
RQ-UKHPR1000-0427	13-Aug-2019	Spent fuel pool tritium production GNSL was requested to provide further information on the:

RQ/RO/RI	Date issued	Title and summary
		• control and optimisation of the SFP water temperature and HVAC flowrate and air temperature to minimise tritium production
RQ-UKHPR1000-0428	13-Aug-2019	Aerial back migration GNSL was requested to provide 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-Aug-2019	Carbon delay beds for gaseous wastes GNSL was requested to provide further information on the: • optimisation of the delay bed parameters • management of the delay beds • prevention of suspended activated particles from the delay beds
RQ-UKHPR1000-0430	13-Aug-2019	Charcoal waste GNSL was requested to provide further information on: • a confirmation of the radioactive waste category of the charcoal waste and the expected activity levels • the management of charcoal waste and the implication of failed fuel pins
RQ-UKHPR1000-0431	13-Aug-2019	Control of carbon-14 production GNSL was requested to provide 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-Aug-2019	Radioactive waste processing techniques optioneering GNSL was requested to provide 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	09-Oct-2019	Primary circuit pH an reactivity control through Li:B coordination

RQ/RO/RI	Date issued	Title and summary
		GNSL was requested to provide 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	09-Oct-2019	Impurity control GNSL was requested to provide further information on: • evidence for the proposed impurity controls levels
RQ-UKHPR1000-0498	17-Oct-2019	BAT systems document request GNSL was requested to provide 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-Nov-2019	Qualification of equipment for its intended environmental protection function GNSL was requested to provide 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-Nov-2019	Gaseous radioactive waste processing techniques optioneering GNSL was requested to provide further information on: • the optioneering of processing techniques for radioactive particles • clarification on the optioneering process used and the next steps following the optioneering
RQ-UKHPR1000-0538	13-Nov-2019	HVAC iodine adsorbers GNSL was requested to provide further information on: • the management of the HVAC iodine adsorbers

RQ/RO/RI	Date issued	Title and summary
RQ-UKHPR1000-0540	13-Nov-2019	Liquid radioactive waste processing techniques optioneering GNSL was requested to provide 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 • clarification on the optioneering process used and the next steps following the optioneering
RQ-UKHPR1000-0618	27-Jan-2020	Decommissioning missed opportunities for BAT demonstration GNSL was requested to provide further information on: • volumes/weights of waste to provide a balanced demonstration of BAT • clarification that temporary treatment facilities will be demonstrated to be BAT
RQ-UKHPR1000-0633	12-Feb-2020	Sampling and monitoring - general queries GNSL was requested to provide 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-Mar-2020	Topic report on startup and shutdown chemistry Rev. C GNSL was requested to provide further information on queries including: • how the hydrazine addition volumes are calculated
RQ-UKHPR1000-0725	03-Apr-2020	Demineraliser decontamination factors GNSL was requested to provide 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	03-Apr-2020	Operator guidance relating to BAT

RQ/RO/RI	Date issued	Title and summary
		GNSL was requested to provide further information on: • what guidance to operators will be provided to ensure operation is BAT
RQ-UKHPR1000-0745	23-Apr-2020	Underground and embedded liquid containment systems GNSL was requested to provide 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
Regulatory Observations		
RO-UKHPR1000-0004	03-Sep-2018	Development of a suitable and sufficient safety case The regulators asked to be provided with evidence to demonstrate that GNSL 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-Oct-2018	Demonstration that the UK HPR1000 design reduces the risks associated with radioactive waste management, so far as is reasonably practicable The regulators asked to be provided with a demonstration that risks relevant to radioactive waste management are reduced to ALARP.
RO-UKHPR1000-0012	30-Jul-2019	Identification and application of relevant good practice applicable to mechanical engineering for the UK HPR1000 design The regulators asked to be provided with a demonstration that the design reduces relevant risks to ALARP. The RP’s strategy is to identify relevant good practice (RGP) and carry out a mechanical engineering gap analysis of the design against it.
RO-UKHPR1000-0015	13-Sep-2019	Demonstration that risks associated with fuel deposits are reduced so far as is reasonably practicable (SFAIRP)

RQ/RO/RI	Date issued	Title and summary
		The regulators asked to be provided with details of the quantity and characterisation of the fuel deposits expected for UK HPR1000.
RO-UKHPR1000-0021	23-Sep-2019	Demonstration of the adequacy of examination, maintenance, inspection and testing (EMIT) of structures, systems and components important to safety GNSL was asked for its overall 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-Dec-2019	Demonstration that radioactivity has been reduced so far as is reasonably practicable (SFAIRP) The regulators asked to be provided with a demonstration that all reasonably practicable measures have been taken to reduce radioactivity in the UK HPR1000 SFAIRP.
RO-UKHPR1000-0031	23-Jan-2020	Control of boron during normal operations and faults The regulators asked to be provided with a demonstration that boron chemistry is adequately controlled and the risks associated with boron dilution to be reduced are SFAIRP.
RO-UKHPR1000-0036	26-Mar-2020	HEPA filter type GNSL was asked to demonstrate 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	03-Apr-2020	In-core instrument assemblies radioactive waste safety case GNSL was asked to demonstrate that risks relevant to the radioactive waste management of ICIAs are reduced to ALARP.
RO-UKHPR1000-0039	07-Apr-2020	Performance analysis of UK HPR1000 heating ventilation and air conditioning systems GNSL was asked to develop an HVAC environmental modelling and analysis strategy, model and analyse the HVAC system, and carry out an ALARP analysis for the HVAC system.

RQ/RO/RI	Date issued	Title and summary
RO-UKHPR1000-0040	15-Apr-2020	Providing an adequate safety case for the interim storage of intermediate level waste (ILW) GNSL was asked to provide 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-Apr-2020	Disposability of higher activity waste from the UK HPR1000 GNSL was asked to: • update the Disposability Submission • provide a draft Disposability Assessment Report or produce 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 forward action plan • update on Progress of the Disposability Assessment
RO-UKHPR1000-0042	29-Apr-2020	Robust demonstration of ALARP for decommissioning the UK HPR1000 The regulators asked for evidence of implementing the method for assessing design requirements for facilitating decommissioning.
RO-UKHPR1000-0049	14-Aug-2020	Generation, Transport and Behaviour of Tritium during Normal Operations GNSL was asked to demonstrate that the behaviour of tritium in the UK HPR1000, during normal operations, is adequately understood and controlled

Appendix 2: GNSL documentation

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.

Title	Document no.
Pre-Construction Environmental Report, Chapter 3 - Demonstration of BAT	HPR/GDA/PCER/0003 Revisions 000-1, 001 and 001-1 (GNSL, 2018a, 2020a and 2020b)
Pre-Construction Environmental Report Chapter 4 - Radioactive Waste Management Arrangements	GX00510004KPGB02GN
Pre-Construction Safety Report V1 Amendment Report for Environment Agency Public Consultation	GHX00100122DPCH03GN
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

Title	Document no.
Optioneering Report for Liquid Radioactive Waste Processing Techniques	GHX00100042DNFF03GN
Optioneering Report for Operational Solid Waste Processing Techniques	GHX00100056DNFF03GN
Requirement Management Summary Report	GHX00100127DOZJ03GN
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

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

The 'Demonstration of BAT' submission (GNSL, 2020b) 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 preliminary conclusions at this stage.

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

We note that at the outset GNSL has identified a number of aspects a future operator will need to consider. These are termed 'forward action plans' and are defined in section 2.16. 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 12: A future operator shall address the post-GDA forward action plans identified by GNSL in the 'Demonstration of BAT' submission, HPR/GDA/PCER/0003, Revision 001-1, October 2020 (GNSL, 2020b).

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 preliminary conclusions at this time.

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

GNSL 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. GNSL 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 pressurised water reactors (PWRs) worldwide.

The type of fuel assembly specified in GDA is an established fuel design and is used worldwide with substantial operating experience (OPEX) (Société Francaise d' Énergie Nucléaire [SFEN], 1999). Our preliminary conclusions are that the fuel assembly includes the features that will minimise the frequency and severity of fuel failures. We also welcome the provision of operational specifications to a future operator that will help to minimise the likelihood of fuel failure (A follow-up action is detailed in section 2.16).

Summary of evidence GNSL presented in support of Argument 1a in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

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

GNSL 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 into 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 follow-up action is detailed in section 2.16).

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, 2020b).

Our preliminary conclusions are that these systems and facilities will provide an effective process to detect and manage failed fuel in the UK HPR1000 and welcome a follow-up action identified by GNSL in section 2.16.

Summary of evidence GNSL presented in support of Argument 1b in the ‘Demonstration of BAT’ submission (GNSL, 2020b).

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

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

GNSL 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, 2020o). A future operator has the flexibility to choose a refuelling programme, so we have raised an Assessment Finding:

Assessment Finding 11: A future operator shall assess the impact of its proposed operating fuel cycle on the radioactive waste generation and disposal before implementing any changes.

Summary of evidence GNSL presented in support of Argument 1c in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL 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. GNSL 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 rods.

GNSL 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 very low failure rate of the assembly. The fuel assembly selected for the UK HPR1000 is a widely-used fuel assembly design (SFEN, 1999).

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 and consequently reduces the amount of lithium hydroxide required for pH control. The regulators queried the control of boron (Including RO-UKHPR1000-0031). The response provided evidence for the systems that control boron addition, dilution, recycling and monitoring and resulted in updates to the 'Topic Report on Power Operation Chemistry' (GNSL, 2020q). The response to the RO is in process, with no impact on the BAT case expected.

GNSL 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, 2020r).

GNSL states that secondary neutron sources (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. GNSL is carrying out a preliminary feasibility assessment to remove SNS assemblies and states that a future operator will need to continue to review the option for removing SNS assembly. We have identified an Assessment Finding for an evaluation of the environmental impact of removing SNS.

Assessment Finding 4: A future operator shall keep under review the possibility to remove secondary neutron sources or to optimise their design at the earliest occasion.

We note that relevant ROs raised by ONR remain open at this time, (RO-UKHPR1000-0026, Demonstration that radioactivity has been reduced so far as is reasonably practicable [SFAIRP] and RO-UKHPR1000-0031, ‘Control of boron during normal operations and faults) and the outcomes are not expected to change the BAT case that the generation of tritium in the primary coolant is minimised.

GNSL 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.

Summary of evidence GNSL presented in support of Argument 1d in the ‘Demonstration of BAT’ submission (GNSL, 2020b).

Argument 1d	Minimise the generation of tritium in the primary coolant
Evidence	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.

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

GNSL 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 in order to obtain minimal corrosion products solubility. The regulators queried the use of the coordinated boron-lithium regime to provide a target pH value of 7.2 for the majority 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, 2020r).

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, 2020s).

Hydrated hydrazine dosing during plant start-up creates a reducing environment that minimises the generation of corrosion products (GNSL, 2020t). 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 chemical volume and control system (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, 2020u).

GNSL 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, 2020v). The benefits of adopting zinc injection are reducing the worker dose and for activity levels during 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 best practice and is adopted as a design modification in the UK HPR1000.

We note that relevant ROs remain open at this time, (RO-UKHPR1000-0015, ‘Demonstration that risks associated with fuel deposits are reduced so far as is reasonably practicable’ [SFAIRP] and 0026, ‘Demonstration that radioactivity has been reduced so far as is reasonably practicable’ [SFAIRP]). Resolving the ROs and the associated submissions are not expected to influence the BAT demonstration for optimising the water chemistry in the primary circuit to minimise the radioactivity of discharges and waste.

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, as this is an important aspect in terms of reducing waste generation. We identify this as an Assessment Finding.

Assessment Finding 6: A future operator shall review and optimise water chemistry regimes presented during GDA to reduce waste generation.

Summary of evidence GNSL presented in support of Argument 1e in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL recognises that material selection of structures, systems and components (SSCs) is an important aspect for demonstrating BAT as corrosion and activation of SSCs form radionuclides and consequently contribute to radioactive waste and discharges. GNSL 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, 2020w).

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 to minimise the production of corrosion products. Austenitic steel and Alloy 690 are widely used for primary circuit materials.

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, 2020x) 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 alloys, at the detailed design stage.

Summary of evidence GNSL presented in support of Argument 1f in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL 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. GNSL 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 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, 2019d) submission. The minimisation submission provided a balanced benefit and detriment review to conclude that using nitrogen will generate more carbon-14. This was outweighed by the safety benefit of eliminating this source of hydrogen, and the associate risks of a hydrogen deflagration that would need to be managed using complex safety-related control systems.

The carbon-14 minimisation submission (GNSL, 2019d) also asserts that nitrogen is the next best choice after hydrogen as a cover gas. Nitrogen is chemical 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.

Our preliminary 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 7: A future operator shall demonstrate that the dissolved nitrogen level in the primary coolant is minimised.

Summary of evidence GNSL presented in support of Argument 1f in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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 preliminary conclusions at this time.

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

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 GNSL, 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 absolutely 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.

We consider the measures for ensuring leak tightness as defined by GNSL to be consistent with a demonstration of BAT at the GDA stage.

Summary of evidence GNSL presented in support of Argument 2a in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

Argument 2a	Minimise leaks of radioactive process fluids from 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.

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

GNSL recognises that the structural integrity of the steam generator (SG) is important in minimising the spread of radioactive contamination into the secondary circuit where it has the potential to contaminate downstream SSCs (GNSL, 2020n). GNSL also argues that leak tightness from the SG primary side to the secondary side is assured by the design and in-service inspection. GNSL has provided evidence that the materials 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, GNSL 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 condensate vacuum system (CVS), which can detect and alert operators of 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 expected list of events (GNSL, 2019d), 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 environment.

We endorse that GNSL 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 follow-up action is detailed in section 2.16).

We consider the measures for minimising the transfer of radioactivity into the secondary circuit as defined by GNSL to be consistent with the demonstration of BAT at GDA. However, we note the 'Steam generator code provisions and mitigation of relevant risks' RO (RO-UKHPR1000-0033) is further assessing relevant aspects. We will consider any results as our assessment progresses.

Summary of evidence GNSL presented in support of Argument 2b in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 2b	Minimise the transfer of radioactivity into the secondary circuit
Evidence	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 for 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.

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

GNSL 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 0.5 m/s to prevent back flow of air.

The regulators have issued an RO with potential implications for the design of the HVAC system (RO-UKHPR1000-0039). The resolution to the RO includes identifying any shortfalls and gaps in the HVAC systems performance and other impacted systems. We will consider any implications arising from resolving this observation when we form our final view.

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 liquid radioactive waste management systems (LRWMS) and supply air centralised treatment in the nuclear auxiliary building (BNX). The resolution of the RO continues and will include providing a robust optioneering study and justification for the choice of HEPA filter type.

The regulators have issued an RO with potential implications for the choice of HEPA filter type (RO-UKHPR1000-0012). The resolution of this RO includes carrying out a mechanical engineering RGP gap analysis against the design, which will include the choice of HEPA filter type. We expect the outcomes of this RO and RO-36 to align.

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 inline 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 particular operations with potential to produce iodine are planned to be carried out.

Our preliminary conclusion is that the HVAC system uses appropriate technologies to minimise the radioactivity of gaseous radioactive waste discharges, including HEPA filters and iodine adsorbers. However, the specific technology for HEPA filters and how it is managed needs clarifying by resolving RO-UKHPR1000-0036 and is, therefore, subject to the following potential GDA Issue:

Potential GDA Issue 3: GNSL has provided environmental justification for the choice of high efficiency particulate air filter design. However, further justification must be provided to demonstrate how best available techniques is applied.

Summary of evidence GNSL presented in support of Argument 2c in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL 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, iodine isotopes, carbon-14, tritium 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. GNSL submitted an optioneering report to support the demonstration of BAT for the selected treatment techniques in the GWTS (GNSL, 2020e). 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.

GNSL 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 very low level waste (VLLW), and the HVAC iodine adsorbers waste is anticipated to be low level waste (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, temperature, pressure, humidity and flowrate. Filters are installed upstream and downstream of the delay beds to retain potential particles generated from the charcoal and, therefore, minimise the discharge of secondary waste.

GNSL 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, 2021a).

We agree with GNSL that using delay bed technology in the UK HPR1000 design and the size of the delay beds is appropriate and demonstrates BAT.

Summary of evidence GNSL presented in support of Argument 2d in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL 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. GNSL submitted an optioneering report to support the demonstration of BAT for the selected treatment techniques in the LRWMS (GNSL, 2020f). 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 techniques in the LRWMS include using filters, demineralisers and evaporators as shown in Figure 3 in section 2.8. The filters remove insoluble solid particles and fibres, the demineralisers remove soluble radionuclides, and the evaporators extract distillate and keep impurities in the concentrate. The demineralisers contain ion exchange resin and the regulators queried the validity of expected decontamination factors (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). 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 5: 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 for liquid waste management systems.

GNSL 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 on the in-process and discharge sampling and monitoring is in a separate assessment report (Environment Agency, 2021a).

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. Overall, at this time, our preliminary conclusion is that the design of the UK HPR1000 liquid radioactive waste management system is consistent with the demonstration of BAT in GDA.

Summary of evidence GNSL presented in support of Argument 2e in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

Argument 2f: Minimise the discharge of tritium

GNSL recognises that the primary sources of gaseous tritium are evaporation from the spent fuel pool (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, 2020b) and additional detailed analysis in the 'Minimisation of the Discharge and Environment Impact of Tritium' (GNSL, 2020y). 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, and it would be disproportionate to change the design.

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

Summary of evidence GNSL presented in support of Argument 2f in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 2f	Minimise the discharge of tritium
Evidence	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.

Argument 2g: Minimise the discharge of carbon-14

GNSL argues that following a technology assessment, including 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 GNSL's view however, given C14 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 8: A future operator shall review the practicability of techniques for abating carbon-14.

Summary of evidence GNSL presented in support of Argument 2g in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 2g	Minimise the discharge of carbon-14
Evidence	Assessment of alternative options for carbon-14 treatment - provides evidence that it is not practicable to abate gaseous 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 preliminary conclusions at this time.

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

GNSL 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. GNSL also argues that the design will not dictate the form 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 higher to the UK and the world population if discharged in gaseous phase and vice versa. Therefore, GNSL's approach to allow a future operator to define the balance between 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 9: A future operator shall optimise the balance between gaseous, liquid and solid phase 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 10: A future operator shall assess the chemical form of carbon-14 discharged to the environment and use this to 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, 2021f).

Summary of evidence GNSL presented in support of Argument 3a in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 3a	Partitioning of radionuclides has been optimised to minimise the impact on members of the public and the environment
Evidence	DPUR for annual discharges - provides evidence for the calculation of DPUR values. The conclusion is that, for tritium, the DPUR is higher if

Argument 3a	Partitioning of radionuclides has been optimised to minimise the
	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, 2020z).

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

GNSL 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. GNSL 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 follow-up action is detailed in section 2.16).

Summary of evidence GNSL presented in support of Argument 3b in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 3b	Eliminate solids, gases and non-aqueous liquids entrained within aqueous radioactive waste
Evidence	Removal of entrained gases by TEP [CSTS] - provides evidence for the degassing process carried out in the CSTS.

Argument 3c: Optimisation of the discharge stack height

GNSL 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. GNSL 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 (300 microsievert per year [μSv/y]) and screening value (10 microgray per hour [μGy/h]), which is adequate for the GDA stage of assessment.

GNSL recognises that determining the stack height will be a site-specific activity for a future operator and captured this as a forward action plan. An Assessment Finding has been raised in the monitoring assessment report (Environment Agency, 2021a).

Summary of evidence GNSL presented in support of Argument 3c in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 3c	Optimisation of the discharge stack height
Evidence	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, 2020z).

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

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

We will require that the timing and location of effluent discharges is a matter to 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, 2021a).

Summary of evidence GNSL presented in support of Argument 3d in the 'Demonstration of BAT' submission (GNSL, 2020b).

Argument 3d	Optimisation of the location and timing of liquid discharge
Evidence	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, 2020z).

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 preliminary conclusions at this time. 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, 2021b).

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

The management, treatment and disposal considerations taken into account during the design of the UK HPR1000 to minimise the volume of solid radioactive waste that is generated. A number of 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.

GNSL 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 abatement of the radioactive waste. 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 preliminary conclusion is that the evolution of the design has removed a number of 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.

Summary of evidence GNSL presented in support of Argument 4a in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

Argument 4b: Minimise the volume of solid radioactive waste by extending the design life of SSC and reusing maintenance equipment and 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 GNSL 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 also 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 three resins beds in series, as two 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 5: 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 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. GNSL also confirmed that the temperature, humidity, pressure and flowrate 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 detailed by GNSL contribute to reducing the volume of solid radioactive waste that will be produced and collectively demonstrate BAT. The resolution of the HEPA filter choice RO (RO-UKHPR1000-0036), see Argument 2c is also BAT.

Summary of evidence GNSL presented in support of Argument 4b in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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

GNSL 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. GNSL 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.

GNSL 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.

GNSL 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). GNSL 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 RO remains open at this time and we will monitor the additional justification of the design for a demonstration of BAT.

We recognise that decay storage can reduce the activity of waste that need 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.

Summary of evidence GNSL presented in support of Argument 4c in the 'Demonstration of BAT' submission (GNSL, 2020b).

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

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 preliminary conclusions at this time. Further assessment of the disposal routes for wastes can be found in the solid waste, spent fuel and disposability assessment report (Environment Agency, 2021b).

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

The design of the UK HPR1000 waste treatment facilities includes 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, GNSL 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 a 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, 2021b).

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

Summary of evidence GNSL presented in support of Argument 5a in the 'Demonstration of BAT' submission (GNSL, 2020b).

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
Evidence	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.

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

GNSL 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 Low Level Waste Repository Limited (LLWR Ltd). The regulators challenged GNSL to find out if there will be hazardous materials associated with the LLW wastes arising from the UK HPR1000 (RQ-UKHPR1000-0636). GNSL's response to the RQ included a number of non-hazardous pollutants. We are satisfied that GNSL has assessed the inventory for hazardous materials and non-hazardous pollutants, for this stage of GDA.

We consider this ‘agreement in principle’ suitably demonstrates waste compatibility with current disposal routes and is 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.

Summary of evidence GNSL presented in support of Argument 5b in the ‘Demonstration of BAT’ submission (GNSL, 2020b).

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

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

GNSL has explored the requirements for the disposability assessments and is obtaining disposability advice from Radioactive Waste Management Limited (RWM). The regulators queried the production of the disposability assessment (RO-UKHPR1000-0041), including seeking assurance that GNSL’s and RWM’s plans are aligned and can be completed within GDA timescales. The regulators queried the management of the in-core instrument assemblies (ICIAs) (RO-UKHPR1000-0037), including seeking justification for the decay storage. We note that the 2 ROs remain open at this time and the outcomes from the resolution plans' actions could influence the BAT demonstration for the generation, minimisation and management of radioactive waste in the UK HPR1000. A potential GDA Issue is noted in the solid waste, spent fuel and disposability assessment report concerning a demonstration that all HAW arisings from the UK HPR1000 will be disposable.

The disposability of all solid higher activity waste (HAW) produced from the UK HPR1000 operation is yet to be demonstrated and confirmed with advice from the nuclear industry, including RWM. This is discussed further in a separate assessment report (Environment Agency, 2021b).

Summary of evidence GNSL presented in support of Argument 5c in the ‘Demonstration of BAT’ submission (GNSL, 2020b).

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
Evidence	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.

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**
	Disposability assessment – intermediate level waste - provides a brief summary of current assessment of compatibility of the proposed waste packaging options with anticipated long-term waste management requirements.

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