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GE Hitachi Nuclear Energy

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BWRX-300 UK Generic Design Assessment (GDA) Chapter E6 - Demonstration of Best Available Techniques Approach

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EXECUTIVE SUMMARY

GEH is progressing the design and development of the BWRX-300 Small Modular Reactor. The BWRX-300 design incorporates the lessons learned from worldwide programmes, building on 60 years of design innovation and Operational Experience. GEH is, as the Requesting Party, presenting an Environment Case submission to the United Kingdom (UK) regulators for a Generic Design Assessment (GDA) at the Step 2 level for the BWRX-300.

The BWRX-300 represents a significant effort to reduce scale and complexity relative to predecessor Boiling Water Reactor designs. This design-to-cost focus has resulted in a reduced volume of plant, and simplification of the associated systems and components. These simplifications contribute to a reduction in manufacturing and construction costs, thereby increasing the commercial viability of the BWRX-300. This enables it to support UK government aspirations to decarbonise the UK economy and meet the target of 'Net Zero' by 2050.

The claims and arguments presented in this chapter of the Preliminary Environmental Report show that, with the addition of supporting evidence, the design and operation of the BWRX-300 are capable of being shown to have been optimised to the extent necessary to demonstrate that Best Available Techniques (BAT) have been applied, in line with Schedule 23 Part 4 of the Environmental Permitting Regulations 2016 (as amended) and the Environment Agency's 2010 guidance on 'Principles of Optimisation'. Demonstration of BAT requires a balanced consideration of positive and negative influences on environmental performance, together with the broader picture of economic and societal impacts.

The methodology adopted by GEH to optimise the environmental performance of the BWRX-300 is described in this report, and demonstrates that the potential impacts on workers, members of the public, and the environment, predicted to arise from the operation of the BWRX-300, have been minimised to the extent possible taking practicality, cost benefit, and wider social and economic factors into consideration. The methodology takes into account applicable regulatory requirements and associated guidance, as well as Relevant Good Practice.

The Demonstration of BAT has been developed using a Claims, Arguments, Evidence (CAE) approach. At this early stage of GDA, only claims and arguments are presented in most cases, with confidence that evidence can be provided in the future. However, worked examples for two arguments, including supporting evidence, are provided in order to demonstrate the application of the BAT methodology.

Gaps and uncertainties identified during the development of the arguments have been recorded within a Forward Action Plan (FAP). The FAP defines the scope and timing of additional work that will be delivered after the production of the CAE model.

GEH considers that the arguments set out in this document, combined with the collation of further evidence and resolution of outstanding FAP items, shall demonstrate that the BWRX-300 has been optimised in accordance with those elements of the environmental regulators' guidance that require the application of BAT.

ACRONYMS AND ABBREVIATIONS

Acronym	Explanation
ABWR	Advanced Boiling Water Reactor
AHU	Air Handling Unit
ALARA	As Low as Reasonably Achievable
ALARP	As Low as Reasonably Practicable
ALPS	Advanced Liquid Processing System
BAT	Best Available Techniques
BL3	Baseline 3
BNP	Brunswick Nuclear Plant
BWR	Boiling Water Reactor
CAE	Claims, Arguments, Evidence
CANDU	Canada Deuterium Uranium
CB	Control Building
CEAP	Continuous Exhaust Air Plenum
CFD	Condensate Filters and Demineralisers System
CFS	Condensate and Feedwater Heating System
CNSC	Canadian Nuclear Safety Commission
CP	Corrosion Product
CST	Condensate Storage Tank
CUW	Reactor Water Cleanup System
CWS	Circulating Water System
DBR	Design Basis Record
DFS	Dry Fuel Store
DZO	Depleted Zinc Oxide
EA	Environment Agency
EFS	Equipment and Floor Drain System
ENDP	Engineering Developed Principle
EPF	Environment Protection Function
EPM	Environment Protection Measure
EPR16	Environmental Permitting Regulations 2016 (as amended)
ESBWR	Economic Simplified Boiling Water Reactor
EUST	End User Source Term
F+DB	Filter plus Deep Bed Demineraliser
FAP	Forward Action Plan
FBS	Fuel Business System
FD	Filter Demineraliser
FME	Foreign Material Exclusion

Acronym	Explanation
FOAK	First-of-a-Kind
FP	Fission Product
FPC	Fuel Pool Cooling and Cleanup System
FPD	Forward Pumped Drain
GDA	Generic Design Assessment
GDP	Generic Developed Principles
GEH	GE-Hitachi Nuclear Energy Americas, LLC
GEZIP	GEH's Zinc Injection Passivation (process)
GNF	Global Nuclear Fuel
GSC	Gland Steam Condenser
HAW	Higher Activity Wastes
HCW	High Chemical Impurities Waste
HEPA	High Efficiency Particulate Air (filter)
HVS	Heating, Ventilation and Cooling System
HWC	Hydrogen Water Chemistry
IAEA	International Atomic Energy Agency
IC	Isolation Condenser
ICC	Isolation Condenser Pools Cooling and Cleanup System
ICS	Isolation Condenser System
IGSCC	Intergranular Stress Corrosion Cracking
ILW	Intermediate Level Waste
IRAT	Initial Radiological Assessment Tool
IWS	Integrated Waste Strategy
LAW	Lower Activity Waste
LLW	Low Level Waste
LLWR	Low Level Waste Repository
LOCA	Loss of Coolant Accident
LTP	Lower Tie Plate
LWM	Liquid Waste Management System
LWR	Light Water Reactor
MCR	Main Control Room
MIDAS	Multi-Inspection and Data Acquisition System
MPS	Missing Pellet Surface
MTE	Main Turbine Equipment
MVP	Mechanical Vacuum Pump
N&Q	Nature and Quantity
NBS	Nuclear Boiler System
NDA	Nuclear Decommissioning Authority

Acronym	Explanation
NNPP	New Nuclear Power Plant
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRW	Natural Resources Wales
NSD	Near-Surface Disposal
NWS	Nuclear Waste Services
OD	Outer Diameter
OGS	Offgas System
ONR	Office for Nuclear Regulation
OPEX	Operational Experience
PCI	Pellet-Cladding Interaction
PCS	Primary Containment System
PER	Preliminary Environmental Report
PREMS	Process Radiation and Environmental Monitoring System
PSR	Preliminary Safety Report
PVS	Plant Vent Stack
PWR	Pressurised Water Reactor
QA	Quality Assurance
RB	Reactor Building
RGP	Relevant Good Practice
RIV	Reactor Isolation Valve
RM	Requirements Management
RO	Reverse Osmosis
RP	Requesting Party
RPV	Reactor Pressure Vessel
RSMDP	Radioactive Substances Management Developed Principle
RSR	Radioactive Substances Regulation
RWB	Radwaste Building
RWST	Refuelling Water Storage Tank
SBWR	Simplified Boiling Water Reactor
SCC	Stress Corrosion Cracking
SCCV	Steel-Plate Composite Containment Vessel
SDC	Shutdown Cooling System
SDD	System Design Description
SF	Spent Fuel
SJAE	Steam Jet Air Ejector
SMR	Small Modular Reactor
SRV	Safety Relief Valve

Acronym	Explanation
SSCs	Structures, Systems, and Components
SWM	Solid Waste Management System
TB	Turbine Building
TGS	Turbine Gland Seal
TGSS	Turbine Gland Seal Subsystem
UK	United Kingdom
U.S.	United States of America
UT	Ultrasonic Testing
VLLW	Very Low Level Waste
WAC	Waste Acceptance Criteria
WGC	Water, Gas and Chemicals Pads
WSF	Waste Services Framework

SYMBOLS

Symbol	Definition
Bq/year	Becquerels per year
MBq/s	Megabecquerels per second
mil	One-thousandth of an inch, equivalent to 0.0254 millimetres
mm	Millimetre
m^3	Cubic metre
ppb	Parts per billion
ppm	Parts per million
TBq/year	Terabecquerels per year
µm	Micrometre
W/cm	Watt per centimeter

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REVISION SUMMARY

Revision #	Section Modified	Revision Summary
A	All	Initial Issuance
B	All	Update for end of GDA Step 2 consolidation

6 DEMONSTRATION OF BEST AVAILABLE TECHNIQUES

Introduction

The claims and arguments presented in this chapter of the Preliminary Environmental Report (PER) show that, with the addition of supporting evidence, the design and operation of the BWRX-300 are capable of being shown to have been optimised to the extent necessary to demonstrate that Best Available Techniques (BAT) have been applied, in line with Schedule 23 Part 4 of "The Environmental Permitting (England and Wales) Regulations 2016," (as amended) (EPR16), (Reference 6-1) and the Environment Agency's 2010 guidance on Radioactive Substances Regulation (RSR), "RSR: Principles of optimisation in the management and disposal of radioactive waste," (Reference 6-2). The design and operation of the BWRX-300 contributes to the prevention and minimisation of the production, management, and disposal of radioactive waste to protect the environment and members of the public. The demonstration of BAT has been developed using a Claims, Arguments, Evidence (CAE) approach, which is described in Section 6.2.

GEH is progressing the design and development of the BWRX-300 Small Modular Reactor (SMR) power station, innovating on 60 years of design and Operational Experience (OPEX). The BWRX-300 SMR revolutionises what is possible when it comes to generating reliable carbon-free power and represents a significant design effort to reduce scale and complexity relative to predecessor Boiling Water Reactor (BWR) designs. This design-to-cost focus has resulted in a reduced volume of plant, and simplification of the associated systems and components. These simplifications contribute to a reduction in manufacturing and construction costs, thereby increasing the commercial viability of the BWRX-300. This enables it to support United Kingdom (UK) government aspirations to decarbonise the UK economy and meet the target of 'Net Zero' by 2050, as outlined in E02678428, "Net Zero Strategy: Build Back Greener," (Reference 6-3).

BWRX-300 Design Concept and Philosophy

The first-of-a-kind BWRX-300 design is being developed in the United States of America (U.S.) for international deployment using a Standard Design approach to minimise the design variation from project to project. The design is based on a wide range of regulatory requirements and recommendations established by the U.S. Nuclear Regulatory Commission (NRC), Canadian Nuclear Safety Commission (CNSC), International Atomic Energy Agency (IAEA) and International Commission on Radiological Protection, with the intention of international deployment (see GEH Requirements Specification document 006N5081, "BWRX-300 As Low As Reasonably Achievable Design Criteria for Standard Design" (Reference 6-4)). This document is an 'A level' document that allocates and enforces requirements for radiation protection, to reduce occupational and public exposure to radiation to levels that are As Low As Reasonably Achievable (ALARA).[1] Inherent flexibility in the design allows the BWRX-300 design to be optimised by a future developer/operator to fulfil UK-specific regulatory requirements at later design phases.

One of the key objectives of the BWRX-300 is to ensure adequate protection of workers, members of the public, and the environment from harm at all lifecycle stages of the power station. This objective is consistent with the fundamental principle of reducing exposures to levels that are As Low as Reasonably Achievable (ALARA) using BAT, as defined in UK environmental legislation, regulatory principles, and regulatory guidance documents.

[1] The ALARA approach adopted by GEH in the BWRX-300 design is based on international regulations and standards (e.g., ICRP Publication 103, "The 2007 Recommendations of the International Commission on Radiological Protection," (Reference 6-5) and IAEA General Safety Requirements GSR Part 3, "Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards," (Reference 6-6)), as distinct from the specific implementation of the ALARA requirement in UK environmental legislation and regulatory guidance.

This report describes the methodology developed by GEH that may be adopted by a future developer/operator for future design development phases to optimise the environmental performance of the BWRX-300 and demonstrate that the potential impacts on workers, members of the public, and the environment, predicted to arise from the operation of the BWRX-300, have been minimised to the extent possible taking practicality, cost benefit, and wider social and economic factors into consideration.

A key feature of the proposed methodology is the integration of BAT into the engineering design process alongside safety and security principles to achieve holistic optimisation of the BWRX-300 power station. The methodology takes into account applicable regulatory requirements and associated guidance, as well as Relevant Good Practice (RGP).

Objective

GEH has entered into the Generic Design Assessment (GDA) process up to Step 2 with the BWRX-300 New Nuclear Power Plant (NNPP) design. This document is one part of the suite of documents required for GDA and specifically is part of the Environment Case submission.

The Environment Case provides claims and arguments, and confidence that evidence can be provided in the future, to demonstrate that the BWRX-300 meets Environment Agency (EA) and Natural Resources Wales (NRW) regulatory requirements and expectations and uses BAT to prevent or minimise harm to workers, members of the public, and the environment. With regard to the provision of evidence, this chapter presents a worked example for two arguments, demonstrating the application of the BAT methodology.

Scope

This report details how decisions relating to the design of systems that have the potential to impact on the environment have been taken with due regard to the considerations above, as well as sustainability. The report will provide a description of the optimisation process used to identify and justify that the proposed techniques are BAT. Specific systems of interest will be those that give rise to the creation of radioactive wastes or generation of radioactive discharges to the environment through either gaseous or aqueous liquid routes. Both primary and secondary radioactive wastes will be considered.

The full range of radioactive wastes and environmental radioactive discharges anticipated to be produced by the plant under normal operations is anticipated to include:

- Aqueous liquid radioactive discharges
- Gaseous radioactive discharges
- Wet solid radioactive wastes
- Dry solid radioactive wastes
- Spent fuel (SF)

The sampling and monitoring of gaseous and aqueous radioactive wastes, and characterisation of solid radioactive wastes, arising during normal operation of the BWRX-300, is not within the scope of this report. The sampling and monitoring regime included in the BWRX-300 design is described in NEDO-34225, “BWRX-300 UK GDA Chapter E8: Approach to Sampling and Monitoring,” (Reference 6-7). Claims and arguments in support of the demonstration of BAT for these systems are also presented in NEDO-34224, “BWRX-300 UK GDA Chapter E7: Radioactive Discharges,” (Reference 6-8).

Design Maturity

The BWRX-300 SMR design is based on licensed reactor technology representing the tenth generation BWR, incorporating decades of learning and enhancements. The BWRX-300 uses proven fuel technology, GNF2, which is manufactured by Global Nuclear Fuel (GNF). GNF2 is a commercial-scale fuel that more than 25 Nuclear Power Plants (NPPs) around the world have used over the last decade.

Final decisions about design features are ongoing and expected to undergo further iteration as the design progresses. This is particularly true for systems that require site-specific information. This document represents the initial BAT case for the BWRX-300, which is aligned to the current design baseline, as described in NEDO-34221, “BWRX-300 Chapter E4: Information about the Design,” (Reference 6-9) and NEDO-34154, “Design Reference Report,” (Reference 6-10). Gaps and uncertainties identified during the development of the arguments have been recorded within a Forward Action Plan (FAP). The FAP defines the scope and timing of additional work that will be delivered after the production of the CAE model.

The optimisation methodology will be subject to a continuous review and improvement cycle. It will be reviewed and updated periodically to reflect feedback from users, lessons from other projects, and any developments in environmental policy and legislation. This methodology is described further in Section 6.2.6.

Document Structure

Following this introductory section, the document is structured in the following manner:

Interfaces with other Chapters

This document interfaces with the following chapters in the PER:

- NEDO-34220, “BWRX-300 UK GDA Chapter E3: Management Arrangements and Responsibilities,” (Reference 6-11)
- PER Chapter E4 (Reference 6-9)
- NEDO-34222, “BWRX-300 UK GDA Chapter E5: Radioactive Waste Management Arrangements,” (Reference 6-12)
- PER Chapter E7 (Reference 6-8)
- PER Chapter E8 (Reference 6-7)
- NEDO-34226, “BWRX-300 UK GDA Chapter E9: Prospective Radiological Assessment,” (Reference 6-13)

This document interfaces with the following supporting documents to the PER:

- NEDC-34231P, “Alignment with Sustainability, the Radioactive Substances Regulation Objective and Principles & Generic Developed Principles,” (Reference 6-14)
- NEDO-34228, “Integrated Waste Strategy,” (IWS) (Reference 6-15)
- NEDC-34229P, “Demonstration of Disposability for Higher Activity Radioactive Wastes (Including Spent Fuel),” (Reference 6-16)
- NEDC-34279P, “Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants,” (Reference 6-17)

This chapter also interfaces with the BWRX-300 UK GDA Preliminary Safety Report (PSR):

- NEDC-34166P, “BWRX-300 UK GDA Chapter 4: Reactor (Fuel and Core),” (Reference 6-18)

- NEDC-34159P, "BWRX-300 UK GDA Fuel Summary Report," (Reference 6-19)
- NEDO-34198, "BWRX-300 UK GDA Chapter 26: Interim Storage of Spent Fuel," (Reference 6-20)

6.1 Regulatory Context

GEH's approach to BAT methodology is the integration of BAT within its design processes to achieve holistic optimisation of the BWRX-300. However, BAT has a specific meaning and requirements in UK environmental legislation.

This section provides a brief overview of the regulatory framework relating to the use of BAT to prevent, or where this is not possible, minimise the generation and disposal of radioactive wastes, and the resulting impact on workers, members of the public, and the environment. Additional details of relevant national and international legislation, as well as regulatory guidance and RGP can be found in the references provided.

6.1.1 Environmental Permitting (England and Wales) Regulations 2016 (as amended)

There is a duty through Schedule 23 of EPR16 (Reference 6-1) to make sure radiological protection is optimised in activities that generate radioactive waste. The requirement to apply BAT to minimise the generation, disposal, and impacts of radioactive wastes is set out in Part 4 of EPR16 Schedule 23, which requires that:

> *"In respect of a radioactive substances activity that relates to radioactive waste, the regulator must exercise its relevant functions to ensure that —*
>
> *(a) 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, taking into account economic and social factors, and*
>
> *(b) the sum of the doses resulting from the exposure of any member of the public to ionising radiation does not exceed the dose limits set out in Article 12 of the Basic Safety Standards Directive subject to the exclusions set out in Article 5(c) of that Directive."*

Under EPR16, operators undertaking radioactive substances activities (as per Paragraph 12 of the regulations) require a permit for those activities. BAT is mainly covered by permit conditions 2.3.1, 2.3.2, and 2.3.3, although there are other conditions that address specific aspects of BAT (see the EA's guidance document, "RSR Permits for Nuclear Licensed Sites: How to Comply," (Reference 6-21)).

> *"2.3.1 The operator shall use the best available techniques to minimise the activity of radioactive waste produced on the premises that will require to be disposed of on or from the premises."*
>
> *"2.3.2 The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to:*
>
> *(a) minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment*
>
> *(b) minimise the volume of radioactive waste disposed of by transfer to other premises*
>
> *(c) dispose of radioactive waste at times, in a form, and in a manner so as to minimise the radiological effects on the environment and members of the public."*
>
> *"2.3.3 The operator shall use the best available techniques to:*
>
> *(a) exclude all entrained solids, gases, and non-aqueous liquids from radioactive aqueous waste prior to discharge to the environment*
>
> *(b) characterise, sort and segregate solid and non-aqueous liquid radioactive wastes, to facilitate their disposal by optimised disposal routes*
>
> *(c) remove suspended solids from radioactive waste oil prior to incineration."*

6.1.2 Environment Agency guidance on Best Available Techniques

The EA has published further guidance that contains provisions relating to the application of BAT, including:

1. "RGN RSR 2: The regulation of radioactive substances activities on nuclear licensed sites," (Reference 6-22)
2. "RSR: Principles of optimisation in the management and disposal of radioactive waste," (Reference 6-2), which states:

   "Operators, when disposing of radioactive waste, need to ensure that the radiological impacts on people are kept as low as reasonably achievable, taking into account economic and social factors. This is the optimisation requirement. We expect operators to achieve this through the use of "Best Available Techniques" (BAT) in the (sic) *relation to the management of the generation and disposal of radioactive waste."*
3. "RSR permits for nuclear licensed sites: how to comply," (Reference 6-21)

6.1.3 Generic Design Assessment Guidance for Requesting Parties

The regulators (Office for Nuclear Regulation (ONR), EA and NRW) have developed the GDA process, which they use to scrutinise NNPP designs and assess their acceptability for use in Great Britain. The EA's and NRW's regulatory responsibilities extend to England and Wales respectively.

The regulators have produced a guidance document: "New nuclear power plants: Generic Design Assessment guidance for Requesting Parties (RPs)," (Reference 6-23). This guidance explains:

- How the GDA process works
- What information the RP needs to provide when requesting a GDA
- The possible outcomes from a GDA

The guidance refers to the development of an Environment Case by the RP. The term 'Environment Case' refers to the collection of documents submitted by the RP during GDA to demonstrate that their NNPP design:

- Meets regulatory requirements and expectations
- Uses BAT to prevent or minimise harm to workers, members of the public, and the environment

Key information requirements and expectations relating to BAT during GDA include:

- Defining the RP's approach and methodology for determining BAT to prevent or minimise the generation of radioactive wastes and their impact during the lifecycle of the plant – design, construction, commissioning, operation, and decommissioning
- Demonstration that the RP's proposals represent BAT for sampling and monitoring
- Information about conventional (i.e., non-radiological) aspects of the design, including information about the approach to applying BAT (where applicable)
- Information on how sustainability is taken into account in decisions relating to the design and how RSR principles relating to optimisation and BAT have been applied

6.1.4 Environmental Permitting Guidance for Radioactive Substances Regulation

The "Environmental Permitting Guidance, Radioactive Substances Regulation, For the Environmental Permitting (England and Wales) Regulations 2010," (Reference 6-24) document is to aid understanding of the permitting and other requirements specific to RSR.

The main objectives of RSR are to establish and maintain control over the keeping, use, and security of radioactive materials including sealed radioactive sources and mobile radioactive apparatus; ensure that the accumulation and disposal of radioactive wastes are managed effectively to limit radiological impact on the general public and the environment; and ensure operators make appropriate financial provisions for re-use, recycling, or disposal of high activity sealed radioactive sources.

The BWRX-300 will be located on a nuclear licensed site. As such, regulation will be carried out jointly by the EA, for disposal of radioactive wastes, and the ONR, for the keeping and use of radioactive materials and accumulation of radioactive waste.

6.1.5 Radioactive Substances Regulation Objective and Principles

The EA has published its "Radioactive Substances Regulation (RSR): objective and principles," (Reference 6-25), which sets out the fundamental objective of RSR and the regulatory principles the EA applies in the delivery of its function as laid out in Schedule 23 of EPR16 and government policy.

The RSR objective and principles (Reference 6-25) are supported by a set of RSR Generic Developed Principles (GDPs), presented in the EA's guidance documents "RSR generic developed principles: regulatory assessment," (Reference 6-26), which set out the EA's expectations on permit holders carrying out radioactive substances activities.

The key RSR principles relevant to underpinning the design of the BWRX-300 include:

Principle 2: Optimisation

> *"Radiological protection must be optimised to make sure that people's exposure to ionising radiation from the disposal of radioactive waste is kept as low as reasonably achievable (ALARA), taking into account environmental, social and economic factors."*

Principle 8: BAT

> *"Operators must use BAT for the management of radioactive waste. … The statutory guidance states that we should make sure that BAT is used to: prevent the unnecessary creation of radioactive waste or discharges, minimise the quantity and activity of any radioactive waste that is created, and minimise the impact of discharges on people and the environment."*

The application of BAT feeds into Principle 2 that requires the optimisation to ensure exposure to ionising radiation meets ALARA criteria.

6.1.6 Environment Act 1995

The "Environment Act 1995" (as amended), (Reference 6-27) provided for the establishment of the EA to carry out functions in relation to England and Wales and to set standards for environmental management. The Act was revised in 2013 to include the formation of NRW.

6.1.7 Well-being of Future Generations (Wales) Act 2015

The "Well-being of Future Generations (Wales) Act 2015," (Reference 6-28) requires public bodies in Wales to do things in the interest of the economic, social, environmental, and cultural well-being of Wales in a way that accords with the sustainable development principle. It requires the public bodies to think about the long-term impact of their decisions, to work better with people, communities, and each other, and to prevent persistent problems such as poverty, health inequalities, and climate change.

6.1.8 Environment (Wales) Act 2016

The "Environment (Wales) Act 2016," (Reference 6-29) puts in place legislation to enable Wales's resources to be managed in a more proactive, sustainable, and joined up manner. It also establishes the legislative framework necessary to tackle climate change. Part 1 aims to promote the sustainable management of natural resources.

The objective is to maintain and enhance the resilience of ecosystems and the benefits they provide. This means using natural resources in a way, and at a rate, that promotes achievement of the objective, taking other action that promotes achievement of the objective, and not taking action that hinders achievement of that objective.

In doing this it will help meet the needs of present generations of people without compromising the ability of future generations to meet their needs and will contribute to the achievement of the well-being goals in Part 2, Section 4 of the Well-being of Future Generations (Wales) Act 2015 (Reference 6-28).

6.1.9 Environment Act 2021

The "Environment Act 2021" (as amended), (Reference 6-30) acts as the UK's new framework for environmental protection. It makes provision regarding targets, plans, and policies for improving the natural environment and provides the government with powers to set new binding targets, including for air quality, water, biodiversity, and waste reduction.

6.1.10 Environment Agency's EA2025 Creating a Better Place

The EA's corporate strategy is presented in "Environment Agency: EA2025 creating a better place," (Reference 6-31). EA2025 identifies three long-term goals:

- A nation resilient to climate change
- Healthy air, land, and water
- Green growth and a sustainable future

These goals, which are consistent with the United Nations' Sustainable Development Goals, align with the regulation of nuclear sites as they help ensure that nuclear facilities are designed and operated in ways that minimise waste and protect members of the public and the environment.

6.2 Methodology for Demonstration of Best Available Techniques

6.2.1 BWRX-300 Best Available Techniques Methodology

GEH has built upon the existing BAT methodology used for the UK Advanced Boiling Water Reactor (ABWR), as presented in GA91-9901-0021-00001, "UK ABWR Generic Design Assessment: Approach to Optimisation," (Reference 6-32) to provide a pathway for future demonstration of the application of BAT to the BWRX-300 design. This breaks the process down into the key BAT-related permit conditions. A future developer/operator may therefore adopt this methodology to be able to demonstrate, following synthesis of underpinning evidence for all arguments, that practicable and proportionate measures have been taken during design development to arrive at a balanced view on optimisation in order to:

- Prevent and minimise (in terms of radioactivity) the creation of radioactive waste
- Minimise (in terms of radioactivity) discharges of gaseous and aqueous radioactive wastes
- Minimise the impact of those discharges on members of the public, and adequately protect other species
- Minimise the volume of solid and non-aqueous liquid radioactive wastes and SF
- Select the optimal disposal routes (taking account of the waste hierarchy and the proximity principle) for those wastes, which also includes the suitability of disposal for those wastes where there is currently no available disposal route

The BAT methodology presented here is considered to be consistent with industry RGP and relevant principles from the RSR objective and principles (Reference 6-25), with "Alignment with Sustainability, the Radioactive Substances Regulation Objective and Principles & Generic Developed Principles," (Reference 6-14), and the approach undertaken by GEH to review and incorporate each of the relevant principles within the GDA submission.

The methodology proposes a systematic and evidence-based approach that aims to demonstrate that the design, manufacture, construction, commissioning, operation, and decommissioning of the BWRX-300 will be optimised to protect members of the public and to minimise the impact on the environment from exposure to ionising radiation.

An overview of GEH's proposed BAT methodology is provided in Figure 6-1 and meets the following Radioactive Substances Management Developed Principle (RSMDP), within the RSR GDPs (Reference 6-26):

> *RSMDP4 – Methodology 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."*

It is noted that, for this revision of the BWRX-300 demonstration of BAT approach, only the evidence required to demonstrate application of the methodology has been synthesised, in the form of a worked example. As the BWRX-300 SMR is a development of previous generations of BWR (including the ABWR and the Economic Simplified Boiling Water Reactor (ESBWR)), GEH is confident that complete synthesis of the evidence required to support the presented claims and arguments will be possible in future updates of this document.

As shown in Figure 6-1, the methodology includes several feedback loops. If a response to a question is 'no', the question will be revisited after the resulting step is completed, to ensure the answer becomes 'yes' before progressing to the next step. The individual steps of the methodology are described in subsequent subsections.

6.2.2 Identification and Quantification of Radioactive Waste/Source Term

The identification and quantification of radioactive wastes/source term has four objectives:

- To understand how an activity or process contributes to the generation of radioactive waste
- To quantify those radioactive wastes that will be generated
- To identify pathways to the environment
- To establish the contribution to radioactive discharges and the consequent radiological impacts on members of the public and the environment

This information is then used, as the CAE model develops, to determine the extent to which optimisation has already been achieved and whether opportunities remain for further optimising the design through the application of BAT. Quantifying the radioactive wastes at the start of the process also supports the ‘proportionality principle’ (i.e., how much time, effort and money is it reasonable to expend managing a waste stream of a given volume and radioactivity) and the identification of uncertainties that might impact on the arguments being developed.

The source term, pathways to the environment, radioactive discharges, and solid radioactive wastes are identified and quantified to support the following:

- Identification of where most effort should be expended in further optimising those activities that contribute to the generation of radioactive waste
- Application of the waste hierarchy (prevent, reduce, reuse, recycle, and dispose)
- Understanding the challenge in terms of management, treatment, and potential impact presented by radioactive waste and discharges
- Determining the potential impacts of radioactive wastes and discharges on members of the public and the environment
- Correctly designing radioactive waste management systems
- Determining the performance of radioactive waste management systems
- Demonstrating control of radioactive substances

The following characteristics of the wastes may be determined as necessary:

- Physical
- Chemical
- Radiological
- Biological

Where gaps are identified in the evidence to support the identification and quantification process, these will be flagged as uncertainties. These uncertainties, and any associated assumptions, will be assessed to determine their potential impact on arguments presented within the CAE model and to formulate Forward Actions as required. It will not be appropriate to deal with all of these Forward Actions during GDA Step 2; some will be addressed during later phases of the project.

The current source term for the BWRX-300 presented at GDA Step 2 has been identified as being conservative and bounding for radioactive discharges and solid radioactive wastes. Further details on the conservatisms are provided within PER Chapter E7 (Reference 6-8). The source term is not reflective of the design features of the BWRX-300 that specifically minimise radioactive discharges and solid radioactive waste generation and is therefore not suitable for future site licensing and environmental permitting phases in the UK. Use of a source term incorporating unrealistic conservatisms to drive ongoing design development would present a risk of 'over-engineering' the plant. This could result in an unnecessary increase in design complexity and associated increased maintenance/decommissioning burden. As a result, the economic benefits of a simplified design to support decarbonisation and 'Net Zero' aspirations in an economically viable manner could be negated. It has been identified that there is a need for a refined "Realistic Model" (RM) source term to support optimisation of the BWRX-300 design for a site-specific installation in the UK, and for quantification of solid radioactive wastes and radioactive gaseous and aqueous liquid discharges.

FAP.PER6-199 - **Design development and quantification of radioactive wastes/discharges beyond GDA Step 2 shall be based on a refined RM source term (see FAP.PSR23-133) for use in the demonstration of BAT for optimised selection, design, implementation, operation, maintenance and decommissioning of Structures, Systems and Components (SSCs) that influence the environmental impact of the BWRX-300.**

A high-level forward action (FAP.PSR23-133) for refinement of the BWRX-300 End User Source Term (EUST) across multiple technical areas has also been identified in NEDO-34195, "BWRX-300 UK GDA Chapter 23: Reactor Chemistry," (Reference 6-33).

FAP.PSR23-133 – "*Although GEH has presented detailed RM and Design Basis Primary Source Terms for reactor water and reactor steam, and some limited additional source terms to aid shielding assessments, preliminary EUSTs derived for:*

- *waste accumulation*
- *liquid/airborne discharges*

are overly conservative and will be re-evaluated. Furthermore, additional radionuclides (most notably carbon-14 and argon-41) will be included in the source term definition.

Due to the proposed adoption of a low Hydrogen Water Chemistry (HWC) dosing regime in combination with the use of Online NobleChem™ (OLNC™) to mitigate Intergranular Stress Corrosion Cracking (IGSCC), the hydrogen concentration in reactor water and, therefore, the generation of volatile nitrogen-16 species in reactor steam will be significantly reduced. The design basis nitrogen-16 reactor steam source term (in steam bearing equipment) will be re-evaluated based on the lower hydrogen concentration.

A comprehensive set of EUSTs will be developed to support the following discipline areas:

- *Radiation protection – PSR Chapter 12*
- *Radioactive waste accumulation and activity – PSR Chapter 11, PSR Chapter 26 and PER Chapter E5*
- *Decommissioning volumes and activity – PSR Chapter 21 and PER Chapter E5*
- *Normal effluent discharges – PER Chapter E7 and PER Chapter E9*
- *Fault Studies – PSR Chapter 15."*

6.2.3 Development of Claims

For the purposes of demonstrating a robust BAT methodology at GDA Step 2, GEH defines a claim as:

- A clear statement of what will be achieved
- A demonstration of compliance with the requirements of the environmental regulators' GDA guidance for RPs (Reference 6-23) and those conditions in a Radioactive Substances Activities Permit that relate to the application of BAT

A claim is developed by:

- Identifying those aspects of a design that contribute to the generation of radioactive waste
- Establishing radioactive waste streams and arisings
- Assessing what is required to demonstrate compliance with relevant permit conditions

Sources of information that support the development of claims are:

- Identification and quantification of radioactive wastes/source term
- Environmental Permits
- Other BAT studies
- Technical advisors

Figure 6-2 illustrates the overall structure used to develop the CAE model, with multiple claims necessary to demonstrate BAT, each supported by multiple arguments and lines of evidence.

Section 6.3.2 provides a worked example of the CAE model, comprising two arguments and their associated evidence that support the first claim to be discussed. It is noted that this claim is also supported by other arguments for which the evidence will be synthesised in future updates to this document.

6.2.4 Gathering Evidence

Evidence is information available to support the demonstration that BAT is being applied and is required to:

- Underpin arguments
- Allow examination and challenge
- Identify key gaps and uncertainties

This methodology addresses the gathering of evidence prior to developing the BAT arguments. This ensures that arguments are evidence based. However, it is recognised that, as the case develops, the process of gathering evidence and developing arguments becomes iterative. This is the case for the BWRX-300, for which numerous arguments already exist from predecessor designs and the key is the refinement of the evidence that reflects improvements along its evolutionary path. Some evidence may not be held by GEH, in which case it will be necessary to identify and engage with the appropriate holder.

Important considerations when gathering evidence are:

- Where does it come from?
- How comprehensive is it?
- How applicable is it?
- How reliable is it?

These questions are used to assess the significance of uncertainties identified within the evidence base and to assess the sensitivity of the arguments to any assumptions that have been made within the evidence base.

The evidence base provided to substantiate the arguments can include a range of sources of evidence, including:

- Analytical data
- Research and Development
- Trials

- Modelling
- Reports
- Records of experience
- Engineering judgement
- Considered opinion
- Output from option assessment studies (if conducted in a manner suitable for use)

In determining when more can be done, and exploring the proportionality argument, the evidence base can be complemented with the output from a range of tools and techniques. These tools and techniques can contribute to:

- Decision making (including options selection)
- Reducing uncertainty
- Substantiating arguments
- Demonstrating performance

A range of tools and techniques is available, the output of which is appropriate to be used as evidence when demonstrating the application of BAT. Some of the more commonly used tools and techniques have been listed below:

- Options assessment processes that address both BAT and the As Low As Reasonably Practicable (ALARP) safety principle in a holistic approach
- Multi-attribute decision analysis
- Cost benefit analysis
- Trials
- Value engineering

Other tools and techniques are available. As with all tools and techniques, these should be assessed to ensure that they meet the requirements of environmental optimisation and the application of BAT prior to implementation.

6.2.5 Development of Arguments

Arguments are a series of statements that are required to:

- Demonstrate that the series of claims is valid
- Draw the evidence into a ‘story’
- Identify uncertainties and assumptions

Important considerations for the preparation of arguments are:

- One or more arguments must be established for each claim
- The contribution that each argument makes to fulfilling the claim must be determined
- The relevance of the argument to the claim
- The evidence that is important to the argument must be identified
- The impact of uncertainties/assumptions must be described

Sources of information that can assist in the preparation of arguments are:

- RGP
- Reports
- Discussions and debate
- Experience
- Historical information

Each argument shall contain:

- A short description of the context/issue and why it is important to the application of BAT
- A discussion on how relevant features of the BWRX-300 contribute (or not[2]) to delivering environmental performance
- A statement that clearly articulates what has been achieved and how the evidence identified fulfils the claim
- Comments on gaps, uncertainties, observations, and actions

Arguments for each claim are provided in Section 6.3.

6.2.6 Review, Learn, and Improve

The 'review, learn, and improve' process will monitor the ability of this methodology for the demonstration of BAT to achieve its intended results, supporting the demonstration that the generic design of the BWRX-300 fulfils UK and international expectations with regard to environmental optimisation and the application of BAT. The review process includes self-assessment, independent review, and management system review, and will enable opportunities for improvement to be identified and implemented where appropriate. The review process has been developed to deliver the following:

- Evaluation of the effectiveness of processes in meeting and fulfilling goals, strategies, plans, and objectives
- Determination of the adequacy of work performance and leadership
- Monitoring of product quality
- Identification of opportunities for improvement

The review process incorporates the output from a range of sources including:

- Stakeholder feedback
- Follow-up actions from previous management reviews
- Outputs from self-assessments and independent reviews
- Results delivered and objectives achieved by GEH and its processes
- Lessons learned from other organisations

6.2.7 Reporting and Ongoing Review

The iterative nature of environmental optimisation is recognised and addressed within this methodology through the review, learn, and improve process (Subsection 6.2.6). This ensures that opportunities to continue optimising environmental performance can be realised

[2] Demonstration of BAT requires a balanced consideration of positive and negative influences on environmental performance, together with the broader picture of economic and societal impacts. A design modification may still represent BAT even if it results in a small environmental detriment if it also positively affects the economic viability of the process being modified.

throughout the BWRX-300 lifecycle. The CAE model and this GDA Demonstration of BAT report should be used by a future developer/operator to inform the ongoing optimisation of the BWRX-300.

To meet this objective, as well as the review of the efficacy of the BAT methodology itself, a review process for the demonstration of BAT will be required. The demonstration of BAT should be reviewed by a future site developer/operator at the start of their respective programme phases.

The following triggers are proposed for initiation of a BAT review:

- BAT should be reviewed every five years as a minimum
- BAT should be reviewed and updated by the developer/operator at the start of their respective programme phases
- BAT should be reviewed on identification of substantive changes to the terms of reference for the BAT. Such changes could include new operating data (e.g., evidence of reduced process efficiency compared with that expected), changes in the available options (e.g., due to technology advancements), changes in legislation, regulation, or related guidance

When a BAT review has been initiated in response to one or more of the triggers identified above, the following routine questions are to be asked regarding changes since the last demonstration of BAT:

- Has regulatory context changed? This may include changes in legislation, regulation, or guidance
- Has the plant process changed? This may include changes to Environment Protection Measures that are claimed to provide an Environment Protection Function (EPF) (see Subsection 6.2.14)
- Are new/updated techniques available? This may include new technology that could impact environmental performance
- Do operational data and experience challenge established arguments and evidence? This may include operational or maintenance issues that could indicate a risk to maintaining BAT

If the answer to any of the above questions is “yes,” the demonstration of BAT is updated, following the BAT methodology, and a proportionate reassessment should be undertaken, involving relevant disciplines. If the answer to all of the above questions is “no,” the existing BAT arguments are considered to remain valid.

6.2.8 Management of Gaps and Uncertainty

The methodology recognises the iterative nature of design development and acknowledges that there will be gaps and uncertainties associated with evidence and arguments. The methodology requires that gaps and uncertainties are identified and their associated impact on the demonstration of BAT is understood. This allows appropriate mitigation and management measures to be put in place to ensure that such measures are delivered at the most appropriate stage of the GDA or site-specific programmes. The methodology includes a decision tool (see Section 6.2.11) for appropriately sentencing gaps and uncertainties when they are identified.

6.2.9 Assessing the Quality of Evidence

Environmental optimisation and demonstrating the application of BAT relies on evidence that is:

- Robust
- Defensible
- Demonstrable

The evidence that is gathered needs to be reviewed to establish the presence and size of:

- **Gaps** – Information related to a particular subject or design element is incomplete or not available
- **Uncertainties –** Confidence in using the information for the BWRX-300 is low because it is of uncertain provenance, has not been subject to an appropriate governance process, or is not directly applicable to BWRX-300 technology

The quality of supporting evidence can be placed in one of two broad groups presented in order of preference:

- **Fact** ('I can show') – Evidence that can be validated and is from a reputable, auditable source
- **Knowledge** ('I know') – Evidence based on individuals' qualifications, expertise, and experience

6.2.10 Determining the Impact of Gaps and Uncertainty on Arguments and Claims

The impact of gaps and uncertainties on arguments must be determined to ascertain the need for additional work. Key considerations are:

- How important is the evidence?
- Does the argument rely on this evidence?
- Can the other, existing evidence be used to support the argument?
- How big is the uncertainty?
- Is information missing?
- Can existing information be interpreted/extrapolated?
- Is expertise missing?

The same approach is adopted for reviewing claims by considering gaps and uncertainties related to arguments.

The tool presented in Figure 6-3 can be used as a simple guide when determining whether additional evidence is required. 'Check other evidence' requires that the current evidence base should be revisited to determine whether there are opportunities to use existing information, by direct reference or extrapolation, prior to undertaking additional evidence gathering. 'More evidence required' and 'OK' are self-explanatory.

6.2.11 The Decision Tool

The decision tool is used to define the scope and timing of additional work that is necessary to fill gaps or address uncertainties. It is pictured in Figure 6-4. The decision tool is a step within the methodology for demonstrating the application of BAT (Figure 6-1), specifically employed when the provided arguments and evidence do not fulfil the BAT claims. The decision tool should be used by suitably qualified experienced persons either individually or collectively. The outcomes from applying the decision tool shall be recorded and scrutinised in accordance with the project governance arrangements.

The decision tool requires the following considerations to be addressed:

- The nature of the additional evidence that is required to fill the gap or address the uncertainty in order to fully substantiate the argument and claim. The context of the requirement for additional evidence must be clearly defined, and a clear scope of work produced to define the information that is needed, focusing on identified issues
- The timescale within which the additional evidence will be required in the project lifetime in order to fill the gap or address the uncertainty, i.e., whether the information is required immediately, is already planned within the project programme, or if it relates to a site-specific issue

A gap or uncertainty that requires assessment using the decision tool can include those associated with a proposed design change. It is also possible that in order to provide the required evidence to update an argument, the decision tool will drive a requirement for a design change.

If it is identified that the required evidence is not currently available to GEH, there is a risk that it may not be available on the timescales required by a future developer/operator to develop the project (or may never be available). In either case, it will be necessary to record the requirement to obtain the evidence in the project risk register and manage the risk accordingly. The risk register should be developed by a developer/operator when collating evidence for the BAT case after GDA Step 2.

If additional evidence is available but is not immediately required, then an action can be placed in the FAP to prompt the future acquisition and inclusion of the evidence at the appropriate time.

6.2.12 Forward Action Plan

The FAP defines the scope and timing of additional work beyond GDA Step 2 that will be delivered after the production of the CAE model described in this chapter, and provides evidence for future iterations of the BAT case for the BWRX-300. The purpose of the FAP is to:

- Identify future tasks that will be delivered at the most appropriate time in the programme
- Identify the person or function responsible for executing the action
- Demonstrate GEH's commitment to engaging with the GDA process and providing a future developer/operator with clarity on the activities required to address identified issues
- Aid the definition of Assessment Findings for GDA

The FAP for the demonstration of BAT is provided in Appendix A (Table A-1).

6.2.13 Proportionality

The environmental regulators have indicated that they will take a proportionate approach, both to the degree of assessment that is required by themselves and operators, as well as to the techniques that they require operators to use to optimise environmental performance (see RSR: Principles of optimisation (Reference 6-2)).

In terms of proportionality, the EA's RSR objective and principles (Reference 6-25) provides the following:

> *"...The effort and resources put into optimisation should be proportionate to the magnitude of the risks from the options being compared. There is no lower level of risk below which optimisation is not required, but there are diminishing returns as the risk is progressively driven lower."*

Information obtained during the evidence gathering process must therefore be of the type and level of detail that supports the determination of proportionality. Key considerations are:

- What has been done to date to address the issue under consideration?
- How much time, trouble, and money have been invested to date?
- What benefit has been achieved (in terms of reduction in dose to members of the public)?
- What more could be done?
- What additional time, trouble, and money would need to be invested to implement further improvement?
- What additional benefits would be achieved?
- How different is the return on investment for the improvement when compared with the original investment?

6.2.14 Environment Protection Functions

The assignment of EPFs is a requirement of the following EA Engineering Developed Principle (ENDP):

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."*

EPFs are assigned (alongside safety functions) to SSCs that prevent, control, or mitigate the consequences of radioactive discharges to members of the public and the environment. SSCs that contribute to the demonstration of BAT are identified in the BAT arguments and will have an appropriate EPF assigned.

It is recognised that many SSCs with EPFs will also have a higher reliability safety function assigned; however, the EPF is still necessary to ensure environmental protection delivery. Assignment of an EPF to an SSC has two key outcomes:

- It flags that any proposed design change to the SSC must consider effects on environmental performance (as well as any safety impacts)
- It ensures that the SSC is added to a maintenance schedule and is managed to maintain its environmental function in line with EA ENDP11 – maintenance, inspection, and testing, which states that: *"Structures, systems and components that are, or comprise part of, environment protection measures should receive regular and systematic examination, inspection, maintenance and testing."*

A methodology for identifying and assigning EPFs has been developed in collaboration with the GDA safety team to ensure alignment with the assignment of safety functions. The methodology identified a forward action (**FAP.EPF-335**) to help ensure that the methodology is implemented.

FAP.EPF-335 - *"The EPF methodology will need to be implemented for the UK deployment of the BWRX-300. Work is required to:*

- *Develop or review the quality management system to identify where there should be consideration of environmental impacts and specifically where there is an interface with EPFs;*
- *Undertake hazard identification to identify all potential sources of radiological risk to people and the environment;*
- *Identify and develop a list of EPFs and Environment Protection Measures (EPMs) required to protect against the impact of identified radiological risks to people and the environment;*

- *Develop an appropriate classification method for classification of EPMs providing the EPFs;*
- *Record EPFs and EPMs on a relevant register, to be determined by the future operating organisation, and integrate into an asset management regime;*
- *Integrate EPMs that provide an EPF into control and management arrangements.*

To ensure an effective handover of the EPF methodology, training and familiarisation should be provided by the RP to the future operating organisation."

6.2.15 Change Management

Any changes to the BWRX-300 Standard Design are managed through the steps defined in GEH's procedure document CP-03-100, "Design Control," (Reference 6-34). This ensures that the design and its associated design documentation meet all applicable technical, regulatory, and contractual requirements. As the scope of the BWRX-300 Standard Design is limited to the generic power block design, it is anticipated that management arrangements would also be developed by a future developer/operator for holistic management of changes to the design/site configuration of a site-specific BWRX-300 installation in the UK.

Any proposed change to the BWRX-300 Standard Design or wider site configuration will need to be assessed to determine the extent to which it impacts on the BAT arguments. Each change will be assessed on the following basis:

- Positive or neutral impact - Small assessment may be required and recorded as part of the change management process. As part of the periodic review of the CAE model and Demonstration of BAT report, this change will be incorporated within the case with the driver for the change (e.g., safety, operability, environment) clearly stated
- Negative impact - Detailed assessment of the change and update of CAE model required

Any proposed change (positive, neutral, or negative) provides an opportunity to revisit key BAT arguments and to determine if the requirement for a change provides an opportunity for further environmental optimisation beyond that delivered by the initial approach. Any opportunities that are identified will be formally communicated to the individual/team instigating the proposed change through the control process. Any design changes will serve as a trigger for initiation of a BAT review (see Subsection 6.2.7)) as part of a future developer/operator's management arrangements for a site-specific BWRX-300 installation in the UK.

6.3 Best Available Techniques Claims and Arguments for BWRX-300

The environmental claims and arguments structure presented in Table 6-1 stems from the following high-level claim:

> "The BWRX-300 is capable of being constructed, operated, and decommissioned in accordance with the standards of environmental, safety, security, and safeguard protection required in the UK."

The environmental Level 1 claim is:

1. "The design of the BWRX-300 SMR has been optimised to reduce environmental impacts to ALARA throughout the whole lifecycle (construction, commissioning, operation, and decommissioning)."

The environmental Level 2 claims applicable to this report are:

- 1.1. Prevention or, where this is not practicable, minimisation of the creation of radioactive waste and SF
- 1.2. Minimisation of the activity of gaseous radioactive waste disposed of by discharge to the environment
- 1.3. Minimisation of the activity of aqueous radioactive waste disposed of by discharge to the environment
- 1.4. Minimisation of the volume of solid radioactive waste disposed of by transfer to other premises
- 1.5. Selection of the optimal disposal routes for wastes and SF
- 1.6. Minimisation of the impact of radioactive discharges on members of the public and the environment

These claims and the associated arguments are presented within the following subsections.

6.3.1 Claim 1: The design of the BWRX-300 SMR has been optimised to reduce environmental impacts to ALARA throughout the whole lifecycle (construction, commissioning, operation, and decommissioning).

Demonstration that this claim has been met is provided at this stage by the arguments given for the six subsidiary claims discussed in the following subsections. Eventually this demonstration will be completed by the provision of detailed evidence to support all of the arguments; however, for Step 2 of the GDA, evidence is only provided for a worked example, this being for two arguments relating to Claim 1.1. **FAP.PER6-314** details the requirement to collate additional evidence when needed in the future.

FAP.PER6-314 - A future developer/operator shall develop the BAT case for BWRX-300 as required to support future applications for site licences, environmental permits or planning permission. This will require:

- **Review of the BAT methodology to be adopted**
- **Full synthesis of the evidence to underpin the arguments presented in the GDA Step 2 Demonstration of BAT submission**
- **Insertion of any additional claims and arguments into the CAE structure as the design develops**

6.3.2 Claim 1.1: Prevention or, where this is not practicable, minimisation of the creation of radioactive waste and SF

The generation of radioactive waste during the operation of the BWRX-300 is undesirable due to:

- The potentially harmful effects of exposure to radiation for workers, members of the public, and the environment
- The time, trouble, and cost incurred in its management

The BWRX-300 design has sought to avoid the generation of radioactive waste at source. Where this has not been practicable, efforts have been made to minimise the radioactivity and quantity of radioactive waste that will require subsequent management and disposal by permitted means.

The arguments presented in support of this claim are considered to demonstrate compliance with the following condition on BAT in permits for Radioactive Substances Activities, as set out in the guidance document "RSR permits for nuclear licensed sites: how to comply," (Reference 6-21).

> *"2.3.1 The operator shall use the best available techniques to minimise the activity of radioactive waste produced on the premises that will require to be disposed of on or from the premises."*

This claim also relates to the regulatory GDA guidance for RPs (Reference 6-23), in which it is stated that the optimisation process for BAT should take account of: *"preventing and minimising (in terms of radioactivity) the creation of radioactive waste."*

The following RSR GDPs are relevant to Claim 1.1:

- RSMDP3 – Use of BAT to minimise waste. This Principle states that: *"BAT 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."*
- ENDP1 – Inherent environmental protection*. "The underpinning environmental aim for any facility should be that the design inherently protects people and the environment, consistent with the operational purpose of the facility."*
- ENDP2 – Avoidance and minimisation of impacts. *"Radiological impacts to people and the environment should be avoided and where that is not practicable minimised commensurate with the operations being carried out."*
- ENDP3 – Defence in depth. *"A facility should be designed as to allow for defence in depth against the occurrence of radiological impacts to people and the environment."*

The relevance of these GDPs to Claim 1.1 is as follows:

- RSMDP3 – Is directly reflected in Claim 1.1.
- ENDP1, ENDP2, and ENDP3 - Alongside the need for inherently safe operation of the facility, the avoidance or minimisation of radioactive waste generation (Claim 1.1) reduces the hazards to workers, members of the public, and the environment associated with the treatment, storage, and disposal of any radioactive wastes that are unavoidably produced. It is considered that this claim is the first element in the defence in depth with regard to radioactive wastes and discharges.

6.3.2.1 Argument 1.1.1: Design and manufacture of fuel gives low rate of fuel failure

The fuel assemblies present the largest source of radionuclides that are created as a result of nuclear fission in the reactor. Collectively these radionuclides are referred to as Fission Products (FPs). Any release of FPs from the fuel into the steam circuit or cooling pool water have the potential to become radioactive waste that will ultimately require treatment and/or discharge to the environment. Ensuring that these FPs remain in the fuel and its cladding is a key element of the design and operation of the BWRX-300, and the single most important factor in preventing the generation of radioactive wastes.

The manufacturer of the fuel for the BWRX-300, GNF, is engaged in a long-standing and comprehensive programme of work to improve the performance of its products and to reduce the frequency of fuel failures. Fuel failures are typically small cracks in the fuel cladding that allow FPs to be released into the steam circuit. Developments include the introduction of new filters within the fuel assembly to remove debris that can damage the fuel (Evidence 1.1.1.a: Debris Removal), quality control improvements to reduce failures at the Pellet-Cladding Interaction (PCI), which can result in the cracking of the fuel cladding leading to a release of FPs from the fuel (Evidence 1.1.1.b: PCI Reduction), and the introduction of a pure zirconium liner to reduce Stress Corrosion Cracking (SCC) (Evidence 1.1.1.c: Selection of Fuel Cladding Materials). GNF's fuel cladding is manufactured from a zirconium alloy known as Zircaloy-2. This material is widely used in the nuclear industry and has been selected because it is transparent to neutrons, resistant to corrosion, and is impermeable to the migration of FPs. The low corrosion rate helps maintain cladding integrity and containment of FPs within the rod.

GNF collaborates closely with its customers to monitor the performance of its fuel and to understand the mechanisms that give rise to fuel failures. Comprehensive data are available on the performance of its fuel in reactors in Japan, the U.S., and Europe. Analysis of these data has been undertaken by GNF, which concludes that GNF's improvement programme has significantly reduced the frequency of fuel failures within Light Water Reactors (LWRs) (Evidence 1.1.1.d: Analysis of Recent Fuel Failures). The data gathered from OPEX is fed back into the GNF fuel programme and is used to support the development of future enhancements (Evidence 1.1.1.e: Manufacturing Improvements).

Any uranium on the external surfaces of the fuel, referred to as 'tramp uranium', has the potential to undergo nuclear fission and to generate FPs that will enter the steam circuit. GNF has developed Quality Assurance (QA) processes that minimise the potential for the external surfaces of its fuel to become contaminated with uranium during manufacturing processes (Evidence 1.1.1.f: Manufacturing and QA Processes to Minimise Tramp Uranium).

Collectively these measures will ensure that the transfer of FPs from the fuel to the steam circuit and the cooling pool water will be minimised and that BAT is being applied to the design and manufacture of nuclear fuel. This in turn will minimise the quantity of secondary waste that is generated from the management and treatment of FPs in the radioactive gaseous and aqueous liquid process fluids.

Detailed information on the GNF2 fuel design and the components of the BWRX-300 reactor core is presented in PSR Chapter 4 (Reference 6-18) and the Fuel Summary Report (Reference 6-19).

Evidence 1.1.1.a: Debris Removal

Debris can become entrained within the coolant and can damage the fuel assemblies, which can result in a release of FPs. Debris fretting occurs when various types of debris in the coolant protrude through the Lower Tie Plate (LTP) and cause through-wall fretting of the cladding.

In 1990 GNF offered its first intra-bundle debris protection by introducing a LTP that has an entry hole that is one third the size used in the previous LTP design. This reduced the size of debris that could enter the bundle.

In 1996, GNF introduced a debris filter LTP that reduced the size of the debris that could enter the bundle by another factor of three. This filter was offered as an option on 9x9 and 10x10 products at that time. As part of GNF’s zero leaker initiative, it was integrated into the GE14 fuel type (as proposed for use in the UK ABWR reactor) as a standard feature in 2001.

The next iteration of the design was to include a debris shield. The debris shield further reduced the size of the debris that could enter the bundle relative to the first generation 10x10 debris filter, with no pressure drop penalty. The debris shield was a perforated metal plate located at the top of the LTP and was held in place by the fuel rods. This design began operation in early 2005. OPEX with the debris shield included eight reloads and ~2,250 bundles, with only one debris failure.

GNF then developed a next generation "Defender™" filter that further reduced the size of debris, but specifically targeted wires or wire-like debris that had been associated with cladding perforations. The first reload began operation in a U.S. reactor in 2006; experience as of January 2013 included ~75 reloads and >15,000 bundles. In general, a debris filter has a potential impact on channel pressure drop. However, the Defender has adopted a non-line-of-sight design that efficiently captures wire debris during operation with no impact on channel pressure drop.

The Defender was subsequently modified to produce the Defender Plus filter. The Defender Plus filter incorporates features from spacers that are known to catch debris (notches and windows) into the Defender. These features are stamped into the corrugated-plate parts so that there is no change to the assembly process where these plates are welded together, and no changes to the cover plate design of the tie plate. Defender Plus was introduced in River Bend reload nineteen which began operation in March 2017, and it has become the standard for GNF2 fuel. For reference, Defender Plus is referred to simply as Defender in the main body of this report. The Defender Plus nomenclature was used during the transition period and has largely been dropped now that the fleet has completely transitioned, as discussed in the Fuel Summary Report (Reference 6-19).

Table 6-2 (reproduced from the Fuel Summary Report (Reference 6-19)) provides relative performance statistics for different debris filters in 10x10 GNF fuel. Defender has achieved a failure rate about a factor of three better than the first-generation Debris Filter LTP, with Defender Plus further improving this.

Spacer modifications to reduce debris have also occurred within the GNF2 design: modification to the corner of the GNF2 spacer and removal of notches on the band. The updated spacer design is interchangeable with the GNF2 spacer (i.e., the updated spacer meets all the mechanical and thermal hydraulic requirements). In the GNF2 spacer, the fuel rod in the corner cell is constrained from lateral motion by three points of contact (two springs and one pair of stops, upper and lower). In the updated design, the corner rod is constrained by four points of contact (two springs and two pairs of stops, upper and lower). All other rods in both spacers are constrained by four points of contact. Another change is that the bathtubs on the band have been moved to more evenly distribute seismic loads on the dividers between cells.

GNF started providing the updated spacer as an option for GNF2 in Q4 2016. The version of GNF2 with modified Defender (i.e., Defender Plus) filter and the updated spacer was called GNF2.02 during the transition but is now the standard version of GNF2. The spacer change greatly improves the margin for handling or seismically-induced damage for the corner rod cells and eliminates the notches on the underside of the bands, which are known debris capture sites as discussed in the Fuel Summary Report (Reference 6-19).

Evidence 1.1.1.b: PCI Reduction

There are several features available to GNF that have been incorporated into the bundle design that contribute to the mitigation of PCI-type failures.

Zirconium-lined barrier fuel cladding was introduced in reload quantities in the mid-1980s as a material solution to PCI-type failures. Power ramp tests and reactor fleet trials demonstrated that a zirconium-lined fuel rod was highly effective in mitigating PCI-type failures. GNF fuel designs have continued to employ barrier cladding since then. Barrier cladding provides significantly improved PCI resistance, especially when combined with other mitigation strategies such as core loading and bundle promotion practices. Core loading and bundle promotion practices consist of moving fuel bundles to different locations within the reactor core at each outage in order to improve the core's efficiency and manage the burnup rates of the different fuel bundles. Because a small number of PCI-type failures have occurred in barrier fuel, operating guidelines have been implemented throughout the BWR fleet, mainly to avoid specific types of operation (for example, very long control intervals followed by step increases in power) that have been correlated with the failure events. Zirconium-lined barrier fuel cladding reduces the pellet area but does not have a significant effect on uranium inventory. The barrier liner is thin but is effective in preventing PCI-type failure.

PCI-like failures have been correlated to fuel rods with chipped pellets (or areas of Missing Pellet Surface (MPS)). These defects can increase the probability of a PCI-type defect because there is an additional localised bending stress in the vicinity of the MPS, over and above the stress from the rod pull/power increase. Since the mid-1990s GNF has adopted improved manufacturing and QA processes that reduce the probability of chipped pellets ending up in fuel rods. The more recent introduction of larger chamfered pellet edges has further reduced the likelihood that pellets will be damaged during the manufacturing process, and improved pellet inspections have been implemented to identify and subsequently reject damaged pellets. Fuel pellet quality is high, and correspondingly, the fuel rod failure rate in the fleet due to PCI-type defects is at an all-time low level.

As a result of applying the above improvements, from the mid-1990s to late 2003, PCI-type failures were observed only in a few legacy 8x8 bundles (and these were found to be in those plants that had not adopted the operational guidance suggestions). No PCI-type failures were observed in the two million 9x9 rods delivered from the GNF factories since the introduction of these products in 1990. In the period from late 2003 to early 2007, and in 2010 at one European plant (Olkiluoto-1), GNF experienced several PCI-type failure events in 10x10 fuel. All PCI-type failures in 10x10 barrier fuel occurred in a small number of reactor manoeuvres. The total failure rate in 10x10 barrier fuel due to PCI mechanisms is less than 4 parts per million (ppm).

PCI-type, “duty-related” failures (which correlate with power/stress increases) have continued to occur through 2020 in the BWR fleet, but they are rare, with isolated failure events at individual plants every ~3 to 5 years in the past 1.5 decades or so. As noted above, PCI represented a significant percentage of failures in the 1970s and early 1980s prior to the invention of PCI-resistant barrier fuel. Barrier fuel has proven to be extremely effective at mitigating PCI, but it is still not immune to this failure mechanism. The failures today tend to occur in higher power density plants, and often correlate with some unusual sequence of events that deviates from normal operation in some way, such as late cycle scram recoveries or unusually long control or low power periods. BWRX-300 is intended to operate as a control cell core, with relatively low core average power density, which is below that of most of the current BWR fleet, and thus there is significantly more margin than in today’s existing fleet.

Evidence 1.1.1.c: Selection of Fuel Cladding Materials

GNF offers a unique version of the zirconium alloy, Zircaloy-2, as its cladding material. Zircaloy-2 is widely used as a cladding material in BWRs, but GNF’s cladding has an inner liner of pure zirconium, with additions of iron for corrosion resistance, in order to serve as a buffer between the Zircaloy-2 and the swelling of the uranium pellet. The softer liner has been effective as a barrier for PCI since the early 1980s. The outer cladding is annealed in order to achieve the final state of full recrystallisation.

In BWRs, a major performance reducer for the cladding is nodular corrosion that occurs due to exposure to the reactor environment. GNF has developed a substantial database reflecting the performance of its cladding that is exposed to today’s modern water chemistries, including hydrogen and zinc injections as well as noble metal applications. The cladding may also be exposed to reactor water chemistry variations experienced within some plants. Based on this growing experience base, GNF has reached the following conclusions:

- Should the cladding be breached due to debris fretting at spacer grid locations, the corrosion resistant liner (mentioned above) is an effective solution to post-failure degradation. It appropriately balances the need for the cladding liner to provide both PCI protection as well as corrosion resistance.

- Modern cladding designs are required to have excellent corrosion resistance to high exposures even in today's reactor environments, with modern water chemistries.

These conclusions have led GNF to develop and introduce the current Zircaloy-2 barrier cladding, known as Process 9 cladding, which combines the best features of previous designs, while taking steps at both the tube shell supplier and GNF's Wilmington tube fabrication facility to reduce process variability.

Process 9 utilises modifications to the alloying elements in order to tighten variability in the ingot chemistry and enhance corrosion resistance. Tightening and biasing the alloying elements of iron, tin, nickel, and chromium, when compared against standard American Society for Testing and Materials Zircaloy-2 specifications, has demonstrated better performance in nodular corrosion resistance. In the raw material manufacturing process, a rapid quench from the beta metallurgical phase at the billet stage, known as hollow billet beta quench, provides a smaller second phase particle size distribution and a more uniformly reproducible product. Tubing made from hollow beta-quenched billets has excellent corrosion resistance in laboratory corrosion tests and in the field. This was one of the earliest corrosion-resisting processes implemented (GA91-9901-0023-00001, "UK ABWR Generic Design Assessment: Demonstration of BAT," (Reference 6-35)).

Evidence 1.1.1.d: Analysis of Recent Fuel Failures

GNF's evolutionary product introduction strategy develops and implements new products and processes that deliver improved fuel performance. The introduction of these design changes has delivered a steady improvement in fuel reliability (Figure 6-5, adapted from the Fuel Summary Report (Reference 6-19)) while maintaining design- and fabrication-related performance.

In the past 10-15 years, fuel reliability performance has been very good. Most GNF-fuelled plants operate leaker-free for years or even decades; a small number of plants experience failures in any cycle, and today these are essentially all debris fretting failures concentrated in a few plants. When plants do experience failures, they are routinely able to continue operation for as long as ~1.5 to 2 years using GNF's failed fuel management practices with no degradation to the failed rods. The 12-month fuel cycle proposed for the BWRX-300 would therefore enable failed fuel to be replaced under normal operations within this timeframe.

Today's reliability has been achieved by systematically identifying failure mechanisms through poolside and hot cell examinations and the associated root cause calculations and modelling, and then eliminating them by applying lessons learned in the design and fabrication of the fuel, as well as into the core design and plant operating practices arena. The improvements that have been introduced as a result of this work, as discussed in the Fuel Summary Report NEDC-34159P (Reference 6-19), include:

- Improved pellet and fuel rod fabrication in the 1970s to eliminate primary hydride failures that resulted in the fuel cladding failing
- Fuel duty operating recommendations in the 1970s, followed by GE's invention and patent of zirconium-lined barrier fuel in the early 1980s, to mitigate PCI failures
- Corrosion-resistant cladding, with chemistry and microstructure to protect against Crud-Induced Local Corrosion failures
- Improved cladding processing, welding, fabrication, and inspection techniques
- Tightened MPS specifications for margin to "duty-related" failures
- LTP debris filter, added in 9x9 and a standard feature starting with GE14, and subsequent advanced debris filter designs to improve resistance to debris ingress (see Evidence 1.1.1.a: Debris Removal)
- Operating guidance to maximise capacity factor while minimising the potential for "duty-related" failures associated with power increases after control rod withdrawals

- PCI risk mitigation reviews as part of the core and fuel design process

Information on fuel failure rates for various GNF fuel types is provided in Table 6-3. In particular, the table shows that the GNF2 fuel that will be used in the BWRX-300 has an overall failure rate of 2.1 failed fuel bundles per thousand operated. For the 60-year life and 12-month fuel cycle assumed for BWRX-300 operations, using a total of 2,128 fuel bundles, this equates to less than five fuel failures over the plant life, with an annualised failure rate of 0.075 bundles per year.

Table 6-3 summarises GNF's 10x10 fuel experience. GNF2 was an evolutionary design based on operating experience with GE12 and GE14, with most of the major features (corrosion-resistant cladding, fuel rod pitch, Defender™ LTPs, partial length rods, Alloy X-750 spacer grids, upper tie plate, channel, etc.) being proven in these earlier designs. The most significant changes introduced in the GNF2 design include the cladding thickness, 2 mils (~0.051 mm) less than GE14; the pellet diameter, 4.6 mil (~0.117 mm) increase; the Alloy X-750 spacer grid; the partial length rod arrangement; and the use of locking retainer springs in the plenum. Within GNF2, there was a change in ~2018 to introduce an improved debris filter (Defender Plus) and changes to the corner rod cell of the spacer and spacer band (see Evidence 1.1.1.a: Debris Removal), as discussed in the Fuel Summary Report (Reference 6-19).

The current performance trends lead to the following conclusions:

- In the 10x10 GNF2 fuel type that will be used in the BWRX-300, historically the leading failure mechanism has been debris fretting, which is where debris becomes entrained within the coolant and can damage the fuel assemblies. The only other significant failure mechanism observed has been a small number of "duty-related" (PCI-type) failures, from a small number of plant manoeuvres in over 15 years of operating experience. Almost no fabrication related defects are known to have occurred in the past 15 years of production, which represents over 7 million fuel rods (In 2010, a single failure occurred at a plant in Spain, which may be related to a fabrication defect from the ENUSA facility. A MPS issue, or some other undetected defect, may have been a factor in a failure in Olkiluoto-1 in May 2010).

- There are no GNF2 failures due to MPS defects, although a small number of older failures in GE14 (~2 or 3) may have been due to MPS. The failure rate in GNF 10x10 barrier fuel due to all duty-related mechanisms (classic PCI, MPS, High-Residence time failures) is below 3 ppm; for perspective, the failure rate due to debris in the same population is about six to seven times higher, ~20 ppm. The failure rate due to MPS is therefore less than 1 ppm. Although industry OPEX indicates evidence of MPS-induced PCI-type fuel failures in non-GNF fuel, mainly in Nordic annual cycles with relatively aggressive approach to all-rods out, the performance record of GNF's 10x10 fuel indicates that MPS is not a significant factor in GNF fuel reliability performance. This performance record is attributable to GNF's longstanding recognition of the role of pellet quality in duty-related failures, and significant investments in ceramics fabrication to ensure that the current outstanding performance continues.

- Today's fuel, with its increased performance capability, has the capability to be operated at increased power levels and for longer durations, both to achieve improved fuel cycle economics and to meet high-energy cycle demands. Power densities, capacity factors, cycle lengths, and resultant cycle energies continue to increase and drive fuel duty. This provides operators with the opportunity to replace less fuel during an outage. GEH's Design Basis Record (DBR) document DBR-0057741, "BWRX-300 Plant Performance Envelope," (Reference 6-36) details that the BWRX-300 is anticipated to replace 32 of 240 fuel bundles each 12-month cycle (i.e., ~13 percent per cycle). Efficient management of the core to optimise the output from each fuel bundle enables operators to replace fewer bundles each cycle, thereby creating less

SF for disposal over the reactor life. In addition to reducing waste creation, it also utilises a finite resource (uranium) in an efficient manner that extends resource availability for future generations.

- Advanced debris filters have performed well to date, with lower debris-related fuel failure rates achieved relative to prior designs.

Evidence 1.1.1.e: Manufacturing Improvements

Over 6 million GNF 10x10 fuel rods have been placed in operation. Within this population, GNF has identified a single fuel rod failure caused by a fabrication defect. GNF attributes this high quality to process improvements implemented since the identification of several factory-related failures in fuel fabricated in the 1980s. Significant attention was given to upgrading the pellet and cladding fabrication and inspection processes, as well as a tightening of the specifications. Multiple inspections were established to assure compliance with the MPS specification to ensure that fuel pellets did not have missing surfaces that could then lead to fuel failures during operation. A state-of-the-art tubing inspection system, called Multi-Inspection and Data Acquisition System (MIDAS), was introduced that provided a thorough clad identification and Outer Diameter (OD) inspection process. It specifically addressed the OD flaws thought to be associated with some past duty-related failures. This system provides two independent flaw inspections: 100 percent of the OD by eddy current (OD only) for gross flaws as well as some geometries difficult to assess via ultrasonic; and >100 percent coverage of the OD and identification by ultrasonic, which is typically capable of identifying flaws in the order of 25 to 50 microns (1 to 2 mils).

MIDAS also uses Ultrasonic Testing (UT) to measure critical dimensions along the full length of the fuel rod, as these directly affect such fuel performance behaviours as fuel rod stress and bow. Tubes that do not meet specifications for dimensions or flaw criteria are automatically rejected. The MIDAS record for each tube is recorded in the Fuel Business System (FBS) and related to a barcode identifier laser-marked on each tube. FBS will not allow a reject tube to be processed into fuel rods or bundles. Additional improvements in the tubing area at GNF include new tube reducer equipment.

Hydrogenous material control is another area that GNF recognised and corrected from early 1970s experience as a potential contributor to fuel failures. In recent years, as reports of occasional failures due to this mechanism have increased in the industry, GNF has added additional focus and surveillance activities, even though no such failures have occurred in GNF fuel.

The GNF fuel rod fabrication process requires a 100 percent UT inspection of the upper and lower end plug welds. All historical weld defects are targeted, including tungsten or other foreign material inclusions, inadequate bonding or penetration, and grain boundary separation. Weld records are tied to the fuel rod via its barcode and entered into the GNF FBS. The system will lock out any weld rejects, precluding further processing, as discussed in the Fuel Summary Report (Reference 6-19).

Although successful in delivering improvements in fuel design resulting in a reduction in the number of potential manufacturing-related failures, GNF recognises that it must continue to drive for manufacturing excellence to assure similar performance in the future. Areas GNF is focused on are described in the UK ABWR GDA Demonstration of BAT (Reference 6-35) and listed below:

- Debris remains the number one cause of failures, and it is imperative that bundles delivered from GNF's factory be free from debris. Many actions have been taken to assure success in this area, including improved inspections and the establishment of debris exclusion zones in the bundle assembly and packing areas. An additional improvement GNF has implemented is the stainless steel fuel-shipping containers, replacing the wooden container, which often presented a risk of paint chips.

- GNF has deployed grinding stations that also include, via a feedback system, the 100 percent OD inspection of each pellet. This system will 1) verify that each pellet meets dimensional specifications; 2) feed back to the grinder any necessary adjustments to maintain process control; and 3) inspect the pellets for OD surface defects. This represents a very significant upgrade to the overall pellet fabrication process.

Evidence 1.1.1.f: Manufacturing and QA Processes to Minimise Tramp Uranium

Tramp uranium is uranium or uranium dioxide dust that clings to the outside of the fuel elements and is insufficiently cleaned off during fabrication. Once in the reactor, it will undergo fission, and its FPs readily enter the reactor coolant.

A number of measures have been introduced to minimise uranium oxide contamination on fuel rod surfaces. The handling process for unsealed uranium oxide (e.g., pellet loading process and upper end plug weld process) has the potential to spread uranium oxide contamination onto the fuel rod surface. The unsealed uranium oxide is exhausted by air conditioning equipment to remove any uranium dust that becomes entrained in the air. In over 99 percent of cases, the measurement result for uranium oxide contamination on the fuel rod surface is lower than the detection limit. QA measures ensure that tramp uranium remains below the QA thresholds.

In order to minimise uranium contained in the Zircaloy raw material, GNF's current material specification is for less than 3.5 ppm uranium in zirconium alloys. In practice the material certification reports indicate that it is usually reported as <0.5 ppm. The uranium content is driven by the input material for zirconium processing, which is sand. A part of the processing from sand to crystals leaves the uranium in the silica waste stream; separation processing takes the majority of the residual uranium to the hafnium side. GNF's Zircaloy tube shell suppliers report that the hafnium content in the feed has been significantly reduced since implementing the processing change with the intermediate step going to crystals.

Additional controls during Zircaloy processing include preventing the use of any Zircaloy that has been irradiated. Use of returned Zircaloy-2 tubing from rods scrapped during manufacturing that had been loaded with pellets can also result in traces of pellet material if the recycled ingot includes material melted from the tubing. Material from these scrapped rods is prevented from entering the manufacturing process.

The low levels of impurities (low ppm levels) result in a very low level of offgas FP activity, even for initial cores with no fuel failures. GNF's monitoring of offgas activity data in the fleet supports the observation that uranium impurities in the cladding are at the lowest levels they have been in BWR history. Many cores today that have not had a fuel failure in a decade or more, have extremely low "tramp uranium based" offgas activity levels, less than 3.7 MBq/s is routinely achieved, and some plants observe less than 1.85 MBq/s, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35).

6.3.2.2 Argument 1.1.2: Effective management, handling, and storage of fuel and SF minimises the generation of radioactive waste by preventing fuel cladding failures and damage to fuel/SF

Improvements in fuel design and manufacture have been accompanied by the production of guidance to the users of GNF's fuel, which clearly defines the operating parameters of the fuel and the means by which fuel failures can be minimised during operating cycles in the reactor (Evidence 1.1.2.a: Manufacturer's Guidance on Fuel Use).

Hitachi-GE has also developed fuel handling equipment that minimises the potential for damage during transportation, loading, unloading, and storage of fuel and SF. OPEX and feedback from the operating fleet of BWRs in Japan, the U.S., and Europe has shown that there is a very low frequency of fuel damage associated with the management of fuel and SF outside of the reactor (Evidence 1.1.2.b: Fuel Handling Equipment – OPEX and Feedback).

The design of the BWRX-300 includes provision of a dry cask route from the fuel pool to the export door from the power block. The specification and selection of SF storage containers, associated equipment, and storage facility will be undertaken by the future operator; however, based on existing BWR SF storage arrangements it is known that safe and secure SF dry storage is feasible using current technology.

As the SF store will not be required for some considerable time (likely to be of the order of ten years after commencement of operations), during the intervening time, evolution of the technology and requirements for disposal is possible. Therefore, it is considered that additional evidence is best gathered when needed in the future. Using the decision tool (Figure 6-4), a forward action (**FAP.PER6-316**) has been raised.

FAP.PER6-316 - A future developer/operator shall demonstrate BAT when selecting their plans for packaging, storage and disposal of SF.

Evidence will then be synthesised once available (**FAP.PER6-314**). In the interim, the current design is considered to offer future operators the flexibility to select and implement techniques that will reflect its operational needs and the regulatory requirements in force at the time. The provision of such flexibility is considered to represent BAT at this stage.

Once removed from the reactor core SF will be stored in the fuel pool, which is described in GEH’s plant specification document 006N5991, "BWRX-300 Plant Architecture Definition," (Reference 6-37). 006N5339, “BWRX-300 Irradiated Fuel Management Plan,” (Reference 6-38) states that there is no known instance of a BWR fuel failure developing in a fuel rod while being stored in the fuel pool after discharge from the reactor. This includes thousands of bundles stored in fuel pools for periods of more than 40 years. PSR Chapter 26 (Reference 6-20) provides further details on the management of SF. Evidence relating to the storage arrangements and conditions will be provided in a future update to this document (**FAP.PER6-314**).

Evidence 1.1.2.a: Manufacturer's Guidance on Fuel Use

GNF-0142-5151, “GNF Fuel Operating Guidelines,” (Reference 6-39) describes that GNF fuel is operated in accordance with a variety of design and licensing limits, such as Thermal-Mechanical Operating Limits for linear heat generation rate (W/cm) as a function of exposure, and limits on exposure in terms of bundle average, rod average, or peak pellet, which can vary by the country in which the fuel is licensed. There are specifications for dry or wet storage prior to irradiation, including water quality. For PCI-type failure mitigation, power manoeuvring guidelines are provided that propose exposure-dependent threshold power levels above which power increases should occur at or below certain rates. These guidelines help to mitigate the tensile stress of the cladding (i.e., limiting the rate of pellet thermal expansion) and the release of embrittling FPs (iodine in particular) that promote SCC (i.e., limiting the rate of pellet temperature increase), both of which are key factors contributing to PCI-type failures. Implementation of these manoeuvring guidelines may limit the operating condition, but it has been shown to have a negligible impact on plant capacity factors in today’s BWR fleet. This is discussed in the “GNF Fuel Operating Guidelines,” (Reference 6-39).

Evidence 1.1.2.b: Fuel Handling Equipment – OPEX and Feedback

Since 1974, Hitachi-GE has manufactured and supplied the Fuel Handling Machine (FHM) for BWR, ABWR, and fuel reprocessing plants. The total number of the manufactured and installed FHMs is twenty. No fuel damage or collision of fuel during fuel handling operations has occurred within this fleet. OPEX validates the effectiveness of the FHM design and systems that preclude the dropping of a fuel assembly. This is discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35).

There are highly reliable and redundant measures to reduce the likelihood of an operator error that results in a fuel drop event/accident while the fuel is in a raised position. Fuel handling grapples are designed to only open the grapple hook if a load is not present. Fuel handling equipment has sufficient interlocks for lift/lower functions, structure collision avoidance, bundle submergence verification, and reactivity control features for individual fuel bundle/cell picks, as discussed in the Plant Architecture Definition (Reference 6-37).

Evidence 1.1.2.c: Relevant United Kingdom Spent Fuel Storage Experience

Modern UK RGP for the management and storage of SF is dry cask storage, with high integrity storage casks stored indoors in a secured containment facility to further ensure security and atmospheric control. This is evidenced by recent applications for Dry Fuel Store (DFS) at Sizewell B and Hinkley Point C. These most recent applications for DFS permits and their construction demonstrate that this approach is in line with current RGP and is in fact the preferred approach for the long-term storage of SF and Irradiated In-Core Components. Further information is provided in PSR Chapter 26 (Reference 6-20) on SF storage RGP, as well as several related forward actions including **FAP.PSR26-155**. Proposed dry cask storage will eliminate the generation of liquid, gaseous and solid radioactive wastes associated with the operation and decommissioning of wet storage systems.

FAP.PSR26-155 *- "A future developer/operator shall establish a comprehensive, site-specific plan for the DFS, including numbers of units, design, layout, on-site transport processes, procedures of the constructed storage facility and any other site-specific details, as required."*

6.3.2.3 Argument 1.1.3: Material selection for the BWRX-300 design reduces the production of corrosion and erosion particles that could cause fretting and failure of fuel cladding, and that would themselves become activated

Materials in the reactor are exposed to neutrons generated by nuclear fission. In some instances, the materials will become radioactive by a process known as 'activation'. Activated Corrosion Products (CPs) are a significant source of direct doses to workers and are a source of radioactive waste.

CPs that are suspended in the reactor water deposit on the surface of the fuel cladding as a result of boiling densification and become activated. This results in fuel cladding hotspots and associated fuel cladding failures, which result in the release of FPs into the coolant.

The activated CPs can then be re-dissolved into the reactor water and subsequently have the potential to deposit on piping surfaces, contributing to an increase in shutdown dose rates.

CPs arise as radioactive waste through:

- Corrosion of irradiated system materials (i.e., structural materials within the reactor that are activated by their proximity to nuclear fuel and the associated neutron flux)
- Corrosion of metals in the steam circuit, that are carried by the process fluids to the Reactor Pressure Vessel (RPV), where they become activated as they pass through the neutron flux in the reactor core

The BWRX-300 takes account of decades of experience in the design, operation, and decommissioning of BWRs and, where practicable, uses materials that are less susceptible to corrosion, deposition, and activation. Efforts to use alternative materials have sought to balance the benefits provided by the characteristics of the materials with their safety and environmental implications. Material selection minimises, to the extent possible, the creation of CPs with the potential to be activated (see GEH's ALARA design criteria (Reference 6-4)).

Materials for the BWRX-300 systems and components are selected to ensure plant personnel radiation exposures are ALARA, and to aid with decontamination and decommissioning efforts, as discussed in the ALARA design criteria (Reference 6-4). Key material design considerations include:

- The reactor coolant system materials are selected to prevent the formation of CPs. Reactor internal components, except for the Zircaloy in the reactor core, are stress corrosion resistant stainless steels or other high alloy steels
- Carbon steel used in systems processing or storing reactor coolant or steam is low in nickel content and contains only very small amounts of cobalt impurity. It is noted that

most of the carbon steel used in the UK ABWR has been replaced with stainless steel in the BWRX-300

- Materials in contact with reactor coolant and subject to significant wear, corrosion, erosion, or neutron activation, except the fuel assemblies, use the lowest cobalt content available with a target cobalt content of 0.02 weight percent or less for stainless steel or nickel base alloys, and with a maximum cobalt content of 0.05 weight percent. Examples of components selected to use low cobalt materials include the main condenser system tubes, heat exchangers, and control rod blades
- Non-stainless-steel equipment has an adequate finish and is protected with a non-corrosive material to aid in decontamination
- For systems in contact with reactor coolant (e.g., pumps, valves), component materials are as degradation mechanism resistant as possible. Degradation mechanisms (e.g., stress corrosion, thermal aging, embrittlement, fatigue, thermal fatigue) are considered jointly during the material selection process
- System components are made of materials that are qualified to withstand the pressure, temperature, and radiation to which they are subject

These design elements all contribute to eliminating or reducing the formation of activated CPs, reducing both the generation of radioactive waste and the potential for fuel damage events. This is achieved by either removing readily activated isotopes from the materials used, or preventing materials from becoming mobile and migrating into or through areas of high neutron flux where they can become activated.

6.3.2.4 Argument 1.1.4: Efficient fuel use minimises SF generation

The efficiency with which the nuclear fuel is used in the BWRX-300 and the frequency with which it is changed will influence the amount of SF and Higher Activity Waste (HAW) that is generated during operations. Reducing the generation of SF and HAW for a given energy output is an important part of optimising the nuclear fuel cycle from an environmental perspective. This applies to the selection of the nuclear fuel and the final choice for its management prior to disposal.

Minimising the quantity of SF produced per unit of electricity generated prevents the unnecessary generation of waste and discharges associated with its management. The final BWRX-300 fuel management strategy will be determined by operational decisions; however, aspects of the BWRX-300 Standard Design that contribute to the efficient use of fuel are summarised below:

The design of the BWRX-300 reactor core is the result of evolution over many years of BWR operation. The reactor core is made up of 240 fuel assemblies arranged to form an upright cylinder. The GNF2 fuel assembly consists of 92 fuel rods and two large central water rods that occupy eight fuel rod locations contained in a 10x10 array (i.e., 100 lattice locations). Fourteen fuel rod locations are occupied by part length fuel rods. GNF2 has eight long-partial length fuel rods and six short-partial length fuel rods that have fuel column lengths that are approximately two thirds and one third of active fuel length, respectively (PSR Chapter 4 (Reference 6-18)). Advantages of use of partial length rods include:

- Increased flow area in the upper regions of the fuel bundle for reduced pressure drop and improved stability compared with earlier fuel designs that did not include partial length fuel rods
- Improved nuclear efficiency by matching the axial hydrogen-to-fissile uranium ratio in fuel with axially varying moderator density
- Reduced core reactivity in the cold condition and increased cold shutdown margins

In addition, the fuel assembly design includes axial enrichment loading with lower enrichment at both the top and bottom end of each fuel rod, providing improved fuel efficiency and reactivity margins, as discussed in the Fuel Summary Report (Reference 6-19).

BWRs operate on approximately 12-, 18-, or 24-month refuelling intervals. However, operating cycles longer than 24 months have been conducted as well as intermediate lengths. The reference BWRX-300 equilibrium core design to support safety and performance evaluations was established to be a 12-month cycle because it illustrates the highest degree of operational flexibility associated with excess thermal margins. Alternate refueling intervals (e.g., 18, or 24 months) may be applied to the BWRX-300 which can be demonstrated to conform to all applicable safety and performance requirements (PSR Chapter 4 (Reference 6-18)). Forward action **FAP.PER6-378** has been raised in relation to this.

FAP.PER6-378 - Future developer/operator to determine BWRX-300 fuel and core management strategy, including refuelling cycle length.

For GDA purposes it is assumed that the BWRX-300 will operate on a 12-month fuel cycle with 32 fuel assemblies replaced during each refuelling outage. 60 fuel cycles would therefore be anticipated during the 60-year operational lifetime of each reactor. Experience from BWRs in Europe shows that use of a 12-month cycle leads to fewer used fuel assemblies overall compared with 24-months operating cycles, reducing lifetime waste yields (005N9751, “BWRX-300 General Description,” (Reference 6-40)).

The requirements specification document 007N7790, “BWRX-300 Reactor Plant Refueling and Servicing General Requirements,” (Reference 6-41) details that the BWRX-300 refuelling outage includes an offload of SF, a shuffle of in-core assemblies, and installation of new fuel. Fuel assemblies that are no longer useful for the efficient production of nuclear heating within the core are removed to SF storage racks in the fuel pool. As one SF assembly is removed from the core, a new fuel assembly is added to the core, or another fuel assembly is shuffled to its position. The final fuel assembly locations in BWRX-300 are determined using a core simulation programme, which provides the ability to reposition fuel assemblies with remaining life in the core to improve operating efficiency.

6.3.2.5 Argument 1.1.5: Effective early detection and management of failed fuel reduces the release of FPs

The GNF2 nuclear fuel that will be used in the BWRX-300 is designed, manufactured, and managed to minimise the potential for fuel cladding failures to occur that could subsequently result in the release of FPs into the steam circuit. In the unlikely event that a fuel cladding failure occurs, and FPs enter the steam circuit, the BWRX-300 has a range of features that allow for prompt detection and management of the failed fuel pin.

Process radioactivity at two sample points in the Offgas System (OGS) are monitored by the Process Radiation and Environmental Monitoring System (PREMS) and the results are available in the Main Control Room (MCR). The High Activity Alarms in the MCR notify the operator so that action may be taken to avoid releases in excess of regulatory or plant-specific limits and to indicate potential fuel cladding failure (see System Design Description (SDD) document 006N7899, “BWRX-300 Offgas System,” (Reference 6-42)). The PREMS SDD 006N7938, “BWRX-300 Process and Radiation Monitoring,” (Reference 6-43), provides details of the noble gas monitoring skid, installed upstream of the charcoal adsorber vault, between the refrigeration dryers and offgas reheater. The monitoring skid includes an online noble gas analyser and grab sampling taps. The skid provides baseline radiological data for monitoring OGS performance and is also the primary point of monitoring/sampling for fuel leakage. Elevated radioactivity levels at this location are typically indicative of fuel cladding failures within the core. At GDA, GEH considers it to be BAT to provide a radiation detector and grab sample analysis to enable the detection and management of a fuel cladding failure. Further information on sampling and monitoring arrangements for the BWRX-300 OGS are presented in PER Chapter E8 (Reference 6-7).

The design of the BWRX-300 reactor core allows the operator to detect the location of the failed fuel bundle via power suppression testing (i.e., flux tilting) by the selective insertion of control rods around fuel assemblies. Insertion of the control rods reduces nuclear fission in immediately adjacent fuel assemblies and allows the operator monitoring the concentration of FPs in gases from the condensers to detect the source of the leak by a sipping inspection. The source of any leak is identified when changes in the concentration of FPs entering the OGS correlate with the movement of control rods at specific locations within the reactor core. Following detection of the failed fuel, a future operator is then able to apply failed fuel management guidelines (see "GNF Fuel Operating Guidelines," (Reference 6-39)). This may involve transfer of the leaking fuel rod to the fuel pool for a more detailed examination and repair if required (NEDC-34041P, "BWRX-300 GNF2 Fuel Assembly Mechanical Design Report," (Reference 6-44)). However, if the activity is less than the prescribed limit, most plants prefer to remain in operation for the balance of the cycle and apply the failed fuel management techniques developed by GNF and adopted by all U.S. plants as well as most BWRs in other countries. In most cases of fuel cladding failures, the degradation resistance of Process 9 cladding affords time to locate and suppress failures and apply local manoeuvring restrictions, before significant secondary damage occurs. In the U.S. and Mexico, where Failed Fuel Management is applied, the vast majority of all cycles affected by fuel cladding failures in the past decade have been operated for the entire cycle (up to 22+ months) with no pellet material loss and no plant contamination, as discussed in the Fuel Summary Report (Reference 6-19).

The design of the BWRX-300 allows a graduated response to be taken to a fuel cladding failure in the reactor and provides sufficient flexibility to allow a future operator to develop operating procedures to manage fuel failures associated with expected events and accident conditions. At the next outage the failed fuel is removed and transferred to the fuel pool. In the fuel pool, a visual inspection is carried out to identify the failed rod and to determine the cause of failure. Other techniques, including UT, are available to the operator to support the inspection if required. Inspection tools are available to deconstruct the assembly for inspections of individual components (e.g., eddy current measurement of oxide thickness and crud buildup of fuel rods) or to reconstitute the assembly with new components (e.g., remove a failed fuel rod and replace it with a dummy rod). It should be noted that there is no known instance of a BWR fuel cladding failure developing in a fuel rod while being stored in the fuel pool after discharge from the reactor.

Depending on the severity of the failure, the future operator has a number of options that can be utilised to store the fuel and to ensure that the spread of contamination is minimised. These include swapping the failed rod for a replacement from a compatible irradiated donor bundle, or insertion into a skeleton bundle that is stored in the SF storage rack. Not foreclosing options in terms of the storage of failed fuel, and the selection of the optimal option by the future operator based on a risk assessment, represents BAT.

As identified in PSR Chapter 4 (Reference 6-9), the management of failed fuel is considered to be beyond the requirements of a two-step GDA and is an operational rather than a design issue. However, it should be noted that there are no aspects of the design of the BWRX-300 that preclude the adoption of standard BWR fuel management strategies. Forward Action **FAP.PSR4-19** has been identified in PSR Chapter 4.

FAP.PSR4-19 – *"Include a section within the pre-construction safety report which details the management of failed fuel for the BWRX-300. This should include detection, identification and in-core and ex-core control of fuel bundles with one or more leaking fuel rods. A dedicated reference providing full details of failed fuel management should be produced in a similar manner as was produced for Step 4 of the UKABWR GDA."*

6.3.2.6 Argument 1.1.6: Commissioning, startup, shutdown, and outage procedures maintain plant cleanliness at the required levels

The process of maintaining plant cleanliness begins during the pre-operational phases. During construction/fabrication testing, flushing, and cleaning is performed and the cleanliness of items validated. All equipment must meet cleanliness specification requirements prior to turnover for pre-operational testing, as detailed in GEH's SDD document 006N7609, "BWRX-300 Reactor Water Cleanup System," (CUW) (Reference 6-45).

Commissioning/Pre-startup

Commissioning of the Water, Gas, and Chemical Pads (WGC) demineralised water subsystem includes any necessary hydrostatic testing and flushing of the system to remove any foreign material present. Following system fill, the system is circulated, and water quality verified to meet the water quality requirements. The diesel fuel oil storage tank that is part of the WGC system also undergoes hydrostatic testing with water and the system is flushed of foreign material. The SDD document 006N7797, "BWRX-300 Water, Gas, and Chemical Pads (WGC)," (Reference 6-46) provides further details of this system.

Demineralised water, if available, is used to fill the Plant Cooling Water (PCW) System (see 006N7769, "BWRX-300 Plant Cooling Water (PCW) System," (Reference 6-47)) during pre-startup. This provides an additional level of confidence that the source of demineralised water is suitable for use across the plant. It avoids the use of water from the normal heat sink (e.g., sea or ocean) for PCW, which could require chemical treatment and could introduce impurities that may elevate the electrochemical corrosion potential.

Startup

During startup, several systems are utilised to achieve the desired water chemistry specification and minimise the introduction of contaminants into the plant. On startup of the feedwater pumps, Depleted Zinc Oxide (DZO) is injected into the feedwater to reduce the rate of radiation buildup on the reactor internals and subsequently minimise radiation dose (described in SDD document 007N4013, "BWRX-300 Zinc Injection Passivation," (Reference 6-48)).

The Main Condenser and Auxiliaries System (see SDD document 006N7757, "BWRX-300 Main Condenser and Auxiliaries System," (Reference 6-49)) will remove dissolved gases from the condensate during startup. The reactor coolant is exposed to the atmosphere prior to installation of the RPV head, therefore significant quantities of dissolved gases must be removed during startup to improve reactor coolant chemistry and prevent degradation of steam condensation and plant efficiency.

Condensate is then cleaned by the Condensate Filters and Demineralisers System (CFD) (described in SDD document 006N7741, "BWRX-300 Condensate Filters and Demineralizers (CFD)," (Reference 6-50)) in order to minimise the time required to achieve low power operation. It provides high purity water to the Condensate and Feedwater Heating System (CFS). The CFS provides recirculation flow paths to assist in cleaning the condenser hotwell and facilitate achieving the desired water chemistry specifications prior to sending feedwater to the reactor.

GEH's SDD document 006N7737, "BWRX-300 Condensate and Feedwater Heating System," (Reference 6-51) details that on startup after an outage, the CFS is also designed to enable the entire condensate and feedwater water volume (including the low pressure and high pressure feedwater heaters) to be recirculated while cleaning the condensate through the CFD before plant startup, ensuring water quality requirements are met before entering the reactor.

Shutdown and Outages

Procedures for Foreign Material Exclusion (FME) during refuelling operations will ultimately be determined by the future developer/operator of the plant, with consideration of the typically large number of personnel required on-site during outages (**FAP.PER6-377**).

FAP.PER6-377 – A future developer/operator shall develop procedures for FME (including during refuelling outages), including an appropriate training and supervision regime.

General requirements for BWRX-300 refuelling and servicing have been developed for the applicable control zones, as discussed in Reactor Plant Refueling and Servicing General Requirements (Reference 6-41). Design specification document F13-E001, “Foreign Materials Exclusion,” (Reference 6-52) identifies design requirements for FME from the reactor vessel, for reactor servicing, reactor inspection, and reactor modifications tooling used in BWR refuel floor FME zones. Some BWRX-300 systems are fitted with foreign material screens (such as the Control Rod Drive and Isolation Condenser Pools Cooling and Cleanup System (ICC)), which are inspected and cleaned as necessary during outages.

GEH’s SDD document 006N7777, “BWRX-300 Containment Cooling System (CCS),” (Reference 6-53) details that Air Handling Units (AHUs) include air filter sections upstream of the cooling coils to permit installation of temporary filters. Filters are expected to be installed during initial outages and shutdown (and also initial startup) and must be confirmed to be removed prior to containment closure. Low-efficiency air filters are used to protect the AHU from particulates remaining in the containment.

Furthermore, if entry to the containment vessel is required during an outage, the Heating, Ventilation and Cooling System (HVS) (described in SDD 006N7781, “BWRX-300 Heating, Ventilation, and Cooling System (HVS),” (Reference 6-54)) supplies outside air into the containment having passed through High Efficiency Particulate Air (HEPA) filters that operate with a minimum of 99.97 percent removal efficiency for particles of 0.3 µm diameter. This prevents any larger particulates entrained in the air from entering the containment.

For vessel washdown during outages, the Condensate Storage Tank (CST), part of the Liquid Waste Management System (LWM) (SDD 006N7729, “BWRX-300 Liquid Waste Management System (LWM),” (Reference 6-55)), supplies clean condensate for decontamination. Other decontamination methods may also be used in addition to this water. Small amounts of organic surfactants may be present in the washdown but can be tolerated by the LWM filtration skid components (sludge consolidation filter, pre-conditioning filter, and ozone system – see Argument 1.3.2).

In preparation for refuelling outages, systems for treatment of process water are prepared in advance to provide maximum clean-up efficiency. Filters are backwashed and demineraliser beds are serviced. Reactor cavity pool water is also recirculated through the Fuel Pool Cooling and Cleanup System (FPC) filters and demineralisers prior to the outage to improve fill water quality.

All water sources used to fill the reactor cavity pools and RPV, such as the CST and Refuelling Water Storage Tank (RWST) will be cleaned to ensure FPC and reactor water quality requirements for drain and refill operations are met. The RWST is fitted with a high flow fine filtration system to ensure water quality is maintained. A water management plan will be established to account for all potential water sources for drain and refill operations. Demineralised water sources may be required for pool makeup water and to support refuelling activities, as discussed in Reactor Plant Refueling and Servicing General Requirements (Reference 6-41).

Information on the BWRX-300 plant cleanliness philosophy is presented in PER Chapter E4 (Reference 6-9).

6.3.2.7 Argument 1.1.7: Water chemistry is controlled to minimise impacts on the fuel and generation of particulates

The fundamental function of the process fluids in the BWRX-300 steam circuit is to transfer heat from the fuel and to generate the steam necessary to drive the turbines. The chemistry of the process water/coolant is carefully managed to deliver the following effects:

- Reducing chemistry-related failures of the fuel cladding (including corrosion and deposit related failures)
- Reducing IGSCC of reactor internals

- Minimising the generation of CPs that could become activated in the reactor core
- Minimising the generation of radioactive waste
- Reducing occupational exposure of workers to ionising radiation

The management of water chemistry has been a fundamental element undertaken by GEH to reduce the failure of fuel, to reduce operator and public dose, to minimise the generation of radioactive waste, and to improve plant availability. GEH's technical requirements specification 006N6766, "BWRX-300 Water Quality," (Reference 6-56), presents requirements used in the material selection and design of plant systems to maintain process water quality and system integrity. Process water quality is determined by materials selection, minimising the introduction of contaminants, generation of CPs, and the application of appropriate water treatment equipment to reduce contaminants introduced through operation and maintenance or from system materials. The chemistry regime of the BWRX-300 takes account of decades of optimisation of process water chemistry in BWRs.

Extensive BWR OPEX has indicated IGSCC is the primary degradation mechanism that can affect the integrity of the stainless steel internals and piping. Although process water quality and design requirements cannot completely prevent IGSCC, maintaining the lowest practically achievable impurity levels through design minimises initiation and the rate of progression. Following process water quality and design requirements aimed at minimising IGSCC also minimises the potential for fuel cladding corrosion, as discussed in "BWRX-300 Water Quality," (Reference 6-56). Limiting CP metals is also necessary to minimise deposits on fuel, minimise radiation levels, and minimise radwaste generation. These impurities are controlled by a combination of material selection, proper oxygen control, and effective water treatment processes (see GEH's DBR document DBR-0060012, "BWRX-300 Water Chemistry Sampling and Monitoring," (Reference 6-57)). The BWRX-300 design will incorporate the sampling and monitoring capability to identify and respond to adverse chemistry trends before damage can occur to SSCs, in order to achieve the desired plant design life.

The water chemistry regime to be adopted in the BWRX-300 will be HWC with OLNC™, zinc addition, and iron control. These elements, and BWRX-300 design features that support reliable maintenance of water quality, are summarised below:

- HWC is adopted to prevent the occurrence of IGSCC of SSCs, as discussed in "BWRX-300 Water Quality," (Reference 6-56), by promoting recombination of hydrogen with dissolved oxygen. This reduces maintenance requirements and associated radioactive waste, reduces occupational exposure of workers, and increases the availability of the plant
- The OLNC™ System works in conjunction with the HWC system by enhancing the hydrogen/oxygen recombination reaction, reducing the hydrogen concentration required to mitigate IGSCC, as discussed in "BWRX-300 Water Quality," (Reference 6-56). This also serves to mitigate adverse effects of HWC that lead to increased operator dose in other areas of the plant through partitioning of nitrogen-16 into the steam phase
- BWRX-300 will utilise GEH's Zinc Injection Passivation (GEZIP) process to control deposition of cobalt-60 on stainless steel piping surfaces to reduce shutdown dose rates, and prevent release of cobalt-60 from fuel rod oxide layers, which ultimately reduces the amount of cobalt-60 present in spent resins and filters. This is discussed in the CFS SDD (Reference 6-51)
- The concentration of iron present in the feedwater is reduced and controlled to limit deposition on the fuel surface and combined with DZO injection, ensure that any iron oxide film that does form on the fuel does not readily dissolve/spallate. This reduces the release of activated CPs from the fuel deposits, most notably cobalt-60, reducing the radioactivity in spent demineraliser resins. Two of the most important factors determining the feedwater iron input levels to the reactor are the type of condensate

treatment system and the design of the heater drain system. This is discussed in GEH's document DBR-0060212, "BWRX-300 A34 Iron Concentration Control in Feedwater," (Reference 6-58). Owing to the widespread use of stainless steel in the BWRX-300 design, combined with cascaded feedwater drains, feedwater iron control is anticipated to be improved relative to the UK ABWR, which featured greater use of carbon steel combined with Forward Pumped Drains (FPDs) (see Argument 1.1.9)

- The majority of the BWRX-300 feedwater system is constructed of stainless steel as discussed in the ALARA design criteria (Reference 6-4), and use of carbon steel is minimised. Due to the corrosion resistant nature of the piping, oxygen injection may not be performed, as discussed in Water Chemistry Sampling and Monitoring (Reference 6-57). However, the capability for oxygen injection is included in the BWRX-300 design to ensure that oxygen levels are maintained above 40 ppb where any materials susceptible to flow assisted corrosion are used for piping or components, as discussed in "BWRX-300 Water Quality," (Reference 6-56)
- The abatement systems utilised in the BWRX-300 (Argument 1.1.9) for treatment and purification of process water have been extensively optimised. These systems will concentrate and contain activated CPs and ionic species in filter backwash sludges and demineraliser resins for disposal as solid radioactive waste. The combined action of these systems will serve to minimise detrimental effects on the fuel performance, reduce the generation of activation products and associated radioactive waste, and reduce occupational exposure to workers.

A summary of the water treatment systems described above are provided in PER Chapter E4 (Reference 6-9). PSR Chapter 23 (Reference 6-33) provides further details of the expected chemistry commissioning stages which are based on existing GEH experience, RGP, and what was proposed for UK ABWR. While it is recognised that the commissioning chemistry regime adopted for the BWRX-300 will be the responsibility of a future developer/operator, GEH, as vendor, intend to develop a chemistry commissioning strategy at a future stage of the UK licensing and environmental permitting process. This commitment is captured in PSR Chapter 23 as a Forward Action (**FAP.PSR23-134**). This strategy will set out a proposed chemistry commissioning plan for a future developer/operator to follow.

FAP.PSR23-134 - *"GEH will develop a strategy for commissioning chemistry to guide the reactor licensee.*

This will include guidance on:

- *defining and providing on-site monitoring of water chemistry*
- *foreign materials exclusion*
- *surface cleanliness*
- *materials compatibility*
- *flushing operations during Cold Hydrostatic Testing*
- *oxide film conditioning during Hot Functional Testing."*

6.3.2.8 Argument 1.1.8: Design simplifications embodied in the BWRX-300 reduce components / pipework within the containment, eliminating associated maintenance and decommissioning wastes

The BWR design has been evolving since its initial conception in the late 1950s. Design simplifications associated with the reactor systems and containment vessel have been made for each subsequent iteration of the BWR, incorporating various technical innovations.

Reactor Systems

Dresden 1, the first commercially operating BWR, was based on a dual steam cycle rather than the direct steam cycle that characterises later-generation BWRs. Steam was generated in the reactor and flowed to an elevated steam drum and secondary steam generator before reaching the turbine. The first step in BWR simplification was elimination of the external steam drum. This was achieved by two technical innovations, the internal steam separator, and the steam dryer at Gundremmingen (KRB-A, 1967).

The first large direct cycle BWRs (e.g., Oyster Creek) appeared in the late-1960s and were characterised by elimination of steam generators and the use of five external recirculation loops. Later plants were simplified by the introduction of internal jet pumps. These pumps boosted recirculation flow so that only two external recirculation loops were needed. Jet pumps first appeared in the Dresden-2 BWR/3 plant. BWR/4, BWR/5, and BWR/6 designs continued the path to simplification through the 1970s and 80s.

The use of reactor internal pumps in the ABWR design represented another simplification. By using pumps attached directly to the vessel, jet pumps and external recirculation systems (with associated pumps, valves, piping, and snubbers) were eliminated. The ESBWR and its smaller predecessor the Simplified Boiling Water Reactor (SBWR) are a result of the logical simplification of using a taller vessel and shorter core to achieve natural recirculation flow without the use of any pumps.

BWRX-300 continues to develop on the SBWR and ESBWR RPV design by using a tall vessel to achieve natural circulation, eliminating the need for pumps and the need for a shorter core. Control rods are the sole means of reactivity control in the BWRX-300 during normal operations, and these have been redesigned to reduce the amount of stainless steel used within the RPV, thereby reducing the amount of material that may become activated and the final decommissioning waste volume. Although the need for boron for reactivity control under normal operating conditions has been removed, the BWRX-300 includes a boron injection system as an emergency backup to the insertion of the control rods to provide a diverse means of making the reactor subcritical. This is described in SDD document 006N7417, “Boron Injection System,” (Reference 6-59).

Challenges to the integrity of the system are minimised by the large water inventory above the core in the RPV, which has in turn eliminated the need for Safety Relief Valves (SRVs). This design change is detailed in GEH’s document 005N9459, “BWRX-300 Research and Development Program,” (Reference 6-60). An Isolation Condenser System (ICS) and associated pools also provide overpressure protection (and emergency core cooling) by removing energy from the RPV rather than directing it into a suppression pool. As the ICS is used for multiple purposes, this has removed the need for a dedicated standalone emergency core cooling system within the containment, subsequently reducing the number of internal components.

Containment

The first BWR containments were spherical “dry” structures. The Mark I containment used for BWR/3 and most BWR/4 plants was the first of the pressure suppression containment designs. The Mark I design has a characteristic “inverted” light bulb configuration for the steel drywell surrounded by a steel torus housing the large pool of water for pressure suppression. The conical Mark II design used for some late BWR/4 and BWR/5 plants is a less-complicated arrangement, allowing simplified construction. The Mark III containment design in BWR/6 plants represented a further improvement in simplicity; the containment structure is a right-circular cylinder that is easy to construct while providing access to equipment and space for maintenance activities.

The ABWR and ESBWR utilise a pressure suppression containment design that allows for a smaller size and the ability to accommodate rapid depressurisation of the RPV. The ABWR containment is smaller than the Mark III containment because the elimination of the recirculation loops translates into a more compact containment and Reactor Building (RB). The ESBWR containment is similar in design but is larger to accommodate the passive Emergency Core Cooling System.

The BWRX-300 has returned to the dry containment configuration. A nitrogen-inerted containment atmosphere is used to prevent the formation of a combustible environment, and to minimise long-term corrosion and degradation of the Steel-Plate Composite Containment Vessel (SCCV) and internal components by limiting their exposure to oxygen during operation.

The BWRX-300 containment is small and simple and is achieved with surface-mounted integral RPV isolation valves to rapidly isolate the flow from a downstream pipe break. This mitigates the impacts of Loss of Coolant Accidents (LOCAs) by minimising pressure and temperature buildup in the containment.

The SDD document 006N7823, "BWRX-300 Primary Containment System," (PCS) (Reference 6-61) specifies that the number of containment penetrations in the BWRX-300 is minimised as far as reasonably practicable (considering the need for separation, redundancy, and consistency with modern designs). For example, fluid system penetrations are situated at or above the top of active fuel + 4 metres, which provides an additional level of safety and results in the use of fewer penetrations for water level monitoring. This is detailed in SDD 006N7828, "BWRX-300 Nuclear Boiler System," (NBS) (Reference 6-62).

In addition, the installation of specific containment and RPV monitoring equipment outside the containment vessel (e.g., hydrogen, oxygen and FP concentration sample panels, Particulate, Iodine, and Noble Gas skids, pressure transmitters, non-neutron flux measurement instruments) improves accessibility and minimises the volume of (potentially) irradiated components required to be managed during decommissioning.

A summary of the BWRX-300 PCS is presented in PER Chapter E4 (Reference 6-9).

6.3.2.9 Argument 1.1.9: Multi-stage in-process aqueous treatment is capable of cleaning water to meet the reactor water quality specification, enabling recirculation of process water and optimal protection of fuel from cladding failures under normal operating conditions

Water is used as the coolant and moderator within the BWRX-300 and to generate the steam that is used in the turbines to generate electricity. The water coolant becomes contaminated with both radioactive and non-radioactive material as it passes through the reactor and around the steam circuit. A high concentration of radioactivity in the steam circuit is undesirable as it can result in increased operational exposure to workers during operational and maintenance activities. Similarly, high concentrations of non-radioactive contaminants can lead to formation of crud if it is allowed to circulate through the reactor core. The disposal of radioactive aqueous liquid waste is also undesirable as it could harm members of the public and the environment.

The BWRX-300 comprises one integral process fluid circuit – from water in the RPV, to steam in the turbine, which is condensed in the main condenser prior to feedwater return to the RPV. Therefore, it is of fundamental importance that this 'loop' incorporates 100 percent flow purification. Recirculating water throughout the BWRX-300 conserves resources, reduces costs, and mitigates the requirement to make radioactive aqueous liquid discharges to the aquatic environment during the operational life of the facility. The abatement systems utilised in the BWRX-300 design ensure that contaminants removed from both the process water in the main steam circuit, and drained process water collected by equipment and floor drains, is concentrated and contained in filter backwash sludges and spent bead resins that are subsequently managed as wet solid radioactive wastes. The BWRX-300 design does incorporate a discharge line should it be necessary to dispose of radioactive aqueous liquid waste from the plant. However, extensive operating experience from BWRs in the U.S. demonstrates that many plants are successfully operated on a basis that enables a 'maximum recirculation' philosophy[3] to be applied to minimise radioactive aqueous liquid discharges or

[3] The terminology that has been adopted to describe GEH's design approach for management of process fluids (both aqueous liquid and gaseous) within the plant and the design intent with respect to radioactive discharges is defined in PER Chapter E7 (Reference 6-8).

eliminate them altogether ("zero release")[4] (see Analysis of Environmental Discharge Data for US Nuclear Power Plants (Reference 6-17)). Further information on the BWRX-300 maximum recirculation philosophy is presented in PER Chapter E7 (Reference 6-8) and Argument 1.3.1.

The design of the BWRX-300 includes the following systems for treating and recirculating process water that is used during operations and maintenance. A summary of individual systems is provided in PER Chapter E4 (Reference 6-9).

- The CFD system, located immediately after the main condenser, treats process water that has passed through the turbines and has been condensed from steam back to water. CFD combines backwashable, high flow ultrafiltration with deep bed demineralisation using mixed anion and cation bead resin to abate all soluble and insoluble impurities in the condensate. The condensate filters include three filter vessels with high efficiency backwash-type filter elements arranged in parallel, and the condensate demineralisers include three demineraliser vessels arranged in parallel (as described in GEH's specification document 006N4916, "BWRX-300 Operational Concept – Normal," (Reference 6-63)), which maximises the residence time of the condensate. In traditional BWRs much of the insoluble material captured at this point is ferrous particulate resulting from corrosion and erosion of carbon steel in the steam supply system, steam turbine, and main condenser. BWRX-300 features greater usage of stainless steel in these systems to reduce the amount of particulate generated. The CFD filters serve to remove this ferrous particulate before it can reach the RPV, thereby preventing it being irradiated to form highly active crud and reducing the amount of solids in the RPV that can plate out on the hot surface of the fuel cladding. This in turn prevents formation of fuel cladding hotspots and associated fuel cladding failures, which result in the release of FPs. Backwash sludge from the filters, and spent bead resin from the demineralisers, are discharged to the Solid Waste Management System (SWM) for onward management.
- The CUW sends reactor coolant from the bottom region of the RPV to the CFD for processing, at a nominal capacity of 1 percent of rated feedwater flow, under normal operating conditions, as discussed in the CUW SDD (Reference 6-45). This enables continuous cleaning of all process fluids in the BWRX-300 reactor circuit during operation, which contributes significantly to mitigating the risk of fuel cladding failures. The BWRX-300 cleanup system configuration differs from typical BWRs, as the CUW does not include any filtering media. The function of the CUW is to optimise the temperature and pressure of the coolant for treatment by the CFD, which performs all of the cleanup of the reactor coolant. In earlier BWRs the CUW comprised a separate circuit that passed a proportion of RPV flow through a precoat powder resin Filter Demineraliser (FD). This resulted in the creation of a highly concentrated spent powder resin and crud waste stream. The ESBWR introduced a simplification to reactor water cleanup by eliminating the dual function FD and instead utilising a deep bed demineraliser using bead resin, resulting in a common bead resin waste stream for subsequent management in the SWM. Removal of the separate deep bed demineraliser and instead routing CUW flow through the highly efficient CFD filters and demineralisers, represents a further design optimisation for BWRX-300.
- The FPC is in service during power operation, maintaining water quality through cooling and cleaning of the fuel pool, reactor cavity pool, and equipment pool. The BWRX-300 design differs from previous generations of BWR, featuring dry containment and an ICS to serve as overpressure protection to the RPV, eliminating the need for a suppression pool. A reactor cavity pool of water is employed to provide shielding to the top of the RPV, which must be drained to allow access to the containment closure head. This replaces the drywell configuration utilised in the UK

[4] Reference to "zero release" of radioactive aqueous liquids in the GEH source documents is aligned with terminology adopted by other international (e.g., U.S. and Canadian) regulatory regimes.

ABWR design. During refuelling outages, the fuel pool, reactor cavity pool, and equipment pool are cross-connected, forming a common body of water with the RPV. The FPC system lineup includes two trains of pumps, heat exchangers, and backwashable filter, along with a single train deep bed demineraliser using mixed anion and cation bead resin. The system is used to meet or exceed the fuel pool's water quality requirements, remove decay heat from the fuel pool, and remove decay heat from the cavity pool during refuelling. The FPC also maintains the pool level and provides makeup water to both ensure the proper volume of water is maintained for boiloff if cooling is lost, and to provide radiation shielding from the SF racks, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63). Use of separate filters and deep bed demineralisers in the FPC, with elimination of precoat powder resin FDs (present in the UK ABWR FPC system) represents a design optimisation for BWRX-300, in an analogous fashion to the CUW system.

- The ICC processes water from the three Isolation Condenser (IC) Cubicle Pools and surrounding Outer Pools to maintain water temperature within the prescribed safety analyses and administrative limits established for the plant. The ICC also purifies the IC pool water to maintain established plant water quality standards, using a single integrated skid-mounted deep bed demineraliser (mixed ion-exchange resin media) to remove dissolved and fine particulate impurities from the pool water (006N7345, "Isolation Condenser Pools Cooling and Cleanup System," (Reference 6-64)). As the ICS comprises a separate water system to the main steam circuit, the IC pools are anticipated to be free from radioactivity under normal operating conditions. However, there is potential for radiological contamination of the pools during refuelling outages (as the IC pools are located below the RB operating deck) and under fault conditions (ICC heat exchanger or pipework leak, resulting in cross-contamination with steam from the RPV). The ICC demineraliser itself is anticipated to be located in a controlled area of the RB (once UK radiological zoning is applied to the design), in which case the spent ICC resin would be designated as radioactive unless proven to be out of scope (see Argument 1.5.6)

- The LWM comprises a series of skid-mounted equipment that receives drained process water from the plant via the Equipment and Floor Drain System (EFS). Drained process water is treated through use of backwashable high flow ultrafiltration and deep bed demineralisation equipment, supported by additional Reverse Osmosis (RO), an ozone system to destroy organics, and 'polishing' resin beds. The LWM features collection tanks to accumulate drained process water for treatment, and sampling tanks to confirm the quality of the treated water, prior to recirculation within the plant. As with previous iterations of BWR, the system includes a large CST to receive and store the treated process water. In practice, the LWM operates as a process water treatment system that restores water to the reactor water quality specification, allowing the treated water to be recirculated in the plant and minimising the need for radioactive aqueous liquid discharges (see Argument 1.3.2).

- The RWST is part of the LWM and serves to hold the reactor cavity pool of water during refuelling operations. It is also configured to allow it to act as a holdup tank for overboarding flow from CUW, Shutdown Cooling System (SDC), and treated process water from the LWM filtering skids when not holding the reactor well contents, in order to maintain the water balance of the plant, as discussed in the LWM SDD (Reference 6-55). The RWST has a maximum working volume of 625 m^3 and is equipped with a high flow fine filtration filter to remove particulate matter. Incorporation of the RWST into the BWRX-300 design represents an improvement on previous generations of the BWR, which used water from the CST during refuelling operations (which was subsequently transferred to the aqueous liquid treatment system and then back to the CST). During BWRX-300 refuelling outages, drained process water from the reactor cavity pool is cleaned using the RWST filter. Following removal of the RPV head, the reactor cavity is flooded with water from the RWST, which is routed through either the FPC filter and demineraliser or the CFS to ensure suitable water quality, as discussed in “BWRX-300 Operational Concept – Normal,” (Reference 6-63).

- The Turbine Gland Seal Subsystem (TGSS) supplies sealing steam to the turbine shaft/casing penetrations and valve stems to both minimise leakage of radioactive steam and limit air in-leakage through the turbine glands. Source steam can be provided by the high pressure turbine packing leakoff supply steam, or the NBS (see SDD document 006N7717, “BWRX-300 Main Turbine Equipment,” (MTE) (Reference 6-65)). Following use in the turbine gland, the steam-air mixture is exhausted to the Gland Steam Condenser (GSC), where it is cooled by the CFS. The condensed water is then routed to the main condenser for recirculation in the plant (see Argument 1.2.5).
- Cascaded feedwater drains are used in the BWRX-300 design, in which condensate from the feedwater heater drains is returned to the condenser for processing through the CFD filters and demineralisers. This allows for removal of silica, ionic species, and CPs before the water is fed back to the RPV, reducing the potential for fuel damage events, as discussed in the CFS SDD (Reference 6-51). By comparison, the UK ABWR design incorporated FPDs, in which condensate from the feedwater drains is pumped forward to the reactor, bypassing the condensate treatment system. Technical report EPRI 1025190, “Comparison of Effects of Filter Demineralizer and Deep Bed Demineralizer Condensate Polishing on Water Quality,” (Reference 6-66) details that it has been observed that debris-induced fuel failures are much more prevalent in plants with FPDs. This is most likely because foreign material from maintenance activities in the feedwater heater and extraction steam systems can go straight to the reactor rather than being returned to the hotwell where the condensate treatment system has a chance to remove it.

The design of the process water treatment systems described above includes demineralisers to remove soluble material including radionuclides. Demineraliser (also referred to as ion-exchange) systems are utilised throughout the nuclear industry to remove soluble material, including radionuclides, from aqueous liquid processes to maintain the water quality within target values. The demineralisers are capable of using a variety of resins, which provides sufficient flexibility to allow a future developer/operator to select the resin based on operating requirements and compatibility with subsequent disposability requirements. This flexibility is considered to represent BAT at GDA. The future developer/operator will determine the selection of demineraliser resins (**FAP.PER6-383**).

FAP.PER6-383 - A future developer/operator shall determine the final choice of demineraliser resins at site-specific stage using BAT, with consideration of:

- **Selection of optimal option for plant/fuel performance**
- **Strategic decision-making for optimal management of BWRX-300 wet solid wastes**

Spent demineraliser resins will be replaced on exhaustion of capacity, in favour of chemical regeneration. Elimination of demineraliser regeneration chemical waste streams removes the need to process a high impurity waste stream for which evaporators were required to separate water from the chemicals (see Argument 1.3.2). Resin disposal is therefore preferable to chemical regeneration, being both more economical and reducing demands on the plant’s aqueous liquid treatment capabilities, supporting an operational of ‘maxiumum recirculation’ philosophy and minimisation of radioactive aqueous liquid discharges. Additionally, redundancy is built into the BWRX-300 filters and demineralisers, which are arranged in parallel with one unit in each array on standby. This allows spent filters and resins to be changed out as required with the plant at full power, with no impact on water cleanup capabilities.

The condensate polishing system adopted throughout the BWRX-300 process water circuit, utilising non-precoat filtration to remove crud particles upstream of deep bed demineralisers, has been demonstrated to be the optimum design for fuel performance assurance. Advantages of Filter Plus Deep Bed Demineraliser (F+DB) systems for fuel protection and plant performance, compared with precoat powder resin FDs, such as those employed in the CUW and FPC systems in UK ABWR, are summarised below:

- The ion exchange capacity of the plants with deep beds is one to two orders of magnitude greater than that for plants with FDs
- Plants with deep bed demineralisers are able to manage small condenser tube leaks or small ingresses of contaminants from other sources without significant impacts on plant operation and power production. Plants with FDs are also able to manage small condenser tube leaks by employing operating strategies such as increasing the precoat loading, increasing the proportion of anion resin in the precoat and establishing fresh precoats more frequently. However, due to the low total ion exchange capacity of a plant with FDs, power reduction or reactor shutdown is required to locate and repair larger leaks
- Ion exchange and surface adsorption processes are dependent on the surface area of the resin particles. The estimated resin surface area for a typical BWR FD is 39 percent lower than for a typical BWR condensate deep bed loaded with bead resin
- The advantage of F+DB systems over dual-function FDs is that each unit's operation performs only one function. The filter performs only filtration, while the deep bed performs only ion exchange. Because of this, the performance of each unit's operation is superior to that for combined unit operations
- Operation of the filter system for F+DB plants is much simpler than for FDs

Additional advantages of the use of F+DB systems for minimisation and streamlined management of wastes include:

- Adoption of a common approach to demineralisation throughout the BWRX-300 plant, using bead resin eliminates the need for segregation of spent resins at source based on physicochemical characteristics, as the 'powder resin plus crud' waste stream associated with precoat powder resin FDs is eliminated. Consequently, there is no requirement for two separate systems for flushing, discharging, transferring, storing, and processing the spent resins, with consequent reduction in the amount of installed plant, supporting maintenance activities and eventual decommissioning burden.
- Lower capital, operational, and decommissioning costs associated with the reduced scale and complexity of plant required
- Replacement of precoat powder resin FDs with deep bed demineralisers provides benefits for minimisation of operational exposure of plant workers to ionising radiation to levels that are ALARP, as a result of the lower specific radioactivity of spent bead resins as compared to the concentrated 'powder resin plus crud' waste stream generated by backwashing FDs

Management of the secondary wet solid radioactive wastes arising from operation of the BWRX-300 F+DB systems is discussed in Arguments 1.5.2 and 1.5.6.

6.3.2.10 Argument 1.1.10: Use of high-efficiency filters upstream of demineralisers ensures ion exchange resins are replaced on exhaustion of capacity and avoids premature changeout due to clogging

The BWRX-300 design features consistent use of deep bed demineralisers combined with pre-filtration by high-efficiency filters in process water treatment systems throughout the plant. As well as producing homogenous filter backwash sludge and spent bead resin waste streams, which simplify processing and onward management of radioactive wastes, the F+DB condensate polishing system has been demonstrated to be the optimum design for fuel performance assurance, as discussed in "Comparison of Effects of Filter Demineralizer and

Deep Bed Demineralizer Condensate Polishing on Water Quality," (Reference 6-66). This system configuration also prevents the build-up of insoluble crud particles in the demineralisers, which otherwise causes unbalanced flows and pressure drop through the beds. This clogging may only be remediated by resin cleaning processes that disturb and reduce the efficiency of the ion exchange zone.

Condensate prefilter septa consist of melt blown polypropylene media arranged in upright or foldover pleats that surround a polypropylene inner core. The filters provide highly efficient removal of insoluble impurities from the condensate before it reaches the demineraliser beds. The resins in the deep beds are therefore not disturbed by resin cleanings and the ion exchange zone remains undisturbed for the several years that the bed is in service. Benefits of the F+DB system include:

- Optimised ion exchange performance
- Lower exposure to high oxygen conditions during periodic cleanings that promote oxidation of cation resins
- Reduced resin loss and damage (fracturing) from the resin transfer and cleaning processes

Protection of the resin beds by pre-filtration results in reduced frequency of changeout and a consequent reduction in the volumes of clean resin imported (improved sustainability) and wet solid radioactive waste produced by the plant, while maximizing both the useful life and performance of the demineralisers. Additionally, the high-impurity waste stream associated with the physical cleaning strategies required to remove insoluble CPs from the demineralisers is eliminated.

6.3.2.11 Argument 1.1.11: The use of secondary neutron sources will be minimised

Secondary neutron sources provide additional neutrons, at a controlled rate, to assist with reactor start-up. Pressurised Water Reactors (PWRs) typically use antimony-beryllium neutron sources, which generate tritium. The cladding for antimony-beryllium neutron sources is typically manufactured from stainless steel that is porous to tritium. Any tritium that is generated can therefore diffuse through the cladding and into the reactor coolant. The BWRX-300 design will use californium-252 as the start-up neutron source, instead of antimony-beryllium. An advantage of using californium-252 over antimony-beryllium neutron sources is that it does not promote the generation of tritium. The BWR design also means that secondary neutron sources are only required during the start-up phase of the first fuel cycle. Due to the flexibility provided by the reactor design, whereby fuel with a range of burn-ups can be used, secondary neutron sources are unlikely to be required after the first cycle and can therefore be removed.

The selection of materials for secondary neutron sources is limited. There are very few materials that have the combined features of neutron generation and a sufficiently long half-life to make them suitable for operations in a nuclear reactor. Neutron sources typically fall into one of three types, which are spontaneous fission sources, alpha-neutron sources, and photoneutron sources. The selection of the source material will have largest impact on the amount of tritium that enters the water coolant. The reference case for the BWRX-300 is that californium-252 sources in stainless steel cladding will continue to be used as there is considerable OPEX available and the quantity of tritium generated is relatively low.

6.3.2.12 Argument 1.1.12: Leak tightness of liquid, gas, and mixed phase systems maintains containment and control of radioactive substances. Leak detection equipment provides the means to detect and isolate leaks, minimising the spread of radioactive contamination

The design of the BWRX-300 includes the provision of containment and ventilation systems that are intended to ensure that radioactive substances are retained within designated facilities during normal and fault conditions, and that they only enter the environment via appropriately permitted routes. Containment systems are also provided to ensure that radioactive substances do not spread unnecessarily around the plant and generate additional quantities of radioactive waste by contaminating structures, equipment, and workers. Collectively, these systems ensure that the radioactivity in discharges from the BWRX-300 will be minimised.

Containment systems have common objectives related to worker safety and environmental protection that are delivered by effective design, manufacture, installation, and operation. GEH has developed a series of design policies and principles that aim to ensure that both safety and environmental protection are an inherent part of the design. These are based on project requirements, which are created from source requirements as part of a Systems Engineering Design approach. GEH's document 005N9036, "BWRX-300 Requirements Management Plan," (Reference 6-67) states that a requirement is a statement, denoted by the word "shall," which requires a discipline, system, sub-system, or component to perform an action or otherwise meet a constraint. Decisions regarding plant, system, and component design are based on the requirements at each design level. BWRX-300 plant level requirements for containment and control of radioactivity are derived from requirements, recommendations, and guidance from the IAEA, U.S. NCR, and CNSC, and have been incorporated into the plant design.

The most relevant of these requirements (italicised) are summarised below, from the ALARA design criteria (Reference 6-4).

Confinement of Systems

Radioactive systems shall, to the extent possible, be isolated from non-radioactive systems by confining them in different enclosures. Otherwise, there shall be adequate shielding between both areas.

This ensures that radioactive systems are confined, with a principal aim of protecting workers from exposure to ionising radiation. From an environmental perspective this also provides containment for any system leakage, preventing the spread of radioactive contamination and generation of cleanup wastes.

Confinement of equipment

Radioactive system equipment with different radiation levels shall be located in different rooms.

Segregation of systems and materials/wastes of different radioactivity levels helps prevent cross-contamination at the higher radioactivity level in the event of a leak and enables waste segregation and management at the appropriate level.

Location of components

- *If possible, radioactive piping shall be accessible and shall be arranged to allow inspection and maintenance with minimum personnel exposure.*
- *The location of equipment shall be arranged to minimise the length of the radioactive piping between them as much as possible.*

Accessibility and visibility of pipe runs assists in the inspection and maintenance of the pipes to avoid leaks from occurring and enables any leaks that do occur to be pinpointed and isolated for remediation. Minimisation of pipe lengths minimises material used during construction and generation of decommissioning wastes and minimises the length of pipe in which a leak could occur.

Leak-tightness

- *The enclosures that house equipment with large volumes of radioactive liquids (e.g., tanks, heat exchangers, filters) that are adjacent to areas with lower radiation zones shall be leak-tight to prevent the spread of contamination. Additionally, suitable containment measures shall be adopted to prevent dispersion in the event of liquid overflow (e.g., curbs, sloping floor drains).*

- *The gaseous radioactive waste system shall also be leak-tight to minimise escape of radioactive gases and potentially flammable hydrogen.*
- *Leakage of radioactive liquids to ground water, and the leakage of ground water into buildings, shall be minimised by avoiding the use of below-grade conduit and piping penetrations through walls that form exterior boundaries. Penetrations through outer walls of a building containing radioactive systems shall be sealed to prevent leaks to the environment, and the integrity of such seals shall be periodically verified.*

System isolation

- *When a contaminated, or potentially contaminated, system is connected to a clean (i.e., non-contaminated) system, provisions shall be implemented to ensure that backflow, from contaminated to non-contaminated, cannot occur.*
- *All contaminated or potentially contaminated systems shall be isolated from the outside environment or shall be otherwise equipped with isolation devices to control their discharges.*
- *Gaseous radioactive systems shall be sealed from the environment to ensure confinement.*

Leak detection and isolation are provided to detect and mitigate degraded conditions prior to becoming severe enough to challenge reactor safety, system control, and on-site as well as off-site radioactive discharges and radiological exposure. Requirements and methods for leak detection in the BWRX-300 are described in 007N0761, “BWRX-300 Leak Detection Requirements,” (Reference 6-68).

6.3.3 Claim 1.2: Minimisation of the activity of gaseous radioactive waste disposed of by discharge to the environment

The BWRX-300 employs a range of features to reduce the discharge of radioactivity from those radioactive wastes that are unavoidably created during operations.

The arguments presented in support of this claim are considered to demonstrate compliance with the following conditions on BAT in permits for Radioactive Substances Activities (see the EA’s guidance document “RSR permits for nuclear licensed sites: how to comply,” (Reference 6-21)).

“2.3.2 The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to:

(a) minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment.”

“2.3.3 The operator shall use the best available techniques to:

(a) exclude all entrained solids, gases and non-aqueous liquids from radioactive aqueous waste prior to discharge to the environment.”

The BWRX-300 design contains a range of features that contribute to the substantiation of this claim including:

- Provision of an OGS that includes processes to reduce radioactivity in the gaseous phase prior to discharge to the environment
- Provision of an offgas charcoal adsorber within the OGS to abate short-lived noble gases
- A HVS system that prevents the uncontrolled discharge of radioactive substances
- Provision of a TGSS to prevent leakage of reactor steam from the turbine
- Holdup for nitrogen-16 decay, which is provided by the main condenser

The following ENDPs are also considered to be relevant and have been taken into account for this claim:

- ENDP14 – *"Best available techniques should be used for the control and measurement of plant parameters and releases to the environment, and for assessing the effects of such releases in the environment."*
- ENDP15 – *"Best available techniques should be used to prevent and/or minimise releases of radioactive substances to the environment, either under routine or accident conditions."*
- ENDP16 – *"Best available techniques should be used in the design of ventilation systems."*

6.3.3.1 Argument 1.2.1: The radioactivity of gaseous radioactive discharges will be minimised by optimising the gaseous waste treatment system

Gaseous radioactive wastes will be generated during the operation of the reactor. Significant efforts are expended to eliminate these wastes but the disposal of radioactive gaseous waste to the environment is required to ensure the safe and efficient operation of the NPP. Some of the radionuclides that are carried in the steam do not condense in the condenser. These radionuclides are carried by the Steam Jet Air Ejector (SJAE), which is used to maintain the vacuum in the condenser and require treatment and disposal as gaseous radioactive waste.

The design of the BWRX-300 includes an OGS that collects, conveys, treats, and discharges gaseous radioactive waste from the condenser during power operation. The OGS includes processes to reduce radioactivity in the gaseous phase prior to discharge to the environment, and consists of the following major equipment:

- Offgas pre-heater
- Catalytic recombiner
- Offgas condenser
- Charcoal adsorber tanks

The OGS takes non-condensable gases from the main condenser SJAEs and passes them through a pre-heater. The pre-heater is used to ensure that there is no moisture going into the catalytic recombiner, as it inhibits the recombination process. After the pre-heater, the offgas recombiner is used to catalytically recombine the radiolytic hydrogen and oxygen; the resulting water vapor is then routed back to the main condenser. The offgas is then routed to the offgas condenser to continue removing moisture from the mixture, and passed through additional cooling and conditioning components, before being routed to the charcoal adsorber tanks.

The charcoal adsorber tanks provide a delay period, through adsorptive holdup of the radioactive isotopes of krypton, xenon, and argon, in order for these radioisotopes to undergo radioactive decay prior to discharge from the plant. Once the mixture is through the adsorber tanks, it is routed through a small HEPA filter to remove particulate material. It is then exhausted to the Continuous Exhaust Air Plenum (CEAP), where it is mixed and diluted with exhaust air from other plant areas, before discharge to the environment via the Plant Vent Stack (PVS), as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63).

A summary of the design of the OGS and radioactive gaseous discharges to the environment is provided in PER Chapter E4 (Reference 6-9) and PER Chapter E7 (Reference 6-8).

Some of the radionuclides in the offgas, such as carbon-14, do not undergo treatment in the OGS and are discharged directly to the environment via the stack. Whilst tritium does not undergo dedicated abatement, the majority of the tritium in the gaseous phase is removed from the offgas by the OGS recombiner and OGS condenser. The hydrogen, and therefore any tritium, is converted to water and is returned to the CST where it is recirculated within the plant. Recirculating tritium within the process water for the lifetime of the NPP delivers additional benefits from radioactive decay. Dedicated abatement is not provided for tritium and carbon-14 because the assessment of treatment techniques for these radionuclides has shown that the costs of installation and operation are very high, while the efficacy of these techniques in reducing radiological impacts on members of the public and the environment is relatively low (see IAEA Technical Reports Series no. 421, "Management of Waste Containing Tritium and Carbon-14," (Reference 6-69)). Installation of such equipment is therefore considered to be grossly disproportionate to any benefit that would be realised. GEH considers that sufficient evidence exists to demonstrate that providing abatement for particulate matter and short-lived radionuclides and not providing treatment for tritium and carbon-14 represents BAT.

The offgas process stream will be sampled and monitored by the PREMS downstream of the dryers and prior to discharge, as discussed in the OGS SDD (Reference 6-42), to allow a future operator to avoid radioactive gaseous discharges in excess of regulatory or plant-specific limits, identify potential fuel cladding failures, and confirm that what has been identified as BAT is performing as expected. Sampling and monitoring arrangements incorporated into the BWRX-300 design are discussed in PER Chapter E8 (Reference 6-7). The requirement to develop appropriate management arrangements for the BWRX-300 sampling and monitoring regime, including monitoring of plant performance to identify deviation from the normal operating state and ongoing review of system performance has been identified in PER Chapter E8 as **FAP.PER8-379**.

FAP.PER8-379 – *"A future developer/operator shall develop a detailed sampling, monitoring, and characterisation programme in order to determine final discharge accountancy and solid waste inventory, and monitor plant/system performance, including a suitable record-keeping system."*

6.3.3.2 Argument 1.2.2: The offgas treatment system provides delay of specific gaseous radionuclides to allow radioactive decay before discharge (carbon beds)

During normal operation, multiple radioactive noble gas isotopes are generated as either FPs (krypton and xenon) or activation products (argon-41). These are non-condensable isotopes that enter the offgas process stream. Low concentrations of FPs arise in the offgas from the reactor cooling circuit due to:

- Tramp uranium
- Fission of fuel material
- Fission of structural uranium
- Ternary fission in fuel

The concentration of these FPs from within the fuel will increase in the unlikely event of a failure in the fuel cladding. The majority of these FPs have relatively short half-lives and undergo rapid radioactive decay. Retention of the FPs in the gaseous radioactive waste treatment system for a period prior to discharge reduces the amount of radioactivity that will enter the environment.

The design of the gaseous radioactive waste treatment system in BWRX-300 includes a series of four delay beds that are filled with granulated activated charcoal, as discussed in the OGS SDD (Reference 6-42). The use of such delay beds is common practice in the UK nuclear industry. The purpose of these delay beds is to retain the FPs for a defined period during which they undergo radioactive decay. This is done through the process of adsorption, where the atoms of the noble gas isotopes are held (by Van der Waals-type forces) to the surfaces of the charcoal granules long enough to delay their migration downstream. The rate at which the FPs are adsorbed on to, and de-adsorbed from the surface of, the charcoal is dictated by the chemical and physical properties of the charcoal, the FP, and other species passing through the delay beds.

The delay bed system has been designed to retain isotopes of xenon for a period of approximately 67 days, isotopes of krypton for approximately 90 hours, and argon-41 for approximately 31 hours, as discussed in the OGS SDD (Reference 6-42). The Nuclear Energy Agency/Organisation for Economic Co-Operation and Development publication, “Effluent Release Options from Nuclear Installations,” (Reference 6-70) describes that whilst the offgas delay beds are designed to hold-up radioactive noble gases, it has been demonstrated that they also abate any volatile iodine FPs that are carried over from the main condenser. This is because radioactive iodine has favorable characteristics that promote its retention within carbon filter beds.

A summary of the BWRX-300 delay bed system is presented in PER Chapter E4 (Reference 6-8) and PER Chapter E7 (Reference 6-8).

Evolution of the BWRX-300 design has introduced a number of improvements to the charcoal adsorber bed system, as described in the OGS SDD (Reference 6-42) and summarised below:

- Increased calculated holdup time that krypton and xenon gases are retained within the gaseous radioactive waste treatment system, compared with previous generations of BWR (which employed delay tanks with a hold-up time of 24 hours), and the UK ABWR (which was anticipated to provide holdup times of 30 days for isotopes of xenon and 40 hours for isotopes of krypton, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35)).
- The BWRX-300 design will include a dedicated temperature-controlled room for the delay beds within the Radwaste Building (RWB), which allows the performance of the system to be maintained whilst reducing the quantity of solid waste generated from drying the offgas
- System reliability is reinforced by configuration of the first charcoal adsorber tank (known as the Guard Bed) to be bypassed if a problem manifests in it (e.g., high moisture or potential combustion issue). This enables the system to operate on the latter three beds for a short period of time, until the issue is resolved
- The expected performance of the charcoal is such that, in the absence of a catastrophic incident, no replacement of the charcoal should be required during a 60-year plant lifespan. Avoiding the necessity for replacement of the charcoal reduces the potential for system leakage or contamination of non-radioactive systems/components. It also reduces material use and waste generation

GEH considers that the use of delay beds with the stated performance represents BAT for the purposes of GDA. However, **FAP.PER6-202** has been raised for a future developer/operator to undertake BAT assessments for waste management techniques.

FAP. PER6-202 – A future developer/operator shall undertake a BAT assessment of waste management techniques taking into account site-specific factors, including number of units on the site, the proximity principle, radioactive decay storage considerations, and any operational experience from in-service BWRX-300 reactors (if available on project timescales) to inform provision of waste management capabilities for a BWRX-300 installation in the UK.

6.3.3.3 Argument 1.2.3: The HVS will control air flows and discharge via a permitted outlet

Gaseous radioactive waste will be discharged to the environment via appropriately permitted outlets. The design of the BWRX-300 includes a HVS that delivers the combined function of:

- Preventing the uncontrolled discharge of radioactive substances
- Providing a pleasant working environment for workers
- Ensuring optimal working conditions for plant and equipment

- Delivering safety-related functions to protect workers in the event of a release of radioactivity

The HVS consists of subsystems for providing fresh air and ventilation of each building listed below. With the exception of the Control Building (CB), Services Building, and Perimeter Building subsystems, all of the potentially radioactive subsystems exhaust to the CEAP, which serves as a large mixing box where potentially contaminated air will be mixed and diluted. During normal operation, up to three CEAP fans take suction on the plenum and discharge to the nearby PVS. The PVS is monitored for radiation, as discussed in the HVS SDD (Reference 6-54).

The HVS consists of subsystems servicing the following buildings/areas:

- CB
- RB
- RWB
- Turbine Building (TB)
- Services Building
- PVS
- Perimeter Buildings

The BWRX-300 ventilation system is designed such that air pressure in plant facilities handling radioactive substances (such as the RB and RWB) are maintained at a lower level than atmospheric pressure to ensure that air flows into the facility from the external environment, as discussed in the HVS SDD (Reference 6-54). This prevents the uncontrolled discharge of any radioactive substances through doors, windows, and gaps in the building fabric. The negative pressure within the facility is maintained by the HVS, which continuously extracts air from within the NPP facility buildings and discharges it to the environment during normal operations. Furthermore, it also makes efficient use of the air that is drawn in to the system by allowing it to flow from areas of lower contamination risk to areas of higher contamination risk (e.g., in the TB and RWB), as discussed in the HVS SDD (Reference 6-54) and “BWRX-300 Operational Concept – Normal,” (Reference 6-63). This limits the spread of radioactive contamination within the plant.

HVS subsystems that serve areas of the plant where radioactive substances are present have filters to remove any particulate matter prior to discharge to the environment, via appropriately permitted outlets. Exhaust air from potentially contaminated areas including the TB, RB, and RWB are filtered using local area HEPA filters before being exhausted to the CEAP as discussed in the HVS SDD (Reference 6-54).

Release to the environment occurs through the PVS, at a height of approximately 35 m, as described in the “BWRX-300 General Description,” (Reference 6-40). However, actual stack height will be dependent on information that will not be available until site-specific issues have been considered, such as the meteorological conditions, topography, location of surrounding buildings, location of sensitive receptors, and the final site layout. An assumed effective stack height of 11.7 m based on a release height of 35 m has been used at GDA for dose modelling assessments, as presented in PER Chapter E9 (Reference 6-13).

The TB, RWB, and RB are provided with area and process radiation monitors to measure levels of radiation within each building. If radiation monitoring from any particular building is measured above setpoint, the building is isolated by the HVS while the CEAP fans maintain flow from the remaining buildings. This restricts an uncontrolled release of radioactivity from the isolated building, consistent with the ALARA principle, as discussed in the HVS SDD (Reference 6-54). Sampling and monitoring arrangements for BWRX-300 are discussed in PER Chapter E8 (Reference 6-7). HVS subsystems that serve areas of the plant where radioactive substances are handled do not provide any abatement other than filters. Additional abatement systems are not considered necessary because, under normal operations, the amount of radioactivity that is expected in the large volumes of waste air drawn through the HVS system will be very low.

A summary of the HVS is provided in PER Chapter E4 (Reference 6-9) and PER Chapter E7 (Reference 6-8).

6.3.3.4 Argument 1.2.4: The HVS will provide filtration of airborne particulate material prior to discharge

The BWRX-300 will employ appropriate filtration techniques to ensure that the concentration of particulate matter within the gaseous radioactive waste stream is minimised during normal and accident conditions. Filtration is considered to be RGP in the UK nuclear industry for the abatement of particulate matter and it is the design intent to provide filtration on the BWRX-300 HVS as appropriate.

The BWRX-300 has been subject to considerable optimisation that has minimised the amount of particulate matter that has the potential to become mobilised within the building areas served by the HVS subsystems. As a result, during normal operations, concentrations of particulate matter are not expected to be significant. The number and specification of the filters to be used to abate airborne particulate matter will be determined through the application of BAT; however, filter selection will be influenced by the safety performance requirements being established to mitigate accident conditions. It is therefore deemed that the performance of the filters will exceed that required for normal operations. Additionally, HEPA filtration of gaseous systems facilitates representative sampling through removal of particulate in the process/discharge stream. A forward action (**FAP.PER6-382**) has been raised for a future developer/operator to determine the number and specification of ventilation filters.

FAP.PER6-382 – A future developer/operator shall determine the number and specification of ventilation filters through holistic consideration of ALARP and BAT principles.

HEPA filtration is an example of ‘best practice’ gaseous filtration techniques implemented within the BWRX-300 design. HEPA filters will be provided to abate gaseous radioactive waste generated in the BWRX-300 where it is demonstrated to be BAT. The HEPA filter type chosen for each system will depend on the environmental and flow-rate conditions anticipated. Dedicated HEPA filters will be provided to the following systems and plant areas, as discussed in the HVS SDD (Reference 6-54):

- Primary containment
- SDC
- FPC room
- RB
- RWB
- TB
- CFD
- OGS exhaust

Additional information on these systems and plants areas is provided in PER Chapter E7 (Reference 6-8).

During startup only, the condenser vacuum flow path is maintained by the Mechanical Vacuum Pump (MVP), and the OGS is bypassed, as stated in the OGS SDD (Reference 6-42). It should be noted that the exhaust from the MVP is not HEPA filtered, as this system is not anticipated to be a source of particulate. The expected type of MVP is a Liquid Ring Vacuum Pump, which will have a separator (demister) which removes non-condensable gases at the discharge. Therefore, no particulates are expected in the exhaust from the MVP and no HEPA filtration is needed. The exhaust from the MVP is routed to the CEAP. Further information on the operation and anticipated radioactive gaseous discharges from the MVP is provided in PER Chapter E7 (Reference 6-8).

6.3.3.5 Argument 1.2.5: TGS steam management will be optimised to minimise the discharge of noble gases. Retention time in the ductwork prior to discharge to the environment is sufficient to allow decay of short-lived radionuclides to below levels of concern

In the BWRX-300 design, the TGSS is used to minimise leakage of radioactive steam from the turbine shaft/casing penetrations and valve stems, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63). The TGSS design reduces the volume and radioactivity of gaseous radioactive waste discharged to the environment by:

- Preventing the leakage of reactor steam from the turbine into the TB and therefore avoiding the discharge of unabated reactor steam directly into the environment
- Preventing the in-leakage of air into the seal and subsequently into the main condenser. Air entering the main condenser would reduce the condenser vacuum pressure leading to a turbine trip. Air that leaks into the main condenser also has the potential to become activated in the reactor, increasing the generation of radioactive waste that would require management in the OGS

The TGSS supplies gland sealing steam (taken from the main steam supply) at a higher pressure than the turbine side of the seal such that all potential steam leakage is into the high- and low-pressure turbines. The GSC operates at a slight vacuum to provide a suction on the gland sealing steam and atmosphere, such that air enters the system, preventing steam leakage into the TB, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63).

The steam-air mixture is exhausted to the GSC, where it is cooled by the CFS. The condensed water is routed to the main condenser, and subsequently recirculated in the plant. Non-condensable gases are routed to the PVS via the HVS ducts and the CEAP, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63). The radioactive discharge contains radioisotopes of krypton and xenon, and very small quantities of iodine. A HEPA filter is provided on the extract from the gland steam exhauster to remove any particulate matter, as discussed in the HVS SDD (Reference 6-54). Radiation monitoring of the GSC exhaust is provided by the PREMS, as discussed in the SDD (Reference 6-43).

A summary of the TGSS design is also presented in PER Chapter E4 (Reference 6-9).

In the UK ABWR design, the TGS extracts water from the CST during normal operations and converts it to steam via a heat exchanger using reactor steam in the turbine gland evaporator. During startup, an auxiliary boiler is used. However, the BWRX-300 is a design evolution of the ESBWR, which incorporates design simplifications to support the macro sustainability principle of providing zero-carbon energy on meaningful timescales and in an economically viable manner. As such, the BWRX-300 design does not contain a permanent auxiliary boiler system, as detailed in GEH's document 007N1078, "Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant," (Reference 6-71), and source steam for the TGSS is provided by the high pressure turbine packing leakoff supply steam (during normal operations), or the NBS (during startup), as discussed in the MTE SDD (Reference 6-65).

The design of the TGSS in the BWRX-300 serves to improve the leak-tightness of the plant, though it is recognised that the design does result in the discharge of gaseous radioactive waste. Conservative and bounding values for radioactive gaseous discharges from the TGSS are presented in PER Chapter E7 (Reference 6-8). The limitations of these data and the conservatisms applied to the methodologies adopted are also discussed in PER Chapter E7.

FAP.PER6-199 details that the design development and quantification of radioactive wastes/discharges beyond GDA Step 2 will be based on a refined 'Realistic Model' (RM) source term.

Dose assessment calculations for total radioactive gaseous discharges across all contributing systems in the BWRX-300, notwithstanding the conservatisms applied to source term data, show that the anticipated radiological dose to the public from these discharges falls well below the dose constraints imposed in Schedule 23, Part 4 of EPR16 (Reference 6-1). A refined dose assessment calculation, using the EA's Initial Radiological Assessment Tool (IRAT2) with an assumed effective stack height of 11.7 m, based on a release height of 35 m, indicated that doses arising from BWRX-300 radioactive gaseous discharges were below 20 µSv/year for humans and below 1 µGy/hour for wildlife (PER Chapter E9 (Reference 6-13)). It is however acknowledged that there is no limit below which the obligation to demonstrate the application of BAT does not apply, and that UK-specific requirements for use of BAT to minimise the radioactivity of environmental discharges (as outlined in standard permit conditions (Reference 6-21)) will need to be considered and implemented at the appropriate time during the BWRX-300 design process.

FAP.PER6-380 - UK requirements for use of BAT to minimise the radioactivity of gaseous and aqueous discharges shall be inserted into the BWRX-300 Requirements Management process at design BL3 for UK site-specific design development.

GEH recognises, in principle, that opportunities may exist to further optimise the BWRX-300 TGSS design. However, the costs of implementation (in terms of time, trouble, and cost) may be disproportionate compared with any benefits in terms of dose reduction, given that the anticipated radiological dose from total radioactive gaseous discharges already falls well below the specified dose constraints. Additionally, the improved performance of GNF2 fuel combined with material selection to prevent corrosion of pipework and the highly efficient abatement systems employed throughout the condensate and feedwater circuit, which prevent crud buildup on fuel elements, effectively prevent fuel failures and minimise release of gaseous FPs. These benefits, coupled with a simplified TGSS design aligned with key economic viability considerations, contribute to the application of BAT.

It should be noted that potential refinements to the TGSS are currently under consideration as part of ongoing development of the BWRX-300 Standard Design using CNSC requirements[5] (see PER Chapter E7 (Reference 6-8), Appendix C). The output of relevant studies, when complete, will form part of the evidence that will be used in the next iteration of the BAT case for BWRX-300 (**FAP.PER6-314**).

6.3.3.6 Argument 1.2.6: Radioactive gaseous discharges resulting from evaporation of aqueous liquids will be minimised

Evaporation of process water will contribute to radioactive gaseous discharges from the BWRX-300 HVS, as described in PER Chapter E7 (Reference 6-8). Sources of airborne contamination in the BWRX-300 arising from evaporation are:

1. Evaporation of process water from the fuel pool, equipment pool, and reactor cavity pool, which contain low levels of radioactivity
2. Evaporation leakage of process water from systems and piping in the RWB, RB, and the area of the TB that contains the turbine condenser and other radioactive systems

As detailed in the ALARA design criteria (Reference 6-4), the BWRX-300 facility is expected to have very low levels of airborne radiation. GEH has considered minimisation and mitigation of these releases during the BWRX-300 design process, as demonstrated by the ALARA Objectives laid out in the ALARA design criteria (Reference 6-4). This document enforces high-level requirements on plant SSCs to maintain containment and control of radioactive

[5] A Best Available Technology and Techniques Economically Achievable assessment is being conducted for the Darlington New Nuclear Project in Ontario, Canada.

substances, and to minimise radiological releases and their impact on plant workers and members of the public. The BWRX-300 design minimises gaseous radioactive discharges resulting from evaporation of process water by:

- Reducing the open pool surface areas where gaseous radioactive discharges can arise through evaporation
    - It should be noted that the IC pools are a separate water system from the main process fluid circuit, and are therefore segregated from sources of aqueous liquid contamination in the plant that may contain tritium and other impurities. The only potential source of radioactivity expected in the IC pools under normal operating conditions is contamination resulting from refuelling activities where the hatches above the IC pools may be opened and small amounts of contaminated reactor water or dust may fall through the hatches into the IC pool water. The ICC runs continuously during normal operation to remove soluble and insoluble impurities from the IC pools to meet or exceed plant water quality requirements. The IC pools are not expected to contribute to gaseous radioactive discharges in the BWRX-300
- Continuous cooling and cleaning of the fuel pool, equipment pool, and reactor cavity pool using the FPC, as discussed in the "BWRX-300 Fuel Pool Cooling and Cleanup," SDD (Reference 6-72). The FPC performs the combined functions of:
    - Maintaining the fuel pool bulk temperature below a maximum value of 60 °C under the most conservative conditions for pool heat load, including a full core offload. However, refuelling outages are typically managed and scheduled such that the temperature of the fuel pool is maintained below 43.3 °C during normal operations, including refuelling
    - Maintaining the temperature of the equipment and reactor cavity pools below a maximum temperature of 43.3 °C during normal operation including refuelling outage activities
    - Continuously filtering the pool water through demineralisers and particulate filters to maintain high water quality. While the FPC does not impact the levels of tritium in the reactor cavity, equipment, and fuel pools it does reduce the levels of all other remaining radionuclides which assists in minimising radioactive discharges resulting from evaporation. Because tritium is not affected by cleanup systems and has a relatively long half-life, once it has been produced and transferred to a process fluid system, the only removal mechanisms are evaporation, steam leaks, aqueous liquid discharges, and radioactive decay (to a lesser extent).
- Reducing the temperature of the pool surfaces
    - In the RB refuelling area, the HVS is designed to sweep the fuel pool and reactor cavity pool surfaces to cool the pool surfaces and reduce evaporative pool losses, as discussed in the ALARA design criteria (Reference 6-4)
- Detection and isolation of aqueous liquid and/or steam leaks from process systems and piping, as described in Argument 1.1.12 (Section 6.3.2.12)
    - Leak detection and isolation are provided to detect and mitigate degraded conditions prior to becoming severe enough to challenge reactor safety, system control, and on-site as well as off-site radioactive discharges and radiological exposure. Requirements and methods for leak detection in the BWRX-300 are described in "BWRX-300 Leak Detection Requirements," (Reference 6-68)
    - The radiation protection design requirements described in the ALARA design criteria (Reference 6-4) include additional leak detection and isolation

provisions to minimise gaseous radioactive discharges that can arise through evaporation

- The fuel pool, spent fuel cask pit, equipment pool, and reactor cavity pool are equipped with stainless steel liners and leak detection drains as part of the FPC. All leak detection drains are designed to permit free gravity drainage to a local drain sump
- For process lines that penetrate the containment, at least two different methods are used for detecting leakage for the affected system. The instrumentation shall be designed to initiate alarms at established leakage limits so that affected systems can be isolated quickly

6.3.4 Claim 1.3: Minimisation of the activity of aqueous radioactive waste disposed of by discharge to the environment

The BWRX-300 employs a range of features to reduce the discharge of radioactivity from those radioactive wastes that are unavoidably created during operations.

The arguments presented in support of this claim are considered to demonstrate compliance with the following conditions on BAT in permits for Radioactive Substances Activities (see the EA's guidance document "RSR permits for nuclear licensed sites: how to comply," (Reference 6-21)):

"2.3.2 The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to this permit to:

(b) minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment."

"2.3.3 The operator shall use the best available techniques to:

(b) exclude all entrained solids, gases and non-aqueous liquids from radioactive aqueous waste prior to discharge to the environment."

The BWRX-300 design contains a range of features that contribute to the substantiation of this claim including:

- Provision of highly effective abatement systems for efficient recirculation of process water, enabling BWRX-300 to operate on the basis of a 'maximum recirculation' philosophy under normal operating conditions
- Treatment techniques for drained process water that minimise any necessary discharge of radioactive aqueous liquid waste to the aquatic environment, through provision of a LWM
- Design features to minimise leaks of radioactive process fluids from the containment system

The following RSR GDPs are considered to be relevant and have been taken into account for this claim:

- RSMDP8 – *"The best available techniques should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing might compromise subsequent effective management or increase environmental impacts or risks."*
- ENDP14 – *"Best available techniques should be used for the control and measurement of plant parameters and releases to the environment, and for assessing the effects of such releases in the environment."*
- ENDP15 – *"Best available techniques should be used to prevent and/or minimise releases of radioactive substances to the environment, either under routine or accident conditions."*

6.3.4.1 Argument 1.3.1: The BWRX-300 can be operated as a ‘maximum recirculation’ reactor with minimal radioactive aqueous liquid discharges to the aquatic environment under normal operating conditions

BWRX-300 is capable of being operated, under normal operating conditions, without recourse to radioactive aqueous liquid discharges to the aquatic environment. This is achieved by use of highly effective abatement systems that clean process water in the main steam circuit, and drained process water collected in equipment and floor drains, to meet the reactor water quality specification, allowing for return to the CST and recirculation in the plant. The plant is designed with sufficient water storage capacity to contain the volumes of water needed for the full range of activities undertaken during the normal operating cycle, including refuelling outages.

For many decades, some BWRs have embraced an operational strategy that enables use of a ’maximum recirculation’ philosophy for management of process water, a philosophy of treating and recirculating process water to minimise radioactive aqueous liquid discharges to the aquatic environment. NUREG/CR-2907, “Radioactive Effluents from Nuclear Power Plants, Annual Report 2016,” (Reference 6-73) explains that such a strategy has cost advantages, because it is expensive to discharge very high-quality process water that could be returned to the steam circuit and ancillary systems. Additionally, adoption of a maximum recirculation philosophy for process water conserves natural resources and virtually eliminates radioactive aqueous liquid discharges in those BWRs that adopt this strategy. Maximum recirculation plants that maintain good control of treating all process water to meet the reactor water quality specification, and that are vigilant in stopping steam leaks, can run for extended periods of time without adding demineralised makeup water to the CSTs. FitzPatrick (Oswego, New York, U.S.) is an example of a BWR that operated for over one year between demineralised water makeup additions. In the absence of steam leaks and excluding refuelling outages, the addition of makeup water to the CSTs may only be needed to recover evaporative losses from the fuel pool.

A review of publicly available data for U.S. NPPs, documented in the Analysis of Environmental Discharge Data for US Nuclear Power Plants (Reference 6-17), for the ten-year period 2012 to 2021 demonstrates that several U.S. BWR plants operate on a maximum recirculation basis and have done so for many years. For some plants, occasional radioactive aqueous liquid discharges are identified. Significantly, five of the BWRs studied (Clinton, Columbia, Fermi 2, and LaSalle Units 1 and 2) reported zero tritium or mixed fission and activation products discharged via the radioactive aqueous liquid pathway over the entire time period. This provides evidence that a maximum recirculation philosophy may be successfully and consistently implemented in practice, dependent on operator decisions and site-specific factors, but that it is appropriate to include an allowance for radioactive aqueous liquid discharges in environmental permits to maintain the overall water balance of the plant if required.

DBR-0060900, “BWRX-300 Zero Release Plan,” (Reference 6-74), states the design intent to treat all process water internally during normal operation, avoiding unnecessary radioactive aqueous liquid discharges to the aquatic environment. The “zero release”[6] objective can be achieved when all process water can be treated to meet CST water specifications. The BWRX-300 LWM incorporates OPEX into the design to optimise this process, examples of which include:

- Minimisation of the number of floor drains that are a part of the EFS
- Incorporation of a RO system into the LWM. Use of RO membranes is identified as facilitating minimisation of radioactive aqueous liquid discharges in the Nuclear

[6] Reference to “zero release” of radioactive aqueous liquid waste in the GEH source documents is aligned with terminology adopted by other international (e.g., U.S. and Canadian) regulatory regimes.

Decommissioning Authority (NDA) document NDA021465, “Nuclear Industry Aqueous Waste Management Good Practice Guidance,” (Reference 6-75), by increasing the efficiency and reliability of process water treatment techniques

- Installation of additional storage tanks to store water for processing and holding, and isolating any “bad batches” of process water that might need additional treatment for contaminants such as organics
- Sizing the LWM to have the capacity to treat drained process water collected via the EFS during normal and abnormal operations
- For emergent issues requiring processing of excess radioactive aqueous liquids, the inclusion of processing capabilities in the plant design for the use of temporary storage and processing resources

Further information on the BWRX-300 maximum recirculation philosophy is presented in PER Chapter E7 (Reference 6-8). BWRX-300 design features that enable process water to be cleaned to meet the reactor water quality specification, allowing recirculation to the CST and facilitating mimimisation of radioactive aqueous liquid discharges, are also discussed in Arguments 1.1.9 and 1.3.2 (subsections 6.3.2.9 and 6.3.4.2 respectively).

In the unlikely event that the plant’s overall water inventory will not allow for the water to be recirculated to the CST, the LWM is equipped with a discharge path to the Circulating Water System (CWS) for dilution and release to the aquatic environment. If a radioactive aqueous liquid discharge is required, the LWM is designed to take a grab sample prior to release to ensure all chemical and radiological contaminants meet the required permits and regulations. Sampling and monitoring arrangements for radioactive aqueous liquid discharges from the BWRX-300 are presented in PER Chapter E8 (Reference 6-7).

Operational Management of Radioactive Aqueous Liquid Discharges

Whilst in principle the BWRX-300 is capable of operating without recourse to radioactive aqueous liquid discharges, it is acknowledged that any future site-specific environmental permit application shall include discharge limits (see PER Chapter E7 (Reference 6-8)) to allow provision for any necessary radioactive discharges via the aqueous liquid pathway. It will be for a BWRX-300 plant developer/operator to determine the operational requirements for radioactive aqueous liquid discharges at the site-specific stage.

A consideration for a future developer/operator is the management of tritium. Considerations relating to site-specific optimisation of the LWM operation to minimise the radiological dose impact of tritium discharges via the gaseous and aqueous liquid pathways are presented in PER Chapter E7 (Reference 6-8), Subsection 7.4.5. However, it should be noted that the BWRX-300 produces only a small fraction of the tritium produced by a Canada Deuterium Uranium (CANDU) reactor or PWR because boron is not used in the reactor water. Additionally, BWRs, including the BWRX-300, do not require radioactive aqueous liquid discharges to lower tritium levels in order to allow refuelling.

The final site-specific arrangements for management of radioactive aqueous liquid discharges will be defined by a future developer/operator following appropriate assessment. This is captured by forward action **FAP.PER7-195** raised in PER Chapter E7 (Reference 6-8).

FAP.PER7-195 - ‘*A future developer/operator shall determine the optimised operational requirements for radioactive aqueous liquid discharges at site-specific stage, including decision-making relating to:*

- *Mode of operation, either employing a 'maximum recirculation' philosophy for management of process water, or with periodic radioactive aqueous liquid discharges during normal operations, taking into account radiological impacts of discharges, economic factors, and relevant OPEX available at the time*
- *Arrangements for management of tritium, with consideration of the relative dose impact via the radioactive gaseous pathway compared to radioactive aqueous liquid releases’.*

Management of any radioactive aqueous liquid discharges will also take into account tidal, hydrological, and geomorphological features and other factors that could affect the dilution and dispersion of radioactive aqueous liquid waste in the environment (see Argument 1.6.3).

6.3.4.2 Argument 1.3.2: The radioactivity of any necessary radioactive aqueous liquid discharges will be minimised by optimising the design, configuration, and operation of the aqueous liquid radioactive waste management system

Significant efforts have been made to minimise the generation of radioactive aqueous liquid waste in the BWRX-300 design. However, the safe and efficient operation of the BWRX-300 may require that small volumes of radioactive aqueous liquids are disposed of to the aquatic environment, after appropriate treatment.

The BWRX-300 LWM collects, cleans, and recirculates drained process water back into plant service. Process water from various plant areas is sent to the LWM collection tanks located in the RWB, by the EFS. The water is pumped and treated in batches with filtration, demineralisation, and RO methods, using skid-mounted processing equipment. Once the treated process water meets the required quality, the water is pumped to the CST for recirculation in the plant. In the unlikely event that the plant's overall water inventory will not allow for the water to be recirculated, the filtered water can be discharged to the aquatic environment, as discussed in the LWM SDD (Reference 6-55). A summary of the LWM is provided in PER Chapter E4 (Reference 6-9) and PER Chapter E7 (Reference 6-8).

Radioactive aqueous liquid discharges to the aquatic environment are monitored by the PREMS. The LWM will automatically halt releases to the CWS offsite discharge upon receiving a trip signal from PREMS, to ensure that concentrations of contaminants are maintained within permissible limits. Sampling and monitoring arrangements for radioactive aqueous liquid discharges are discussed in PER Chapter E8 (Reference 6-7).

The LWM processing system in the BWRX-300 is currently presented as a conceptual design. The design of this system is modular and based on a series of skids to provide maximum flexibility to respond to the full range of activities and anticipated events during plant operations. Design development utilises and builds on extensive OPEX and learning from previous BWR designs. The system is anticipated to be fully configurable, allowing a future operator the scope to sample and characterise batches of drained process water, and tailor treatment processes to the contaminants present. This provides opportunities for waste minimisation through streamlining of processes and responsible use of resources, avoiding any unnecessary treatment stages while providing a comprehensive toolkit to tackle the full range of radioactive and non-radioactive contaminants.

The LWM filtration skid consists of multiple components for treatment of process water on a batch basis at a rate of approximately 265 litres per minute to meet the reactor water quality standard for recirculation in the plant. These systems comprise the:

- Sludge Consolidation Filter
- Pre-conditioning Filter
- Ozone System
- Ion Exchanger
- RO System
- Polishing Ion Exchanger

The Sludge Consolidation Filter is a disposable roughing filter responsible for removing most of the total suspended solids in the aqueous liquid stream, in addition to removal of oil and grease, if found to be present. The Pre-conditioning Filter is an organic absorber/filter utilising granular activated carbon, for removal of heavy organics that pass through the Sludge Consolidation Filter. The combined action of these components allows the downstream systems to function correctly and efficiently by reducing contaminant fouling.

The Ozone System destroys remaining organics to ppb levels, as well as processing chemical and detergent waste that may enter the LWM. Ion exchange resins/water demineralisers are then used to remove dissolved ionic compounds and reduce loading on the RO System. Partially expended resin from the downstream Polishing Ion Exchange system may be used for this purpose.

The RO System removes approximately 95 percent of the dissolved contaminants (radioactive and non-radioactive) and all colloidal matter, before a final removal of dissolved solids and purification of the RO permeate by the Polishing Ion Exchanger. Treated process water is then sampled to ensure that the treated water meets the reactor water quality specification, prior to return to the CST. The RO system generates a reject stream, which is reprocessed through the filtration skid and does not have to be concentrated and solidified for disposal.

Segregation of Drained Liquids

The EA's Generic Developed Principle RSMDP8 specifies the requirement to prevent mixing of radioactive substances with other materials (including other radioactive substances), where such mixing might compromise subsequent effective management. The UK ABWR employed a system of segregated drains, which allowed separate treatment of drained process water based on the level of chemical contamination. Radioactive discharges to the environment were to be made from the High Chemical Impurities Waste (HCW) system. This utilised an evaporator to concentrate and contain the majority of the radioactivity from the HCW into a solid form, that would enable solid waste disposal and thereby minimise the radioactivity of any aqueous liquid discharges.

Separate treatment of drained process water from different sources is not required in the BWRX-300 design, as the LWM is capable of cleaning all drained process water collected to meet the reactor water quality specification. As stated in 006N7789, "BWRX-300 Equipment and Floor Drain System (EFS)," (Reference 6-76) all process water drained from various plant systems and areas is regarded as HCW. Since HCW is generally regarded physically and chemically as the 'dirtiest' water in the plant this provides for a bounding and conservative approach to treatment of drained process water in the LWM. Therefore, collection of drained process water in a common collection tank prior to treatment does not compromise its subsequent management or increase environmental impacts or risks.

Whilst the HCW (drained process water) generated by operation of the BWRX-300 can be combined and batch processed by the LWM, the EFS has been designed to segregate drained aqueous and non-aqueous liquids, and prevent the mixing of non-radioactive with radioactive substances. Overall process control of the EFS is achieved through the provision of a segregated set of sump tanks. The detailed design for EFS is under development and indicates that the system will comprise 22 sump tanks, located to collect drained process water from appropriate areas of the plant. These tanks are sub-divided into tanks for collection of radioactive aqueous liquids and tanks for non-radioactive aqueous liquids, thereby providing in-built segregation and a means for isolating, diverting and controlling any out-of-specification aqueous liquids that may be generated through an AOO. Oils are collected in segregated EFS sump tanks that discharge to drums and are not connected to any downstream systems, thereby mitigating the risk of inadvertent cross-contamination of aqueous liquid streams. A similar arrangement is provided for the draining of uncontaminated boron liquid (Reference 6-76).

The EFS sump tanks have in-built capability for homogenisation and recovery of representative samples to ensure compatibility with the LWM treatment process prior to transfer to the LWM collection tanks. If the aqueous liquid collected in the sump tanks is incompatible with the LWM filtration skids, or is found to not be radiologically contaminated, the sump tanks have built-in capability to divert the output via a temporary connection (006N7790, "Equipment and Floor Drain System Piping and Instrumentation Diagram," (Reference 6-77)). This prevents off-spec and non-radioactive aqueous liquids from entering the LWM. It is acknowledged that prevention of ingress of off-spec inventory to the LWM will also depend on a future developer/operator's management arrangements, foreign materials exclusion policy and staff training programme, which is beyond the scope of GDA Step 2. The need to define appropriate procedures and training has been identified as a Forward Action in NEDO-34190, "BWRX-300 UK GDA PSR Chapter 18: Human Factors Engineering," (Reference 6-78).

FAP.PSR18-173 – *"Include information on the development of procedures and the training program in the next version of the Safety Case – PSCR."*

Advantages Compared to Predecessor BWRs and UK ABWR

The BWRX-300 LWM system and multi-step processing skid delivers considerable design optimisation relative to previous BWR generations and the equivalent systems in the UK ABWR, as summarised below:

- Simplification of built-in aqueous liquid processing systems (common collection tanks for drained process water from equipment and floor drains), allowing all drained process water intended for treatment and recirculation in the plant to be treated on a batch basis, with elimination of the SSCs associated with segregated processing (with associated benefits for resource use and waste generation compared with previous designs)
- Introduction of a skid-mounted, fully configurable system with the flexibility to tailor treatment stages to individual batches of drained process water, including the capability to effectively manage and mitigate in-leakage of off-spec inventory (e.g., oils, organics, chemicals, and salt water)
- Elimination of the need for an evaporator
- Use of skid-mounted equipment, which provides the flexibility to exchange the constituent components for newer, improved technologies as they become available, as well as facilitating decommissioning at plant end-of-life
- Opportunities for waste minimisation through optimisation of treatment stages, avoiding, for example, unnecessary contaminant fouling of filters and resin beds
- Batch processing allows a future operator to consign solid radioactive waste to the appropriate disposition route, through direct application of the waste hierarchy, with the capability to sentence wastes as Low Level Waste (LLW) / borderline / Intermediate Level Waste (ILW) as appropriate
- The multi-stage aqueous liquid processing system produces water purified to the reactor water quality specification. This minimises the need to make radioactive aqueous liquid discharges while providing an alternative source of high purity make-up (i.e., demineralised) water to mitigate make-up water system downtime and requirements for off-spec demineralised water supply, noting that production of reactor grade demineralised water using a make-up water plant is both expensive and resource intensive

Operational Experience and Relevant Good Practice

The BWRX-300 LWM builds on extensive OPEX from the Fukushima Advanced Liquid Processing System (ALPS) in the wake of the March 2011 tsunami and the resulting radioactive aqueous liquid waste crisis at the Fukushima Daiichi site. "Overcoming Challenges in Delivering 5 AVANTech Water Treatment Systems at Fukushima," (Reference 6-79) details that ALPS provides a configurable multi-stage process for abatement and dilution of the very large quantities of contaminated radioactive aqueous liquid waste stored on the site, utilising AVANTech's Simplified Active Water Retrieval and Recovery System as an integral process stage for abatement of caesium and strontium radioisotopes. In light of the fact that Fukushima site restoration has presented the most significant radioactive aqueous liquid waste challenge of our age, it stands to reason that technologies employed and developed throughout this effort may be considered the BAT at this time, and represent RGP for the BWRX-300 EFS and LWM. Fukushima ALPS provides robust evidence that the deployment of modular treatment capability for the most challenging radioactive aqueous liquids can achieve water of an adequate quality for discharge to the environment (see IAEA independent monitoring programme "Fukushima Daiichi ALPS Treated Water Discharge," (Reference 6-80)).

A similar multi-stage system to the LWM filtration skids proposed for BWRX-300 has been supplied to the Brunswick Nuclear Plant (BNP) by AVANTech, with the goal of augmenting the flexibility and resilience of the original BNP radioactive aqueous liquid processing systems through mitigation of intrusions of off-spec inventory, including in-leakage of salt water, oils, and organics.

The efficacy and versatility of the modular approach has demonstrated that it is no longer necessary to segregate drained process water into separate high and low conductivity streams in the BWRX-300 design, and this has enabled a significant simplification of the EFS and associated LWM systems when compared with earlier BWR designs. This results in a simplified design, less plant and equipment, reduced capital, operating and decommissioning expenditure, and reduced decommissioning waste volumes.

Tritium and Carbon-14

Some of the radionuclides in the drained process water, such as tritium and carbon-14, do not undergo treatment in the LWM and are discharged directly to the environment. The majority of the techniques that could be used to treat these radionuclides have been shown to have installation and operating costs that are very high and considered grossly disproportionate compared with the low impacts associated with the discharges. Therefore, tritium and carbon-14 are typically returned to the reactor system, where an equilibrium concentration will be reached, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35). BWRX-300 is designed to operate on a 'maximum recirculation' basis, such that only a small proportion of radioactive aqueous liquid waste is disposed of to the aquatic environment during normal operations. Radioactive aqueous liquid discharges would only be necessary in the event that the total process fluids within the cooling circuit and pools exceed the maximum working capacity. Additionally, concentrations are low and significant challenge is associated with treating low concentrations of tritium and carbon-14 in radioactive aqueous liquid wastes. As such, disposal to the aquatic environment subject to reassurance monitoring is considered to represent BAT.

It should be noted that as a result of recirculating process water and minimising radioactive aqueous liquid discharges, the majority of the tritiated water remains within the NPP for its lifetime. As the half-life of tritium is 12.3 years and the BWRX-300 is designed for an operational lifetime of 60-80 years, the residence time of the process water within the plant for the lifetime of the NPP will contribute to minimising the radioactivity that becomes waste as a result of radioactive decay.

While tritium releases cannot be eliminated, it has been shown that BWRs provide the optimal design for minimisation of tritium discharges to the environment. A study was conducted by the Ministry of Economy, Trade, and Industry (Japan) of tritium discharges from NPPs around the world in 2022 (with the exception of Japanese plants, for which data was provided for 2008-2010) (see "What is "ALPS treated water"?," (Reference 6-81)). On average, BWRs yielded annual tritium discharges via the aqueous liquid pathway of 2.6 TBq/year; the corresponding average figure for PWRs was 52 TBq/year.

6.3.4.3 Argument 1.3.3: Leaks of radioactive process fluids from the containment system will be minimised

The first BWR containments were spherical "dry" structures. Dry spherical and cylindrical containments are still used today in PWR designs. Later BWRs, including the ABWR and ESBWR, utilised a pressure suppression containment design that allowed for a smaller size and the ability to accommodate rapid depressurisation of the RPV (see "ESBWR Plant General Description," (Reference 6-82)). The BWRX-300 utilises the dry containment configuration, featuring design optimisations to introduce ICs, which manage RPV pressure, and elimination of SRVs, as discussed in "BWRX-300 General Description," (Reference 6-40). The BWRX-300 containment is small and simple and is achieved with surface-mounted integral RPV isolation valves to rapidly isolate the flow from a downstream pipe break to minimise pressure and temperature buildup in the containment, while the ICS removes energy from the RPV rather than directing the energy into a suppression pool.

The BWRX-300 PCS includes the SCCV, which encloses and supports the RPV, connected piping systems, and other SSCs within containment. Mechanical and electrical penetrations that function as part of the containment boundary are sleeved and attached from the outboard containment isolation valve and welded to the SCCV. The SCCV functions as a leak tight pressure boundary that confines design basis accident and design extension conditions FP releases from the core and prevents the release of radioactive contamination to the environment (006N7823 (Reference 6-61)). A majority of the SCCV is located underground to provide protection from natural and human induced events, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63).

Design features that minimise leaks from the containment system in BWRX-300 build on improvements incorporated into the ESBWR design to address the Action Plan Items arising from the Three Mile Island loss of cooling event in 1979, as detailed in 007N1411, "BWRX-300 Operating Experience Report," (Reference 6-83).

Optimisations of the ESBWR design to provide enhanced integrity and leak-tightness of the PCS in BWRX-300 are summarised below:

- The BWRX-300 RPV is equipped with isolation valves that are integral to the RPV that rapidly isolate a ruptured pipe to help mitigate the effects of a LOCA. All large fluid pipes with RPV penetrations are equipped with double isolation valves
- Historically, BWR SRVs have been the most likely cause of a LOCA; however, SRVs and associated pipework have been eliminated from the BWRX-300 design
- The large capacity ICS in conjunction with the large steam volume in the RPV provides the overpressure protection for the primary reactor system. The ICS does not rely on cycling valves open and closed in order to maintain the reactor pressure
- The BWRX-300 has a dry containment. This has been proven to effectively contain the releases of steam, water, and FPs after a LOCA

A summary of design information on the BWRX-300 PCS is presented in PER Chapter E4 (Reference 6-9).

6.3.5 Claim 1.4: Minimisation of the volume of solid radioactive waste disposed of by transfer to other premises

The arguments presented in support of this claim are considered to demonstrate compliance with the standard BAT permit conditions (as outlined in the EA's guidance document "RSR permits for nuclear licensed sites: how to comply," (Reference 6-21)):

- Condition 2.3.2(b) *"The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to the permit to minimise the volume of radioactive waste disposed of by transfer to other premises."*

This is also considered to fulfil the following requirement of the environmental regulators' GDA guidance for RPs (Reference 6-23):

- Minimising solid and non-aqueous liquid radioactive wastes and SF

The BWRX-300 design contains a range of features that contribute to the substantiation of this claim including:

- Design changes that will minimise the volumes of operational and decommissioning waste arisings

- Provision of a number of features that will allow future operators to adopt an operating philosophy that will minimise the quantity of solid radioactive waste associated with routine operations and maintenance
- Provision of dedicated facilities for the management, treatment, and storage of solid radioactive waste
- Availability of a range of decontamination techniques during decommissioning

In developing the arguments presented to demonstrate the validity of Claim 1.4, the RSR GDPs have been taken into account. The following RSMDP is considered to be specifically relevant to this claim:

- RSMDP3 – *"BAT 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."*

6.3.5.1 Argument 1.4.1: The BWRX-300 is designed to minimise the generation of operational and decommissioning wastes (see also Argument 1.1.8)

The operation, maintenance, and subsequent decommissioning of the BWRX-300 will generate solid radioactive waste that will require management and treatment before it is consigned for either disposal to other premises or storage on-site pending future disposal. The design of the BWRX-300 has evolved to reduce the quantities of solid radioactive waste that will be generated during its lifecycle and to ensure that those wastes that are unavoidably created are compatible with waste management techniques typically used in the UK. The design changes that have had the greatest impact on the volume of solid radioactive waste generated are*:*

- Flow through the BWRX-300 core is by natural circulation ("BWRX-300 Operational Concept – Normal," (Reference 6-63)); pumps are not required to force reactor coolant through the RPV. Natural circulation is enabled by a tall chimney between the top of the core, at the top guide, and the bottom of the steam separators. This represents a design simplification with elimination of pumps and associated pipework
- Control rods are the sole means of reactivity control in the BWRX-300 during normal operations, as discussed in "BWRX-300 Operational Concept – Normal," (Reference 6-63). These have been redesigned to reduce the amount of stainless steel used within the RPV (see GEA-18437A, "ULTRA™ Control Rod Blades Fact Sheet," (Reference 6-84)), thereby reducing the amount of material that may become activated and the final decommissioning waste volume
- Use of a 12-month refuelling cycle, which leads to fewer used fuel assemblies overall compared with 18 or 24-months operating cycles, as discussed in "BWRX-300 General Description," (Reference 6-40)
- Introduction of techniques that reduce the amount of IGSCC experienced on reactor components as discussed in "BWRX-300 Water Quality," (Reference 6-56). These techniques contribute to a reduction in the frequency that components require replacement as a result of corrosion. Consequently, this will result in a reduction in the quantity of waste associated with the replacement of damaged components and any related maintenance activities. The BWRX-300 reactor internals and pipework are stress corrosion resistant stainless steel or other high alloy steels
- The concept minimises below grade excavation and buried utilities to the extent possible. The design has been optimised for constructability, which in turn will be beneficial for dismantling the facility during decommissioning
- GEH's document 006N8670, "BWRX-300 Modularization Strategy Report," (Reference 6-85) will be used to inform construction of the BWRX-300 SMR on the

selected site. The modular design will facilitate dismantling at plant end-of-life and inform the disassembly strategy employed during decommissioning

- The BWRX-300 containment is small and simple and is achieved with surface-mounted integral RPV isolation valves ("BWRX-300 Operational Concept – Normal," (Reference 6-63)) to rapidly isolate the flow from a downstream pipe break
- The introduction of backwashable filters for treatment of process water can extend the life of the filters; OPEX for this type of filter shows that the backwash process is highly effective in removing all adherent sludge.

The above improvements have been developed and implemented as a result of GEH's on-going commitment to improving performance. GEH has a comprehensive research and development programme that explores opportunities to reduce the materials used during construction and operations.

006N8745, "BWRX-300 Incorporation of Decommissioning in Design Considerations," (Reference 6-86) includes a series of design objectives that minimise radioactive contamination during operation and decommissioning of the BWRX-300. These include:

- Provide containment in areas where leaks and spills are most likely to occur
- Provide leak detection capability to provide prompt detection of leakage from SSCs
- Use leak detection methods (e.g., instrumentation, automated samplers) capable of early detection of leaks in areas where it is difficult (inaccessible) to conduct regular inspections (such as the fuel pool, and buried, embedded, or subterranean piping) to avoid release of contamination; there are no tanks containing radioactivity in contact with the ground in the BWRX-300 conceptual design
- Reduce the need to decontaminate equipment and structures by decreasing the probability of any release, reducing any amounts released, and decreasing the spread of the contaminant from the source
- Facilitate decommissioning by minimising embedded piping, sumps, or buried equipment
- Design the plant to facilitate the removal or replacement of equipment or components during facility operation or decommissioning
- Minimise the generation of radioactive contamination and waste during operation and decommissioning by reducing the volume of components and structures that become contaminated during plant operation

GEH is currently engaged in decommissioning activities all around the world and this OPEX is to be included in the BWRX-300 design considerations, as detailed in NEDO-34193, "BWRX-300 UK GDA Chapter 21: Decommissioning and End of Life Aspects," (Reference 6-87). Design features and lessons learned which reduce the volume and radioactivity of decommissioning waste are presented in Argument 1.4.5.

6.3.5.2 Argument 1.4.2: Backwashable filters for treatment of process water concentrate and contain sludges and enable spent filter modules to be managed as LLW

Sludge will arise as a wet-solid ILW stream from backwashing of high flow fine filters in the reactor coolant cleaning circuits and LWM. Sludges will be generated from the following systems: CFD, FPC, and RWST. Filter backwash sludge from these systems will be routed to the SWM sludge tanks for decant and storage, as detailed in SDD document 006N7733, "BWRX-300 Solid Waste Management System (SWM)," (Reference 6-88).

The backwashable fine filters utilised in the CFD, FPC, and RWST systems comprise a vessel housing multiple filter modules. The vessels are backwashed to remove adherent sludge, and this is flushed to the SWM sludge storage tank. OPEX for this type of filter shows that the backwash process is highly effective in removing all adherent sludge. Over time the filter media itself will degrade, and underlying differential pressure across the filter will rise, ultimately resulting in a requirement for the filter modules to be replaced. OPEX from EPRI 1019223 "Technical Evaluation of Hollow Fiber Filtration for Liquid Radwaste Processing," (Reference 6-89) demonstrates that filters can last for more than ten years if operated under an appropriate regime. The filters have a longer in-service life due to the highly effective backwash process. This in turn will result in fewer filter replacements and a reduction in overall waste volume for spent filter modules. Additionally, due to the highly efficient backwash process the filter modules themselves contain very little radioactive material and are anticipated to arise as LLW, while radioactivity is concentrated and contained in the sludge waste, which is managed as ILW.

Further information on the management of spent filter modules is presented in PER Chapter E5 (Reference 6-12).

It should be noted that dual function FDs have been eliminated from the BWRX-300 design (present in the CUW and FPC systems in the UK ABWR). This eliminates a highly radioactive mixed waste stream (powder resin plus crud) from operation of the BWRX-300, and represents an optimised design evolution, building on the ESBWR design, which also eliminated dual function FDs (see Argument 1.1.9).

6.3.5.3 Argument 1.4.3: The BWRX-300 design does not foreclose operating philosophies that will minimise the generation of solid radioactive waste associated with routine operations and maintenance

The methods adopted by a future developer/operator of the BWRX-300 for operations and maintenance will influence the quantity of solid radioactive wastes requiring treatment, storage, and disposal. Non-foreclosure of operational philosophies that will minimise generation of solid radioactive waste through application of the waste hierarchy and optimisation principles has been considered in the BWRX-300 design. Design features that support this principle are summarised below:

- The SWM spent resin and sludge storage tanks provide a flexible opportunity to optimise plant operations for management and processing of wet solid radioactive wastes, when interfaced with downstream processing capabilities. The design intent of the SWM storage tanks in the international BWRX-300 Standard Design is to receive, accumulate, homogenise, and characterise batches of spent resin or sludge prior to onward processing, as discussed in the SWM SDD (Reference 6-88). Tanks are sized for roughly a years' worth of arisings, though it is noted that over the course of a 60-year operating life it is anticipated that events will occur that will affect the radiological inventory of these batches, e.g., a failed fuel element. The inherent flexibility of the SWM design allows spent resins and sludges to be transferred and processed on a batch-by-batch basis, allowing an operator to segregate wastes from different plant sources on the basis of their radiological characteristics. Batch processing of sludges and spent resins will provide the ability to divert waste to the appropriate disposition route and will also enable additional routes (such as Near Surface Disposal (NSD), once quantified) to be incorporated into management arrangements. This gives the capability to sentence the waste as LLW / borderline / ILW as appropriate. It should be noted that this represents an advance over historic UK NPP operations whereby all wet solid wastes from a particular source were sentenced to a common route and not segregated based on radioactivity concentration. The BWRX-300 design therefore provides the capability for a more optimised disposition process. Further information on the management of wet solid wastes is provided in Arguments 1.5.2 and 1.5.6.
- The LWM utilises skid-mounted equipment for treatment of drained process water prior to recirculation in the plant, as discussed in the LWM SDD (Reference 6-55). Use of skid-mounted equipment provides the flexibility to exchange the constituent components (such as filters and resin beds) for newer, improved technologies as they

become available. Additionally, the LWM is fully configurable, allowing for waste minimisation through optimisation of treatment stages to prevent unnecessary contaminant fouling of filters, RO media and resin beds. Resin that has been previously used in the final Polishing Ion Exchanger may be redeployed in the upstream Ion Exchanger system, preventing premature disposal of the resin and responsible use of resources, while minimising waste volumes (see Argument 1.3.2).

- The LWM also treats drained process water on a batch basis (see LWM SDD (Reference 6-55)), allowing a future operator to consign waste to the appropriate disposition route, and optimise the frequency of changeout of resin beds, filters, RO, and charcoal media.
- The provision of office accommodation outside of controlled areas, which reduces occupancy of controlled areas and the associated generation of waste from office equipment and consumables, as discussed in “BWRX-300 General Description,” (Reference 6-40).

Information on sources of solid radioactive waste arising from the operation and maintenance of BWRX-300, and their onward management, is presented in PER Chapter E5 (Reference 6-12).

6.3.5.4 Argument 1.4.4: The BWRX-300 design does not foreclose options for the future volume reduction of solid radioactive wastes

All solid radioactive waste is stored, transported, and disposed of in containers that have been designed to meet the requirements of relevant legislation and regulatory guidance. In the majority of cases the waste is disposed of in the container in which it is transported to the waste management facility. Making the most efficient use of space in containers has the combined effect of reducing the size of storage facilities, decreasing the number of vehicle movements during transportation, and minimising the demand on disposal capacity at appropriately permitted disposal sites (Claim 1.5: Selection of the optimal disposal routes for wastes and SF).

It is anticipated that the BWRX-300’s solid radioactive waste management building will incorporate sufficient space and services to allow the introduction of a range of volume reduction techniques such as a waste compactor. This allows the future developer/operator the flexibility to review the performance of techniques in the context of regulatory requirements, prevailing operating conditions, and demonstration of BAT at the time (UK ABWR GDA Demonstration of BAT (Reference 6-35)). The future developer/operator will be able to select the techniques most suited to current requirements. The final specification and selection of equipment for use in the RWB is beyond the scope of GDA Step 2. Appropriate BAT assessments for radwaste management will be required at the site-specific phase to select the most suitable equipment available at the time (**FAP.PER6-201**).

FAP.PER6-201 – A future developer/operator shall undertake BAT assessments to support the specification and selection of equipment for use in the RWB, taking into account relevant OPEX, and with consideration of the potential for shared waste management facilities between multiple BWRX-300 units for a site-specific installation.

It is therefore considered that the flexibility to select appropriate volume reduction techniques as part of future site-specific decision making demonstrates the application of BAT at this stage.

The potential for volume reduction of solid radioactive wastes arising from BWRX-300 is discussed in the BWRX-300 UK IWS (Reference 6-15).

6.3.5.5 Argument 1.4.5: The BWRX-300 design will enable the application of decommissioning techniques to reduce the radioactivity and volume of decommissioning waste

It is recognised that decommissioning operations will generate significant quantities of radioactive waste. A number of decommissioning techniques are available in order to reduce the radioactivity and volume of this waste. System decontamination using chemical decontamination techniques is carried out in order to remove radioactive contamination attached to inner surfaces of pipes. Decontamination after dismantling can lead to a lowering of the radioactivity category of the wastes, potentially reducing it to out of scope waste. The actual decommissioning of the BWRX-300 and the selection of techniques will be the responsibility of a future developer/operator and subject to site-specific decision making and demonstration of BAT at the time. However, at GDA it is considered to be adequate to demonstrate that a technique is available to undertake this task.

Although the BWRX-300 is an LWR, it has lower lifetime waste yields, and a lower end-of-life decommissioning volume compared with the current generation of operational reactors. This is due to the use of proven improvements from the current fleet of BWRs for both piping material (stainless steel) and modern in-use radioactive waste demineraliser resin material. In addition, the fuel cycle for this plant is efficient and the use of a 12-month cycle leads to fewer used fuel assemblies overall compared with 18 or 24-months operating cycles, which is the experience from BWRs in Europe. The focus on design-to-cost and a reduced construction schedule duration led to a construction method that yields less material for decommissioning purposes.

Due to the focus on reduced quantities and overall SSC simplification, the amounts of material (e.g., concrete, steel) is lower for the BWRX-300 compared with existing LWRs. Also, as the BWR is a direct cycle plant, there are fewer and smaller highly contaminated pieces. The RPV has bolted internal components designed to be removed, which simplifies the handling of contaminated materials.

At the time of BWRX-300 decommissioning, the current generation BWRs are all expected to have been decommissioned, and the lessons learned from those activities are being considered in the BWRX-300 design, operation, and decommissioning strategies. GEH is currently involved in decommissioning activities worldwide including reactor vessel and internal cutup projects in Europe, the U.S., and Japan. There are no FOAK issues for the BWRX-300 that pose a risk to future decommissioning processes, as discussed in “BWRX-300 General Description,” (Reference 6-40).

The Modularization Strategy Report (Reference 6-85), will be used to inform construction of the BWRX-300 SMR on the selected site. The module and skid assemblies are intended to be built offsite, transported to the site, and erected onsite. This strategy will provide input to the disassembly strategy employed during decommissioning.

BWRX-300 design objectives that minimise radioactive contamination and reduce the activity of decommissioning waste are provided in Argument 1.4.1.

Additional information on decommissioning requirements and principles is provided in the BWRX-300 UK IWS (Reference 6-15) and PSR Chapter 21 (Reference 6-87). It is acknowledged in PSR Chapter 21 that although a high-level overview exists, a complete decommissioning plan has not yet been produced for the BWRX-300 NPP (**FAP.PSR21-154**).

FAP.PSR21-154 – *“Once site-specific considerations can be accounted for, GEH will develop an initial decommissioning plan, which will be maintained and adapted by the future site licensee.”*

6.3.6 Claim 1.5: Selection of the optimal disposal routes for wastes and SF

The design of the BWRX-300 RWB includes the space and services that are required to install the equipment necessary to undertake characterisation, treatment, and storage of wastes to enable a future operator to select the optimal waste disposal route for radioactive solid wastes.

For the purposes of GDA this report provides an indicative selection of disposal routes to demonstrate that the waste can be disposed of. A future developer/operator will determine the actual selection of disposal routes (**FAP.PER6-315**).

PER6-315 - The final choice of waste route and the quantity of waste to be discharged or consigned shall be determined by a future developer/operator, taking into account refined EUST and volume estimates of wastes and demonstration of BAT at the site-specific design stage.

The arguments presented in support of this claim demonstrate compliance with the following standard permit conditions (as outlined in the EA's guidance document "RSR permits for nuclear licensed sites: how to comply," (Reference 6-21)):

- Condition 2.3.3(b) *"characterise, sort and segregate solid and non-aqueous liquid radioactive wastes, to facilitate their disposal by optimised disposal routes."*
- Condition 3.1.3. *"The operator shall ensure the use of an optimised disposal route when disposing of any radioactive waste in accordance with Table S3.4."*

This is also considered to fulfil the following requirement of the environmental regulators' GDA guidance for RPs (Reference 6-23):

- Selecting optimal disposal routes (taking account of the waste hierarchy and the proximity principle) for those wastes

The BWRX-300 design contains a range of features that contribute to the substantiation of this claim including:

- Flexibility to enable the integration of suitable and sufficient waste management facilities
- Flexibility to select optimal disposal routes at an appropriate time, through non-foreclosure of options
- Lower Activity Wastes (LAW) arising from operation of BWRX-300 are anticipated to be similar to the UK ABWR, for which agreements-in-principle were obtained from suppliers of waste management services in the UK
- Disposability assessments will be prepared for BWRX-300 HAW streams

In developing the arguments presented to demonstrate the validity of Claim 1.5 the RSR GDPs have been taken into account. The following RSR GDPs are considered to be specifically relevant to this claim:

- RSMDP7 – *"When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised."*
- RSMDP8 – *"The best available techniques should be used to prevent the mixing of radioactive substances with other materials, including other radioactive substances, where such mixing might compromise subsequent effective management or increase environmental impacts or risks."*

6.3.6.1 Argument 1.5.1: The BWRX-300 design will enable the integration of suitable and sufficient waste management facilities

A range of facilities and equipment are required to ensure the effective and efficient use of available waste management routes. The design of the BWRX-300 RWB includes the space and services to install the equipment necessary to undertake the characterisation, sorting, treatment, and storage of waste prior to consignment to an appropriately permitted waste management service supplier. These facilities reflect the outputs of the BWRX-300 UK IWS (Reference 6-15), that has been developed for the wastes that will be produced by the BWRX-300.

The BWRX-300 is served by a single RWB that houses the equipment for handling, processing, and packaging liquid and solid radioactive wastes through the LWM and SWM. The specification and selection of equipment used within the RWB will be undertaken by the future developer/operator (**FAP.PER6-201**). The current size and configuration of the RWB is considered to offer a future developer/operator the flexibility to select and implement techniques that will reflect its operational needs and the regulatory requirements in force at the time. The provision of such a flexible facility is considered to represent BAT at this stage.

At this early stage of GDA the concept for a single BWRX-300 unit is being presented, with initial estimates of the volume and activity of radioactive waste arisings from the NPP calculated on this basis (see PER Chapter E5 (Reference 6-12) and the Demonstration of Disposability document (Reference 6-16)). Future plans for UK deployment are not yet established. In the event that multiple units were to be constructed on a single site, work towards site-specific optimisation would require consideration of the potential for a shared RWB and associated facilities for onward waste management, including collection tanks, waste conditioning plant, and storage arrangements. A similar optimisation process was undertaken for the proposed UK ABWR Wylfa Newydd twin unit plant (WN0908-HZCON-PAC-REP-00003, "Wylfa Newydd Project Radioactive Substances Regulation – Environmental Permit Application," (Reference 6-90)).

FAP.PER6-202 captures this requirement for a future developer/operator to undertake a BAT assessment of waste management techniques taking into account site-specific factors, including number of units on the site to inform provision of waste management capabilities for a BWRX-300 installation in the UK.

Further consideration of optimisation of waste management facilities for BWRX-300 is presented in the BWRX-300 UK IWS (Reference 6-15).

6.3.6.2 Argument 1.5.2: BAT will be used to select optimal disposal routes at an appropriate time

Low Level Waste

The UK government and devolved administrations published the "Policy for the Long Term Management of Solid Low Level Radioactive Waste in the United Kingdom," (Reference 6-91) in 2007. This policy recognised that the previous preference for disposing of LLW from nuclear sites to the national Low Level Waste Repository (LLWR) was no longer sustainable and that alternatives for the management of these wastes were required. The revised policy requires nuclear operators to consider a range of options when developing plans for the management of solid LLW. These options are to be based on the waste hierarchy and are to take into account a broad range of environmental and sustainability principles in addition to those related to the risk of exposure to potentially harmful ionising radiation.

Since 2007 the nuclear industry and its suppliers have made significant progress in developing alternatives to the disposal of LLW to the national LLWR. A range of techniques have been implemented that allow LLW to be:

- Minimised at source
- Re-used/recycled
- Volume-reduced prior to disposal
- Disposed of at alternative sites to the national LLWR

The "UK policy framework for managing radioactive substances and nuclear decommissioning," (Reference 6-92) builds on the existing policy. The policy should be used to enable and encourage waste producers and waste owners to dispose of their radioactive waste in an optimal manner, that takes account of the radioactive and non-radioactive properties of the waste.

The design of the BWRX-300, as presented in PER Chapter E5 (Reference 6-12), provides the capability to implement a range of waste management options for the management of LLW that will arise during the operation of the BWRX-300 NPP. Strategic consideration of options related to the provision of on-site waste treatment facilities has concluded that incinerators, metal treatment, and disposal facilities will not form part of the generic design for the BWRX-300.

For the purposes of the GDA Step 2 submission the services offered by LLWR will be used, although any future site operators may choose their own arrangements based on the site-specific requirements and the demonstration that they have selected the optimal disposal route at the time (**FAP.PER6-315**). A site operator will also need to make business decisions, which will include commercial and logistical requirements, which may indicate that there are other ways of dealing with specific wastes. The design of the BWRX-300 solid waste management facilities allows a future developer/operator a high degree of flexibility in the selection and deployment of LLW disposition techniques. This will enable them to review the availability and performance of LLW treatment/disposal techniques that are available at the time and to implement any measures required to ensure that their LLW is compatible with the Waste Acceptance Criteria (WAC) for such techniques. The outcomes of such reviews will be incorporated within a site-specific IWS and will demonstrate that BAT and the waste hierarchy are being applied to the management of these wastes, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35). **FAP.PER6-385** has been raised in relation to this.

PER6-385 – A future developer/operator shall undertake a review of the availability and performance of LLW treatment/disposal techniques available at the time for UK site-specific development and implement any measures that are required to ensure that LLW is compatible with the WAC for such techniques.

Wet Solid Radioactive Wastes

Wet solid radioactive wastes from plant operation (filter backwash sludges and spent demineraliser resins) will arise in batches in the SWM spent resin and sludge storage tanks, which are sized for roughly a year's worth of arisings (see Argument 1.4.3 and 1.5.6). Filter backwash sludges and spent resins have been classified as ILW at GDA Step 2, based on source term data presented in 008N0133, "BWRX-300 Solid Waste Management System – Contained Source Activity," (Reference 6-93). This is a Design Basis (DB) source term based on a fuel cladding defect model, that has been derived to provide bounding and conservative values for the purposes of dose and shielding calculations, and is therefore unsuitable for accurate classification of BWRX-300 radwaste streams. It should also be noted that specific radioactivity concentration will vary from batch to batch, dependent on prevailing plant operating conditions.

As the initial UK BWRX-300 will be a FOAK in this country, consideration will need to be given to maintaining flexibility in approach until the actual Nature and Quantity (N&Q) of radioactive waste arisings can be confirmed. FOAK features that will influence N&Q include:

- Use of GNF2 fuel, which is anticipated to result in a lower incidence of fuel cladding failures
- Material specification for the reactor coolant, condensate, and feedwater circuit, noting in particular replacement of carbon steel with stainless steel, and reduced cobalt inventory
- Enhanced water chemistry utilising a combination of HWC, On-Line NobleChem™, and GEZIP, which is anticipated to reduce particulate resulting from corrosion, and minimise cobalt deposition on coolant facing surfaces

These considerations reinforce the need to avoid early foreclosure of options and will therefore inform site-specific decision making in respect of overall 'raw' waste storage capacity, opportunity for obtaining representative waste samples and timing of implementation of waste processing, packaging, and storage activities. No specification for NSD is currently available, so emphasis will be placed on non-foreclosure of options where this is determined to represent the strategic BAT disposal outcome. **FAP.PER6-199** captures the requirement to develop refined EUST for BWRX-300 technical areas to inform future design development beyond GDA Step 2 and provide evidence for application of BAT. A specific Forward Action (**FAP.PER5-113**) has been raised in PER Chapter E5 to develop a RM radwaste EUST for wet solid radioactive wastes.

FAP.PER5-113 – *"A future developer/operator shall derive RM EUST Values for BWRX-300 wet solid waste streams to provide an estimated inventory of these wastes under normal operating conditions, to allow strategic decision-making for provision of appropriate processing and storage arrangements aligned with UK relevant good practice and related regulatory requirements."*

It is also recognised in PER Chapter E5 that 'actual' waste characterisation data from the first BWRX 300 unit(s) to be operated should be used to provide the most accurate quantification of wet solid wastes before committing to final design of UK waste processing and storage solutions. These data will quantify the impact of the above FOAK design enhancements on the volume and radioactivity of the waste streams produced and inform alignment of these wastes to UK strategy and policy expectations for radwaste management and disposal. However, the full extent of the usefulness of these data can only be established once timeframes for a UK BWRX-300 deployment are clearly defined.

FAP.PER5-114 – *"A future developer/operator should utilise available wet solid waste stream characterisation data from the first operating BWRX-300 SMR(s) to inform decision-making relating to waste processing and storage capabilities for a UK version of the BWRX-300 SMR, wherever practicable."*

The BWRX-300 Standard Design incorporates the flexibility to allow for segregation to be performed based on the radiological characteristics of each batch of spent resin/sludge, ensuring an appropriate optimised waste route for each batch can be selected. The opportunities afforded by this flexibility are discussed in Argument 1.5.6.

Application of the waste hierarchy to the operational wastes arising from BWRX-300 is discussed further in PER Chapter E5 (Reference 6-12) and the Demonstration of Disposability document (Reference 6-16). The requirement to demonstrate BAT for selection of optimal disposal routes is also discussed in the BWRX-300 UK IWS (Reference 6-15).

To ensure that appropriate decision making on the selection of waste disposal containers is undertaken, NEDO-34174, "BWRX-300 UK GDA Chapter 11: Management of Radioactive Waste," (Reference 6-94) has raised a dedicated FAP (**FAP.PSR11-417**) requiring the developer to formally select an appropriate range of waste disposal containers during the site-specific phase.

FAP.PSR11-417 – *'Undertake formal decision making to determine an appropriate selection of radioactive waste disposal containers, in support of finalising the integrated waste strategy for a UK BWRX-300 installation, that demonstrates the application of BAT and reduction of risks to ALARP.'*

6.3.6.3 Argument 1.5.3: LAW will be sufficiently similar to that from the UK ABWR that it will be compatible with the UK's National Waste Programme, LLWR WAC, and the LLWR Waste Services Framework (WSF). The WSF provides a range of optimal disposition routes to support application of the Waste Hierarchy, and therefore optimisation

Each of the routes for solid and non-aqueous LAW has a series of requirements that the consignor of the waste must fulfil before it can be accepted. Compliance with the WAC is a requirement of the terms and conditions agreed between contracting parties. Compliance with WAC is also a requirement of the EA's standard environmental permit template for disposals of radioactive waste from nuclear licensed sites as they are 'instructions' given by the person to whom the waste is consigned. GEH, as the RP for GDA, will not dispose of waste; the final choice of waste route and the quantity of waste to be consigned will be determined by a future developer/operator. However, it is anticipated that the LAW streams that will be produced by the BWRX-300 are compatible with the range of waste routes and services available in the UK for such wastes and will be comparable with those produced by the UK ABWR. Agreements-in-principle were obtained from suppliers of waste management services for the UK ABWR for the following waste routes, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35):

- Metallic waste for physical decontamination and recycling
- Combustible waste for volume reduction by incineration
- Very Low Level Waste (VLLW) for disposal at appropriately permitted commercial landfills
- Compaction of compressible LAW followed by disposal in the national LLWR
- Disposal of non-compressible LAW in the national LLWR

Given that the wastes generated by the BWRX-300 will be largely similar to those from the UK ABWR, it is considered that they will also be capable of achieving agreement in principle for disposal. Where necessary, further engagement with waste service providers will be undertaken to confirm, or put in place, the required agreements in principle. The final choice of waste route and the quantity of waste to be consigned will be determined by the future developer/operator (**FAP.PER6-315**).

Normal operation of the BWRX-300 is anticipated to generate the following LAW streams, comprising both LLW and VLLW:

- Ventilation filters
- Aqueous liquid filter modules
- Heterogeneous dry solid wastes
- Non-aqueous wet solid and liquid wastes

Further information on LAW streams arising from normal operation of the BWRX-300, and strategy for their onward management, is presented in the BWRX-300 UK IWS (Reference 6-15).

The LAW streams that will be produced by the BWRX-300 are demonstrably compatible with the range of waste routes and services available in the UK for such wastes. This may be considered to represent BAT for the GDA process.

6.3.6.4 Argument 1.5.4: Disposability assessments will be completed for HAW generated by the BWRX-300 (an expert view will be obtained from Nuclear Waste Services (NWS) for GDA Step 2). Wastes will be very similar to those from UK ABWR, which has successfully undergone disposability assessments

Some of the solid radioactive wastes that will be created in the BWRX-300 will be too radioactive to be disposed of via existing routes; HAW and SF will be stored until a long-term management solution is available. Any treatment and storage arrangements must accord with the current management and/or disposal concepts for these wastes. NWS is the source of authoritative guidance regarding management and disposal concepts. NWS undertakes assessments to determine the degree to which proposals for the management of HAW and SF accord with management and disposal concepts.

GEH has engaged extensively with NWS during the development of the Step 2 GDA submission for the BWRX-300*.* The Demonstration of Disposability document (Reference 6-16) has been prepared in accordance with NWS document RWPR63-WI11, “Preparation of Expert Views to Support Step 2 of the Generic Design Assessment Process,” (Reference 6-

95). This was submitted to NWS in support of a request for them to provide an expert view on the disposability of the radioactive wastes and SF arising from commissioning, operation, and subsequent decommissioning of the BWRX-300.

The disposability assessments demonstrate that the HAW that will be produced by the BWRX-300 will be compatible with the range of waste routes and services available in the UK for such wastes. The final choice of waste route and the quantity of waste to be discharged or consigned shall be determined by a future developer/operator (**FAP.PER6-315**).

FAP.PER6-316 has also been raised for a future developer/operator to demonstrate BAT when selecting their plans for packaging, storage and disposal of SF.

6.3.6.5 Argument 1.5.5: Where compatible, wastes will be managed in line with existing UK waste BAT studies (see also Argument 1.5.3 for LAW)

Selection of appropriate waste routes is an important element of demonstrating that waste management practices form part of an integrated strategy that is focused on waste minimisation, the application of the waste hierarchy, and demonstrating the application of BAT. A series of strategic BAT assessments has been prepared by LLWR at the request of the NDA to examine the degree to which certain waste routes underpin the development of IWS's for producers of radioactive waste and support delivery of the waste hierarchy. These assessments adopted a systematic, robust, and transparent approach to determining the strategic BAT option for groups of radioactive wastes with broadly similar characteristics.

Hitachi-GE Nuclear Energy undertook a series of assessments to determine the degree to which the findings of these studies are applicable to the following types of waste that would be generated by the UK ABWR, as discussed in the UK ABWR GDA Demonstration of BAT (Reference 6-35):

- Metal waste that has radioactive contamination on its surfaces
- Combustible wastes that are lightly contaminated with beta and gamma emitting radionuclides and/or very lightly contaminated with alpha emitting radionuclides
- Waste with very low levels of radioactivity

It was concluded that the LLWR assessments would be applicable to the UK ABWR and that BAT was demonstrated at a strategic level for metallic wastes, combustible wastes, and wastes with very low levels of radioactivity. Given the similar nature of the wastes that will be generated by the BWRX-300, it is assumed that these will also be managed in line with existing UK waste studies where these are shown to be appropriate either by reference to UK ABWR wastes or completion of additional studies.

A forward action (**FAP.PER6-384**) has been raised for a future developer/operator to consider these assessments.

PER6-384 - A future developer/operator shall consider the relevant LLWR strategic BAT assessments when undertaking BAT studies for the management of BWRX-300 radioactive wastes.

6.3.6.6 Argument 1.5.6: BAT will be used in the management, processing, and disposal of wet solid radioactive wastes generated by BWRX-300 water treatment systems

The design simplifications incorporated into the BWRX-300 process water treatment systems, with elimination of precoat powder resin FDs and adoption of F+DB systems throughout the plant as a common approach to demineralisation, is described in Argument 1.1.9. These features provide benefits in terms of cost and economic viability, optimal protection of fuel from cladding failures, reduced/simplified SSCs with associated advantages for reduction of maintenance and decommissioning wastes, and benefits for minimisation of occupational exposure to ionising radiation to levels that are ALARP (see Argument 1.1.9).

Wet solid radioactive waste streams arising from operation of the BWRX-300 F+DB systems will consist of filter backwash sludges and spent demineraliser resins, generated by treatment of process water in the main process fluid circuit, and drained process water collected in equipment and floor drains, to remove both soluble and insoluble impurities. The BWRX-300 Standard Design incorporates the following design features for management of these secondary wastes:

- Filter backwash sludge from the CFD, FPC, and RWST high flow fine filtration filters will be routed to the SWM sludge tanks for decant and storage. The sludge tanks have a capacity of 41.64 m^3 each and are designed to collect a total of four backwash water volumes sent from the CFD. Tank capacities were selected to accommodate at least 30 days of waste generation at normal generation rates, as discussed in the SWM SDD (Reference 6-88). There are two sludge tanks to provide flexibility of operation. While one tank is settling, the other can be receiving. However, the total annual volume of sludge waste arising from BWRX-300 during normal operations is low, anticipated to be 0.7 m^3, providing considerable capacity for onsite storage.
- Bead resins are used in the demineralisers in the CFD, FPC, LWM, and ICC. The spent bead resin is discharged by backwashing the demineralisers and is transferred to storage tanks in the RWB for storage prior to processing. The Spent Resin Tank has a capacity of 26.5 m^3 and is designed to collect a total of two resin transfer volumes sent from the CFD. Tank capacities were selected to accommodate at least 60 days of waste generation at normal generation rates, as discussed in the SWM SDD (Reference 6-88). The annual volume of spent demineraliser resin arising from BWRX- 300 is anticipated to be 27.63 m^3, such that approximately one year's worth of arisings may be collected in the spent resin tank.
- The BWRX-300 facility has adequate space for on-site storage of three High Integrity Containers, shielded filter containers, and 208-litre drums. Storage space for processed wet wastes (i.e., stabilised or dewatered wastes) is available for at least 30 days of waste generation at normal generation rates, as discussed in the SWM SDD (Reference 6-88).

The design intent of the SWM reflects the U.S. and Canadian regulatory context applied to the BWRX-300 Standard Design, and is based on an operational strategy of collating spent resins and sludges from several systems into respective common resin and sludge collection tanks prior to onward transfer and processing. The reduced number of collection tanks compared to predecessor BWRs (e.g., the UK ABWR) is a result of the significant process design simplification enabled by adoption of a common demineraliser resin material throughout the plant. However, it is acknowledged that the final strategy for management of wet solid radioactive wastes for a BWRX-300 installation in the UK will be subject to determination of accurate waste classification, demonstration of BAT and related decision-making by a future developer/operator at the appropriate phase of design development. This requirement has been captured by **FAP.PER6-375**.

FAP.PER6-375 - A future developer/operator shall determine a management strategy for wet solid wastes (including frequency of batch processing and decay storage considerations), and demonstrate that the proposed management arrangements are BAT, reduce risks to ALARP, and comply with UK regulatory expectations for segregation of wastes.

Key considerations relating to site-specific strategic decision-making for optimised management, processing, and disposal of these wastes are summarised below:

- Refined EUST for wet solid radioactive wastes. Filter backwash sludges and spent bead resins have been classified as ILW at GDA Step 2, based on SWM source term data (Reference 6-93). This is a Design Basis (DB) source term based on a fuel cladding defect model, that has been derived to provide bounding and conservative values for the purposes of dose and shielding calculations. This DB source term is not reflective of the BWRX-300 design features that minimise the activity and volume of radioactive waste (including use of GNF2 fuel, increased use of stainless steel and reduced cobalt inventory, and plant water chemistry regime), and is therefore not suitable for quantification of wet solid radioactive wastes or design optimisation of systems and processes for their management (see Argument 1.5.2)**. FAP.PER5-113** and **FAP.PER5-114** have been raised in PER Chapter E5 to develop a RM radwaste EUST for wet solid radioactive wastes, with incorporation of preliminary waste characterisation data from operational BWRX-300 reactors, if this information is available on the timescales required for a UK site-specific BWRX-300 project.

Information relating to ongoing strategy for refinement of wet solid radioactive waste estimates is also included in PER Chapter E7 (Reference 6-8), Appendix C

- Segregation of wastes. It is a UK regulatory expectation that BAT should be used to segregate radioactive wastes, and prevent mixing with other materials (including other radioactive substances), as laid out in RSMDP8. The simplified approach to demineralisation adopted in the BWRX-300 design (see Argument 1.1.9) eliminates the need to segregate spent resins according to physicochemical properties, as a common bead resin will be used throughout the plant. However, the radiological properties of spent resins and sludges from various plant systems, and associated waste classifications, cannot be determined until refined EUST have been produced (**FAP.PER5-113**). Additionally, the radiological characteristics of wet solid radioactive waste streams may vary over time, depending on upstream events (e.g., a fuel failure). The BWRX-300 SWM design has the operational flexibility to enable spent resin and filter backwash sludges from different sources to be transferred to onward processing capabilities as individual batches depending on their radiological characteristics, enabling an optimised waste route for each batch to be selected. This capability allows for segregation, sentencing, and transfer of each batch of spent resin/sludge before the next batch (arising from backwashing of a different filter/demineraliser system) is collected in the respective storage tank. Additionally, waste batches with similar properties may be combined for processing if this represents the optimised solution. It should be noted that cross-contamination between different batches of spent resin as they are collected in, and transferred from, the Spent Resin Tank is unlikely, as a result of the properties of ion exchange resins to bind and retain ionic species (including radionuclides), and the protection of the demineraliser beds from particulate fouling by pre-filtration

- Radioactive decay considerations. Allowing radioactive waste to undergo radioactive decay before disposing of it to the environment or another premises will reduce the amount of radioactivity that is disposed of in the waste. The reduction of radioactivity will be a function of the half-life of the radionuclides and the length of time over which the waste is stored. A reduction in radioactivity means that a broader range of waste management and disposal options may become feasible. The BWRX-300 SWM includes flexible capability for decay storage if this is deemed to form part of an optimised solution for management of wet solid radioactive wastes, noting that the radioactivity of spent resin and sludge batches may vary significantly over the lifetime of the plant as described above, and that wastes designated as ILW will remain on-site for a protracted period of time with associated benefits from radioactive decay. As part of developing a packaging solution it will be necessary to consider the effect of both decay storage and the effect of the immobilisation matrix on final waste package characterisation to determine the appropriate strategy, particularly if the final waste package is close to ILW/LLW borderline

6.3.7 Management of spent resin from the ICC demineraliser. ICC spent resin is anticipated to be free of radioactivity under normal operating conditions. Under fault conditions (ICC heat exchange or pipework leak in one or more of the three ICS pools) there is potential for cross-contamination with steam from the RPV. It is not currently known whether this would be classified as an expected event, but it is considered unlikely.Claim 1.6: Minimisation of the impact of radioactive discharges on members of the public and the environment

The design of the BWRX-300 has focused on reducing the amount of radioactivity in gaseous and aqueous liquid wastes that are discharged from the facility. However, where discharges of radioactivity to air and water are unavoidable, techniques have been adopted to ensure that the subsequent impacts to the environment and members of the public are very low.

The arguments presented in support of this claim are considered to demonstrate compliance with the following permit condition (as outlined in the EA’s guidance document “RSR permits for nuclear licensed sites: how to comply,” (Reference 6-21)):

> Condition 2.3.2(c) *“The operator shall use the best available techniques in respect of the disposal of radioactive waste pursuant to the permit to: dispose of radioactive waste at time, in a form, and in a manner so as to minimise the radiological effects on the environment and members of the public.”*

This is also considered to fulfil the following requirement of the environmental regulators’ GDA guidance for RPs (Reference 6-23):

- Minimising the impact of those discharges on people, and protecting other species

The BWRX-300 design contains a range of features that contribute to the substantiation of this claim including:

- Minimising the impact of radioactive discharges to the environment by means of optimising the design and operation of any discharge outlets

In developing the arguments presented to demonstrate the validity of Claim 1.6, RSR GDPs have been taken into account. The following RSR GDPs are considered to be specifically relevant to this claim:

- RSMDP7 – *“When making decisions about the management of radioactive substances, the best available techniques should be used to ensure that the resulting environmental risk and impact are minimised.”*
- RPDP1 – *“All exposures to ionising radiation of any member of the public and of the population as a whole shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account.”*
- ENDP2 – *“Radiological impacts to people and the environment should be avoided and where that is not practicable minimised commensurate with the operations being carried out.”*
- ENDP16 – *“Best available techniques should be used in the design of ventilation systems.”*

6.3.7.1 Argument 1.6.1: The location and height of the gaseous discharge system main stack will be designed to minimise the impact of aerial radioactive discharges

Significant efforts have been expended to remove radioactivity from gaseous wastes generated in the BWRX-300, but some radioactivity will be discharged to the environment. The location of the discharge points will have a bearing on the impact to members of the public and the environment, however, as the radioactive gaseous discharges will be continuous, timing of discharges is not a consideration for minimising the impact.

The majority of the gaseous radioactive waste will be discharged via the PVS, which is located on the roof of the TB. It is provided with exhaust air from four PVS exhaust fans, venting the potentially radioactive air up and away from the TB. Each of the PVS exhaust fans takes suction on the CEAP, which receives and mixes discharge air from the various building exhaust AHUs.

Modelling of the impacts associated with radioactive gaseous discharges will be undertaken to demonstrate the relationship between the height of the stack and the impact to members of the public from the radioactivity of the waste that is discharged. The assessment will also consider the costs of the engineering associated with increasing stack-height, which are impacted by relevant factors including seismic requirements, civil engineering, and hazards. Additionally, it will explore at what point further increases in the height of the stack is grossly disproportionate to the benefits that are realised from reductions in impacts to members of the public and the environment.

Undertaking a systematic determination of stack height at the GDA stage is not possible, as the actual stack height will be dependent on information that will not be available until site-specific issues have been considered, such as the meteorological conditions, topography, location of surrounding buildings, location of sensitive receptors, and the final site layout. However, an effective stack height of 11.7 m, based on a release height of 35 m above ground level has been used at GDA for radiological dose modelling assessments. The height of the stack will be determined by a suitably qualified and experienced person, using an appropriate tool or technique to ensure effective dilution and dispersion of gaseous radioactive waste in order to minimise the dose to members of the public and the environment. The height will be determined, taking into account local site topography and wind patterns. **FAP.PER6-203** has been raised to capture the requirement for a future developer/operator to determine the optimal height for the PVS.

PER6-203 - A future developer/operator shall determine the optimal PVS height and design to ensure that public exposures to gaseous discharges are ALARA. This will include:

- **Undertaking BAT assessments to support the design and location of the gaseous discharge system main stack when site-specific data become available. This will include consideration of meteorological conditions, topography, location of surrounding buildings, location of sensitive receptors, and the final site layout**
- **Performing a stack height study using Atmospheric Dispersion Modeling Software (or equivalent) to identify the stack height above which benefits of improved dispersion from greater release height start to diminish**
- **Consideration of UK sampling and monitoring requirements for final discharge accountancy, including provision of laminar flow conditions for representative sampling, flow measurement requirements, and space/access requirements for independent sampling and monitoring by the regulator or their representative (see PER Ch E8).**

Further information on the radiological impact of radioactive gaseous discharges from the BWRX-300 PVS is presented in PER Chapter E9 (Reference 6-13).

The design of the BWRX-300 main stack includes the provision of equipment that allows for sampling and monitoring of gaseous radioactive waste that is discharged to the environment. Sampling and monitoring arrangements for radioactive gaseous discharges from the BWRX-300 are presented in PER Chapter E8 (Reference 6-7).

6.3.7.2 Argument 1.6.2: Minimisation of radioactive aqueous liquid discharges to the aquatic environment by implementing maximum recirculation of process fluids during normal operations will reduce overall impacts on the sea, rivers, or other bodies of water

GEH has formulated a Zero Release Plan (Reference 6-74) in accordance with U.S. regulatory standards. This approach aligns with the 'maximum recirculation' philosophy, which aims to retain as much of the process fluids as possible within the plant, thereby minimising the disposal of radioactive aqueous liquid wastes to the aquatic environment (see Argument 1.3.1).

The BWRX-300 design is equipped to operate on a maximum recirculation basis, enabled by a LWM that is capable of treating all drained process water during normal operation and occasional emergent issues (see Argument 1.3.2). This will allow the NPP to operate indefinitely with minimal radioactive aqueous liquid waste released to the environment. If a radioactive aqueous liquid discharge is required, the LWM is designed to get a grab sample prior to release to ensure all chemical and radiological contaminants meet the required permits and regulations. Sampling and monitoring arrangements for necessary radioactive aqueous liquid discharges from the BWRX-300 are described in PER Chapter E8 (Reference 6-7).

6.3.7.3 Argument 1.6.3: The radioactive aqueous liquid waste management system and its discharge location will be optimised to minimise the impact of necessary radioactive aqueous liquid discharges

Significant efforts have been expended to remove radioactivity from radioactive aqueous liquid wastes that are generated in the BWRX-300, but some radioactivity will be discharged to the environment. The location and timing of these radioactive discharges will have a direct bearing on the impact to members of the public and the environment from operations of the BWRX-300.

In the BWRX-300 design, drained process water is collected in two collection tanks and treated in batches by the LWM filtration skids, before being sent to two sample tanks of volume 100 m^3 and 60 m^3. The sample tanks are the end process point of the LWM where treated process water from the filtering skids is sampled. The water is returned to the CST if chemistry is acceptable or can be discharged to the environment if water inventory does not allow return to the CST. If the water chemistry is not acceptable, the tanks can be recirculated to the collection tanks for reprocessing.

In the unlikely event that the plant's overall water inventory will not allow for the water to be recirculated to the CST, the Waste Sampling Subsystem is equipped with a discharge path to the CWS for dilution and discharge to the environment, as discussed in the LWM SDD (Reference 6-55). For the purposes of GDA it is assumed that the generic site is coastal, and the cooling will be provided by a once through sea water cooling system.

The design of the BWRX-300 LWM has significant holdup capacity, both in the collection tanks for drained process water, and in sample tanks containing treated water for sampling/analysis prior to recirculation in the plant. This holdup or surge capacity provides the plant operator flexibility in operations when deciding if a radioactive aqueous liquid discharge to the aquatic environment is necessary, and allows the timing of the discharges to be controlled to take account of any prevailing environmental conditions and regulatory requirements, as discussed in the LWM SDD (Reference 6-55). The cooling water will be discharged into the sea adjacent to the location of the BWRX-300. The exact position of the discharge point will be defined by a future developer/operator of the NPP when site-specific data become available (**FAP.PER6-204**).

PER6-204- A future developer/operator shall undertake BAT assessments to support the design and location of the aqueous discharge location when site-specific data become available, taking account of:

- **Tidal, hydrological, and geomorphological features and any other factors that could affect the dilution and dispersion of radioactive aqueous liquid discharges**
- **Final site layout including the number of BWRX-300 units on site and the configuration of the CWS.**

The models used to determine the impacts to members of the public and the environment from radioactive aqueous liquid discharges reflect the generic site description and are insensitive to the position of the radioactive discharge, provided it is within 10 km (~6 miles) of the site and within 5 km (~3 miles) of the shore. Assessment of the radioactive aqueous liquid discharges using the IRAT2 tool has demonstrated that the impacts of the discharges will be very low, indicating that doses resulting from radioactive aqueous liquid discharges will be orders of magnitude below 20 µSv/year for humans (PER Chapter E9 (Reference 6-13)).

The sampling capabilities built into the BWRX -300 LWM will allow the operator to undertake analysis and to confirm that the characteristics of the waste conform with any specific limitations and conditions within the site's environmental permit. Sampling and monitoring arrangements for radioactive aqueous liquid waste arising from normal operation of the BWRX-300 are presented in PER Chapter E8 (Reference 6-7).

6.4 Conclusion

The claims and arguments for the BWRX-300 Demonstration of BAT have been developed using information held by GEH. Evidence has been provided as a worked example for Arguments 1.1.1 and 1.1.2 to demonstrate how information is used to develop the claims and arguments. Further evidence will be provided for all claims and arguments as appropriate for applications for a site licence or environmental permits (**FAP.PER6-314**). Gaps and uncertainties identified during the development of the arguments have been recorded as Forward Actions to ensure that they are managed and closed out at the most appropriate time in the project lifecycle.

Collectively the CAE model supports the demonstration that the design and operation of the BWRX-300 are capable of being shown to have been optimised to the extent necessary to demonstrate that BAT has been applied, allowing examination and challenge and where applicable identifying key gaps or uncertainties.

Demonstration of BAT is an iterative process that feeds back to the design. If during the process any areas of insufficient evidence remain, design changes may be made to support the application of BAT. The determination of whether a design change is required will utilise the optimisation decision tool described in Section 6.2.11 of this document, in conjunction with GEH's design control procedure presented in Section 6.2.15. GEH believe that the arguments set out in this Demonstration of BAT report and the collation of further evidence, combined with the resolution of outstanding FAs shall demonstrate that the BWRX-300 has been optimised in accordance with those elements of the environmental regulators' guidance that require the application of BAT.

Table 6-1: Structure of Best Available Techniques, Claims and Arguments

BWRX Claim	Top Level Claims		Area Level Claims		Chapter Level Claims	
		(Goals)		(Claims)		(Arguments)
The BWRX-300 is capable of being constructed, operated, and decommissioned in accordance with the standards of environmental, safety, security, and safeguard protection required in the UK.	1	The design of the BWRX-300 SMR has been optimised to reduce environmental impacts to ALARA throughout the whole lifecycle (construction, commissioning, operation, and decommissioning).	1.1	Prevention or, where this is not practicable, minimisation of the creation of radioactive waste and SF.	1.1.1	Design and manufacture of fuel gives low rate of fuel failure
					1.1.2	Effective management, handling, and storage of fuel and SF minimises the generation of radioactive waste by preventing fuel cladding failures and damage to fuel/SF
					1.1.3	Material selection for the BWRX-300 design reduces the production of corrosion and erosion particles that could cause fretting and failure of fuel cladding, and that would themselves become activated
					1.1.4	Efficient fuel use minimises SF generation
					1.1.5	Effective early detection and management of failed fuel reduces the release of FPs
					1.1.6	Commissioning, startup, shutdown, and outage procedures maintain plant cleanliness at the required levels
					1.1.7	Water chemistry is controlled to minimise impacts on the fuel and generation of particulates
					1.1.8	Design simplifications embodied in the BWRX-300 reduce components / pipework within the containment, eliminating associated maintenance and decommissioning wastes
					1.1.9	Multi-stage in-process aqueous treatment is capable of cleaning water to meet the reactor water quality specification, enabling recirculation of process water and optimal protection of fuel under normal operating conditions
					1.1.10	Use of high-efficiency filters upstream of demineralisers ensures ion exchange resins are replaced on exhaustion of capacity and avoids premature changeout due to clogging
					1.1.11	The use of secondary neutron sources will be minimised
					1.1.12	Leak tightness of liquid, gas, and mixed phase systems maintains containment and control of radioactive substances. Leak detection equipment provides the means to detect and isolate leaks, minimising the spread of radioactive contamination
			1.2	Minimisation of the activity of gaseous radioactive waste disposed of by discharge to the environment.	1.2.1	The radioactivity of gaseous radioactive discharges will be minimised by optimising the gaseous waste treatment system
					1.2.2	The off-gas treatment system provides delay of specific gaseous radionuclides to allow radioactive decay before discharge (carbon beds)
					1.2.3	The HVS will control air flows and discharge via a permitted outlet
					1.2.4	The HVS will provide filtration of airborne particulate material prior to discharge
					1.2.5	TGS steam management will be optimised to minimise the discharge of noble gases. Retention time in the ductwork prior to discharge to the environment is sufficient to allow decay of short-lived radionuclides to below levels of concern
					1.2.6	Radioactive gaseous discharges resulting from evaporation of aqueous liquids will be minimised

BWRX Claim	Top Level Claims		Area Level Claims		Chapter Level Claims	
		(Goals)		(Claims)		(Arguments)
			1.3	Minimisation of the activity of aqueous radioactive waste disposed of by discharge to the environment.	1.3.1	The BWRX-300 can be operated as a 'maximum recirculation' reactor with minimal radioactive aqueous liquid discharges to the aquatic environment under normal operating conditions
					1.3.2	The radioactivity of any necessary radioactive aqueous liquid discharges will be minimised by optimising the design, configuration, and operation of the aqueous liquid radioactive waste management system
					1.3.3	Leaks of radioactive process fluids from the containment system will be minimised
			1.4	Minimisation of the volume of solid radioactive waste disposed of by transfer to other premises.	1.4.1	The BWRX-300 is designed to minimise the generation of operational and decommissioning wastes (see also Argument 1.1.8)
					1.4.2	Backwashable filters for treatment of process water concentrate and contain sludges and enable spent filter modules to be managed as LLW
					1.4.3	The BWRX-300 design does not foreclose operating philosophies that will minimise the generation of solid radioactive waste associated with routine operations and maintenance
					1.4.4	The BWRX-300 design does not foreclose options for the future volume reduction of solid radioactive wastes
					1.4.5	The BWRX-300 design will enable the application of decommissioning techniques to reduce the radioactivity and volume of decommissioning waste
			1.5	Selection of the optimal disposal routes for wastes and SF.	1.5.1	The BWRX-300 design will enable the integration of suitable and sufficient waste management facilities
					1.5.2	BAT will be used to select optimal disposal routes at an appropriate time
					1.5.3	LAW will be sufficiently similar to that from the UK ABWR that it will be compatible with the UK's National Waste Programme, LLWR WAC, and the LLWR WSF. The WSF provides a range of optimal disposition routes to support application of the Waste Hierarchy, and therefore optimisation
					1.5.4	Disposability Assessments will be completed for HAW generated by the BWRX-300 (an Expert View will be obtained from Nuclear Waste Services for GDA Step 2). Wastes will be very similar to those from UK ABWR, which has successfully undergone Disposability Assessment
					1.5.5	Where compatible, wastes will be managed in line with existing UK waste BAT studies (see also 1.5.3 for LAW)
					1.5.6	BAT will be used in the management, processing, and disposal of wet solid radioactive wastes generated by BWRX-300 water treatment systems
			1.6	Minimisation of the impact of radioactive discharges on members of the public and the environment.	1.6.1	The location and height of the gaseous discharge system main stack will be designed to minimise the impact of aerial radioactive discharges
					1.6.2	Minimisation of radioactive aqueous liquid discharges to the aquatic environment by implementing maximum recirculation of process fluids during normal operations will reduce overall impacts on the sea, rivers, or other bodies of water
					1.6.3	The radioactive aqueous liquid waste management system and its discharge location will be optimised to minimise the impact of necessary radioactive aqueous liquid discharges

Table 6-2: GNF 10x10 Debris Failure Statistics vs. Type of Debris Filter

As of September 2023	Standard (cast) DFLTP	Defender	Defender Plus
Bundles	~22,800	~32,500	~16,350
Debris Failures	~140	~66	11
Failure Rate (failed bundles from debris per 1000 bundles)	6.2	2.0	0.7

Table 6-3: Fuel Failure Rates for Different GNF Fuel Types, as of September 2023

Fuel Rod Type	GE12	GE14	GNF2	Total 10x10
Fuel Operated				
Reloads	31	204	130	391
Bundles	~4,300	~37,800	~26,500	~75,000
Fuel Rods	~396,000	~3,480,000	~2,450,000	~6,900,000
Lead Exposure				
Batch Average	50	53	52	-
Peak Bundle Average	68.0	73.0	63.5	-
Leaker Bundles (discharged)				
Debris Fretting	22	75	51	150
Manufacturing	0	1	0	1
Not Inspected & Indeterminate	0	2	0	2
Duty-Related (PCI-type)	2	12	4	18
Corrosion	0	0	0	0
In Operation (estimated)	0	0	1	-
Total	24	90	~55	171
Relative Failure Rate (bundles/1000 operated)	5.6	2.4	2.1	-

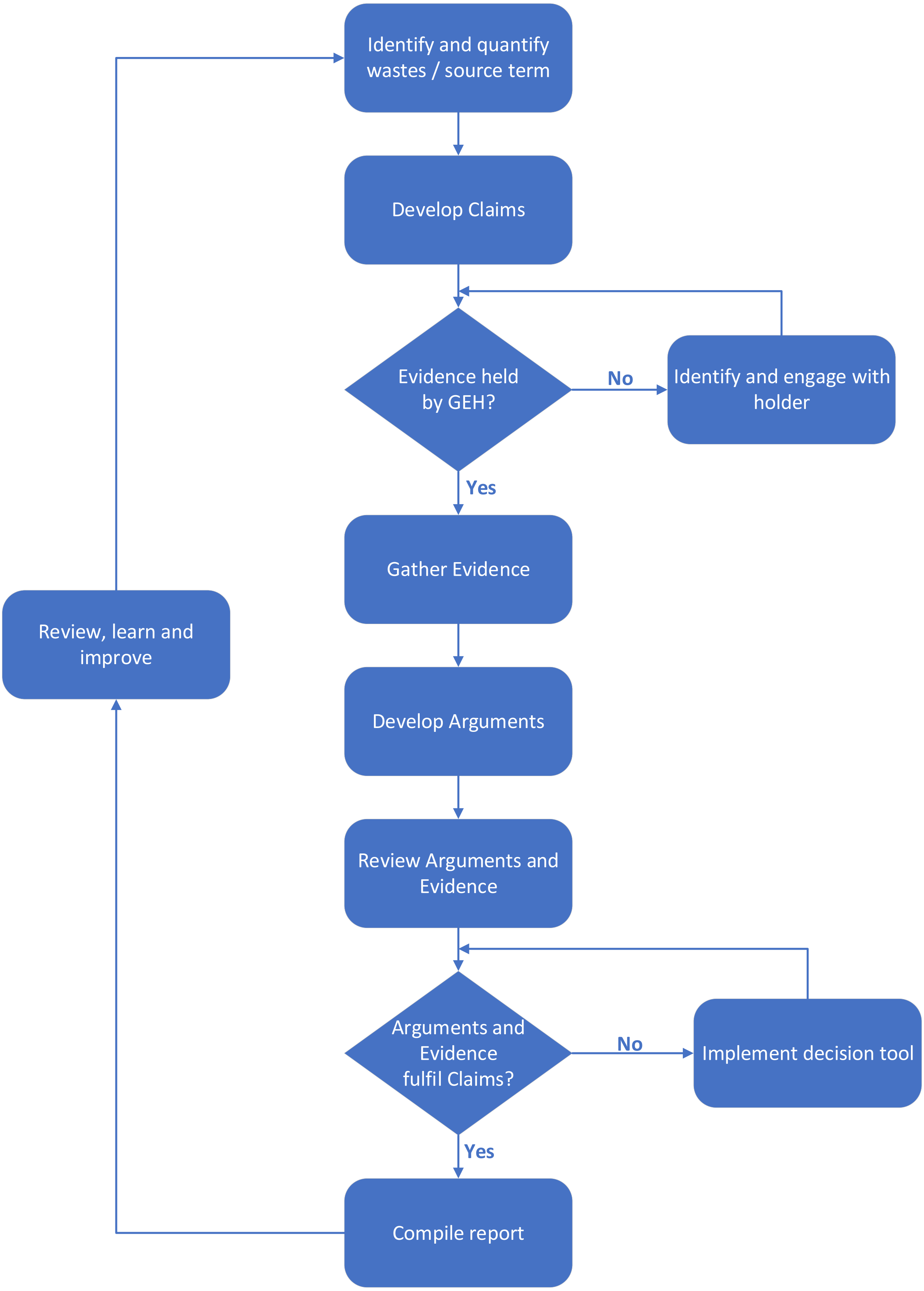

Figure 6-1: Methodology for Demonstrating the Application of BAT

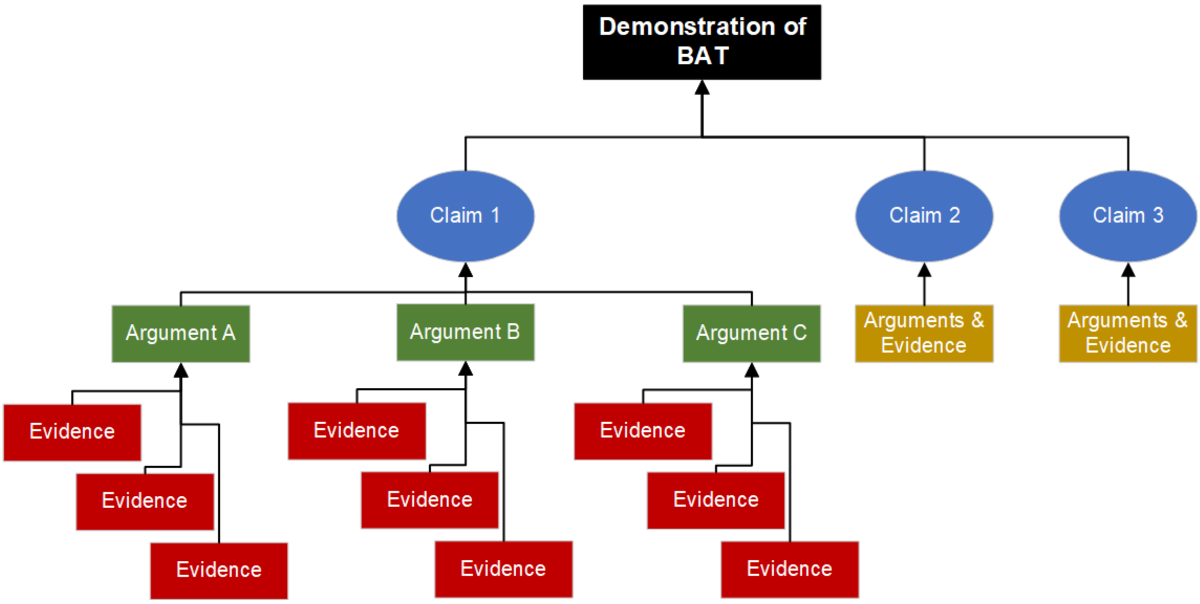

Figure 6-2: Illustration of the Claim, Argument, Evidence Structure

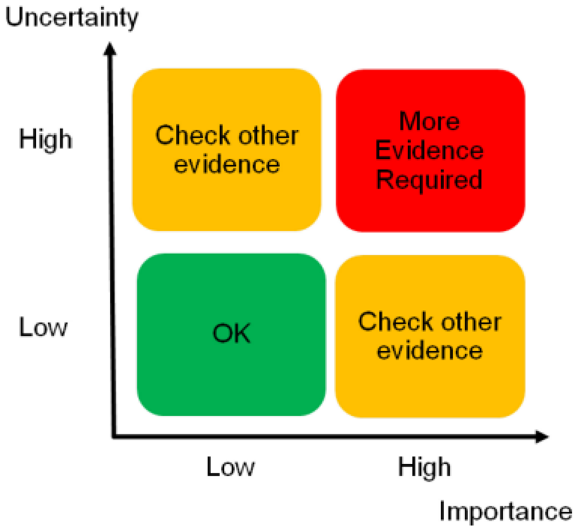

Figure 6-3: Gap/Uncertainty Tool

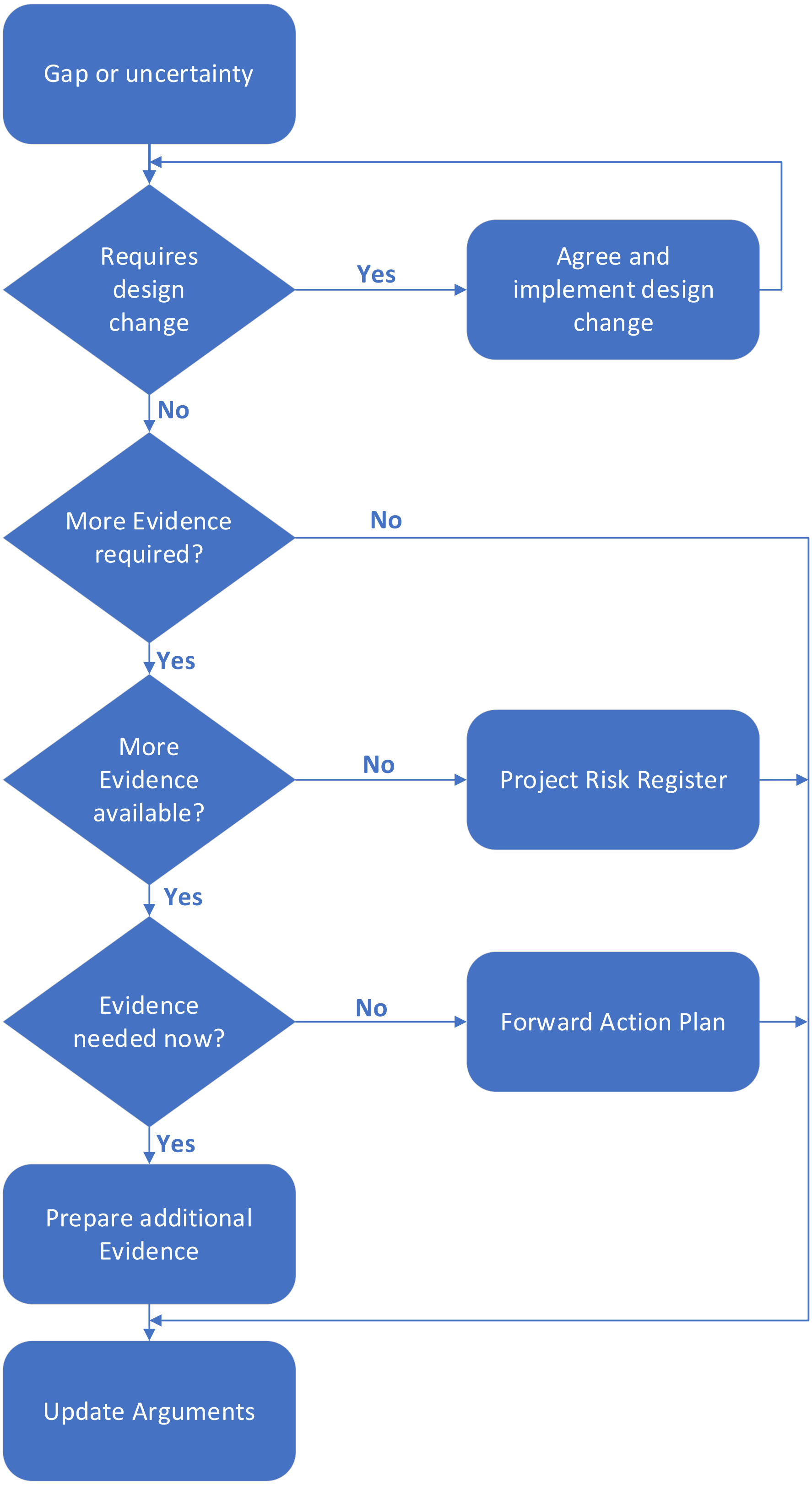

Figure 6-4: The Decision Tool

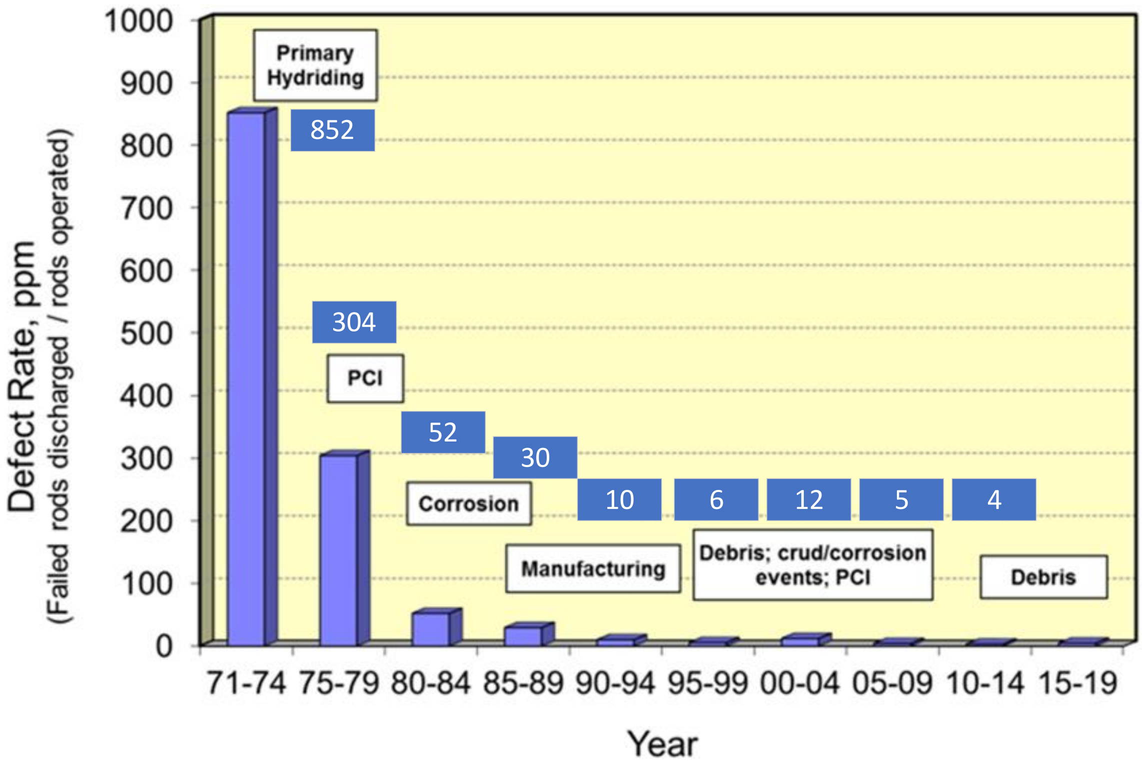

Figure 6-5: GNF Historical Fuel Reliability Performance

Note:

White text boxes show dominant failure mechanisms at different times, and blue boxes the number of failures in a given period

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APPENDIX A FORWARD ACTION PLAN

Table A-1: Forward Action Plan

Action ID	Finding	Forward Action	Delivery Phase
PER6-199	It has been identified that a “realistic model” end user source term based on normal operations is required for future design development of BWRX-300 beyond GDA Step 2. Use of the current conservative source term data for further optimisation of plant SSC would risk unnecessary 'over-engineering' of the plant and associated increases in cost and complexity.	Design development and quantification of radioactive wastes/discharges beyond GDA Step 2 shall be based on a refined 'realistic model' source term (see FAP.PSR23-133) for use in the demonstration of BAT for optimised selection, design, implementation, operation, maintenance and decommissioning of Structures, Systems and Components (SSCs) that influence the environmental impact of the BWRX-300.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-201	The final specification and selection of equipment for use in the RWB is beyond the scope of GDA Step 2. Appropriate BAT assessments will be required at the site-specific phase to select the most suitable equipment available at the time.	A future developer/operator shall undertake BAT assessments to support the specification and selection of equipment for use in the RWB, taking into account relevant OPEX, and with consideration of the potential for shared waste management facilities between multiple BWRX-300 units for a site-specific installation.	For PCSR/PCER
PER6-202	Final design of waste management capabilities will require site-specific information (e.g., number of units generating waste).	A future developer/operator shall undertake a BAT assessment of waste management techniques taking into account site-specific factors, including number of units on the site, the proximity principle, radiaoctive decay storage considerations, and any operational experience from in-service BWRX-300 reactors (if available on project timescales) to inform provision of waste management capabilities for a BWRX-300 installation in the UK.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase

Action ID	Finding	Forward Action	Delivery Phase
PER6-203	Step 2 assumed an effective stack height of 11.7 m is presented as the DRP, based on a release height of 35 m noting that the turbine building roof is at an elevation of approximately 31.5 m, which may not be the optimum stack height to ensure that public exposures to gaseous discharges are ALARA. The final design of the gaseous discharge stack will require site-specific data.	A future developer/operator shall determine the optimal Plant Vent Stack height and design to ensure that public exposures to gaseous discharges are ALARA. This will include: - Undertaking BAT assessments to support the design and location of the gaseous discharge system main stack when site-specific data becomes available. This will include consideration of meteorological conditions, topography, location of surrounding buildings, location of sensitive receptors, and the final site layout. - Performing a stack height study using Atmospheric Dispersion Modeling Software (or equivalent) to identify the stack height above which benefits of improved dispersion from greater release height start to diminish. - Consideration of UK sampling and monitoring requirements for final discharge accountancy, including provision of laminar flow conditions for representative sampling, flow measurement requirements, and space/access requirements for independent sampling and monitoring by the regulator or their representative (see PER Ch E8).	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-204	Final design of the aqueous discharge location will require site-specific data.	A future developer/operator shall undertake BAT assessments to support the design and location of the aqueous discharge location when site-specific data become available, taking account of: - Tidal, hydrological and geomorphological features and any other factors that could affect the dilution and dispersion of radioactive aqueous liquid discharges - Final site layout including the number of BWRX-300 units on site and the configuration of the CWS.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase

Action ID	Finding	Forward Action	Delivery Phase
PER6-314	The BAT case for BWRX-300 will need to be developed as part of the environmental permitting process under RSR. At GDA Step 2 the Demonstration of BAT is limited to claims and arguments. Evidence needs to be collated to underpin the claims and arguments to support future development phases.	A future developer/operator shall develop the BAT case for BWRX-300 as required to support future applications for site licencees, environmental permits or planning permission. This will require: - Review of the BAT methodology to be adopted - Full synthesis of the evidence to underpin the arguments presented in the GDA Step 2 Demonstration of BAT submission - Insertion of any additional claims and arguments into the CAE structure as the design develops	For PCSR/PCER
PER6-315	Final waste routes for waste streams to be determined.	The final choice of waste route and the quantity of waste to be discharged or consigned shall be determined by a future developer/operator, taking into account refined End User Source Term and volume estimates of wastes (see FAP.PSR23-133) and demonstration of BAT at the site-specific design stage.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-316	Final packaging, storage and disposal for SF to be determined.	A future developer/operator shall demonstrate BAT when selecting their plans for packaging, storage and disposal of SF.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-375	The design intent of the BWRX-300 Standard Design presented at GDA Step 2 is to collate spent resins from several systems in a single tank for decay storage prior to onward transfer and processing. However, the design provides sufficient operational flexibility to enable a future operator to manage spent resins on a batch-by-batch basis in a manner that satisfies UK regulatory expectations, in line with RSMDP8.	A future developer/operator shall determine a management strategy for wet solid wastes (including frequency of batch processing and decay storage considerations), and demonstrate that the proposed management arrangements are BAT, reduce risks to ALARP, and comply with UK regulatory expectations for segregation of wastes.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase

Action ID	Finding	Forward Action	Delivery Phase
PER6-377	Future operator will need to develop procedures for Foreign Material Exclusion during refuelling operations, taking account of the typically large number of personnel required on site during outages.	A future developer/operator shall develop procedures for Foreign Material Exclusion (including during refuelling outages), including an appropriate training and supervision regime	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-378	The reference BWRX- 300 equilibrium cycle has been selected to be an annual cycle (i.e., 12-month refuelling interval) with high, albeit normal, discharge exposure. Alternative refuelling intervals (e.g., 18, or 24 months) may be applied to the BWRX-300 which can be demonstrated to conform to all applicable safety and performance requirements.	Future developer/operator to determine BWRX-300 fuel and core management strategy, including refuelling cycle length.	For PCSR/PCER
PER6-380	UK-specific requirements for use of BAT to minimise the radioactivity of gaseous and aqueous discharges (as outlined in standard permit conditions) will need to be considered and implemented at the appropriate time during the BWRX-300 design process.	UK requirements for use of BAT to minimise the radioactivity of gaseous and aqueous discharges shall be inserted into the BWRX-300 Requirements Management process at design BL3 for UK site-specific design development.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-382	Provision of HEPA filters on equipment and building exhausts primarily serves to mitigate radiological consequences of accidents and also provides environmental benefits during normal operations; additionally, HEPA filtration of gaseous effluents facilitates representative sampling through removal of particulate. However, spent ventilation filters will also contribute to the volume of solid waste generated by the BWRX-300.	A future developer/operator shall determine the number and specification of ventilation filters through holistic consideration of ALARP and BAT principles.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase

Action ID	Finding	Forward Action	Delivery Phase
PER6-383	Final selection of demineraliser resins is to be determined.	A future developer/operator shall determine the final choice of demineraliser resins at site-specific stage using BAT, with consideration of: - Selection of optimal option for plant/fuel performance - Strategic decision-making for optimal management of BWRX-300 wet solid wastes.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-384	It is assumed that LAW generated by the BWRX-300 will be managed in line with existing UK waste studies.	A future developer/operator shall consider the relevant LLWR strategic BAT assessments when undertaking BAT studies for the management of BWRX-300 radioactive wastes.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase
PER6-385	The selection and deployment of LLW treatment techniques is yet to be determined.	A future developer/operator shall undertake a review of the availability and performance of LLW treatment/disposal techniques available at the time for UK site-specific development and implement any measures that are required to ensure that LLW is compatible with the WAC for such techniques.	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase