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GE Hitachi Nuclear Energy

NEDO-34223

Revision A

January 2025

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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.

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ACRONYMS AND ABBREVIATIONS

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

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Acronym	Explanation
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
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
N&Q	Nature and Quantity
NBS	Nuclear Boiler System
NDA	Nuclear Decommissioning Authority
NNPP	New Nuclear Power Plant
NPP	Nuclear Power Plant
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

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Acronym	Explanation
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
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
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

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SYMBOLS

Symbol	Definition
Bq/year	Becquerels per year
kW/ft	Kilowatt per foot
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

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6. DEMONSTRATION OF BEST AVAILABLE TECHNIQUES

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).

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.

This report describes the methodology adopted by GEH 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 adopted 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

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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 discharges to the environment through either gaseous or liquid effluent routes. Both primary and secondary wastes will be considered.

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

- Aqueous 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 NEDC-34225P, “BWRX-300 UK GDA Ch. E8: Approach to Sampling and Monitoring,” (Reference 6-4). Claims and arguments in support of the demonstration of BAT for these systems are also presented in NEDC-34224P.

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 NEDC-34221P, “BWRX-300 Ch. E4: Information about the Design,” (Reference 6-5) and NEDC-34154P, “Design Reference Report,” (Reference 6-6).

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.

Document Structure

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

- Section 6.1 Regulatory Context
- Section 6.2 Methodology for Demonstration of BAT
- Section 6.3 BAT Claims and Arguments for BWRX-300
- Section 6.4 Conclusion
- Section 6.5 References
- Appendix A Forward Action Plan

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Chapter Interfaces

This document interfaces with the following chapters in the PER:

NEDC-34221P (Reference 6-5)

NEDC-34222P, "BWRX-300 UK GDA Ch. E5: Radioactive Waste Management Arrangements," (Reference 6-7)

NEDC-34224P, "BWRX-300 UK GDA Ch. E7: Radioactive Discharges," (Reference 6-8)

NEDC-34225P (Reference 6-4)

NEDC-34226P, "BWRX-300 UK GDA Ch. E9: Prospective Radiological Assessment," (Reference 6-9)

Supporting Document Interfaces

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 6-10)

NEDC-34228P, "Integrated Waste Strategy," (IWS) (Reference 6-11)

NEDC-34229P, "Demonstration of Disposability for Higher Activity Radioactive Wastes (Including Spent Fuel)," (Reference 6-12)

NEDC-34279P, "Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants," (Reference 6-13)

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

NEDC-34166P, "BWRX-300 UK GDA Ch. 4: Reactor (Fuel and Core)," (Reference 6-14)

NEDC-34159P, (Reference 6-15)

NEDC-34198P, "BWRX-300 UK GDA Ch. 26: Interim Storage of Spent Fuel," (Reference 6-16)

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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 6-17)).

"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."

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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 6-18)
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 6-17)

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 6-19). 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 6-20) 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

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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 6-21), 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 6-21) 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 6-22), 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 6-23) 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 6-24) 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 6-25) 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

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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 6-24).

6.1.9 Environment Act 2021

The “Environment Act 2021” (as amended) (Reference 6-26) 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 6-27). 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.

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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 6-28) for demonstrating the application of BAT. This breaks the process down into the key BAT-related permit conditions. GEH will therefore be able to demonstrate, following synthesis of underpinning evidence for all arguments, that it has taken practicable and proportionate measures during design 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 6-21), with NEDC-34231P (Reference 6-10), 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 BAT methodology is provided in Figure 6-1 and meets the following Radioactive Substances Management Developed Principle (RSMDP), within the RSR GDPs (Reference 6-22):

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 BAT demonstration, 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.

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 three 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

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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, discharges, and 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

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.

6.2.3 Development of Claims

For the demonstration of BAT in GDA, 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 6-19) 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 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

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- 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.

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

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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 are available, whose output 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 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 are 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 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

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- A discussion on how relevant features of the BWRX-300 contribute (or not¹) to delivering environmental performance
- A statement that clearly articulates what has been achieved
- 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 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 6.2.10) for appropriately sentencing gaps and uncertainties when they are identified.

6.2.8 Assessing the Quality of Evidence

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

- Robust
- Defensible
- Demonstrable

¹ 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.

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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.

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.

6.2.9 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.

6.2.10 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 presented diagrammatically in Figure 6-4. The decision tool shall 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.

What additional evidence is required to fill the gap or address the uncertainty in order to fully substantiate the argument and claim?

- Context clearly defined – why it is needed
- Clear scope of work – what is needed
- Focus on filling gaps or resolving uncertainty – limited to identified issues

When is the additional evidence required in the project lifetime in order to fill the gap or address the uncertainty?

- Required immediately?

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- Is it already on the project programme?
- 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, there is a risk that it may not be available on the timescales required by 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.

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

6.2.11 Forward Action Plan

The FAP defines the scope and timing of additional work that will be delivered after the production of the CAE model. 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 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).

6.2.12 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 6-21) 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?

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6.2.13 Reporting

The iterative nature of environmental optimisation is recognised and addressed within this methodology through the review, learn, and improve process. This ensures that opportunities to continue optimising environmental performance can be realised throughout the BWRX-300 lifecycle. The CAE model and this GDA Demonstration of BAT report shall be used by a future operator to inform the ongoing optimisation of the BWRX-300.

6.2.14 Environment Protection Functions

The assignment of Environment Protection Functions (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 Structures, Systems and Components (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); and
- 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 is being developed in collaboration with the GDA safety team to ensure alignment with the assignment of safety functions. The methodology will be included in a future version of this chapter (FAP.PER6.306).

6.2.15 Change Management

Any changes to the design are managed through the steps defined in GEH’s procedure document CP-03-100, “Design Control” (Reference 6-29) to ensure that any impact on the strength of BAT arguments can be appropriately assessed.

Any proposed change to the generic design will be managed through GEH’s change management process. The change 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.

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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.

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 activity 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

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out in the guidance document “RSR permits for nuclear licensed sites: how to comply” (Reference 6-17).

“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 6-19), 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 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 (FP). Any release of FP 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 FP 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 FP 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 FP 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 FP. The low corrosion rate helps maintain cladding integrity and containment of FP within the rod.

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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 United States of America (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 FP 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 FP 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 FP in the gaseous and aqueous effluents.

Detailed information on the GNF2 fuel design and the components of the BWRX-300 reactor core is presented in NEDC-34166P (Reference 6-14) and NEDC-34159P (Reference 6-15).

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 FP. 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

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largely been dropped now that the fleet has completely transitioned (NEDC-34159P (Reference 6-15)).

Table 6-2 (reproduced from NEDC-34159P (Reference 6-15)) 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 (NEDC-34159P (Reference 6-15)).

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

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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. In addition, based on extensive ramp testing, additive fuel pellets (pellets containing an aluminosilicate dopant to modify grain boundaries) are an option to further increase the margin to PCI (NEDC-34159P (Reference 6-15)).

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

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corrosion-resisting processes implemented (GA91-9901-0023-00001, "UK ABWR Generic Design Assessment: Demonstration of BAT" (Reference 6-30)).

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 NEDC-34159P (Reference 6-15)) 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 include (NEDC-34159P (Reference 6-15)):

- 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

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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) (NEDC-34159P (Reference 6-15)).

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 6-31) 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

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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 (NEDC-34159P (Reference 6-15)).

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 below (GA91-9901-0023-00001 (Reference 6-30)):

- 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 FP 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.

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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 (GA91-9901-0023-00001 (Reference 6-30)).

6.3.2.2 Argument 1.1.2: Effective management of fuel maintains a low failure rate

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).

GEH has 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. This represents a current gap in the evidence required to support this argument. Based on existing BWR SF storage arrangements it is known that safe and secure SF dry storage is feasible using current technology. However, 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.PER6.314) relating to the future synthesis of evidence has been raised. 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 6-32). 006N5339, "BWRX-300 Irradiated Fuel Management Plan" (Reference 6-33) 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. NEDC-34198P (Reference 6-16) provides further details on the management of SF. Evidence relating to the

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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 6-34) 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 (kW/ft or 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 FP (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 (GNF-0142-5151 (Reference 6-34)).

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

Since 1974, GEH 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 (GA91-9901-0023-00001 (Reference 6-30)).

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 (006N5991 (Reference 6-32)).

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 (CP) are a significant source of direct doses to workers and are a source of radioactive waste.

CP 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 FP into the coolant.

The activated CP 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.

CP 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

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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 CP with the potential to be activated (see GEH's requirements specification 006N5081, "BWRX-300 As Low As Reasonably Achievable Design Criteria for Standard Design" (Reference 6-35)).

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 (006N5081 (Reference 6-35)). Key material design considerations include:

- The reactor coolant system materials are selected to prevent the formation of CP. 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 CP, 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

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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 (NEDC-34166P (Reference 6-14)). 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 (NEDC-34159P (Reference 6-15)).

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 (NEDC-34166P (Reference 6-14)). 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 6-36)).

The requirements specification document 007N7790, "BWRX-300 Reactor Plant Refueling and Servicing General Requirements" (Reference 6-37) 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 FP

The GNF2 nuclear fuel that will be used in the BWRX-300 is designed, manufactured, and managed to minimise the potential for fuel failures to occur that could subsequently result in the release of FP into the steam circuit. In the unlikely event that a fuel failure occurs, and FP 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 failure (see System Design Description (SDD) document 006N7899, "BWRX-300 Offgas System" Reference 6-38)). The PREMS SDD 006N7938, "BWRX-300 Process Radiation and Environmental Monitoring System" (Reference 6-39), 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

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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 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 failure. Further information on sampling and monitoring arrangements for the BWRX-300 OGS are presented in NEDC-34225P (Reference 6-4).

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 FP 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 FP 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-0142-5151 (Reference 6-34)). This may involve transfer of the leaking fuel rod to the fuel pool for a more detailed examination and repair if required (007N0111, "GNF2 Fuel Assembly Mechanical Design Report for BWRX-300" (Reference 6-40)). 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 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 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 (NEDC-34159P (Reference 6-15)).

The design of the BWRX-300 allows a graduated response to be taken to a fuel 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 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.

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 6-41).

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Commissioning/Pre-startup

Commissioning of the Water, Gas, and Chemicals 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 6-42) 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 (E6-43)) 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 6-44)).

The Main Condenser and Auxiliaries System (see SDD document 006N7757, "BWRX-300 Main Condenser and Auxiliaries System" (Reference 6-45)) 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 6-46)) 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 6-47) 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

Although procedures for Foreign Material Exclusion (FME) during outages will ultimately be determined by the future owner/operator of the plant, general requirements for BWRX-300 refuelling and servicing have been developed for the applicable control zones (007N7790 (Reference 6-37)). Design specification document F13-E001, "Foreign Materials Exclusion" (Reference 6-48) 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 System Pool Cooling and Cleanup System), which are inspected and cleaned as necessary during outages.

GEH's SDD document 006N7777, "BWRX-300 Containment Cooling System (CCS)" (Reference 6-49) details that Air Handling Units (AHUs) include air filter sections upstream of

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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 6-50)) 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 6-51)), 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).

In preparation for refuelling outages, effluent processing systems 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 (007N7790 (Reference 6-37)).

Information on the BWRX-300 plant cleanliness philosophy is presented in NEDC-34221P (Reference 6-5).

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 water coolant 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 coolant is carefully managed to deliver the following effects:

- Reducing chemistry-related failures of the fuel cladding (including corrosion and deposit related failures)
- Reducing Intergranular Stress Corrosion Cracking (IGSCC) of reactor internals
- Minimising the generation of CP 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 6-52), presents requirements used in the material selection and design of plant systems to maintain water quality and system integrity. Water quality is determined by materials selection, minimising the introduction of contaminants, generation of CP, and the application of appropriate water treatment equipment to reduce contaminants introduced through operation and maintenance or from system

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materials. The chemistry regime of the BWRX-300 takes account of decades of optimisation of 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 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 water quality and design requirements aimed at minimising IGSCC also minimises the potential for fuel cladding corrosion (006N6766 (Reference 6-52)). 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 6-53)). 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 Hydrogen Water Chemistry (HWC) with noble metal chemical addition, 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 (006N6766 (Reference 6-52)) 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 On-Line NobleChem™ System works in conjunction with the HWC system by enhancing the hydrogen/oxygen recombination reaction, reducing the hydrogen concentration required to mitigate IGSCC (006N6766 (Reference 6-52)). 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 (006N7737, CFS SDD (Reference 6-47)).
- 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 CP from the fuel deposits, most notably cobalt-60, reducing the activity 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 6-54). 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 (006N5081 (Reference 6-35)), and use of carbon steel is minimised. Due to the corrosion resistant nature of the piping, oxygen injection may not be performed (DBR-0060012 (Reference 6-53)). 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 (006N6766 (Reference 6-52)).

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- The abatement systems in BWRX-300 (Argument 1.1.9), for purification of the condensate and processing of liquid effluents, have been extensively optimised. These systems will concentrate and contain activated CP and ionic species in filter backwash sludges and demineraliser resins for disposal as solid 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 NEDC-34221P (Reference 6-5).

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 6-55).

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 6-56). 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

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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 6-57) 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 6-58).

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 NEDC-34221P (Reference 6-5).

6.3.2.9 Argument 1.1.9: Multi-stage in-process aqueous treatment is capable of cleaning water to reactor water quality specifications, enabling recirculation of water and zero aqueous discharges under normal operating conditions

Water is used as the coolant within the BWRX-300 and to generate the steam that is used in the turbines to generate electricity. The water coolant becomes contaminated with 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. The disposal of the contaminated water is also undesirable as it could harm members of the public and the environment.

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The BWRX-300 comprises one integral 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. Recycling water throughout the BWRX-300 conserves resources, reduces costs, and mitigates the requirement to make aqueous discharges to the environment during the operational life of the facility. The abatement systems utilised in the BWRX-300 design ensure that radioactivity removed from both the circulating water and drained effluents 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 discharge excess water from the plant, but extensive operating experience from BWRs in the U.S. demonstrates that many plants are successfully operated with zero aqueous radioactive effluent discharge (see NEDC-34279P (Reference 6-13)).

The design of the BWRX-300 includes the following systems for recycling water that is used during operations and maintenance. A summary of individual systems is provided in NEDC-34221P (Reference 6-5).

- The CFD system, located immediately after the main condenser, treats 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 6-59)), 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 FP. 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 (006N7609 (Reference 6-41)). This enables continuous cleaning of all fluids in the BWRX-300 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.

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- 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 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 (006N4916 (Reference 6-59)). 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 LWM comprises a series of skid-mounted equipment that receives effluents drained from the plant via the Equipment and Floor Drain System (EFS). The LWM features collection tanks to accumulate effluents for treatment and sampling tanks to confirm the quality of the treated water, prior to return to the plant for reuse. As with previous iterations of BWR, the system includes a large CST to receive and store the treated water. In practice, the LWM operates as a liquid effluent treatment system that restores water to reactor water quality specification, such that plant effluents do not need to be designated as waste and discharged to the environment. Drained effluents are processed 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. Design optimisation in BWRX-300 allows the collection tank contents to be pretreated if they exceed the filter skid influent requirements, by routing to the SWM for processing through the spent resin tank prior to processing through the filter skids (006N7729 (Reference 6-51)). This provides the flexibility to mitigate against the impact of "bad batches" of effluents as and when they arise.
- 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 processed fluid from the LWM filtering skids when not holding the reactor well contents, in order to maintain the water balance of the plant (006N7729 (Reference 6-51)). The RWST has a maximum working volume of 625 m³ and is equipped with a high flow fine filtration filter to clean liquid effluents. 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 liquid effluent system and then back to the CST). During BWRX-300 refuelling outages, drained effluents from the reactor cavity pool are 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 (006N4916 (Reference 6-59)).
- 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

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SDD document 006N7717, “BWRX-300 Main Turbine Equipment” (MTE) (Reference 6-60)). 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 reuse 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 CP before the water is fed back to the RPV, reducing the potential for fuel damage events (006N7737, CFS SDD (Reference 6-47)). 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 6-61) 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 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 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 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 operator will determine the selection of demineraliser resins.

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. Resin disposal is therefore preferable to chemical regeneration, being both more economical and reducing demands on the plant’s liquid effluent processing capabilities, supporting an operational principle of fluid recirculation and minimisation of 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 fluid 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 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 easily able to manage small condenser tube leaks or small ingresses of contaminants from other sources. 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.

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- 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.

The design simplifications incorporated into BWRX-300's water treatment and solid waste management systems serve to replace precoat powder FDs with F+DB systems throughout the plant and combine spent demineraliser resins from all systems into a common spent resin tank for characterisation and onward processing. These features provide benefits in terms of cost and economic viability, optimal protection of fuel from cladding failures, and reduced/simplified SSCs with associated advantages for maintenance and decommissioning. Potential drawbacks of these design features may be the generation of relatively increased volumes of wet solid waste (resulting from replacement of dual-function FDs utilising powder resin with demineraliser beds comprised of bead resin) and the potential for mixing of higher and lower activity bead resin waste streams in a single spent resin tank. While it is acknowledged that compromises exist, it may be argued that these design change decisions are justified on the basis that:

- Potentially increased volumes of wet solid bead resin waste are offset by the enhanced fuel protection capabilities offered by F+DB systems over dual-function FDs.
- First-of-a-kind (FOAK) features of the UK BWRX-300 design, including use of GNF2 fuel, increased use of stainless steel, and reduced cobalt inventory are anticipated to reduce the activity of wet solid radioactive waste arisings. This is anticipated to result in minimised frequency of changeout for demineraliser beds.
- It is assumed that raw demineraliser resin wastes will initially be buffer stored to enable characterisation. This will inform strategy for onward processing and management and allow for optimisation. The wastes are anticipated to be processed in batches, enabling wastes to be diverted to appropriate disposition routes at the point of characterisation. This flexible approach, combined with non-foreclosure of options for onward processing, enables effective management of wet solid wastes. This is discussed further in NEDC-34222P (Reference 6-7) and NEDC-34229P (Reference 6-12).

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 condensate and effluent processing 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 wastes, the F+DB condensate polishing system has been demonstrated to be the optimum design for fuel performance assurance (EPRI 1025190 (Reference 6-61)). 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:

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- 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 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 CP 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

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 6-62) 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,

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and guidance from the International Atomic Energy Agency, U.S. Nuclear Regulatory Commission, and Canadian Nuclear Safety Commission, and have been incorporated into the plant design.

The most relevant of these requirements (italicised) are summarised below (006N5081 (Reference 6-35)).

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 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 activity levels helps prevent cross-contamination at the higher activity 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.*

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- *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.*

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 6-17)).

"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 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 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

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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 release 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 release to the environment via the Plant Vent Stack (PVS) (006N4916 (Reference 6-59)).

A summary of the design of the OGS and discharges to the environment is provided in NEDC-34221P (Reference 6-5) and NEDC-34224P (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 reused within the plant. Recirculating tritium within the process water for the lifetime of the NPP delivers additional benefits from 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 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 6-63)). 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.

Offgas effluent will be sampled and monitored by the PREMS downstream of the dryers and prior to release (006N7899, OGS SDD (Reference 6-38)) to allow a future operator to avoid releases in excess of regulatory or plant-specific limits, identify potential fuel 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 NEDC-34225P (Reference 6-4).

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

During normal operation, multiple radioactive noble gas isotopes are generated as either FP (krypton and xenon) or activation products (argon-41). These are non-condensable isotopes that enter the offgas effluent stream. Low concentrations of FP 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 FP from within the fuel will increase in the unlikely event of a failure in the fuel cladding. The majority of these FP have relatively short half-lives and undergo rapid decay. Retention of the FP in the gaseous waste treatment system for a period prior to discharge reduces the amount of radioactivity that will enter the environment.

The design of the gaseous waste treatment system in BWRX-300 includes a series of four delay beds that are filled with granulated activated charcoal (006N7899, OGS SDD (Reference 6-38)). The use of such delay beds is common practice in the UK nuclear industry. The purpose of these delay beds is to retain the FP 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 FP 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 (006N7899, OGS SDD (Reference 6-38)). The Nuclear Energy Agency/Organisation for Economic Co-Operation and Development publication, "Effluent Release Options from Nuclear Installations" (Reference 6-64) 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 FP 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 NEDC-34221 (Reference 6-5) and NEDC-34224P (Reference 6-8).

Evolution of the BWRX-300 design has introduced a number of improvements to the charcoal adsorber bed system, as summarised below (006N7899, OGS SDD (Reference 6-38)):

- Increased calculated holdup time that krypton and xenon gases are retained within the gaseous 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 (GA91-9901-0023-00001 (Reference 6-30)).
- 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

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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, to further substantiate this argument commissioning data shall be used to demonstrate the performance of the delay beds as a FAP item (FAP.PER6.200).

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) subsystem, 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 (006N7781 (Reference 6-50)).

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 (006N7781 (Reference 6-50)). 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) (006N7781 (Reference 6-50) and 006N4916 (Reference 6-59)). This limits the spread of 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

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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 (006N7781, HVS SDD (Reference 6-50)).

Release to the environment occurs through the PVS, at a height of approximately 35 m (005N9751 (Reference 6-36)). 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 stack height of 35 m has been used at GDA for dose modelling assessments, as presented in NEDC-34226P (Reference 6-9).

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 (006N7781 (Reference 6-50)). Sampling and monitoring arrangements for BWRX-300 are discussed in NEDC-34225P (Reference 6-4). 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 NEDC-34221P (Reference 6-5) and NEDC-34224P (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.

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 (006N7781 (Reference 6-50)):

- Primary containment
- SDC
- Fuel pool cooling room
- RB
- RWB
- TB

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- Plant Services Area
- CUW heat exchanger
- CFD system

Additional information on these systems and plants areas is provided in NEDC-34224P (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 (006N4916 (Reference 6-59)). 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 (006N4916 (Reference 6-59)).

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 reused in the plant. Non-condensable gases are routed to the PVS via the HVS ducts and the CEAP (006N4916 (Reference 6-59)). The 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 (006N7781 (Reference 6-50)). Radiation monitoring of the GSC exhaust is provided by the PREMS (006N7938 (Reference 6-39)).

A summary of the TGSS design is also presented in NEDC-34221P (Reference 6-5).

In the UK ABWR design, the TGS extracts water from the CST and converts it to steam via a heat exchanger using reactor steam in the turbine gland evaporator. 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 6-65), and source steam for the TGSS is provided by the high pressure turbine packing leakoff supply steam, or the NBS (006N7717 (Reference 6-60)).

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.

Source term data are available for releases from the BWRX-300 TGSS, with a total anticipated annual release of $1.51\text{E}+13$ Bq/year (007N1078 (Reference 6-65)). Contributions to this discharge are comprised of the thirteen principal radioisotopes of krypton and xenon, along with small amounts of radioiodines. It should, however, be noted that this value represents a

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bounding case, as the current available source term information is based on a number of conservative assumptions (007N1078 (Reference 6-65)):

- It is assumed that 0.1 percent of the main steam flow is released from the TGSS
- It is assumed that no holdup of noble gases occurs prior to release from the TGSS
- An elevated noble gas release rate is assumed, reflective of a certain amount of fuel cladding failure

It has been identified that a refined End User Source Term based on normal operations is required to assess the likely radioactivity of discharges from this system (FAP.PER6.199). Conservatism applied to discharge assessments for gaseous systems are discussed in further detail in NEDC-34224P (Reference 6-8).

Dose assessment calculations for total gaseous discharges across all contributing systems in BWRX-300, notwithstanding the conservatism applied to source term data, show that the anticipated 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 stack height of 35 m, indicated that doses arising from BWRX-300 gaseous discharges were below 20 $\mu\text{Sv}/\text{year}$ for humans and below 1 $\mu\text{Gy}/\text{hour}$ for wildlife (NEDC-34226P (Reference 6-9)). It is however acknowledged that there is no limit below which the obligation to demonstrate the application of BAT does not apply.

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 dose from total gaseous discharges already falls well below the specified dose limits. 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 FP. These benefits, coupled with a simplified TGSS design aligned with key economic viability considerations, contribute to the application of BAT.

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 6-17)):

"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:

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- Provision of highly effective abatement systems for efficient recycling of process water and drained effluents, enabling BWRX-300 to operate as a zero liquid discharge reactor under normal operating conditions
- Treatment techniques for aqueous wastes that minimise any necessary discharge of radioactivity to the environment, through provision of a LWM
- Design features to minimise leaks of radioactive process fluids from the containment system

The following ENDPs are 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.”*

6.3.4.1 Argument 1.3.1: The BWRX-300 can be operated as a zero aqueous discharge reactor under normal operating conditions

BWRX-300 is capable of being operated, under normal operating conditions, without recourse to aqueous effluent discharges to the environment. This is achieved by use of highly effective abatement systems that clean process water and drainage effluents to meet the reactor water quality specifications, allowing for return to the CST and reuse. 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 a zero-release strategy for radioactive liquid effluents, a philosophy of processing liquid effluents generated at the power plant to minimise releasing into local bodies of water and the environment in general. NUREG/CR-2907 “Radioactive Effluents from Nuclear Power Plants, Annual Report 2016” (Reference 6-66) explains that such a strategy has cost advantages, because it is expensive to discharge very high-quality water that could be reused in plant systems. Additionally, a zero-release strategy for liquid effluents conserves natural resources and virtually eliminates radioactive liquid effluent discharges in those BWRs that adopt this strategy. Zero-discharge plants that maintain good control of liquid radwaste processing and 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 (NEDC-34279P (Reference 6-13)) for the ten-year period 2012 to 2021 demonstrates that several U.S. BWR plants operate on a zero aqueous effluent discharge basis and have done so for many years. For some plants, occasional aqueous effluent 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 aqueous pathway over the entire time period. This provides evidence that a zero aqueous liquid discharge operational 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 aqueous effluent discharge in environmental permits to maintain the overall water balance of the plant if required.

The BWRX-300 design includes a Zero Release Plan, presented in DBR document DBR-0060900, “BWRX-300 Zero Release Plan” (Reference 6-67), stating the design intent to

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process all liquid effluents internally during normal operation, avoiding unnecessary releases to the local environment. A Zero Release Plan can be achieved when all liquid effluents can be processed 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 zero liquid discharge in the Nuclear Decommissioning Authority (NDA) document NDA021465, "Nuclear Industry Aqueous Waste Management Good Practice Guidance" (Reference 6-68), by increasing the efficiency and reliability of aqueous waste treatment techniques
- Installation of additional storage tanks to store water for processing and holding, and isolating any "bad batches" of water that might need additional processing for contaminants such as organics
- Sizing the LWM to have the capacity to process liquid waste during normal and abnormal operations
- For emergent issues requiring processing of excess effluents, the inclusion of processing capabilities in the plant design for the use of temporary storage and processing resources.

Further information on the BWRX-300 zero aqueous liquid discharge philosophy is presented in NEDC-34224P (Reference 6-8). BWRX-300 design features that enable process water and drained effluents to be cleaned to meet the reactor water quality specification, allowing recycling to the CST and facilitating zero aqueous liquid discharge, 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 recycled to the CST, the LWM is equipped with a discharge path to the Circulating Water System (CWS) for dilution and release to the environment. If a release 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 aqueous liquid discharges from BWRX-300 are presented in NEDC-34225P (Reference 6-4).

Management of any aqueous discharges will take into account tidal, hydrological, and geomorphological features and other factors that could affect the dilution and dispersion of radioactive liquid effluents in the environment. The arrangements will be defined by the future operator following appropriate assessment (FAP.PER6.205).

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

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

The BWRX-300 LWM collects, cleans, and distributes liquid effluents to recirculate the water back into plant service. Water from various plant areas is sent to the LWM collection tanks located in the RWB, by the EFS. The water is pumped and processed in batches with filtration, demineralisation, and RO methods, using skid-mounted processing equipment. Once the effluent water meets the required quality, the water is pumped to the CST for reuse in the plant. In the unlikely event that the plant's overall water inventory will not allow for the water to be recycled, the filtered water can be discharged to the environment (006N7729 (Reference 6-51)). A summary of the LWM is provided in NEDC-34221P (Reference 6-5) and NEDC-34224P (Reference 6-8).

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Discharges to the 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 aqueous liquid discharges are discussed in NEDC-34225P (Reference 6-4).

The LWM processing system in 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 effluent batches, 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 processing liquid effluents on a batch basis at a rate of 70 gallons per minute (approximately 265 litres per minute) to meet the reactor water quality standard for reuse 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 effluent 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 ~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. Processed effluents are then sampled to ensure that the treated water meets the reactor water quality specifications, prior to return to the CST. The RO system generates a reject stream, which is recycled through the filtration skid and does not have to be concentrated and solidified for disposal.

Design optimisation in BWRX-300 allows the LWM collection tank contents to be pretreated if they exceed the filter skid influent requirements, by routing to the SWM for processing through the spent resin tank prior to processing through the filter skids (006N7729 (Reference 6-51)). This provides the flexibility to mitigate against the impact of “bad batches” of effluents as and when they arise.

By contrast, the UK ABWR employed a system of segregated drains, which allowed separate processing of liquid effluents based on the level of chemical contamination. Discharges to the environment were to be made from the High Chemical Impurities Waste (HCW) system. This

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utilised an evaporator to concentrate and contain the majority of the radioactivity from the HCW liquid into a solid form, that would enable solid waste disposal and thereby minimise the radioactivity of any liquid effluent release. 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 effluent processing systems (common collection tanks for drained effluents), allowing all liquid effluents collected via floor drains to be processed together 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 effluent batches, 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 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 effluent processing system produces water purified to the reactor water quality specification. This minimises the need to make 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.

The BWRX-300 LWM builds on extensive OPEX from the Fukushima Advanced Liquid Processing System (ALPS), developed by AVANTech in the wake of the March 2011 tsunami and the resulting effluent crisis at the Fukushima Daiichi site. "Overcoming Challenges in Delivering 5 AVANTech Water Treatment Systems at Fukushima" (Reference 6-69) details that ALPS provides a configurable multi-stage process for abatement and dilution of the very large quantities of contaminated effluents 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 effluent challenge of our age, it stands to reason that technologies employed and developed throughout this effort may be considered the BAT at this time. 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 liquid effluent processing systems through mitigation of intrusions of off-spec inventory, including in-leakage of salt water, oils, and organics.

Some of the radionuclides in the aqueous effluent, 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 (GA91-9901-0023-00001, UK ABWR GDA: Demonstration of BAT

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(Reference 6-30)). BWRX-300 is designed to operate on the basis of a zero liquid discharge philosophy, such that only a small proportion of liquid waste is disposed of to the environment during the operational phase of the NPP. Liquid discharges would only be necessary in the event that liquids 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 liquid wastes. As such, disposal to the environment subject to reassurance monitoring is considered to represent BAT.

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 6-70)). On average, BWRs yielded annual tritium discharges via the aqueous 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 6-71)). The BWRX-300 has gone back to the dry containment configuration, featuring design optimisations to introduce Isolation Condensers, which manage RPV pressure, and elimination of SRVs (005N9751 (Reference 6-36)). 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 6-57)). A majority of the SCCV is located underground to provide protection from natural and human induced events (006N4916 (Reference 6-59)).

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 6-72). 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 FP after a LOCA.

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A summary of design information on the BWRX-300 PCS is presented in NEDC-34221P (Reference 6-5).

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 6-17)):

- 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 6-19):

- 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 waste generated are:

- Flow through the BWRX-300 core is by natural circulation (006N4916 (Reference 6-59)); 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 (006N4916 (Reference 6-59)). These have been redesigned to reduce the amount of stainless steel used within the RPV (see GEA-18437A, "ULTRA™ Control

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Rod Blades Fact Sheet” (Reference 6-73)), 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 (005N9751 (Reference 6-36)).
- Introduction of techniques that reduce the amount of IGSCC experienced on reactor components (006N6766 (Reference 6-52)). 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 6-74) 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 (006N4916 (Reference 6-59)) to rapidly isolate the flow from a downstream pipe break.
- The introduction of backwashable effluent filters 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 ongoing 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 6-75) 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

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GEH is currently engaged in decommissioning activities all around the world and this OPEX is to be included in the BWRX-300 design considerations. Design features and lessons learned which reduce the volume and activity of decommissioning waste are presented in Argument 1.4.5.

6.3.5.2 Argument 1.4.2: Backwashable effluent filters 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 6-76).

The backwashable fine filters utilised in the CFD, FPC, and RWST systems comprise a vessel housing multiple filter module. 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 6-77) demonstrates that filters can last for more than ten years if operated under an appropriate regime. 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 effluent filter modules is presented in NEDC-34222P (Reference 6-7).

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 removes a highly active mixed waste stream (powder resin plus crud) from 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 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 storage tanks provide the ability to receive, accumulate, homogenise, and characterise a batch of spent resin or sludge (006N7733 (Reference 6-76)). Tanks are sized for roughly a years' worth of arisings. 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, for example a failed fuel element. Batching and homogenising sludges and resins on this scale 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.
- The LWM utilises skid-mounted equipment for processing of liquid effluents (006N7729 (Reference 6-51)), which provides the flexibility to exchange the constituent components (such as filters and resin beds) for newer, improved technologies as they

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become available. Additionally, the LWM is fully configurable, allowing for waste minimisation through optimisation of treatment stages to prevent unnecessary contaminant fouling of filters 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 processes effluents on a batch basis (006N7729 (Reference 6-51)), allowing a future operator to consign waste to the appropriate disposition route, and optimise the frequency of changeout of resin beds, filters, 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 (005N9751 (Reference 6-36)).

Information on sources of solid radioactive waste arising from the operation and maintenance of BWRX-300, and their onward management, is presented in NEDC-34222P (Reference 6-7).

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 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 (GA91-9901-0023-00001 (Reference 6-30)). The operator will be able to select the techniques most suited to current requirements (FAP.PER6.201). 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 NEDC-34228P (Reference 6-11).

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

It is recognised that decommissioning operations will generate significant quantities of waste. A number of decommissioning techniques are available in order to reduce the activity and volumes 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 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

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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 (005N9751 (Reference 6-36)).

Document 006N8670, "BWRX-300 Modularization Strategy Report" (Reference 6-74), 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 NEDC-34228P (Reference 6-11).

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. The future site operator will determine the actual selection of disposal routes (FAP.PER6.315).

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 6-17)):

- 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 6-19):

- 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

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- 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 GDP is 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.”*

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 NEDC-34228P (Reference 6-11), 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 wastes through the LWM and SWM. The specification and selection of equipment used within the RWB will be undertaken by the future operator (FAP.PER6.201). The current size and configuration of the RWB 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 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 NEDC-34222P (Reference 6-7) and NEDC-34229P (Reference 6-12)). 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 6-78)).

Further consideration of optimisation of waste management facilities for BWRX-300 is presented in NEDC-34228P (Reference 6-11).

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

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 6-79) 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

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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 6-80) 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, and NEDC-34222P (Reference 6-7), recognise that a range of waste management options are available for the management of LLW that will arise during the operation of the 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 submission, GEH will use the services offered by LLWR, 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. 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 future operators a high degree of flexibility in the selection and deployment of LLW treatment 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 included in the waste management plans and will demonstrate that BAT and the waste hierarchy are being applied to the management of these wastes (GA91-9901-0023-00001 (Reference 6-30)).

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 arising 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 Nobel Chem™, 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.

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A FAP item (FAP.PER6.200) has also been identified for obtaining preliminary waste characterisation data from the first BWRX-300 unit(s) to be operated. These data will quantify the impact of the above 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.

Wet solid wastes from plant operation (filter backwash sludges and spent demineraliser resins) will arise in batches in the SWM resin and sludge storage tanks, which are sized for roughly a year's worth of arisings. Raw wastes will initially be buffer stored to enable characterisation. This will inform strategy for onward processing and management and allow for optimisation (see NEDC-34229P (Reference 6-12)). The ability to homogenise, characterise, and batch process on this scale enables wastes to be diverted to the appropriate disposition route through application of the waste hierarchy and optimisation principles, recognising that radiological characteristics of wastes may vary over the 60-year operating life of the plant due to upstream events (e.g. a failed fuel element). Such a flexible approach also enables additional disposition routes (such as NSD, once quantified) to be incorporated into management arrangements.

Application of the waste hierarchy to the operational wastes arising from BWRX-300 is discussed further in NEDC34222P (Reference 6-7) and NEDC-34229P (Reference 6-12). The requirement to demonstrate BAT for selection of optimal disposal routes is also discussed in NEDC-34228P (Reference 6-11).

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 the future 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 (GA91-9901-0023-00001 (Reference 6-30)):

- 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 operator (FAP.PER6.315).

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

- Ventilation filters
- Aqueous effluent 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 NEDC-34228P (Reference 6-11).

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. NEDC-34229P (Reference 6-12) 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 6-81). This will be 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 and SF routes, and the quantity of waste to be consigned, will be determined by the future operator (FAP.PER6.316).

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 (GA91-9901-0023-00001 (Reference 6-30)):

- Metal waste that has radioactive contamination on its surfaces

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- 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. Additional information will be provided in future updates to this chapter (FAP.PER6.315).

6.3.6.6 Argument 1.5.6: Radioactive decay during storage will reduce the activity of wet solid wastes prior to treatment

Over time, the amount of radioactivity associated with all radioactive wastes will reduce as a result of radioactive decay. The rate at which the radioactivity reduces depends on the half-life, which is different for each of the radionuclides present within the waste streams. Allowing solid and liquid 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 optimal disposal route will be identified at an appropriate time.

Wet solid waste streams arising from operation of the BWRX-300 will consist of filter backwash sludges and spent demineraliser resins, generated by treatment of process water and drained effluents to remove both soluble and insoluble impurities. Management of these waste streams, including the frequency of running batch treatment plants for processing waste prior to disposal, will be subject to decision-making by a future operator, taking account of radioactive decay considerations (FAP.PER6.202). The design of the BWRX-300 includes a number of features that allow wet solid radioactive wastes to undergo radioactive decay prior to disposal, as summarised below:

- Filter backwash sludge from the CFD, FPC, and RWST high flow fine filtration filter will be routed to the SWM sludge tanks for decant and storage. The sludge tanks have a capacity of 41.64 m³ (11,000 U.S. gallons) 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 (006N7733 (Reference 6-76)). 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 m³, providing considerable scope 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 decay storage prior to processing. The Spent Resin Tank has a capacity of 26.5 m³ 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 (006N7733 (Reference 6-76)) and to allow sufficient time for the decay of shorter-lived radionuclides. The annual volume of spent demineraliser resin arising from BWRX-300 is anticipated to be 27.63 m³ (~7,300 U.S. gallons), 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

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processed wet wastes (i.e., stabilised or dewatered wastes) is available for at least 30 days of waste generation at normal generation rates (006N7733 (Reference 6-76)).

6.3.7 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 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 6-17)):

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 6-19):

- 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 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:

- RSM DP7 – *"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."*
- RPD P1 – *"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."*
- END P2 – *"Radiological impacts to people and the environment should be avoided and where that is not practicable minimised commensurate with the operations being carried out."*
- END P16 – *"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 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 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.

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Modeling of the impacts associated with 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 assumed stack height at 35 m above ground level has been used at GDA for 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 (FAP.PER6.203). The height will be determined, taking into account local site topography and wind patterns. Further information on the radiological impact of gaseous discharges from the BWRX-300 PVS is presented in NEDC-34226P (Reference 6-9).

The design of the BWRX-300 main stack includes the provision of equipment that allows for sampling of gaseous radioactive waste that is discharged to the environment. Sampling and monitoring arrangements for gaseous discharges from BWRX-300 are presented in NEDC-34225P (Reference 6-4).

6.3.7.2 Argument 1.6.2: Zero aqueous discharges during normal operations will reduce overall impacts on the sea, rivers, or other bodies of water

GEH has formulated a Zero Release Plan (DBR-0060900 (Reference 6-67)). Zero Release is a philosophy of processing liquid radioactive waste generated at the power plant to minimise releasing it into local bodies of water and the environment in general.

The BWRX-300 design is equipped to maintain a Zero Release Plan capable of processing all liquid radwaste during normal operation and occasional emergent issues. This will allow the power plant to operate indefinitely with minimal aqueous waste released to the environment. If a release 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 aqueous discharges from the BWRX-300 are described in NEDC-34225P (Reference 6-4).

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

Significant efforts have been expended to remove radioactivity from liquid wastes that are generated in the BWRX-300, but some radioactivity will be discharged to the environment. The location and timing of these 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, liquid effluents are collected in two collection tanks and processed in batches by the LWM filtration skids, before being sent to two sample tanks of volume 100 m³ and 60 m³ (approximately 26,420 and 15,850 U.S. gallons, respectively). The sample tanks are the end process point of the LWM where effluent from the filtering skids is sampled. The water is returned to the CST if chemistry is acceptable or can be released to the environment if water inventory does not allow return to the CST. If the water chemistry is not acceptable, the tanks can be recycled 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 recycled to the CST, the Waste Sampling Subsystem is equipped with a discharge path to the

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CWS for dilution and release to the environment (006N7729 (Reference 6-51)). 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 waste collection tanks and in sample tanks containing processed water. This holdup or surge capacity provides the plant operator flexibility in operations when deciding if an effluent release to the environment is necessary and allows the timing of the discharges to be controlled to take account of any prevailing environmental conditions and regulatory requirements (006N7729 (Reference 6-51)). 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 the future operator of the NPP (FAP.PER6.204). The models used to determine the impacts to members of the public and the environment from liquid effluent discharges reflect the generic site description and are insensitive to the position of the discharge, provided it is within 10 km (~6 miles) of the site and within 5 km (~3 miles) of the shore. Assessment of the discharges using the IRAT2 tool has demonstrated that the impacts of the discharges will be very low, indicating that doses resulting from liquid discharges will be orders of magnitude below 20 $\mu\text{Sv}/\text{year}$ for humans (NEDC-34226P (Reference 6-9)).

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 aqueous liquid waste arising from normal operation of the BWRX-300 are presented in NEDC-34225P (Reference 6-4).

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. 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 6.2.10 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.

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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 of fuel maintains a low failure rate
					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 FP
					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 reactor water quality specifications, enabling recirculation of water and zero aqueous discharges 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
			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 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
			1.3	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 zero aqueous discharge reactor under normal operating conditions
1.3.2	The radioactivity of any necessary aqueous discharges will be minimised by optimising the design, configuration, and operation of the liquid radioactive waste management system					
1.3.3	Leaks of radioactive process fluids from the containment system will be minimised					

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BWRX Claim	Top Level Claims		Area Level Claims		Chapter Level Claims	
	(Goals)		(Claims)		(Arguments)	
			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 effluent filters 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 activity 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	Radioactive decay during storage will reduce the activity of wet solid wastes prior to treatment
			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 discharges
					1.6.2	Zero aqueous discharges during normal operations will reduce overall impacts on the sea, rivers, or other bodies of water
					1.6.3	The liquid effluent system and its discharge location will be optimised to minimise the impact of necessary aqueous discharges

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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

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

Fuel Rod Type	GE12	GE14	GNF2	GNF3	Total 10x10
Fuel Operated					
Reloads	31	204	130	26	391
Bundles	~4,300	~37,800	~26,500	~6,200	~75,000
Fuel Rods	~396,000	~3,480,000	~2,450,000	~600,000	~6,900,000
Lead Exposure					
Batch Average	50	53	52	~43	-
Peak Bundle Average	68.0	73.0	63.5	~46	-
Leaker Bundles (discharged)					
Debris Fretting	22	75	51	2	150
Manufacturing	0	1	0	0	1
Not Inspected & Indeterminate	0	2	0	0	2
Duty-Related (PCI-type)	2	12	4	0	18
Corrosion	0	0	0	0	0
In Operation (estimated)	0	0	1	0	-
Total	24	90	~55	2	171
Relative Failure Rate (bundles/1000 operated)	5.6	2.4	2.1	0.3	-

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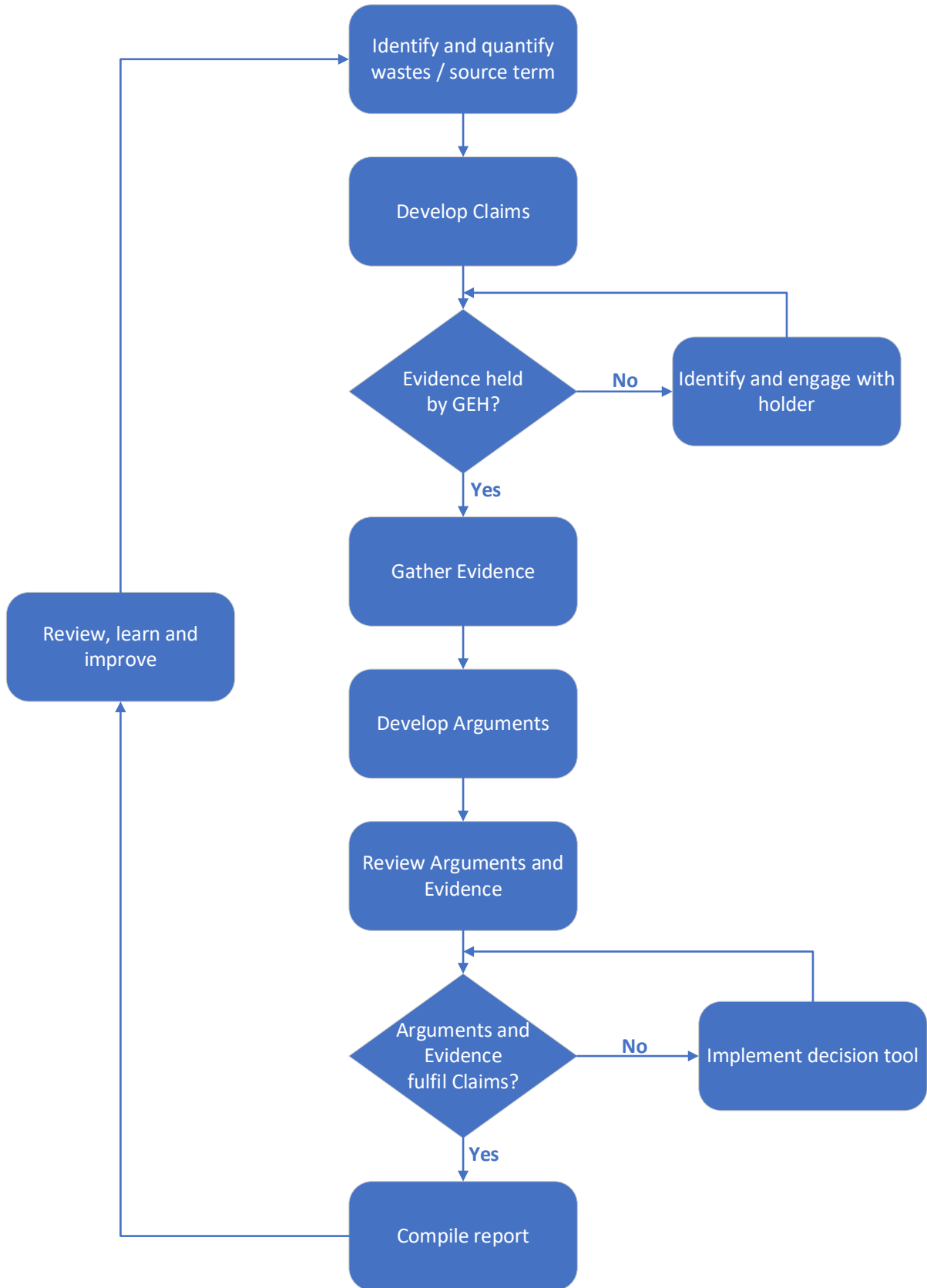


Figure 6-1 Methodology for Demonstrating the Application of BAT

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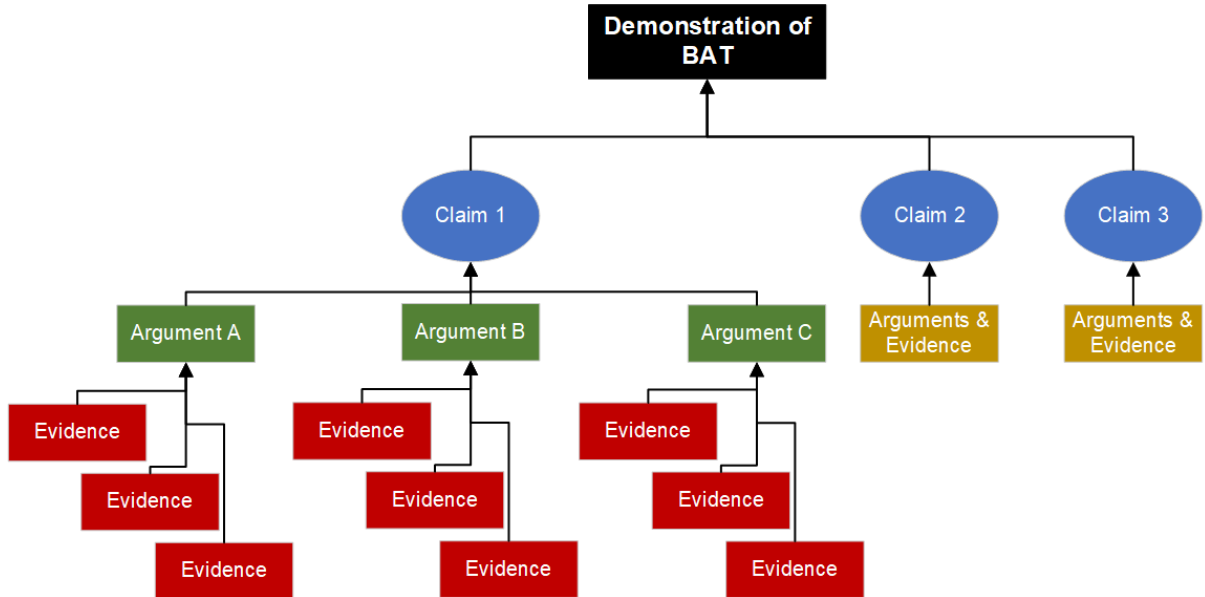


Figure 6-2: Illustration of the Claim, Argument, Evidence Structure

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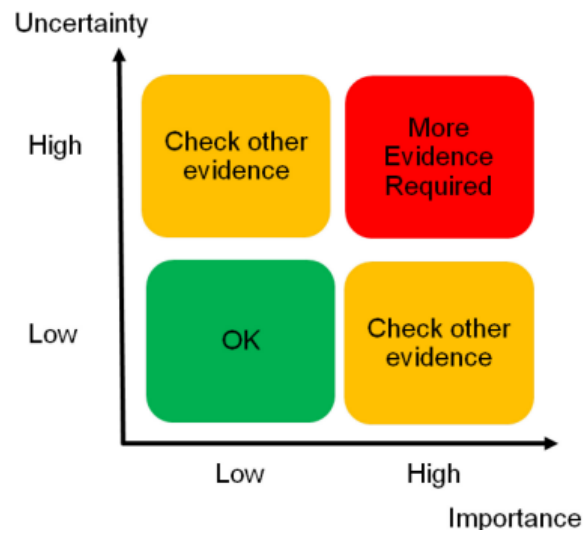


Figure 6-3: Gap/Uncertainty Tool

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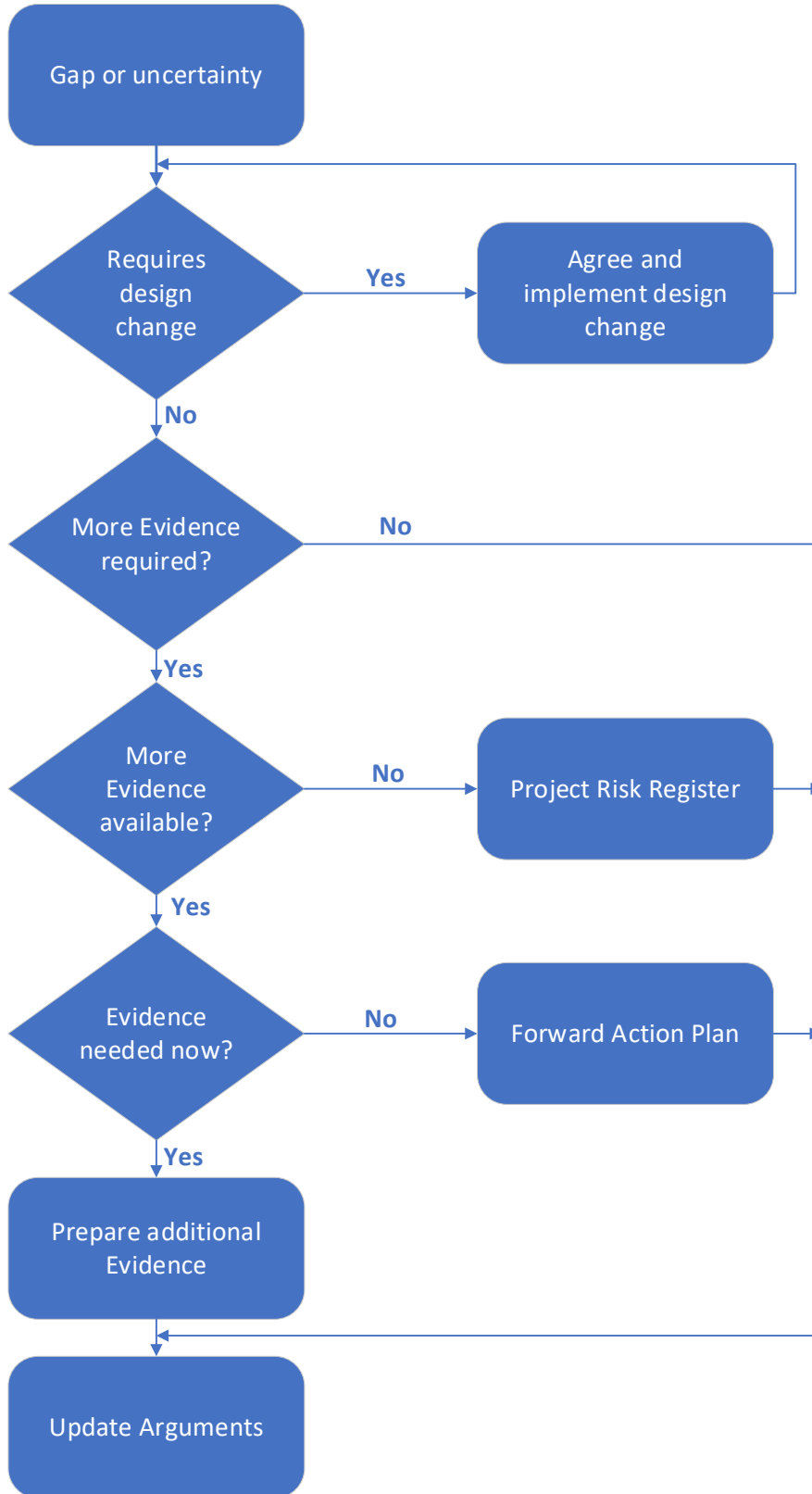


Figure 6-4: The Decision Tool

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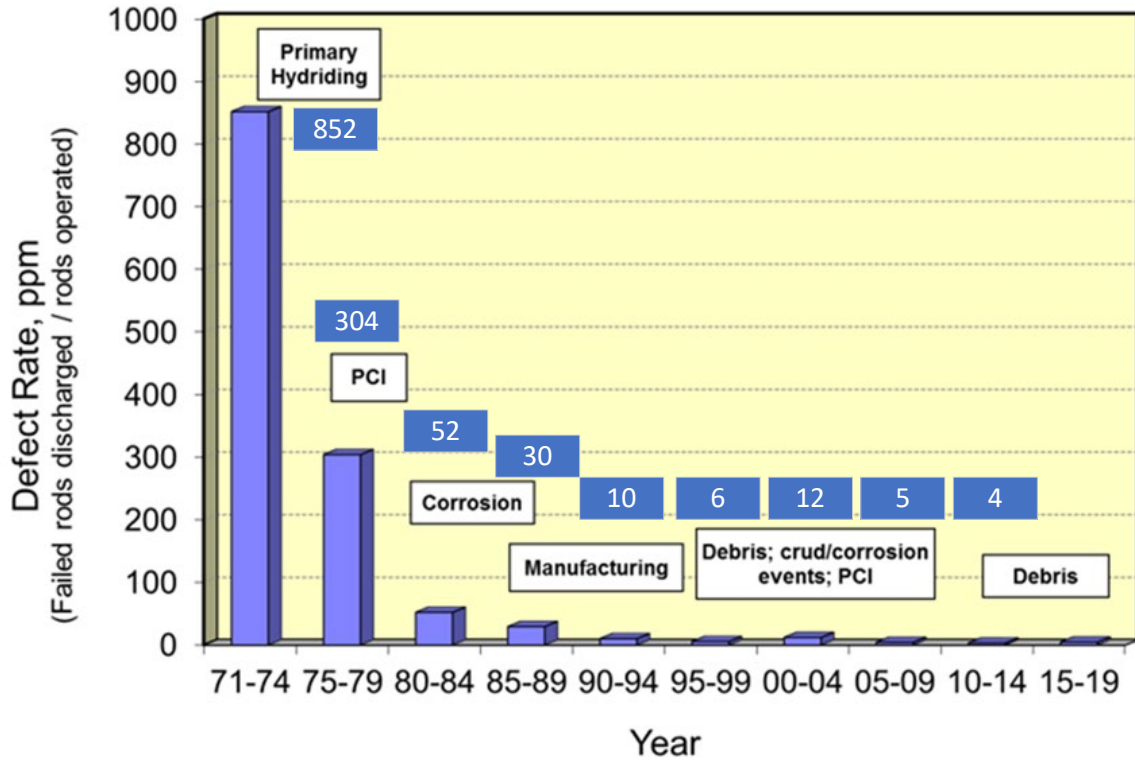


Figure 6-5: GNF Historical Fuel Reliability Performance

(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	Source	Finding	Forward Action	Lead Discipline	Delivery Phase
PER6.306	PER Chapter E6 Section 6.2.14	Currently there is no methodology for the assignment of EPFs to SSCs.	Develop the outline methodology for identifying and assigning EPFs to SSCs during GDA Step 2 and include in an update to PER Chapter E6 Note: detailed methods development and performance of analysis will be in a later licensing phase.	Environment – Demonstration of BAT Approach	Within Step 2
PER6.314	PER Chapter E6 Section 6.3.1 (Claim 1) and Section 6.3.2.2 (Argument 1.1.2)	Evidence needs to be collated to underpin claims and arguments.	Full synthesis of the evidence to underpin the arguments presented in the GDA demonstration of BAT will be completed as required to support future applications for site licences, environmental permits or planning permission.	Environment – Demonstration of BAT Approach	For PCSR/PCER
PER6.200	PER Chapter E6 Section 6.3.3.2 and Section 6.3.6.2 (Argument 1.2.2 and 1.5.2)	OPEX is required to initiate BAT assessments for radwaste management.	Gather waste generation data from operational BWRX 300 reactors to inform the provision of waste management capabilities using BAT.	Environment – Demonstration of BAT Approach	For Site License Application
PER6.199	PER Chapter E6 Section 6.3.3.5 (Argument 1.2.5)	It has been identified that a “realistic model” end user source term based on normal operations is required.	Develop a normal operations source term for use in the demonstration of BAT for optimised selection, design, implementation, operation, maintenance and decommissioning of SSCs that influence the environmental impact of the BWRX-300. (A wider action relating to source terms has also been identified in PSR23-133, originating from PSR Chapter 23: Reactor Chemistry).	Environment – Demonstration of BAT Approach	For Site License Application

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Action ID	Source	Finding	Forward Action	Lead Discipline	Delivery Phase
PER6.205	PER Chapter E6 Section 6.3.4.1 (Argument 1.3.1)	The BWRX-300 can be operated as a zero aqueous discharge reactor. However, site-specific information, including the economics of the required investment, may dictate that discharges during normal operations are the optimal solution.	A future operator shall determine the management and discharge arrangements for aqueous wastes.	Environment – Demonstration of BAT Approach	For Site License Application
PER6.201	PER Chapter E6 Section 6.3.5.4 and Section 6.3.6.1 (Arguments 1.4.5 and 1.5.1)	OPEX is required to initiate BAT assessments for radwaste management.	Undertake BAT assessments to support the specification and selection of equipment for use in the radioactive waste management building.	Environment – Demonstration of BAT Approach	For PCSR/PCER
PER6.315	PER Chapter E6 Section 6.3.6, Section 6.3.6.3, and Section 6.3.6.5 (Claim 1.5 and Arguments 1.5.3 and 1.5.5)	Final waste routes for waste streams to be determined.	The final choice of waste route and the quantity of waste to be consigned will be determined by the future operator.	Environment – Demonstration of BAT Approach	For Site License Application
PER6.316	PER Chapter E6 Section 6.3.6.4 (Argument 1.5.4)	Final packaging, storage and disposal for SF to be determined.	A future operator shall demonstrate BAT when selecting their plans for packaging, storage and disposal of SF.	Environment – Demonstration of BAT Approach	For Site License Application
PER6.202	PER Chapter E6 Section 6.3.6.6 (Argument 1.5.6)	Final design of waste management capabilities will require site-specific information (e.g., number of units generating waste).	Undertake a BAT assessment of waste management techniques, taking into account site-specific factors, including the proximity principle, and any OPEX from in-service BWRX-300 reactors.	Environment – Demonstration of BAT Approach	For Site License Application

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Action ID	Source	Finding	Forward Action	Lead Discipline	Delivery Phase
PER6.203	PER Chapter E6 Section 6.3.7.1 (Argument 1.6.1)	Final design of the gaseous discharge stack will require site-specific data.	Undertake BAT assessments to support the design and location of the gaseous discharge system main stack when site-specific data become available.	Environment – Demonstration of BAT Approach	For Site License Application
PER6.204	PER Chapter E6 Section 6.3.7.3 (Argument 1.6.3)	Final design of the aqueous discharge location will require site-specific data.	Undertake BAT assessments to support the design and location of the aqueous discharge location when site-specific data become available.	Environment – Demonstration of BAT Approach	For Site License Application