GE Hitachi Nuclear Energy

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BWRX-300 UK Generic Design Assessment (GDA) Chapter E7 – Radioactive Discharges

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EXECUTIVE SUMMARY

The GE-Hitachi Nuclear Energy Americas, LLC (GEH) BWRX-300 is a Boiling Water Reactor (BWR) that is designed as a Small Modular Reactor. The tenth generation BWRX-300 design incorporates the lessons learned from worldwide programmes and the operational experience/programmes of several BWRs, most notably the Economic Simplified Boiling Water Reactor and the Advanced Boiling Water Reactor.

The BWRX-300 design has focused on:

- Preventing/eliminating the generation of radioactive waste
- Where the generation of radioactive waste cannot be avoided then minimising the generation of that waste (radioactivity and volume)
- Treating/abating any radioactive waste generated so that it is concentrated/contained or minimised before release to the environment

GEH is, as the Requesting Party, presenting an Environment Case submission to the United Kingdom regulators for a Generic Design Assessment (GDA) at the Step 2 level for the BWRX-300.

This document is a chapter within the Preliminary Environmental Report and is one of the documents that makes up the Environment Case.

This chapter provides conservative and bounding assessments of the radioactivity of the radioactive discharges (gaseous and aqueous liquids) to the environment that will be generated from the normal operation of the BWRX-300. These assessments therefore provide maximum values for the radioactivity of the radioactive gaseous and aqueous liquid discharges. The design intent of the BWRX-300 is to operate according to a ‘maximum recirculation’ philosophy with retention and recirculation of process fluids to the maximum extent possible, and minimisation of radioactive aqueous liquid discharges to the aquatic environment. However, it should be noted that the radioactive aqueous liquid discharge volumes from the BWRX-300 are yet to be confirmed at this early stage of regulatory assessment, and therefore a range of scenarios for these discharges is presented for illustrative purposes.

The conservative and bounding scenarios presented in this chapter for radioactive gaseous and aqueous liquid discharges may be considered to represent the discharge limits at GDA Step 2.

The BWRX-300 conservative and bounding estimates for radioactive gaseous and aqueous liquid discharges, and a representative ‘realistic’ scenario for radioactive aqueous liquid discharges, have also been compared to international plants and are comparable, when normalised for power output and operating hours.

This chapter presents a level of detail commensurate with a two-step GDA. A Forward Action Plan is presented in Appendix A, which defines the scope and timing of additional work beyond GDA Step 2.

GEH considers that the radioactive discharge assessment presented in this report satisfies Step 2 of the GDA.

ACRONYMS AND ABBREVIATIONS

Acronym	Explanation
ABWR	Advanced Boiling Water Reactor
ActP	Actinide Product
AHU	Air Handling Unit
ALARA	As Low As Reasonably Achievable
ANS	American Nuclear Society
ANSI	American National Standards Institute
AOO	Anticipated Operational Occurrence
AP	Activation Product
ASD	Adjustable Speed Drive
BAT	Best Available Techniques
BATEA	Best Available Technology and Techniques Economically Achievable
BL3	Baseline 3
BWR	Boiling Water Reactor
CEAP	Continuous Exhaust Air Plenum
CFD	Condensate Filters and Demineralisers System
CIS	Containment Inerting System
CNSC	Canadian Nuclear Safety Commission
CP	Corrosion Product
CST	Condensate Storage Tank
CUW	Reactor Water Cleanup System
CWS	Circulating Water System
DB	Design Basis
D&ID	Ducting and Instrumentation Diagram
DNNP	Darlington New Nuclear Project
DP	Developed Principle
EA	Environment Agency
EFS	Equipment and Floor Drain System
EPR16	The Environmental Permitting (England and Wales) Regulations 2016 (as amended)
ESBWR	Economic Simplified Boiling Water Reactor
EUST	End User Source Term
FAP	Forward Action Plan
FOAK	First of a Kind
FP	Fission Product
FPC	Fuel Pool Cooling and Cleanup System

Acronym	Explanation
GDA	Generic Design Assessment
GEH	GE-Hitachi Nuclear Energy Americas, LLC
GSC	Gland Steam Condenser
HEPA	High Efficiency Particulate Air
HVS	Heating, Ventilation and Cooling System
HWC	Hydrogen Water Chemistry
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
LWM	Liquid Waste Management System
MCA	Main Condenser and Auxiliaries
MTE	Main Turbine Equipment
MVP	Mechanical Vacuum Pump
NBS	Nuclear Boiler System
NC	Noncondensable
NNPP	New Nuclear Power Plant
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
OGS	Offgas System
OPEX	Operational Experience
OPG	Ontario Power Generation
PCER	Pre-Construction Environmental Report
PCSR	Pre-Construction Safety Report
PER	Preliminary Environmental Report
P&ID	Piping and Instrumentation Diagram
PLSA	Plant Services Area
PREMS	Process Radiation and Environmental Monitoring System
PrST	Process Source Term
PSR	Preliminary Safety Report
PST	Primary Source Term
PVS	Plant Vent Stack
PWR	Pressurised Water Reactor
RB	Reactor Building
RG	Regulatory Guide
RM	Realistic Model
RP	Requesting Party
RPV	Reactor Pressure Vessel

Acronym	Explanation
RSR	Radioactive Substances Regulation
RWB	Radwaste Building
SCCV	Steel-Plate Composite Containment Vessel
SDC	Shutdown Cooling System
SDD	System Design Description
SJAE	Steam Jet Air Ejector
SMR	Small Modular Reactor
TB	Turbine Building
TGSS	Turbine Gland Seal Subsystem
UK	United Kingdom
URC	Ultrasonic Resin Cleaner
U.S.	United States
WGC	Water, Gas, and Chemical Pads

DEFINITIONS

Term	Definition
U41	Heating, Ventilation, and Cooling System (HVS)

SYMBOLS

Symbol	Definition
α	Alpha particle
Ar-40	Argon-40
Ar-41	Argon-41
ɣ	Gamma ray
Bq/GWh	Becquerel per Gigawatt hour
Bq/y	Becquerel per year
C-14	Carbon-14
GWe	Gigawatt electric
GWh	Gigawatt hour
H-2	Deuterium
H-3	Tritium
kPa	Kilopascal
m	Metre
m^3	Cubic metre
MBq/y	Megabecquerel per year
mSv	Millisievert
MWe	Megawatt electrical
m^3/y	Cubic metre per year
n	Neutron
O-17	Oxygen-17

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

7 RADIOACTIVE DISCHARGES

Introduction

The GE-Hitachi Nuclear Energy Americas, LLC (GEH) BWRX-300 is a Boiling Water Reactor (BWR) that is designed as a Small Modular Reactor (SMR). At GDA Step 2, a single BWRX-300 unit of 300 Megawatt electric (MWe) capacity is presented, located on a generic coastal site.

The tenth generation BWRX-300 design incorporates the lessons learned from worldwide programmes and the Operational Experience (OPEX)/programmes of several GEH BWRs, most notably the Economic Simplified Boiling Water Reactor (ESBWR) and the Advanced Boiling Water Reactor (ABWR).

GEH is, as the Requesting Party (RP), 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.

This document is a chapter within the Preliminary Environmental Report (PER), which forms the main part of the Environment Case.

BWRX-300 Design Concept and Philosophy

The First of a Kind (FOAK) BWRX-300 design is being developed in the United States (U.S.) for international deployment using a Standard Design approach to minimise the design variation from project to project. A phased design process based on Requirements Management has been adopted, as described in NEDO-34220, “BWRX-300 UK GDA Chapter E3: Management Arrangements and Responsibilities,” (Reference 7-1). A hierarchical flow of design requirements, from ‘source’ top-level legislative and regulatory requirements through to plant, system, and component levels, places constraints on the plant design to ensure that the final design fulfils all source requirements via logical and traceable decision-making processes.

The design requirements for the BWRX-300 Standard Design are based on recommendations and safety standards established by the International Atomic Energy Agency (IAEA), the International Commission on Radiological Protection (ICRP), the U.S. Nuclear Regulatory Commission (NRC), and the Canadian Nuclear Safety Commission (CNSC) (see GEH Requirements Specification document 006N5081, “BWRX-300 As Low As Reasonably Achievable Design Criteria for Standard Design,” (Reference 7-2)). This document is an ‘A level’ document that allocates and enforces requirements for radiation protection, to reduce occupational and public exposure to radiation to levels that are As Low As Reasonably Achievable (ALARA).[1]

Aligned with the high-level ALARA objectives and requirements presented in the As Low As Reasonably Achievable Design Criteria for Standard Design document (Reference 7-2), the BWRX-300 design has focused on:

- Preventing/eliminating the generation of radioactive waste
- Where the generation of radioactive waste cannot be avoided, then minimising the generation of that waste (radioactivity and volume)

[1] The ALARA approach adopted by GEH in the BWRX-300 design is based on international regulations and standards (e.g., ICRP Publication 103, “The 2007 Recommendations of the International Commission on Radiological Protection,” (Reference 7-3) and IAEA General Safety Requirements GSR Part 3, “Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards,” (Reference 7-4)), as distinct from the specific implementation of the ALARA requirement in UK environmental legislation and regulatory guidance.

- Treating/abating any radioactive waste generated so that it is concentrated/contained or minimised before release to the environment

Purpose

The purpose of this chapter is to describe the radioactive gaseous and aqueous liquid discharges arising from normal operation of the BWRX-300. It addresses the following key questions:

- How is the radioactivity created?
- How does the radioactivity become gaseous and aqueous liquid radioactive waste?
- Where in the plant/process does the gaseous and aqueous liquid radioactive waste arise?
- How is the gaseous and aqueous liquid radioactive waste conveyed through the plant/process?
- How is the gaseous and aqueous liquid radioactive waste collected/segregated from the process water and steam?
- How is the gaseous and aqueous liquid radioactive waste treated to reduce the amount of radioactivity in it?
- How is the gaseous and aqueous liquid radioactive waste monitored to determine whether it can be discharged to the environment?
- How is the gaseous and aqueous liquid radioactive waste discharged to the environment?
- What is the anticipated radioactivity of gaseous and aqueous liquid discharges?
- How do the radioactive gaseous and aqueous liquid discharges from BWRX-300 compare with the discharges from other Nuclear Power Plants (NPPs) around the world?

Table 7-1 shows how these questions have been considered within the scope of this report at GDA Step 2.

Scope

This chapter provides conservative and bounding assessments of the radioactivity of radioactive discharges (gaseous and aqueous liquids) to the environment that will be generated from the normal operation[2] of the BWRX-300. These assessments therefore provide maximum values for the radioactivity of the radioactive gaseous and aqueous liquid discharges. The design intent of the BWRX-300 is to operate according to a ‘maximum recirculation’ philosophy with retention and recirculation of process fluids to the maximum extent possible, and minimisation of radioactive aqueous liquid discharges to the aquatic environment. However, it should be noted that the radioactive aqueous liquid discharge volumes from the BWRX-300 are yet to be confirmed at this early stage of regulatory assessment, and therefore a range of scenarios for these discharges is presented for illustrative purposes.

[2] Normal operation includes the operational fluctuations, trends, and events that are expected to occur over the lifetime of the facility. This includes start-up, shutdown, and maintenance as well as expected faults. It does not include increased radioactive discharges arising from other events, inconsistent with the use of BAT, such as accidents, inadequate maintenance, and inadequate operation.

The conservative and bounding scenarios presented in this chapter for radioactive gaseous and aqueous liquid discharges may be considered to represent the discharge limits at GDA Step 2.

The BWRX-300 conservative and bounding estimates for radioactive gaseous and aqueous liquid discharges, and a representative 'realistic' scenario for radioactive aqueous liquid discharges, have also been compared to international plants and are comparable, when normalised for power output and operating hours.

The level of detail presented in this chapter is commensurate with this early stage of the GDA. A Forward Action Plan (FAP) is presented in Appendix A, which defines the scope and timing of additional work beyond GDA Step 2. Discussions on Best Available Techniques (BAT), optimisation, and radioactive waste management arrangements are not included in this chapter as they are addressed in NEDO-34223P, "BWRX-300 UK GDA Chapter E6: Demonstration of Best Available Techniques Approach," (Reference 7-5) and NEDO-34222, "BWRX-300 UK GDA Chapter E5: Radioactive Waste Management Arrangements," (Reference 7-6).

Terminology for BWRX-300 Process Fluids and Radioactive Discharges

Throughout this chapter and the Environment Case for the BWRX-300, the following terms have been adopted to describe GEH's design approach for management of process fluids (both aqueous liquid and gaseous) within the plant and the design intent with respect to radioactive discharges:

- **Process fluids** – all high-purity fluids (aqueous liquids and gases) that are associated with the steam circuit and ancillary processes (such as the fuel pool and the Isolation Condenser System)
- **Recirculating process fluids** – by extension, those process fluids which are retained and continuously circulated through the plant to drive the turbine and provide ancillary functions
- **Maximum recirculation philosophy** – GEH's design approach to retaining as much of the process fluids in the plant as possible and minimising disposal of aqueous liquid wastes to the aquatic environment
- **Aqueous liquid waste** – aqueous liquid process fluids that can no longer be recirculated and which must be disposed of to the aquatic environment
- **Radioactive aqueous liquid waste** – by extension, those aqueous liquid wastes that contain radioactive substances

Assumptions

The following key assumptions about the BWRX-300 have been made:

- The operating cycle is 12 months
- The outage period is 10 to 20 days

Specific assumptions used in the methodologies for production of BWRX-300 radioactive discharge assessments are stated in the relevant subsections of this chapter.

Document Structure

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

Section 7.1 Regulatory Context

Section 7.2 Source Terms

Section 7.3 Radioactive Discharge Routes – Gaseous

Section 7.4 Radioactive Discharge Routes – Aqueous Liquid

Section 7.5 Radioactive Discharge Assessments

Section 7.6 Comparison with International Plants

Section 7.7 Conclusion

Section 7.8 References

Appendix A Forward Action Plan

Appendix B Annual Gaseous Radioactivity Contribution by Route

Appendix C Refinement of BWRX-300 Source Term

Interfaces with other Chapters

This document interfaces with the following chapters in the PER:

- NEDO-34219, "BWRX-300 UK GDA Chapter E2: Generic Site Description," (Reference 7-7)
- PER Chapter E3 (Reference 7-1)
- NEDO-34221, "BWRX-300 UK GDA Chapter E4: Information about the Design," (Reference 7-8)
- PER Chapter E5 (Reference 7-6)
- PER Chapter E6 (Reference 7-5)
- NEDO-34225, "BWRX-300 UK GDA Chapter E8: Approach to Sampling and Monitoring," (Reference 7-9)
- NEDO-34226, "BWRX-300 UK GDA Chapter E9: Prospective Radiological Assessment," (Reference 7-10)

It also interfaces with the following chapters in the Preliminary Safety Report (PSR):

- NEDO-34195, "BWRX-300 UK GDA Chapter 23: Reactor Chemistry," (Reference 7-11)

7.1 Regulatory Context

GEH has entered the GDA process up to Step 2 with the BWRX-300 design. This approach has been informed by regulatory guidance and decision documents, supplemented by regulatory engagement. Regulator feedback from GDA Step 1 has been taken into account in the GDA Step 2 PER submission.

This section provides a brief overview of the regulatory framework relating to radioactive discharges of gaseous and aqueous liquid wastes. Additional details of relevant national and international legislation, as well as regulatory guidance and good practice can be found in the references provided.

7.1.1 The Environmental Permitting (England and Wales) Regulations 2016

Through Schedule 23, Section 11(2)(b) of "The Environmental Permitting (England and Wales) Regulations 2016," (as amended) (EPR16) (Reference 7-12):

"A radioactive substances activity is carried on where a person uses premises for the purposes of an undertaking and that person disposes of radioactive waste on or from those premises."

Based on EPR16 Schedule 23, the future operator of the BWRX-300 will be undertaking a radioactive substances activity by virtue of gaseous and aqueous liquid radioactive discharges to the environment. These discharges will necessarily result in exposure of members of the public to radioactivity.

EPR16 (Reference 7-12) applies specified dose limits on the annual radiation exposure of members of the public. The principal aims of the legislation are that the environmental regulators, in exercising their duties and functions under the regulations, ensure that:

- *"All exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable, taking into account economic and social factors"*
- The sum of the doses arising from such exposures does not exceed the individual public dose limit of 1 millisievert (mSv) per year
- The individual dose received from any new discharge source since 13th May 2000 does not exceed 0.3 mSv per year
- The individual dose received from any single site does not exceed 0.5 mSv per year

The Environmental Permitting Regulations (England and Wales) 2010 "Criteria for setting limits on the discharge of radioactive waste from nuclear sites," (Reference 7-13) provides a lower dose threshold for the most exposed group of members of the public of 10 microsieverts per year, below which the Environment Agency (EA) should not seek to further reduce the discharge limits that are in place, provided that the holder of the permit continues to apply BAT.

Information on anticipated radiological doses to members of the public arising from radioactive gaseous and aqueous liquid discharges from the operation of BWRX-300 are presented in PER Chapter E9 (Reference 7-10).

7.1.2 Permits for Radioactive Substances Activities

The EA's guidance document, "Nuclear sites Radioactive Substances Regulation (RSR): environmental permits," (Reference 7-14) states that:

"If you are going to carry out a radioactive substances activity you may need to apply to the Environment Agency for a permit. You must do this before you start the activity."

Note that although the guidance specifically refers to the EA, if the permit application were to be in Wales, then Natural Resources Wales would be the relevant regulatory authority.

The guidance also states that:

"If you are nuclear site licensee, you should apply for an unsealed sources and waste permit if you plan to:

- *dispose of radioactive waste"*

Applications for radioactive substances activity permits for unsealed sources and radioactive waste for nuclear sites under EPR16 must be made using EP-RSR-B3, "Application for an environmental permit Form RSR-B3 – New bespoke radioactive substances activity permit (nuclear site – unsealed sources and radioactive waste)," (Reference 7-15). Under Section 4 (Disposal of radioactive wastes), the applicant must submit the following details:

"4a Provide quantitative estimates for normal operation of

- *discharges of gaseous and aqueous radioactive wastes*
- *arisings of combustible waste and disposals by on-site or off-site incineration*
- *arisings of other radioactive wastes, by category and disposal route (if any)*

4b Provide your proposed limits for

- *gaseous discharges*
- *aqueous discharges*
- *disposal of combustible waste by on-site incineration"*

7.1.3 Standard Permit Conditions and Application of Best Available Techniques

The guidance document, "RSR permits for nuclear licensed sites: how to comply," (Reference 7-16), sets out some standard permit conditions that the holder of the license is required to comply with. Although also concerned with BAT, Permit Operating Conditions 2.3.1, 2.3.2, and 2.3.3 address radioactive gaseous and aqueous liquid discharges:

"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."

The generation, treatment, management, and disposal of all radioactive waste that will arise as result of the operation of the GEH BWRX-300 have been assessed against the requirements to apply BAT. The approach to assessing BAT is described in PER Chapter E6

(Reference 7-5) and PER Chapter E8 (Reference 7-9). Claims and arguments for application of BAT are provided at GDA Step 2 to demonstrate that optimisation to the ALARA requirements of EPR16 will be fulfilled by the BWRX-300 design.

7.1.4 Requirements

The environmental regulators' expectations for radioactive discharges and limits are set out in the joint guidance document "New nuclear power plants: Generic Design Assessment guidance for Requesting Parties," (Reference 7-17) and the environmental regulator presentation to the RP, "Environment: Introductions and Expectations," (Reference 7-18), for a three-step GDA. It should be noted that the scope of this document requires the guidance to be interpreted to GDA Step 2 only at this stage. Table 7-2 sets out the regulator expectations for a three-step GDA and the GEH interpretation of these expectations to Step 2.

7.1.5 Alignment with the RSR Objective, Principles and Generic Developed Principles

The methodologies presented in this report have been developed with consideration of previous GDAs (e.g., the UK ABWR GDA submissions and regulatory assessment reports), the relevant RSR objective and principles, "Radioactive Substances Regulation (RSR): objective and principles," (Reference 7-19), and the supporting RSR generic Developed Principles (DPs), "RSR generic developed principles: regulatory assessment," (Reference 7-20). These guidance documents set out the EA's expectations on permit holders carrying out radioactive substances activities.

NEDC-34231P, "Alignment with Sustainability, the Radioactive Substances Regulation Objective and Principles & Generic Developed Principles," (Reference 7-21) details the approach undertaken by GEH to reviewing and taking account of the relevant objective, principles, and DPs within this GDA Step 2 submission.

7.2 Source Terms

This section describes the main sources of gaseous and aqueous liquid radioactive waste, including the radiological source term used in calculating the radioactivity of these waste streams.

Sources of solid radioactive wastes, and non-aqueous liquid wastes, are described in PER Chapter E5 (Reference 7-6).

7.2.1 Sources of Radioactive Waste

Gaseous radioactive waste is generated as a result of activation of the reactor coolant during normal operation, trace amounts of uranium that may adhere to the outside of the fuel cladding during fabrication, and leakage of gaseous Fission Products (FPs) through miniscule defects in the fuel cladding.

Aqueous liquid radioactive waste is generated by cleanup of the reactor coolant, cleanup of the fuel pool, leakage from process streams, and decontamination activities. Information on the treatment of drained aqueous process fluids by the Liquid Waste Management System (LWM) is presented in Subsection 7.4.3.

7.2.2 Production Mechanisms

The radionuclides present in the reactor water and steam within the Reactor Pressure Vessel (RPV) of the GEH BWRX-300 fall into three distinct categories based on their production mechanism within the reactor core (see NAS-NS-3119, "Radiochemistry in Nuclear Power Reactors," (Reference 7-22)):

- FPs and Actinide Products (ActPs)
- Corrosion Products (CPs)
- Activation Products (APs)

The principal means of generation of these radionuclides in the reactor is described in the subsections below.

7.2.2.1 Fission Products and Actinide Products

The presence of FPs and ActPs in the reactor water and steam are mainly due to two mechanisms:

- Trace amounts of uranium that may be present on the external surfaces of the fuel assemblies, so called "tramp uranium"
- Leakage of volatile FPs through small pinhole defects in the cladding surrounding the fuel during irradiation in the core

Typical FPs include radioisotopes of krypton, xenon, iodine, strontium-90, and caesium-137 Typical ActPs include plutonium-239 and americium-241 .

It should be noted that plutonium-239 and americium-241 are alpha emitters. However, these radionuclides are not anticipated to contribute to radioactive gaseous and aqueous liquid discharges from the BWRX-300, as during normal operations they will be retained in the fuel. Additionally, Quality Assurance processes applied to the manufacture of GNF2 fuel (the reference fuel design for BWRX-300 – see PER Chapter E6, Argument 1.1.1 (Reference 7-5)) minimise tramp uranium on the external surface of the fuel. Even at the bounding limits presented in Section 7.5 of this chapter, these radionuclides are not considered to be significant in terms of total radioactivity or radiological dose.

7.2.2.2 Corrosion Products

CPs are formed as a result of corrosion that occurs during the normal wear and tear of reactor operations and may arise in soluble or particulate form. CPs become radioactive waste as a result of:

- 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 water and steam to the RPV, where they become activated as they pass through the neutron flux in the reactor core

Examples of radioactive CPs are iron-55, iron-59 and cobalt-60.

Particulates, such as activated CPs, are produced in the core and are retained within the water circuit, i.e., they are not carried over into the steam circuit.

7.2.2.3 Activation Products

In addition to the formation of activated CPs by activation of metallic species generated by corrosion of metals in the steam circuit (see Subsection 7.2.2.2), neutron activation of the reactor water itself will also produce radioactive species. Of particular interest for radioactive gaseous and aqueous liquid discharges are tritium (H-3), carbon-14 (C-14) and argon-41 (Ar-41). The main production mechanisms for these nuclides are described in the following paragraphs.

7.2.2.4 Carbon-14

Carbon-14 is mainly produced by the O-17 (n,α) C-14 reaction in the reactor water. The carbon-14 produced because of activation of the reactor water is likely to be present as carbon dioxide, as conditions in the upper part of the reactor core are oxidising and is transferred to the reactor steam. Therefore the analyses presented in this chapter are based on the assumption that carbon-14 behaves like a noble gas FP, i.e., all carbon-14 produced will be released through the main condenser Offgas System (OGS) and carbon-14 is not anticipated to be a component of radioactive aqueous liquid discharges from the BWRX-300. This assumption is supported by information in EPRI 1021106, “Estimation of Carbon-14 in Nuclear Power Plant Gaseous Effluents Report,” (Reference 7-23).

7.2.2.5 Argon-41

Argon-41 is produced by the Ar-40 (n,ɣ) Ar-41 reaction in reactor water (see NS-TAST-GD-088, “Chemistry of Operating Civil Nuclear Reactors,” (Reference 7-24)). The reactor water contains a very small amount of residual entrained air, which itself contains trace amounts of naturally occurring stable argon. The argon becomes activated as the reactor water passes through the reactor core. The argon-41 produced is transferred to the reactor steam.

7.2.2.6 Tritium

Tritium is mainly produced by activation of naturally occurring deuterium (H-2) in the reactor water, H-2 (n,ɣ) H-3. Tritium is assumed to partition equally between steam and plant process water (see NUREG-0016, “Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from Boiling-Water Reactors,” (Reference 7-25)). The concentration of tritium reached is controlled by the rate of loss of water from the system by evaporation (especially from the fuel pool) or leakage.

The radioactive gaseous discharge assessment presented in this chapter employs the assumption that 50 % of the gaseous tritium is released from the Turbine Building (TB), and the remaining 50 % from the Reactor Building (RB). A bounding value for tritium in radioactive aqueous liquid discharges has been calculated from the concentration of tritium in the reactor coolant (see Subsection 7.5.3.2).

7.2.3 Coolant Radiation Concentrations

The concentration of each radionuclide in the reactor water and reactor steam within the primary system (i.e., the reactor core and coolant) is known as the Primary Source Term (PST). The radioactive concentrations in the ancillary systems are known as the Process Source Term (PrST). The PST and PrST are used to derive and assess the radiological doses and radionuclide activity associated with all aspects of plant operation and lifecycle, including radiation protection, radioactive waste, decommissioning, and radioactive discharge assessments. These are termed “technical areas” and each has its own associated End User Source Term (EUST). In this document the EUST of interest is that for “discharge assessment”.

7.2.4 The Basis of the End User Source Term

The PST for the BWRX-300 reactor coolant is calculated using American National Standards Institute (ANSI) and American Nuclear Society (ANS) ANSI/ANS-18.1-2020, “Radioactive Source Term for Normal Operation of Light Water Reactors,” (Reference 7-26). This standard is based on available measured radionuclide concentrations during normal operation at operating BWRs. It should be noted that as a result of being based on measured radionuclide data in the U.S., the ANSI/ANS-18.1-2020 standard does not include carbon-41.

The BWRX-300 PST is presented in 005N4258, “BWRX-300 Coolant Radiation Concentrations,” (Reference 7-27). Data are provided for normal operation coolant concentrations (referred to in this chapter as the ‘Realistic Model’ (RM) source term) and Design Basis (DB) coolant concentrations based on a fuel cladding defect model. The RM PST is used to calculate the EUST for radioactive gaseous and aqueous discharges from the BWRX-300.

The validation of the current BWRX-300 PST is discussed in PSR Chapter 23 (Reference 7-11). As a result of the validation work undertaken in PSR Chapter 23, it was considered that GEH’s derivation of PST values is sufficient for completion of GDA Step 2 for BWRX-300.

The RM PST is used to produce the EUST for radioactive gaseous and aqueous liquid discharges using the methodologies described below.

7.2.4.1 End User Source Term for Radioactive Gaseous Discharge

The BWRX-300 radioactive gaseous discharge assessment, 007N1078, “Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant,” (Reference 7-28), is performed with the GALE-BWR methodology, which implements the assumptions outlined in NRC Regulatory Guide (RG) 1.112, “Calculation of Releases of Radioactive Materials in Gaseous and Liquid Effluents from Light-Water-Cooled Nuclear Power Reactors,” (Reference 7-29). The GALE-BWR methodology is described in NUREG-0016 (Reference 7-25), and calculates releases based on:

- Standardised coolant activities derived from ANS Standards 18.1 Working Group recommendations
- Release and transport mechanisms that result in the appearance of radioactive material in aqueous liquid and gaseous waste streams
- Plant-specific design features used to reduce the quantities of radioactive waste ultimately released to the environment
- Information received on the operation of NPPs

The calculations are based on data generated from operating reactors, field tests, laboratory tests, and plant-specific design considerations incorporated to reduce radioactive discharges to the environment. The GALE-BWR method determines the release of gaseous radionuclides (noble gases, particulates, carbon-14, tritium, argon-41, and iodine) from normal operation including Anticipated Operational Occurrences (AOOs) from the following sources:

- Main condenser OGS
- Turbine Gland Seal Subsystem (TGSS)
- Mechanical Vacuum Pump (MVP)
- Ventilation exhaust air from buildings in the BWRX-300 power block (RB, Plant Services Area (PLSA), TB, and Radwaste Building (RWB))

For the purpose of this evaluation the BWRX-300 PLSA is treated as an auxiliary building as defined in NUREG-0016 (Reference 7-25).[3]

The parameters defined in NUREG-0016 are adjusted for BWRX-300 radioactive gaseous discharges to account for:

- The increased plant capacity factor as compared to older BWRs, and the BWRX-300 outage fraction (5%)
- The natural circulation core in BWRX-300
- The difference in thermal power between BWRX-300 and the NUREG-0016 reference plant
- Removal of particulate by High Efficiency Particulate Air (HEPA) filters in the RB, TB, and RWB ventilation systems
- The holdup times of noble gas radioisotopes in the OGS charcoal beds

7.2.4.2 End User Source Term for Radioactive Aqueous Liquid Discharge

The BWRX-300 radioactive aqueous liquid discharge assessment, 007N1460, "BWRX-300 Annual Average Liquid Effluent Activity Releases," (Reference 7-30), is performed with the GALE--BWR 3.2 code described in NUREG-0016 (Reference 7-25), which implements the analysis methods and assumptions for radioactive aqueous liquid discharges in RG 1.112 (Reference 7-29).

The radioactivity of aqueous liquid discharges is calculated based on the parameters described in Subsection 7.2.4.1, including consideration of the BWRX-300 LWM design features which reduce the quantities of radioactive waste released to the environment. The following design features are considered in the GALE-BWR 3.2 analysis:

- The BWRX-300 LWM does not use regenerant solutions. This eliminates the high impurity waste streams associated with chemical regeneration of demineraliser resin beds
- The BWRX-300 will not utilise any copper tubing in the condenser or anywhere in the reactor coolant pressure boundary. This reduces corrosion of pipework relative to older BWRs, thereby reducing the formation of activated CPs

[3] As a result of ongoing design development during GDA timescales, the PLSA exhaust is no longer considered to contribute to radioactive gaseous discharges from the BWRX-300. However, a contribution from the PLSA (comprising 1.4% of the total annual radioactive gaseous discharges) is included in the radioactive discharge assessments presented in Section 7.5.

- The BWRX-300 Condensate Filters and Demineralisers System (CFD) will not employ an Ultrasonic Resin Cleaner (URC).[4] This eliminates the high impurity waste streams associated with ultrasonic resin cleaning
- Because the BWRX-300 LWM implements a 'maximum recirculation' philosophy (see Subsection 7.4.2) to minimise radioactive aqueous liquid discharges, no tritium is released to the environment via the aqueous liquid pathway.[5]

7.2.4.3 Conservatism in the Radioactive Discharge Assessments

Although they are based on a "normal operations" RM PST, the current estimates of the radioactivity of the annual radioactive gaseous and aqueous liquid discharges for the BWRX-300 presented later in this chapter (see Section 7.5) are conservative, and provide bounding values for the radioactive discharges. This is due to the assumptions and input parameters that are included in the GALE-BWR methodology used to calculate the EUST (described in Subsection 7.2.4), and application of a conservative noble gas release rate of 3.7E+01 megabecquerels per second to the PST (Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant, (Reference 7-28)), reflective of a radioactivity contribution arising from fuel failure.

An analogous radioactive discharge assessment for radioactive gaseous and aqueous liquid discharges was conducted for the UK ABWR (GA91-9901-0025-0001, "UK ABWR Generic Design Assessment, Quantification of Discharges and Limits," (Reference 7-31)). The conservatism in the PST for BWRX-300 is demonstrated if the BWRX-300 and UK ABWR RM PST are compared (Table 7-3). A like-for-like comparison is achieved by generating ratios of the geometric means of the radionuclide concentrations for each given class as BWRX-300:UK ABWR.

Additionally, it should be noted that the UK ABWR PST is based on OPEX containing no fuel failures, while the ANSI/ANS-18.1-2020 (Reference 7-26) reference plant (utilised for derivation of the BWRX-300 PST) is underpinned by OPEX containing some plant data where fuel failures have occurred, as detailed in PSR Chapter 23 (Reference 7-11).

Further examples of conservatism in the assessment of BWRX-300 radioactive gaseous discharges are summarised below (Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant, (Reference 7-28)):

- Radioactive gaseous discharges from primary containment are based upon the standard NUREG-0016 assumptions, and an assumed BWRX-300 containment steam and water leak rate of 3.79 litres per minute, and 24 purges per year. As normal operation of the BWRX-300 only requires purging of the containment at the start and end of an outage (Subsection 7.3.2.1), with an assumed operating cycle of 12 months, the NUREG-0016 assumption of 24 purges per year for calculating the EUST may be considered conservative
- A bounding flash fraction for coolant leaks in primary containment is used in the analysis
- A conservative iodine-131 reactor water concentration of 1.4E-04 megabecquerels per gram is used in the analysis

[4] A URC is not required in the BWRX-300 design as the demineraliser resin beds are protected from crud deposition by pre-filtration.
[5] For the purposes of the GDA Step 2 radioactive discharge assessment, a bounding value for tritium in radioactive aqueous liquid discharges has been calculated from the concentration of tritium in the reactor coolant (see Subsection 7.5.3.2).

- It is assumed that no holdup of radioactive gaseous waste from the TGSS exhaust occurs prior to discharge

It is acknowledged that the current EUST data for radioactive discharges and solid radioactive waste generation (see PER Chapter E5 (Reference 7-6)) are not fully reflective of the design features of the BWRX-300 that specifically minimise radioactive discharges and solid radioactive waste generation. This is discussed in detail in PER Chapter E6 (Reference 7-5).

Information relating to strategy and opportunities for refinement of the EUST for radioactive discharges and wet solid radioactive wastes for future design development phases is presented in Appendix C and PSR Chapter 23 (Reference 7-11). A high-level forward action for refinement of the BWRX-300 EUST across multiple technical areas has been identified in PSR Chapter 23.

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

- *Waste accumulation*
- *Liquid/airborne discharges*

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

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

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

- *Radiation protection – PSR Chapter 12*
- *Radioactive waste accumulation and activity – PER Chapter E5*
- *Decommissioning volumes and activity – PER Chapter E5*
- *Normal effluent discharges – PER Chapter E7*
- *Fault studies – PSR Chapter 15*

7.2.4.4 Anticipated Operational Occurrences

The environmental regulators have stated an expectation (see regulator GDA guidance for RPs (Reference 7-17)) that AOOs (analogous to "frequent design basis faults" as defined by the Office for Nuclear Regulation in their document NS-TAST-GD-006, "Nuclear Safety Technical Assessment Guide – Design Basis Analysis," (Reference 7-32)) that result in an environmental radiological impact, should be identified as an inclusive consideration of environmental radiological discharges and radioactive wastes arising from normal operation of the BWRX-300.

The ANSI/ANS-18.1-2020 (Reference 7-26), GALE-BWR, and NUREG-0016 (Reference 7-25) codes and standards discussed in Subsection 7.2.4 include AOOs based on OPEX from BWRs. The GALE-BWR code (see NUREG-0016 (Reference 7-25)) also includes a source term adjustment for AOOs of 3,700 megabecquerels per year (MBq/y).

A preliminary review of 005N3558, "BWRX-300 Fault Evaluation," (Reference 7-33), has not resulted in the identification of any relevant AOOs. The current safety analysis relates primarily to reactor faults and, as such, faults that could primarily result in fuel damage. All of the faults listed present adequate mitigation through design and therefore do not give rise to environmental impact consequences within AOO frequency. It is recognised that further work is required to assess the wider BWRX-300 design for faults that could give rise to environmental consequences at frequencies that would define them as AOOs. This has been identified as a forward action in PER Chapter E5 (Reference 7-6).

FAP.PER5-110 – *"A future developer/operator shall undertake a systematic review of initiating events across the entirety of the BWRX-300 design to identify a comprehensive list of faults that may result in an environmental radiological impact, through an increase in radioactive discharges, waste volumes or activities, and at frequencies that would define them as AOOs. The findings shall be incorporated into the relevant documentation."*

7.2.5 Radionuclides Considered

Only the ANSI/ANS-18.1-2020 (Reference 7-26) generated radionuclides are currently considered in the EUST for the BWRX-300 and reported in the annual radioactivity releases for radioactive gaseous and aqueous liquid discharges.

It is recognised that the generated radionuclide lists for the aqueous liquid and gaseous EUST (see Table 7-8 and Table 7-9) do not exactly match those in the 2004/2/Euratom recommendation, C(2003) 4832, "Commission Recommendation 2004/2/Euratom of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation," (Reference 7-34). 2004/2/Euratom radionuclides that are not included in the current radioactive discharge assessments for the BWRX-300 are shown in Table 7-4.

Additional radionuclide activities can be calculated from the existing data, but this has not yet been completed at this early stage of regulatory assessment. It is acknowledged that compliance with the 2004/2/Euratom reporting recommendations is a UK requirement for final discharge accountancy (see PER Chapter E8 (Reference 7-9)).

7.2.6 Refinement of the End User Source Term for Radioactive Discharges

In summary, the radioactive discharge assessments presented in this chapter are based on the methodologies presented in Subsection 7.2.4, and it is acknowledged that the EUST for radioactive gaseous and aqueous liquid discharges will require refinement for later stages of regulatory assessment. The current lack of refined EUST for radioactive gaseous and aqueous discharges means that:

- The radioactive discharge assessments at GDA Step 2 are conservative and require refinement in order for discharge limits to be established and justifiable headroom factors calculated. This will also enable a refined radiological dose assessment to be performed at the proposed discharge limits, in line with regulator expectations
- AOOs with environmental consequences may not be fully accounted for in the discharge assessments, meaning that monthly and rolling monthy discharge assessments cannot be produced
- The current BWRX-300 EUST listed radionuclides for radioactive gaseous and aqueous liquid discharges do not exactly match those in the 2004/2/Euratom recommendation. This means that the significant radionuclides discharged from the gaseous and aqueous liquid systems have not yet been fully identified. Identification of the significant radionuclides is required to enable suitable sampling and monitoring equipment to be selected for determination of final discharge accountancy
- The assumptions and calculation methodologies used for determination of the EUST will need to be reviewed to ensure that they accurately reflect, as far as possible, the design of the BWRX-300, with consideration of relevant OPEX

- Sensitivity analysis will need to be considered as a means to inform prioritisation of effort for ongoing design optimisation

These findings have resulted in identification of the following specific forward action for source term refinement relating to radioactive discharges:

FAP.PER7-196 - The PST and EUST data for radioactive gaseous and aqueous liquid discharges from the BWRX-300 shall be refined, taking into account:

- **AOOs with environmental consequences (see FAP.PER5-110)**
- **The 2004/2/Euratom reporting recommendations**
- **A review of the assumptions and calculation methodologies to be used, with consideration of relevant OPEX available at the time**
- **Consideration of the use of sensitivity analysis to inform prioritisation of effort for ongoing design optimisation**

This will allow more realistic updated radioactive discharge assessments to be produced. These data shall include estimates of:

- **Total radioactive gaseous and aqueous liquid discharges (final discharges)**
- **Radioactive discharges by route/source**
- **The impact on anticipated radioactive discharges of:**
  - **Different plant operational modes (e.g., startup and refuelling outages)**
  - **Expected events (e.g., a fuel pin failure)**
  - **Short-term releases (e.g., containment purging)**

These data shall then be used to:

- **Establish discharge limits, and enable the radiological dose assessment to be performed at the proposed limits**
- **Determine headroom factors**
- **Generate monthly and rolling monthly discharge assessments of the proposed operating cycle**
- **Determine the significant radionuclides that require sampling and monitoring in the radioactive discharges, such that suitable sampling and monitoring equipment can be selected**

The scope of ongoing design development activities by GEH towards fulfilment of **FAP.PSR23-133** and **FAP.PER7-196** and future opportunities for further refinement of the EUST for BWRX-300 technical areas, is presented in Appendix C and PSR Chapter 23 (Reference 7-11).

7.2.6.1 BWRX-300 Operational Data – Ontario Power Generation Darlington New Nuclear Project

Refinement of the radioactive discharge assessments for radioactive gaseous and aqueous liquid discharges from the BWRX-300 will require consideration of relevant available OPEX.[6] Ontario Power Generation (OPG) are planning to construct up to four BWRX-300 SMRs at the Darlington New Nuclear Project (DNNP) site in Ontario, Canada. In principle, radioactive

[6] The considerations relating to the EA's Radioactive Substances Management DP 12 (limits and levels on discharges) state that: *"The process by which limit and levels are determined should be based on a data set of appropriate quality and breadth."*

gaseous and aqueous liquid discharge data from the FOAK BWRX-300 installation currently under development in Canada may be used as part of the source term refinement process described in Subsection 7.2.6 and Appendix C. However, respective project schedule durations may mean that these data are not available on the timescales required for licensing and environmental permitting activities relating to a BWRX-300 installation in the UK.

The first OPG BWRX-300 reactor is scheduled to be in service by the end of 2030 ("OPG ready to begin building North America's first Small Modular Reactor," (Reference 7-35).

FAP.PER7-430 - A future developer/operator should utilise operational data for radioactive gaseous and aqueous liquid discharges from the first operating BWRX-300 SMR(s), and/or other relevant OPEX available at the time, in order to:

- **Further refine the radioactive discharge assessments for a BWRX-300 installation in the UK (see FAP.PER7-196)**
- **Provide additional evidence to support the BWRX-300 'maximum recirculation' philosophy for minimisation of radioactive discharges to the aquatic environment (see Subsection 7.4.2)**

7.3 Radioactive Discharge Routes – Gaseous

This section considers the means by which radioactive gaseous discharges that arise from the operation of the BWRX-300 process steam and water systems are collected, conveyed, treated, and discharged.

Figure 7-1 shows a simplified diagram of the components of the radioactive gaseous discharges, based on information from GEH's System Design Description (SDD) document 006N7899, "BWRX-300 Offgas System," (Reference 7-36), Ducting and Instrumentation Diagram (D&ID) 006N7782, "BWRX 300 Heating, Vent & Cooling System, HVS (U41)," (Reference 7-37), SDD 006N7948, "BWRX-300 Containment Inerting System," (CIS) (Reference 7-38), and 006N7717, "BWRX-300 Main Turbine Equipment," (MTE) (Reference 7-39).

The radioactive gaseous discharges from the BWRX-300 arise from:

- The HVS exhaust. This system includes the exhausts from:
  - The RB. This includes any purges of the containment via the CIS
  - The TB. This includes the radioactive gaseous releases from the TGSS
  - The RWB
- The OGS exhaust
- The occasional exhausts from the MVP

All the above exhausts discharge into the Continuous Exhaust Air Plenum (CEAP) and then the Plant Vent Stack (PVS). They are then discharged to atmosphere.

Each of the components above are described in the subsections that follow. Additional information is provided in PER Chapter E4 (Reference 7-8).

Radioactive discharges from potential sources outside of the power block are beyond the scope of a two-step GDA and so are not considered in this report. An assessment of additional radioactive discharges from other sources will be assessed at the site-specific stage, where relevant.

FAP.PER7-194 - Additional sources of gaseous or aqueous liquid radioactive discharges outside of the BWRX-300 power block (e.g., spent fuel store) are beyond the scope of GDA Step 2; these sources shall be included in future radioactive discharge assessments at the site-specific design stage.

7.3.1 Offgas System

The BWRX-300 OGS is described in detail in the OGS SDD (Reference 7-36) and Piping and Instrumentation Diagram (P&ID) 006N6528, "BWRX-300 K30 Offgas System," (Reference 7-40), and is summarised in this subsection.

The OGS processes Noncondensable (NC) gases from the Main Condenser and Auxiliaries (MCA) system that are produced through normal nuclear power operations. The main process influent to the system is a mix of steam, air, hydrogen, and radioactive noble gases from the MCA Steam Jet Air Ejectors (SJAEs). The objective of the OGS is to process this influent prior to release to the environment from the HVS. This processing reduces the release of gaseous radionuclides.

The processing includes two main functions:

- Recombination of hydrogen and oxygen into water to maintain plant water inventory and reduce hydrogen detonation risk
- Controlled adsorptive holdup of the radioactive isotopes of krypton, xenon, and argon to achieve adequate decay, thereby reducing the radioactivity of gaseous discharges from the plant

The OGS comprises the following components, as shown in the OGS SDD (Reference 7-36):

- Offgas recombiner: preheater section, catalytic recombiner section, and condenser section
- Cooler condenser and moisture separator
- Refrigeration dryers (two)
- Gas analyser (hydrogen, oxygen) including humidity monitor
- Offgas reheater
- Charcoal adsorber vault with heating, ventilation, and air conditioning equipment
- Charcoal adsorber tanks (four)
- Offgas HEPA filter

Further detail on the OGS is provided in PER Chapter E4 (Reference 7-8).

7.3.1.1 Mechanical Vacuum Pump

During startup only, the vacuum flow path is maintained by the MVP, and the OGS is bypassed, as stated in the OGS SDD (Reference 7-36).

The MVP, provided as a skid-mounted package, is used to remove the air from the condenser shells and associated turbine, creating the initial vacuum which allows the startup of the turbine unit. The MVP is capable of creating a sufficient vacuum of 34 kPa from atmospheric pressure within two hours.

The MVP takes suction from the shell side of the condenser and discharges the air extracted, which contains NC gases, along with excess seal water to the seal water separator. The separator collects moisture in the mixture in the bottom and discharges the compressed air to the CEAP/PVS (006N7757, “BWRX-300 Main Condenser and Auxiliaries System,” (Reference 7-41)).

7.3.2 Heating, Ventilation, and Cooling System

The BWRX-300 HVS is described in detail in the SDD document 006N7781, “BWRX-300 Heating Ventilation and Cooling System,” (Reference 7-42), and the HVS D&ID (Reference 7-37), and is summarised in this subsection.

The HVS serves all areas of the power block during normal operation, except for Primary Containment, which is serviced by the Containment Cooling System. The HVS maintains space design temperatures, quality of air, and pressurisation. It provides a controlled environment for personnel safety and comfort, and for the proper operation and integrity of equipment located in the power block. All of the potentially radioactive HVS subsystems exhaust to a common plant exhaust stack (via the CEAP) during all normal operation modes (HVS SDD (Reference 7-42)). The BWRX-300 RB, TB, and RWB are equipped with Air Handling Units (AHUs) to provide ventilation, which take suction on the respective buildings/areas. These AHUs are also provided with Adjustable Speed Drives (ASDs) to be able to adjust speed to maintain the buildings/areas at a negative pressure relative to outdoors. The design of the ventilation system thus ensures that air pressure in plant facilities handling radioactive substances are maintained at a lower level than atmospheric pressure, such that air flows into the facility from the external environment (HVS SDD (Reference 7-42)). This prevents the uncontrolled discharge of any radioactive substances through doors, windows, and gaps in the building fabric. Furthermore, the HVS 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) (HVS SDD (Reference 7-42)). 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. 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 (HVS SDD (Reference 7-42)).

Table 7-5 shows the main sources of radioactive gases exhausted from each building HVS (information extracted from HVS SDD (Reference 7-42) and HVS D&ID (Reference 7-37)).

7.3.2.1 Containment Inerting System

The CIS function is described in PER Chapter E4 (Reference 7-8). The principal objective of the CIS is to preclude the development of a combustible atmosphere by maintaining an oxygen deficient atmosphere inside containment, described in the CIS SDD (Reference 7-38). Purging of the CIS results in a radioactive gaseous discharge via the PVS. Purging occurs only at the start of an outage (nitrogen), and at the end of an outage (air).

The containment exhaust flow path begins where it penetrates in upper containment, on the opposite side of containment from the supply injection point. The exhaust flow path connects to the HVS before discharging to the PVS (CIS SDD (Reference 7-38)). Figure 7-2 shows a simplified diagram of the CIS, from the CIS SDD (Reference 7-38).

7.3.2.2 Turbine Gland Seal Subsystem

The TGSS supplies sealing steam (taken from the main steam supply) to the turbine shaft/casing penetrations and valve stems to prevent the escape of radioactive steam and to prevent air in-leakage through sub-atmospheric turbine glands (MTE SDD (Reference 7-39)).

Two 100% capacity Gland Steam Condenser (GSC) exhaust blowers maintain a slight vacuum on the GSC shell to remove NC gases and seal the turbine prior to startup. Water condensed by the GSC (which may contain tritium) is routed to the main condenser for recirculation in the plant, and NC gases are exhausted to the TB HVS (MTE SDD (Reference 7-39)). Operational experience has shown that during startup when the turbine gland sealing system is establishing a seal, any tritium that may be in the radioactive gaseous discharge from the TGSS is below the limit of detection. It is assumed in Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant (Reference 7-28) that 0.1% of the main steam flow is released from the TGSS, and that any tritium discharges from this subsystem are included in the TB HVS radioactive discharge assessment (see Table B-1).

Further detail on the TGSS is provided in PER Chapter E4 (Reference 7-8).

Figure 7-3 shows a simplified line diagram of the TGSS (adapted from MTE SDD (Reference 7-39)).

7.3.2.3 HEPA Filter Requirements

HEPA filters are specified for various building filtration systems and consist of extended medium dry-type filters in a rigid frame, having a minimum particle collection efficiency of 99.97% on 0.3-micron particles. Filters meet the applicable efficiency rating specified in ASME AG-1-2019, “Code on Nuclear Air and Gas Treatment,” (Reference 7-43), as described in the HVS SDD (Reference 7-42).

Potentially contaminated systems, areas, and rooms that exhaust to the HVS, other system exhausts that are passed through HEPA filtration before being routed to the CEAP are:

- TB HVS:
  - TB Shield Area
  - CFD
  - RB Access Arc areas
- RB HVS:
  - Inerting gases (from the CIS)
  - Shutdown Cooling System (SDC) room
  - Fuel Pool Cooling and Cleanup System (FPC) room
- RWB HVS:
  - Tank and pump rooms
  - Processing and storage area
  - Chemistry laboratory
  - Sampling areas
- OGS

It should be noted that the exhaust from the MVP is not HEPA filtered, as this system is not anticipated to be a source of particulate. The expected type of MVP is a Liquid Ring Vacuum Pump, which will have a separator (demister) that removes NC gases at the discharge. Therefore, no particulates are expected in the exhaust from the MVP and no HEPA filtration is needed.

7.3.2.4 Continuous Exhaust Air Plenum and Plant Vent Stack

The CEAP and PVS are integral to the TB and are located on the roof. Figure 7-4 shows a simplified flow diagram of the CEAP and PVS, as detailed in the HVS SDD (Reference 7-42). The top of the PVS is at ~35 m above ground level (005N9751, "BWRX-300 General Description," (Reference 7-44)).

The CEAP serves as a large mixing box where air collected by the HVS, OGS, TGSS, and the MVP 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 CEAP fans are provided with ASDs to be able to maintain the CEAP negatively pressurised relative to the atmosphere, and to allow for adjustments to CEAP inputs from varying exhaust flow rates from various buildings, based on the operation of the exhaust AHUs at each building (HVS SDD (Reference 7-42)).

The TB and RWB are provided with area and process radiation monitors to measure levels of radiation within each building. If radiation monitoring from the building is measured above setpoint, the supply air handlers and exhaust fans shut down and the building exhaust damper closes, isolating the building. The CEAP fans adjust speed to maintain flow from the remaining buildings (HVS SDD (Reference 7-42)). Further information on sampling and monitoring of radioactive discharges from the PVS is provided in PER Chapter E8 (Reference 7-9).

7.3.3 Operational Modes

It is assumed that the BWRX-300 is operating on a 12-month cycle with an outage of 10 to 20 days.

The BWRX-300 plant operational modes are defined in Table 7-6, adapted from Nuclear Boiler System (NBS) SDD document 006N7828, “BWRX-300 Nuclear Boiler System,” (Reference 7-45). A description of the operational modes can be found in the NBS SDD (Reference 7-45).

A discussion of the monthly and rolling monthly discharges based on the operational modes and cycles is presented in Subsection 7.5.1.2.

The key differences between radioactive gaseous discharges during power operations, start-up, and shutdown compared to those at outage are as follows:

- There is no radioactive discharge via the OGS and the TGSS during an outage, as the reactor is shut down during outage and no steam is produced
- The OGS only functions when the reactor has exceeded 5% of rated power output and the SJAEs are in service. During startup, the vacuum flow path is maintained by the MVP of the MCA system and the OGS is bypassed, as described in the OGS SDD (Reference 7-36)
- There are additional discharges via the HVS during an outage. This is due to increased evaporation as a result of the temporarily elevated fuel pool temperature as reactor water mixes with the fuel pool water and fuel is transferred from the reactor, as well as additional discharge routes from the reactor well, equipment pool, and the main condenser hotwell
- Additional discharges also occur from the CIS during outages. The CIS exhausts containment air to the HVS to support containment inerting and de-inerting (CIS SDD (Reference 7-38)). During shutdown and plant outages the nitrogen-interted atmosphere of the Steel Plate Composite Containment Vessel (SCCV) is purged to allow entry by plant workers (see SDD document 006N7823, “BWRX-300 Primary Containment System,” (Reference 7-46)). Breathable air is supplied by the HVS to personnel working within containment after containment has been de-inerted. The exhaust flow path from containment connects to the HVS in the de-inerting mode. It should be noted that the containment hatches are open during outages to allow personnel access (CIS SDD (Reference 7-38)).

The conservative total annual radioactive gaseous discharge estimates include any transient discharges generated from the CIS and MVP. However, it is acknowledged that the current analysis does not include a breakdown of radioactive gaseous discharges according to the operational mode of the plant. The regulatory requirement to quantify radioactive discharges both by source and operational mode (as presented in “New nuclear power plants: Generic Design Assessment guidance for Requesting Parties,” (Reference 7-17)) will be taken into account as part of **FAP.PER7-196** for refinement of the BWRX-300 EUST for radioactive discharges at the appropriate stage of design development.

7.4 Radioactive Discharge Routes – Aqueous Liquid

This section considers the aspects of the design that facilitate the BWRX-300 'maximum recirculation' philosophy, the LWM and, should it be required, the discharge route for any radioactive aqueous liquids.

At GDA Step 2 a single BWRX-300 unit is presented, which is situated in a coastal area. Therefore, should it be required, any radioactive aqueous liquids discharged will be into the marine environment. Details on the generic site description are provided in PER Chapter E2 (Reference 7-7).

Discharges from potential sources outside of the power block are beyond the scope of a two-step GDA and so they are not considered in this report. An assessment of discharges from other sources will be assessed at the site-specific stage, where relevant (**FAP.PER7-194**).

It is shown in 006N7789, "BWRX-300 Equipment and Floor Drain System (EFS)," (Reference 7-47), that any non-aqueous liquids are managed by other systems.

7.4.1 BWRX-300 Process Water Management

The BWRX-300 is a direct cycle plant and comprises one integral process water 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% flow purification. The water treatment systems utilised in the BWRX-300 design ensure that radioactivity removed from both the process water in the main steam circuit, and drained process water collected by equipment and floor drains, is concentrated and contained in filter backwash sludges and spent demineraliser resins that are subsequently managed as wet solid radioactive wastes. The process water management arrangements in the BWRX-300 design can be summarised as follows:

- Process water in the main steam circuit is treated by the CFD to maintain water purity prior to return to the reactor
- Process water captured in drains etc. is cleaned by the LWM to meet the reactor water quality specification prior to being returned to the steam circuit
- Out of specification or excess aqueous liquids are discharged to the environment. It should however be noted that the LWM is a multi-stage, fully configurable system designed to mitigate the impact of in-leakage of off-spec inventory including oils, grease, and organics, if present (see PER Chapter E6 (Reference 7-5))

An overview diagram of the BWRX-300 arrangements for process water management is provided in PER Chapter E5 (Reference 7-6).

It should be noted that sanitary waste from welfare facilities within the power block are handled by the Water, Gas, and Chemical Pads (WGC) System and are not treated as radioactive wastes, as described in the EFS SDD (Reference 7-47).

7.4.2 Maximum Recirculation Plant

The design intent of the BWRX-300 is to operate on the basis of a 'maximum recirculation' philosophy, whereby process fluids are retained within the plant to the maximum extent possible, and radioactive aqueous liquid discharges to the aquatic environment are minimised. This is achieved by use of highly effective treatment systems that clean process water, both in the main steam circuit and drained process water collected by the EFS, to meet the high purity standards detailed in the specification document 006N6766, "BWRX-300 Water Quality," (Reference 7-48). This allows the treated process water to be returned to the main steam circuit or used for ancillary functions within the plant. This promotes sustainability and minimises the requirement to top up the water system with fresh, demineralised water. It also minimises the volume and radioactivity of radioactive aqueous liquid discharges to the environment.

The BWRX-300 is capable of being operated, under normal operating conditions, without recourse to radioactive aqueous liquid discharges. GEH has formulated a Zero Release Plan, DBR-0060900, “BWRX-300 Zero Release Plan,” (Reference 7-49), which describes a philosophy of treating all process water within the plant such that the BWRX-300 may operate with zero[7] radioactive aqueous liquid discharges to the aquatic environment. 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. However, occasional radioactive aqueous liquid discharges may be required in order to maintain the overall water balance of the plant.

OPEX from the U.S. demonstrates that many BWRs are successfully operated on a basis that enables a ‘maximum recirculation’ philosophy to be applied to minimise radioactive aqueous liquid discharges or eliminate them altogether (“zero release”), for extended periods of time. A review of publicly available data for U.S. NPPs, NEDC-34279P, “Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants,” (Reference 7-50), shows that several U.S. BWR plants operate on a zero radioactive aqueous liquid discharge basis and have done so for many years. Some other plants generally operate on a “zero release” basis with occasional radioactive aqueous liquid discharges.

It should be noted that whilst information is available in the public domain that supports the ‘maximum recirculation’ philosophy for BWRs, no operational data are currently available for the FOAK BWRX-300 plant. OPG are planning to construct up to four BWRX-300 SMRs at the DNNP site in Ontario, Canada. In principle, provision of radioactive aqueous liquid discharge data from the BWRX-300 installation currently under development in Canada may provide additional evidence for implementation of the ‘maximum recirculation’ philosophy in an operational BWRX-300 facility. However, respective project schedule durations may mean that these data are not available on the timescales required for licensing and environmental permitting activities relating to a BWRX-300 installation in the UK (see Subsection 7.2.6.1 and **FAP.PER7-430**).

7.4.3 The Liquid Waste Management System

The BWRX-300 LWM reclaims, processes, and stores treated process water from various streams for use by other plant systems. The LWM cleans process water collected from plant areas via the EFS (floor drains and process drains) in the RB, TB, RWB, and SCCV (EFS SDD (Reference 7-47)). It also filters, stores, and refills the reactor cavity water volume during refuelling operations. The system is described in SDD document 006N7729, “BWRX-300 Liquid Waste Management System (LWM),” (Reference 7-51). The system is called the LWM, but it should be noted that aqueous liquids treated in the LWM are process fluids intended for appropriate treatment followed by recirculation in the plant, noting that is expensive to discharge very high-quality water that could be returned to the steam circuit and ancillary systems. The process water treated by the LWM only becomes waste if it can no longer be recirculated, in which case it must be disposed of to the aquatic environment. The LWM filtration skids (see PER Chapter E4 (Reference 7-8)) treat the collected process water on a batch basis and then send the treated water to the Waste Sampling Subsystem (see Subsection 7.4.3.1). Treated process water that meets the criteria in accordance with the Reactor Water Quality Specification (Reference 7-48), will be pumped to the Condensate Storage Tank (CST) for recirculation within the plant (LWM SDD (Reference 7-51)). The various water systems within the BWRX-300 are suitably sized such that the total process water volume (within the systems) can be accommodated at all times under all normal

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

operating conditions (including outages), as described in 006N7673, “GEH BWRX-300 Water Balance,” (Reference 7-52).

In the unlikely event that the plant’s overall water inventory will not allow for the water to be recirculated, the treated process water can be discharged to the environment. Any potential environmental discharge is controlled to ensure concentrations of contaminants are maintained within permissible discharge limits. Radioactive discharges to the environment are monitored by the Process Radiation and Environmental Monitoring System (PREMS). PREMS will automatically halt the discharge upon receiving a trip signal to ensure the release of radioactive aqueous liquids meets any discharge permit requirements (LWM SDD (Reference 7-51)). The trip will identify if any preset values/limits (aligned to permit requirements) are exceeded. PER Chapter E8 (Reference 7-9) presents the PREMS in more detail.

Further detail on the systems for management and treatment of process water, and detailed design information on the LWM is provided in PER Chapter E5 (Reference 7-6) and PER Chapter E4 (Reference 7-8) respectively.

7.4.3.1 Radioactive Aqueous Liquid Discharge

In the event that a radioactive aqueous liquid discharge is required, the BWRX-300 Waste Sampling Subsystem (described below) is equipped with a discharge path to the Circulating Water System (CWS) for release to the aquatic environment. The discharge path contains a locked closed manual valve, a radiation monitor, sample line, flow control valve, flow meter, and two air operated valves for automatic isolation if radiation greater than a preset limit is detected in the flow stream. A demineralised water line from the WGC system is provided for flushing the discharge line (LWM SDD (Reference 7-51)).

The Waste Sampling Subsystem consists of two Sample Tanks, two transfer pumps, and associated piping and valves. The Sample Tanks are the end process point of the LWM where treated process water from the filtering skids is sampled. The water is returned to the CST if the reactor water quality specification (Reference 7-48) is met or can be released to the environment if water inventory does not allow return to the CST. If the water quality specification is not met, the Sample Tank contents can be routed to the LWM Collection Tanks for reprocessing. The Sample Tanks may also receive overboarding[8] flow from the SDC and the Reactor Water Cleanup System (CUW).

Figure 7-5 shows a simplified diagram of the Waste Sampling Subsystem. The LWM discharge line connects with the outlet line of the main condenser, part of the CWS, within the TB, as shown in P&ID 006N7762, “BWRX-300 Circulating Water System (CWS),” (Reference 7-53). The system contains a return line to the Collection Tanks. Therefore, treated process water that does not meet the required water quality for recirculation can be returned for further treatment rather than having to be discharged.

7.4.4 Operational Modes Considered

It should be noted that the operational mode of the plant (see Table 7-6) does not influence the volume or frequency of radioactive aqueous liquid discharges from the BWRX-300, as drained process water is collected and processed on a batch basis by the LWM. The BWRX-300 design also includes processing capabilities for the use of temporary storage if excess water is used or enters the plant (i.e., during an outage) (BWRX-300 Zero Release Plan (Reference 7-49)). Refuelling outages typically place the greatest demands on NPP water storage and treatment facilities compared to other operational events. The BWRX-300 Water Balance (Reference 7-52), for BWRX-300 refuelling outages aims to stay within the available storage capacity limits to reduce, or avoid, radioactive discharges to the environment

[8] The term “overboarding” refers to how the system maintains the overall water balance and/or level control.

of treated aqueous liquids. Any necessary radioactive aqueous liquid discharges from the BWRX-300 will be determined by operational decisions to maintain the overall water balance of the plant, as described in the following subsection.

7.4.5 Operational Management of Radioactive Aqueous Discharges

Whilst in principle the BWRX-300 is capable of operating without recourse to radioactive aqueous liquid discharges, it is acknowledged that any future site-specific environmental permit application shall include discharge limits (**FAP.PER7-196**) to allow provision for any necessary radioactive discharges via the aqueous liquid pathway. It will be for a BWRX-300 plant developer/operator to determine the operational requirements for radioactive aqueous liquid discharges at the site-specific stage.

A consideration for a future developer/operator is the management of tritium. The BWRX-300 produces only a small fraction of the tritium produced by a CANDU[9] or Pressurised Water Reactor (PWR) because boron is not used in reactor water. However, tritium has a relatively long half-life and is unaffected by the LWM and other cleanup systems. BWRs that periodically make radioactive aqueous liquid discharges release roughly half of the tritium produced in gaseous forms through the plant ventilation systems. When all radioactive aqueous liquid discharges are eliminated, the tritium in the process water eventually reaches an equilibrium level that is twice that of a BWR that discharges radioactive aqueous liquids to the environment, and all the new tritium produced is released through the gaseous release points.[10]

The radiological dose due to tritium discharged from a gaseous release point can, depending on plant design and site characteristics, be higher than the same amount of tritium discharged from an aqueous liquid release point. This along with economic considerations provides the plant developer/operator an opportunity to optimise the mode of LWM operation to be ALARA for any given site.

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

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

[9] CANada Deuterium Uranium
[10] It should be noted that BWRs, including the BWRX-300, do not require radioactive aqueous liquid discharges to lower tritium levels in order to allow refuelling.

7.5 Radioactive Discharge Assessments

As the BWRX-300 is a FOAK plant, no radioactive discharge measurement data are presently available. The radioactive discharge assessments presented here are calculations based on U.S. codes and standards which produce conservative outputs. The basis of these calculations and the conservatisms within are discussed in Subsection 7.2.4 of this chapter.

As no developer/operator is yet in place, three scenarios for radioactive aqueous liquid discharge are presented and bounding cases, for both radioactive gaseous and aqueous liquid discharges, established.

In the subsections that follow, these, and other aspects of the radioactive discharge assessments for radioactive gaseous and aqueous liquid discharges from the BWRX-300, are presented.

7.5.1 Scenarios Presented and Bounding Case

As the operating decisions on radioactive aqueous liquid discharges have not yet been determined, three scenarios are presented for radioactive gaseous and aqueous liquid discharges under normal operations over a year. This will help the future developer/operator when making site-specific decisions on plant operation and applications for permit discharge limits. The lack of an operations decision on management arrangements for radioactive aqueous liquid discharges was identified earlier as a forward action (**FAP.PER7-195**)

The three scenarios presented for annual radioactive aqueous liquid discharge are:

- Minimal discharge (0 cubic metres per year (m^3/y)). All process water is retained and recirculated (‘maximum recirculation’) within the plant, with no recourse to radioactive aqueous liquid discharges to the aquatic environment
- Maximum discharge (5,968 m^3/y). 100% of the radioactive aqueous liquids processed through the LWM are discharged
- Realistic discharge (600 m^3/y). Approximately 10% of the radioactive aqueous liquids processed through the LWM are discharged

These scenarios are described in Table 7-7.

The conservative bounding radioactive discharge assessments have been used to calculate the radiological dose assessments and impacts to members of the public at a generic site. This is discussed in PER Chapter E9 (Reference 7-10).

The future developer/operator is not committed to the chosen scenarios (**FAP.PER7-195**).

7.5.1.1 Headroom Factors and Discharge Limits

The minimal and maximum scenarios for radioactive aqueous liquid discharge (defined in Subsection 7.5.1) represent the bounding cases for radioactive discharges to the environment from the BWRX-300. As a result of the conservatism built into the maximum radioactive aqueous liquid discharge scenario, no additional headroom factors have been applied at this stage of the GDA. To include a headroom factor onto the radioactive discharges presented in Subsections 7.5.2 and 7.5.3 will only add further conservatism.

For the purposes of GDA Step 2, the conservative and bounding scenarios presented in the following subsections for radioactive gaseous and aqueous liquid discharges may be considered to represent the discharge limits at this early stage of regulatory assessment. It is acknowledged that the radioactive discharge assessments for future environmental permitting phases will require further refinement (after Step 2 of the GDA). Once refined PST and EUST are determined then updated assessments of radioactive gaseous and aqueous liquid discharges, headroom factors, and proposed discharge limits can be presented (**FAP-PER7-196).**

7.5.1.2 Monthly Discharges

A prediction of monthly and rolling monthly radioactive discharges is not presented in this chapter, as at this stage of the GDA, GEH considers this to be premature. This is for the following reasons:

- The radioactive gaseous discharge is relatively steady over an operating cycle with minor changes at outages
- The refined EUST have not yet been determined
- Design basis AOOs and their impacts on radioactive discharges have not yet been fully determined
- The management arrangements for radioactive aqueous liquid discharges (see Subsection 7.4.5) have not yet been determined

Evidence of the steady nature of the discharges from BWR operation is provided in Quantification of Discharges and Limits (Reference 7-31). This contrasts with PWRs where there can be spikes in discharge volumes when delay tanks are released.

GEH recognise that, in the future, monthly and rolling monthly radioactive discharge assessments will be required (**FAP.PER7-196**)).

7.5.2 Radioactive Gaseous Discharge Assessments

The anticipated radioactivity of annual gaseous discharges for the three scenarios discussed in Subsection 7.5.1 are presented in the following subsections. For the maximum and realistic radioactive aqueous liquid discharges, only the total annual radioactivity of gaseous discharges are presented.

For the minimal radioactive aqueous liquid discharge scenario, which is the conservative bounding scenario for radioactive gaseous discharges, a breakdown by discharge route is also provided in Table B-1 in Appendix B.

7.5.2.1 Radioactive Gaseous Discharge Assessment for the Minimal Radioactive Aqueous Liquid Discharge Scenario

The data presented in Table 7-8 is extracted from Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant (Reference 7-28). The methodology for calculation of the radioactivity of gaseous discharges is also described in detail in Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant (Reference 7-28).

Table 7-8 is for normal operations, including AOOs.

The total annual gaseous discharge radioactivity is produced from summing the radioactivity expected to be generated from the following sources:

- HVS:
  - RB
  - PLSA[11]
  - TB
  - RWB
  - MVP
  - TGSS
  - Containment
- OGS

The annual gaseous radioactivity contribution from each route is presented in Table B-1 in Appendix B.

7.5.2.2 Radioactive Gaseous Discharge Assessment for the Realistic Radioactive Aqueous Liquid Discharge Scenario

In this scenario the radioactive gaseous discharges are as presented in Table 7-8, except that the tritium discharge will be reduced. The exact reduction has not been calculated.

7.5.2.3 Radioactive Gaseous Discharge Assessment for the Maximum Radioactive Aqueous Liquid Discharge Scenario

In this scenario the radioactive gaseous discharges are as presented in Table 7-8, except that the tritium discharge will be reduced. The exact reduction has not been calculated.

7.5.3 Radioactive Aqueous Liquid Discharge Assessments

The radioactivity of aqueous liquid discharges for the three scenarios discussed in Subsection 7.5.1 are presented in the following subsections.

7.5.3.1 Radioactive Aqueous Liquid Discharge Assessment for the Minimal Radioactive Aqueous Liquid Discharge Scenario

In this scenario there will be 0 m^3/y radioactive aqueous liquid discharges from the BWRX-300 plant.

7.5.3.2 Radioactive Aqueous Liquid Discharge Assessment for the Maximum Radioactive Aqueous Liquid Discharge Scenario

The data presented in Table 7-9 is for normal operations, including AOOs, and is taken directly from BWRX-300 Annual Average Liquid Effluent Activity Releases (Reference 7-30). The methodology for calculation of the radioactivity of aqueous liquid discharges using the GALE-BWR 3.2 code is described in detail in BWRX-300 Annual Average Liquid Effluent Activity Releases (Reference 7-30).

[11] As a result of ongoing design development during GDA timescales, the PLSA exhaust is no longer considered to contribute to radioactive gaseous discharges from the BWRX-300 (see Subsection 7.2.4.1), and is not routed to the CEAP/PVS at the DRP for GDA Step 2. However, a contribution from the PLSA (comprising 1.4% of the total annual radioactive gaseous discharges) is included in the radioactive discharge assessments generated using the GALE-BWR methodology described in NUREG-0016 (Reference 7-25), which are presented in this section.). As bounding conditions are presented in this section, the PLSA contribution has continued to be included.

The concentration of tritium in radioactive aqueous liquid discharges is expected to be the same as in the reactor coolant, as described in BWRX-300 Coolant Radiation Concentrations (Reference 7-26). Assuming a maximum volume of 5,968 m^3/y (calculated from data in BWRX-300 Annual Average Liquid Effluent Activity Releases (Reference 7-30)), this would equate to a maximum annual tritium discharge radioactivity of 3.10E+12 Becquerels per year (Bq/y), assuming normal operation coolant concentrations. It is noted that this would effectively be as short-term releases (from the Sample Tank(s), see Subsection 7.4.3.1), rather than a continuous annual radioactive discharge.

This scenario represents the conservative bounding case for radioactive aqueous liquid discharges.

7.5.3.3 Radioactive Aqueous Liquid Discharge Assessment for the Realistic Radioactive Aqueous Liquid Discharge Scenario

The data presented in Table 7-10 is the data from Table 7-9 adjusted for a radioactive aqueous liquid discharge of 600 m^3/y rather than a 100% radioactive aqueous liquid discharge (5,968 m^3/y).

The annual tritium discharge radioactivity for a 600 m^3/y radioactive aqueous liquid discharge is 3.12E+11 Bq/y. This would be as short-term releases (from the Sample Tank(s), see Subsection 7.4.3.1), rather than a continuous annual radioactive discharge.

7.5.4 Significant Radionuclides

Based on the assessments undertaken in Subsections 7.5.2 and 7.5.3, and PER Chapter E9 (Reference 7-10), the current significant radionuclides (in terms of total radioactivity and radiological dose considerations) identified for radioactive gaseous discharges are:

- Krypton-89
- Other noble gases
- Iodine-131
- Tritium
- C-14

The current significant radionuclides identified for radioactive aqueous liquid discharges are:

- Tritium
- Cobalt-60
- Zinc-65
- Phosphorus-32

However, as has been established earlier in this chapter, the EUST require refinement and this may impact the radioactivity and radiological dose contributions of significant radionuclides (**FAP.PER7-196**).

7.6 Comparison with International Plants

This section provides a comparison between the bounding conservative estimates of the radioactivity of BWRX-300 gaseous and aqueous liquid discharges and the radioactive discharges from other NPPs. The BWRX-300 radioactive discharge scenarios used in the comparisons in the following subsections are:

- Radioactive gaseous discharges - the conservative, bounding case (discharge limit for GDA Step 2) aligned with the minimal discharge scenario for radioactive aqueous liquid discharges (see Subsection 7.5.2.1) is used
- Radioactive aqueous liquid discharges – both the maximum (conservative, bounding case and discharge limit for GDA Step 2 – see Subsection 7.5.3.2) and the ‘realistic’ (see Subsection 7.5.3.3) discharge scenarios are presented

The bounding case for radioactive gaseous discharges and the ‘realistic’ scenario for radioactive aqueous liquid discharges have been selected as representative of the design intent of the BWRX-300 to recirculate process fluids to the maximum extent possible, while recognising that occasional radioactive aqueous liquid discharges to the aquatic environment may be required during the course of normal plant operations. The bounding case (maximum discharge) for radioactive aqueous liquid discharges, presented as the discharge limit for GDA Step 2, is also included for comparative purposes; however, it should be noted that this is a highly unlikely mode of plant operation.

As the BWRX-300 is a FOAK BWR SMR that has not yet been operated, a direct comparison of radioactive discharges to operational BWRX-300 reactors is not possible. Therefore, for the purposes of satisfying the requirements of the GDA, comparisons of radioactive discharges to the environment have been made to the following:

- Proposed radioactive discharges from the BWRX-300 reactor being constructed at DNNP site, Ontario, Canada (see Subsection 7.2.6.1)
- Proposed radioactive discharges from the UK ABWR
- Measured radioactive discharge data from a range of operational U.S. BWRs
- Measured radioactive discharge data from selected European and UK reactors
- Proposed radioactive discharges from the Rolls-Royce SMR

The radioactivity of all discharges is presented as Becquerel per Gigawatt hour (Bq/GWh) as this normalises the radioactive discharges against power output and operating time.

When comparing radioactive discharges, it should be noted that the BWRX-300 radioactive gaseous and aqueous liquid discharges presented in this chapter are the bounding cases based on a cautious and conservative EUST, which are presented as the discharge limits at GDA Step 2. However, the values provided for the international plants are based on measured operating data, and may be expected to be well below the permitted limits for the selected facilities.

7.6.1 Comparison with Darlington BWRX-300 and UK ABWR

OPG are planning to construct up to four BWRX-300 SMRs at the DNNP site in Ontario, Canada (Subsection 7.2.6.1).

The UK ABWR was a proposed twin BWR conventional power plant that was to be built in the UK at Wylfa, Anglesey by Horizon, detailed in WN0908-HZCON-PAC-REP-00003, “Wylfa Newydd Project Radioactive Substances Regulation – Environmental Permit Application,” (Reference 7-54). The proposal was eventually withdrawn in the late-2010s.

These are useful comparisons as they are current/recent BWR plants designed by GEH. The BWRX-300, while primarily a design evolution of the ESBWR, was also partially developed from the ABWR, and the Canadian SMR is based on the same BWRX-300 Standard Design as the BWRX-300 presented in this GDA report. However, OPG have produced an EUST for radioactive aqueous liquid and gaseous discharges, generated using the ANSI/ANS-18.1-2020 standard (see Subsection 7.2.3) and GALE-BWR methodology (see Subsection 7.2.4), tailored to the DNNP BWRX-300 site-specific application. These data therefore provide an indication of how the anticipated radioactivity of gaseous and aqueous liquid discharges may be expected to change for a site-specific project, noting that the EUST will be refined for future development phases of a BWRX-300 installation in the UK (**FAP.PER7-196**). It should be noted that the UK ABWR data are also based on a refined RM PST for radioactive gaseous discharges.

The comparison is based on data in UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31), Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant (Reference 7-28), BWRX-300 Annual Average Liquid Effluent Activity Releases (Reference 7-30), the UK ABWR Wylfa Newydd Environmental Permit Application (Reference 7-54), and NEDO-33970, "Darlington New Nuclear Project, BWRX-300 Preliminary Safety Analysis Report Chapter 20: Environmental Aspects," (Reference 7-55).

7.6.1.1 Comparison of Radioactive Gaseous Discharges

The comparison of the anticipated radioactive gaseous discharges of the three plants (based on single units) is presented in Table 7-11.

For clarity, the BWRX-300 presented for this GDA is referred to as BWRX-300 (GEH) in this subsection. The OPG Canadian BWRX-300 is referred to as the BWRX-300 (OPG).

The BWRX-300 (GEH) normalised annual radioactive gaseous discharge activity (Bq/GWh), as presented, is currently the largest out of the three units. This serves to highlight the conservatisms applied to calculation of the BWRX-300 (GEH) estimated radioactive gaseous discharges, based on the available EUST data. Significant decreases in the anticipated radioactivity of BWRX-300 (GEH) gaseous discharges can be expected when a EUST based on a refined RM PST is applied and unrealistic conservatisms applied by the GALE-BWR methodology are addressed (as has been done for the BWRX-300 (OPG) and UK ABWR) (**FAP.PER7-196**). This will allow a more representative comparison to be made. Information relating to opportunities for future refinement of the BWRX-300 EUST are presented in Appendix C.

7.6.1.2 Comparison of Radioactive Aqueous Liquid Discharges

The comparison of the radioactive aqueous liquid discharges of the three plants (based on single units) is presented in Table 7-12. This allows for comparison of annual radioactivity discharged, normalised for unit power output. However, the analysis does not consider the impact of the annual volume of the radioactive aqueous liquid discharges. The radioactive aqueous liquid discharge volumes used in this comparison are as follows:

- BWRX-300 (GEH, maximum) – maximum discharge volume of 5,968 m^3/y (total volume of all drained process water anticipated to be treated annually by the LWM)
- BWRX-300 (GEH, realistic) – 'realistic' discharge volume of ~600 m^3/y (~10% by volume of all drained process water treated annually by the LWM)
- BWRX-300 (OPG) – a discharge volume was not specified by OPG
- UK ABWR – discharge volume of 600 m^3/y

The total normalised radioactivity of the radioactive aqueous liquid discharges from the BWRX-300 (GEH, realistic), BWRX-300 (OPG), and UK ABWR per GWh are broadly similar, and the radioactivity is dominated by the tritium radioactivity. The radioactivity of the BWRX-300 (GEH, maximum) normalised annual radioactive aqueous liquid discharge is approximately an order of magnitude higher than the other estimates presented, as this scenario represents the conservative, bounding case and the discharge limit for GDA Step 2.

7.6.2 Comparison with Selected International NPPs

A review of annual discharges of gaseous and aqueous liquid radioactive waste from similar reactor types in Europe and the UK, and BWRs in the U.S., was undertaken as part of the UK ABWR quantification of discharges and limits, presented in UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31).

It is considered useful to compare this data with the proposed BWRX-300 and the 470 MWe Rolls-Royce SMR estimated radioactive discharge data, aligned with the UK regulators' expectation that the RP must demonstrate that radioactive discharges from New Nuclear Power Plants (NNPPs) will not exceed those of comparable power stations across the world, as required by UK government policy (see "New nuclear power plants: Generic Design Assessment guidance for Requesting Parties," (Reference 7-17) and CM 7296, "Meeting the Energy Challenge, A White Paper on Nuclear Power," (Reference 7-56).

The radioactive discharge data for the selected international NPPs (European and UK reactors, and U.S. BWRs) was extracted for the period 2005 to 2014 and averaged. In the case of the NNPP designs for which operational data is not available, estimates of the radioactivity of the gaseous and aqueous liquid discharges are used:

- UK ABWR data are taken from UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31)
- BWRX-300 (GEH) data are taken from Subsections 7.5.2 and 7.5.3 of this report
- BWRX-300 (OPG) data are taken from Darlington New Nuclear Project, BWRX-300 Preliminary Safety Analysis Report Chapter 20: Environmental Aspects (Reference 7-55)
- Rolls-Royce SMR data are taken from SMR0004486, "Environment, Safety, Security and Safeguards Case Version 2, Tier 1, Chapter 29: Quantification of Radioactive Effluent Discharges and Proposed Limits," (Reference 7-57)

It is important to note that the degree to which a comparison may be made between the anticipated radioactive discharges from the BWRX-300 and those of the international NPPs presented is limited at GDA Step 2. This is because 'actual' operational data for the international NPPs (which may be expected to be well below the permitted limits for the selected facilities) is being compared with conservative and bounding estimates of the radioactive discharges from the BWRX-300 (GEH) (which represent the discharge limits for GDA Step 2). Whilst in principle future opportunities may exist for use of measured discharge data from the FOAK BWRX-300 (OPG) installation currently under development in Canada, respective project schedule durations may mean that these data are not available on the timescales required for licensing and environmental permitting activities relating to a BWRX-300 installation in the UK (see Subsection 7.2.6 and **FAP.PER7-430**).

7.6.2.1 Radioactive Gaseous Discharge Comparison

Normalised data for radioactive gaseous discharges from selected European and UK reactors, and U.S. BWRs, are reproduced in Table 7-13 from UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31). Estimated data for the proposed BWRX-300 (GEH) (see Subsection 7.5.2), BWRX-300 (OPG), UK ABWR, and the 470 MWe

Rolls-Royce SMR (see SMR0004486 (Reference 7-57)) are included for comparative purposes.

The data indicates that the bounding case radioactivity of the radioactive gaseous discharges for the BWRX-300 is at the top end of the comparable plant radioactive discharges when normalised for radioactivity per GWh. It is not, however, orders of magnitude higher than other plants at the top end of radioactive gaseous discharges and it is noted that the BWRX-300 (OPG) data show reduced radioactive discharges of noble gases and carbon-14 compared to BWRX-300 (GEH). GEH anticipates that the radioactivity of these discharges will be reduced when refined EUST are produced (**FAP.PER7-196** and Appendix C), noting the conservatisms applied to the current analysis (see Subsection 7.2.4.3).

7.6.2.2 Radioactive Aqueous Liquid Discharge Comparison

Normalised data for radioactive aqueous liquid discharges from selected European and UK reactors, and U.S. BWRs, are reproduced in Table 7-14 from UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31). Estimated data for the proposed BWRX-300 (GEH, maximum), BWRX-300 (GEH, realistic), BWRX-300 (OPG), UK ABWR, and Rolls-Royce SMR (SMR0004486 (Reference 7-57)) are again included for comparative purposes.

The data indicates that when normalised for radioactivity per GWh the ‘realistic’ radioactivity of the tritium and beta/gamma radioactive aqueous liquid discharges for the BWRX-300 is comparable to the international NPPs and operational U.S. BWRs. The BWRX-300 (GEH, maximum) conservative, bounding case for normalised annual radioactive aqueous liquid discharges (discharge limit for GDA Step 2) is an order of magnitude higher than the international BWRs, but is comparable to Sizewell B and Heysham 2.

Extensive OPEX from U.S. BWRs indicates that similar NPPs to the BWRX-300 may operate successfully on the basis of a ’maximum recirculation’ philosophy to minimise radioactive aqueous liquid discharges, or eliminate them altogether (“zero release”), for extended periods of time (up to ten years for selected plants studied), in accordance with Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants (Reference 7-50). The BWRX-300 radioactive aqueous liquid discharge volume for future environmental permitting stages will be determined by a future developer/operator, and refined EUST will be produced, to provide a refined estimate of the radioactivity of aqueous liquid discharges (**FAP.PER7-195 and FAP.PER7-196**).

7.7 Conclusion

This chapter of the PER has presented conservative bounding estimates of the radioactivity of the gaseous and aqueous liquid radioactive discharges for the GEH BWRX-300, which may be considered to be the discharge limits for the purposes of GDA Step 2.

In addition, to the discharge limit, radioactive aqueous liquid discharge scenarios are also presented for minimal radioactive aqueous liquid discharge (aligned with the design intent of the BWRX-300 to operate according to a 'maximum recirculation' philosophy) and an indicative 'realistic' radioactive aqueous liquid discharge volume of 600 m^3/y. GEH considers that the radioactive discharge assessment presented satisfies Step 2 of the GDA.

The BWRX-300 conservative bounding radioactive gaseous and aqueous liquid discharges, and a 'realistic' scenario for radioactive aqueous liquid discharges, have been compared to international plants and are comparable, when normalised for power output and operating hours.

GEH fully expect the anticipated radioactivity of gaseous and aqueous liquid discharges to reduce once refined EUST have been produced, and the radioactive aqueous liquid discharge volume is confirmed.

Forward actions to develop the radioactive discharge assessments, beyond Step 2 of the GDA, have been identified and a FAP produced.

Table 7-1: Overview of Document Scope

Key Area	Document Scope	Relevant Section(s)
Origin of the radioactivity in gaseous and aqueous liquid radioactive waste	Sources and production mechanisms of relevant radionuclides are presented, including the radiological source terms used in calculating the radioactivity of the gaseous and aqueous liquid radioactive discharges to the environment.	Section 7.2
Systems and processes from which gaseous and aqueous liquid radioactive waste arise	Relevant systems, processes, and plant areas are identified.	Subsection 7.2.1
Conveyance, collection, and segregation of gaseous and aqueous liquid radioactive waste	Plant systems and processes that perform these functions are identified, and high level descriptions presented.	Section 7.3 and 7.4
Treatment of gaseous and aqueous liquid radioactive waste	• Systems and processes that reduce the radioactivity of gaseous and aqueous liquid radioactive waste prior to release are identified and described. • Design features supporting a ‘maximum recirculation’ philosophy that enable the BWRX-300 to operate, under normal operating conditions, with minimal radioactive aqueous liquid discharges to the environment are presented.	Subsection 7.3.1, 7.3.2.3, 7.4.2, and 7.4.3
Sampling and monitoring of gaseous and aqueous liquid radioactive waste	It is identified where provision for sampling and monitoring of radioactive discharges for final discharge accountancy has been incorporated into the BWRX-300 design. Detailed information on sampling and monitoring is provided in PER Chapter E8 (Reference 7-9).	Subsection 7.3.2.4, 7.4.3, and 7.4.3.1
Radioactive gaseous and aqueous liquid discharge routes to the environment	Radioactive discharge routes are identified and described.	Subsection 7.3.2.4 and 7.4.3.1
Radioactivity of gaseous and aqueous liquid discharges	Radioactive discharge assessments are presented for radioactive gaseous and aqueous liquid discharges. As the radioactive aqueous liquid discharge volumes from the BWRX-300 are yet to be confirmed, three different radioactive aqueous liquid discharge scenarios are described. From these three scenarios, conservative bounding assessments of the radioactivity of the gaseous and aqueous liquid radioactive discharges to the environment from the normal operation of the BWRX-300 are generated.	Section 7.5

Key Area	Document Scope	Relevant Section(s)
Comparison of the radioactive gaseous and aqueous liquid discharges from BWRX-300 with other NPPs	A comparison is presented, with the radioactivity normalised for power output and operating hours, of the BWRX-300 radioactive gaseous and aqueous liquid discharges (conservative bounding cases), and a(‘realistic’ scenario for radioactive aqueous liquid discharges, with operational reactors in the UK, U.S., and Europe. Additional comparisons are made to: • UK ABWR • Data provided by OPG for a site-specific BWRX-300 project • Rolls Royce SMR	Section 7.6

Table 7-2: Regulatory Expectations and GDA Step 2 Scope

Regulatory Expectation (3 Step GDA)	GEH Response (2 Step GDA)
A requirement for quantitative estimates of discharges of gaseous and aqueous radioactive wastes for normal operation.	• Conservative bounding annual quantitative estimates are provided – Section 7.5. • The estimates include AOOs.
The RP must estimate the monthly discharges for significant radionuclides at each discharge point and route.	• Monthly estimates have not been provided – see Subsection 7.5.1.2. • The significant radionuclides are identified – Subsection 7.5.4. These are discussed further in PER Chapter E8 (Reference 7-9).
The radionuclide selection should be consistent with 2004/2/Euratom.	• Radionuclide selection is discussed in Subsection 7.2.5. • Although this selection is not fully consistent with 2004/2/Euratom, GEH consider that the approach presented in this 2-Step GDA meets requirements.
Estimates of discharges and disposals should clearly show the contribution of each aspect of normal operations.	• Annual conservative bounding quantitative estimates are provided – Section 7.5. A breakdown by source for the bounding case gaseous discharge only is provided – Appendix B. GEH consider that this meets the requirements necessary for a 2-Step GDA. • Operational modes are discussed in Subsection 7.3.3 and AOOs are discussed in Subsection 7.2.4.4.
Discharge estimates must be supported with performance data from similar facilities, where such facilities exist. Where such data is unavailable, discharges could be derived from the primary coolant source term.	• Section 7.2 describes how the EUST for the discharges have been derived. • As no decision has yet been taken on the volume of radioactive aqueous liquids that will be discharged, three scenarios are presented to allow a range of annual quantitative estimates to be calculated.
The RP must demonstrate that discharges will not exceed those of comparable power stations across the world, as required by UK government policy, according to CM 7296, “Meeting the Energy Challenge, A White Paper on Nuclear Power,” (Reference 7-56).	A comparison with other NPPs is provided – Section 7.6.
The RP must provide proposed limits for: • Gaseous discharges • Aqueous discharges	Conservative bounding annual quantitative estimates are provided – Section 7.5. GEH considers that these represent the maximum limit of gaseous and aqueous liquid radioactive discharges from the BWRX-300 and may be considered to be the discharge limits for the purposes of GDA Step 2.

Regulatory Expectation (3 Step GDA)	GEH Response (2 Step GDA)
The RP must provide proposals for: • Annual site limits (on a rolling 12-month basis) for gaseous and aqueous discharges. • The RP must describe how they derived these limits. They can also propose limits to reflect an operating cycle (campaign limits).	GEH considers that this is premature for the submission of a 2-Step GDA. This is discussed under Subsection 7.5.1.2.

Table 7-3: Comparison of BWRX-300 and UK ABWR RM PST

	Geometric Mean of BWRX-300 RM: UK ABWR RM PST Radionuclide Ratios by Class[1]					
	Class 1	**Class 2**	**Class 3**	**Class 4**	**Class 5**	**Class 6 (FPs Only)**
Water	N/A	26.4	15.5	1.5	2.9	0.7
Steam	245.4	26.3	15.5	3.1	2.9	0.7

Note:

1. Radionuclide classes are defined as follows:

- Class 1 – Noble gas
- Class 2 – Halogens (iodines)
- Class 3 – Caesium, rubidium
- Class 4 - Water APs (nitrogen-16)
- Class 5 – Tritium
- Class 6 – Other radionuclides

Table 7-4: 2004/2/Euratom Radionuclides not Included in the BWRX-300 Radioactive Discharge Assessments

Radioactive Gaseous Discharges	Radioactive Aqueous Liquid Discharges
Antimony-122	Strontium-90
Antimony-125	Antimony-122
Plutonium-238	Tellurium-123m
Plutonium-239 + plutonium-240	Antimony-124
Americium-241	Antimony-125
Curium-242	Caesium-134
Curium-243	Lanthanum-140
Curium-244	Plutonium-238
	Plutonium-239 + plutonium-140
	Americium-241
	Curium-242
	Curium-243
	Curium-244

Table 7-5: Main Sources of Gaseous Radioactive Waste in Buildings/Areas Served by the HVS

Building HVS	Main Sources of Radioactive Gases
RB	• Equipment pool • Reactor cavity pool • Fuel pool[12] • FPC • SDC Operating deck • Entry/truck bay • CIS (additional description provided in Subsection 7.3.2.1) • General workspace
RWB	• Refuelling staging area • Chemistry laboratory • Tank/pump areas (includes sludge and spent resin storage tanks) • Part of OGS • Drum evaporator • General workspace/processing and storage area • Sampling areas
TB	• TB Shield Area – includes the Main Turbine, Main Condenser, Moisture Separator Reheater, and Feedwater Heaters • CFD • TGSS (additional description provided in Subsection 7.3.2.2) • Part of OGS • RB Access Arc areas

[12] Design features that contribute to minimisation of radioactive gaseous discharges arising from evaporation of process water from the fuel pool, equipment pool, and reactor cavity pool are presented in PER Chapter E6 (Reference 7-5).

Table 7-6: BWRX-300 Operational Modes

Mode	Title
1	Power Operation
2	Startup
3	Hot Shutdown
4	Stable Shutdown
5	Cold Shutdown
6	Refuelling

Table 7-7: Annual Radioactive Aqueous Liquid Discharge Scenarios

Scenario	Volume of Radioactive Aqueous Liquid Discharged (m^3/y)	Comment
Minimal discharge	0	• Scenario consistent with the BWRX-300 design intent to operate with maximum recirculation of process fluids • Plant design for normal operating conditions and AOOs • Gives conservative bounding case for radioactive gaseous discharges to the environment • Gives maximum tritium release in the radioactive gaseous discharges to the environment
Maximum (100%) discharge	5,968	• Total estimated annual input of drained process water to the LWM (during normal operations and AOOs), based on industry data from operating BWRs (NUREG-0016 (Reference 7-25) and Annual Average Liquid Effluent Activity Releases (Reference 7-30)). It is assumed that all process water treated by the LWM is discharged to the environment, with no return to the CST for recirculation in the plant • Gives conservative bounding case for radioactive aqueous liquid discharges to the environment • Gives minimum tritium release in the radioactive gaseous discharges to the environment • Increases the volume of fresh demineralised water that would have to be imported into the plant
Realistic (~10%) discharge	600	• Approximately 10% of the 100% radioactive aqueous liquid discharge scenario. • Similar volume to that considered for the UK ABWR High Chemical Impurity Waste System in UK ABWR Generic Design Assessment, Quantification of Discharges and Limits (Reference 7-31).

Table 7-8: BWRX-300 Bounding Annual Radioactive Gaseous Discharges

Radionuclide	Annual Discharge (MBq/y)	Radionuclide	Annual Discharge (MBq/y)	Radionuclide	Annual Discharge (MBq/y)
Kr-83m	3.3E+05	Ar-41	3.2E+02	Mo-99	2.6E+00
Kr-85m	3.4E+04	Cr-51	2.0E+01	Tc-99m	2.2E-01
Kr-85	2.2E+06	Mn-54	1.2E+01	Ru-103	4.5E-01
Kr-87	1.2E+05	Mn-56	4.5E-01	Rh-103m	1.9E-03
Kr-88	1.2E+05	Fe-55	2.4E+01	Ru-106	7.3E-02
Kr-89	1.2E+07	Fe-59	5.8E+00	Rh-106	1.0E-02
Xe-131m	3.8E+04	Co-58	5.2E+00	Ag-110m	2.4E-02
Xe-133m	1.1E+03	Co-60	1.1E+01	Sb-124	4.9E-04
Xe-133	1.6E+06	Ni-63	2.5E-02	Te-129m	8.4E-01
Xe-135m	1.2E+06	Cu-64	5.8E+00	Te-131m	1.5E-01
Xe-135	1.3E+06	Zn-65	4.9E+00	Te-132	6.8E-02
Xe-137	1.7E+06	Rb-89	4.4E-02	Cs-134	6.6E-01
Xe-138	2.4E+06	Sr-89	8.0E-02	Cs-136	3.7E-01
I -131	5.2E+02	Sr-90	3.6E-03	Cs-137	1.0E+00
I -132	3.1E+03	Y-90	8.8E-04	Cs-138	1.1E-01
I -133	2.4E+03	Sr-91	1.7E+00	Ba-140	7.1E+00
I -134	8.7E+03	Sr-92	1.0E+00	La-140	1.6E+00
I -135	4.6E+03	Y-91	8.9E-01	Ce-141	4.5E-01
H-3	9.7E+05	Y-92	4.1E-01	Ce-144	7.2E-02
C-14	4.0E+05	Y-93	1.3E-01	Pr-144	8.4E-05
Na-24	1.4E+00	Zr-95	1.9E+00	W-187	5.3E-01
P-32	6.9E-01	Nb-95	1.8E+00	Np-239	1.8E+00
				Total	**2.44E+07**

Note: This scenario represents the conservative bounding case and may be considered to represent the discharge limits for radioactive gaseous discharges for the purposes of GDA Step 2.

Relevant radionuclides are ordered by radionuclide class and atomic mass.

Table 7-9: BWRX-300 Maximum Annual Radioactive Aqueous Liquid Discharge, Excluding Tritium

Radionuclide	Annual Discharge (Bq/y)	Radionuclide	Annual Discharge (Bq/y)	Radionuclide	Annual Discharge (Bq/y)
I-131	4.07E+07	Ni-65	1.48E+06	Ru-103	9.99E+06
I-132	5.55E+06	Cu-64	2.74E+08	Ru-105	2.92E+07
I-133	7.03E+07	Zn-65	9.99E+07	Ru-106	1.78E+07
I-135	3.18E+07	Zn-69m	1.55E+08	Ag-110m	2.59E+06
Cs-134	8.51E+07	Br-83	2.48E+07	Te-129m	1.85E+07
Cs-136	4.81E+07	Sr-89	1.85E+06	Te-131m	7.77E+06
Cs-137	1.30E+08	Sr-91	7.40E+07	Te-132	2.59E+06
Na-24	7.03E+07	Sr-92	1.78E+07	Ba-139	8.14E+06
P-32	1.74E+07	Y-91	2.48E+07	Ba-140	1.81E+08
Cr-51	4.44E+08	Y-92	5.55E+07	La-142	6.66E+06
Mn-54	2.41E+08	Y-93	5.92E+06	Ce-141	1.22E+07
Mn-56	7.40E+06	Zr-95	4.07E+07	Ce-143	5.92E+06
Fe-55	5.18E+08	Zr-97	7.40E+05	Ce-144	8.51E+06
Fe-59	1.30E+08	Nb-95	4.44E+07	Nd-147	1.48E+06
Co-58	1.26E+08	Nb-98	3.70E+05	Pr-143	2.18E+07
Co-60	2.44E+08	Mo-99	1.04E+08	W-187	2.74E+07
Ni-63	3.70E+06	Tc-99m	1.04E+08	Np-239	7.77E+07
				Total	**3.68E+09**

Note: This scenario represents the conservative bounding case and may be considered to represent the discharge limit for radioactive aqueous liquid discharges (excluding tritium) for the purposes of GDA Step 2.

Relevant radionuclides are ordered by radionuclide class and atomic mass.

Table 7-10: BWRX-300 Realistic Annual Radioactive Aqueous Liquid Discharge, Excluding Tritium

Radionuclide	Annual Discharge (Bq/y)	Radionuclide	Annual Discharge (Bq/y)	Radionuclide	Annual Discharge (Bq/y)
I-131	4.09E+06	Ni-65	1.49E+05	Ru-103	1.00E+06
I-132	5.58E+05	Cu-64	2.75E+07	Ru-105	2.94E+06
I-133	7.07E+06	Zn-65	1.00E+07	Ru-106	1.79E+06
I-135	3.20E+06	Zn-69m	1.56E+07	Ag-110m	2.60E+05
Cs-134	8.56E+06	Br-83	2.49E+06	Te-129m	1.86E+06
Cs-136	4.84E+06	Sr-89	1.86E+05	Te-131m	7.81E+05
Cs-137	1.31E+07	Sr-91	7.44E+06	Te-132	2.60E+05
Na-24	7.07E+06	Sr-92	1.79E+06	Ba-139	8.18E+05
P-32	1.75E+06	Y-91	2.49E+06	Ba-140	1.82E+07
Cr-51	4.46E+07	Y-92	5.58E+06	La-142	6.70E+05
Mn-54	2.42E+07	Y-93	5.95E+05	Ce-141	1.23E+06
Mn-56	7.44E+05	Zr-95	4.09E+06	Ce-143	5.95E+05
Fe-55	5.21E+07	Zr-97	7.44E+04	Ce-144	8.56E+05
Fe-59	1.31E+07	Nb-95	4.46E+06	Nd-147	1.49E+05
Co-58	1.27E+07	Nb-98	3.72E+04	Pr-143	2.19E+06
Co-60	2.45E+07	Mo-99	1.05E+07	W-187	2.75E+06
Ni-63	3.72E+05	Tc-99m	1.05E+07	Np-239	7.81E+06
				Total	**3.70E+08**

Note: Relevant radionuclides are ordered by radionuclide class and atomic mass.

Table 7-11: Comparison Table of Normalised Annual Radioactive Gaseous Discharges from BWRX-300 (Conservative Bounding Case) and UK ABWR

	BWRX-300 (GEH)	BWRX-300 (OPG)	UK ABWR
	Radioactivity (Bq/y)		
Total Radioactive Gaseous Discharge	2.44E+13[1]	4.73E+12[2]	5.56E+12[3]
	Power Output (Gigawatt electric (GWe))		
Power (GWe)	0.3	0.3	1.35
Operating Hours/y	8322[4]	8322[4]	8273.3[5]
	Normalised Radioactivity (Bq/GWh)		
Total Radioactive Gaseous Discharge	**9.77E+09[1]**	**1.89E+09[2]**	**4.98E+08[3]**

Notes:

1. Conservative and bounding value for annual radioactive gaseous discharges from the BWRX-300, presented as the discharge limit at GDA Step 2. This value is anticipated to be reduced when refined EUST data are produced for radioactive gaseous discharges (**FAP.PER7-196**).

2. Estimate of annual radioactive gaseous discharges from the BWRX-300, produced by OPG for a site-specific BWRX-300 project in Darlington, Ontario, Canada.

3. The UK ABWR PST does not include any contribution from leaking fuel. However, a radioactive gaseous discharge activity of 1.90E+11 Bq/y was postulated for an Expected Event of a fuel pin failure, anticipated to occur at a rate of once every 20 years (WN0908-HZCON-PAC-REP-00003 (Reference 7-54)). The total radioactive gaseous discharge as presented for UK ABWR in Table 7-10 includes a fuel failure contribution equivalent to 9.50E+10 Bq/y.

4. Based on 8,760 hours per year and a 95% lifetime capacity factor. The lifetime capacity factor is defined as Lifetime GWe-years delivered / (GWe capacity × Design Life), including outages.

5. Based on 8,760 hours per year and 94.4% capacity factor, assuming an 18 month operating cycle (17 months power operations and 1 month outage).

Table 7-12: Comparison Table of Normalised Annual Radioactive Aqueous Liquid Discharges from BWRX-300 (Maximum and Realistic Discharge Scenarios) and UK ABWR

	BWRX-300 (GEH, maximum)[1]	**BWRX-300 (GEH, realistic)[2]**	**BWRX-300 (OPG)[3]**	**UK ABWR**
	Radioactivity (Bq/y)			
H-3	3.10E+12	3.12E+11	4.81E+11[4]	2.00E+11
Beta/gamma	3.68E+09	3.70E+08	3.92E+09	1.36E+06
Total	**3.10E+12**	**3.12E+11**	**4.85E+11**	**2.00E+11**
	Power Output			
Power (GWe)	0.3	0.3	0.3	1.35
Operating Hours/y[5]	8322	8322	8322	8273.3
	Normalised Radioactivity (Bq/GWh)			
H-3	1.24E+09	1.25E+08	1.93E+08	1.79E+07
Beta/gamma	1.47E+06	1.48E+05	1.57E+06	1.22E+02
Total	**1.24E+09**	**1.25E+08**	**1.94E+08**	**1.79E+07**

Notes:

1. Conservative bounding case for radioactive aqueous liquid discharges, considered to represent the discharge limit for the purposes of GDA Step 2. This value is anticipated to be reduced when refined EUST data are produced for radioactive aqueous liquid discharges (**FAP.PER7-196**).

2. 'Realistic' scenario for radioactive aqueous discharges, described in Subsection 7.5.3.3.

3. Estimate of annual radioactive aqueous liquid discharges from the BWRX-300, produced by OPG for a site-specific BWRX-300 project in Darlington, Ontario, Canada. The radioactive aqueous liquid discharge volume used in the analysis was not specified.

4. No data for tritium in radioactive aqueous liquid discharges was provided by OPG. This figure was estimated by halving the total radioactive gaseous discharge tritium radioactivity value supplied by OPG.

5. Operating hours based on assumptions as per Table 7-11.

Table 7-13: Comparison of Normalised Annual Radioactive Gaseous Discharges for BWRX-300 (Conservative Bounding Case) and Selected International NPPs (Measured Operational Data)[13]

NPP	Normalised Radioactivity (Bq/GWh)				
	Total Noble Gases	Total Iodine Gases	Total Beta/Gamma	H-3	C-14
BWRX-300 (GEH)[1]	**9.23E+09**	**7.74E+06**	**1.75E+05**	**3.89E+08**	**1.60E+08**
BWRX-300 (OPG)[2]	**1.48E+09**	**8.20E+06**	**1.97E+05**	**3.85E+08**	**2.22E+07**
UK ABWR	**1.50E+08**	**2.70E+04**	**2.10E+01**	**2.30E+08**	**7.70E+07**
Olkiluoto	4.00E+08	3.40E+03	1.50E+03	2.70E+07	5.70E+07
Gundremmingen B+C	1.90E+08	2.70E+03	1.90E+01	3.60E+07	4.10E+07
Isar 1[3]	3.30E+08	4.50E+03	Not reported	1.70E+07	5.00E+07
Philippsburg 1[3]	2.70E+08	7.80E+03	3.80E+03	7.10E+06	6.10E+07
Cofrentes	2.30E+09	1.10E+06	6.50E+06	1.10E+08	5.20E+07
Santa Maria de Garona	3.20E+09	4.60E+05	6.70E+04	3.10E+08	6.00E+07
Forsmark	3.90E+08	1.20E+04	9.20E+03	3.80E+07	9.10E+07
Oskarshamn	8.10E+08	3.20E+04	2.00E+05	5.10E+07	4.80E+07
Ringhals 1	7.30E+08	2.80E+04	8.10E+06	3.00E+07	7.80E+07
Leibstadt	5.90E+07	1.00E+04	1.10E+03	2.00E+08	7.10E+07
Clinton-1[4]	1.80E+07	7.3E+01	4.5E+02	8.80E+07	6.50E+07
Grand Gulf-1	3.10E+09	4.5E+03	5.9E+02	1.10E+08	4.00E+07
LaSalle county 1&2[4]	4.60E+09	8.8E+04	2.7E+04	5.00E+07	5.80E+07
Limeric-1&2	2.10E+08	1.7E+02	2.0E+03	9.70E+07	6.10E+07
Nine Mile Point-2[4]	9.10E+08	1.1E+04	1.6E+04	2.90E+08	6.70E+07
Perry-1	1.80E+08	6.6E+02	2.6E+01	2.20E+07	6.30E+07

[13] The degree to which a comparison may be made between the anticipated radioactive discharges from the BWRX-300 and those of the international NPPs presented is limited at GDA Step 2. This is because ‘actual’ operational data for the international NPPs (which may be expected to be well below the permitted limits for the selected facilities) is being compared with conservative and bounding estimates of the radioactive discharges from the BWRX-300 (GEH) (which represent the discharge limits for GDA Step 2).

NPP	Normalised Radioactivity (Bq/GWh)				
	Total Noble Gases	Total Iodine Gases	Total Beta/Gamma	H-3	C-14
Susquehanna-1&2	1.60E+07	< MDC[5]	4.0E+02	4.50E+07	6.60E+07
Sizewell B PWR	4.00E+08	1.00E+04	1.40E+03	1.00E+08	2.90E+07
Heysham 2 AGR	1.60E+09	8.60E+03	1.20E+03	1.20E+08	1.70E+08
Rolls-Royce SMR	**2.90E+09**	**1.60E+04**	**8.80E+02**	**1.10E+07**	**5.40E+06**

Notes:

1. Data calculated from the conservative and bounding values for annual radioactive gaseous discharges from the BWRX-300, presented as the discharge limit at GDA Step 2. This value is anticipated to be reduced when refined EUST data are produced for radioactive gaseous discharges (**FAP.PER7-196**).

2. Data calculated from an estimate of annual radioactive gaseous discharges from the BWRX-300, produced by OPG for a site-specific BWRX-300 project in Darlington, Ontario, Canada.

3. Power generation ceased in 2011.

4. U.S. BWRs that have reported zero release of mixed fission and activation products and tritium via the aqueous liquid pathway between 2012 and 2021 (“Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants,” (Reference 7-50)).

5. MDC = minimum detectable concentration.

Table 7-14: Comparison of Normalised Annual Radioactive Aqueous Liquid Discharges for BWRX-300 (Maximum and Realistic Discharge Scenarios) and Selected International NPPs (Measured Operational Data)[14]

NPP	Normalised Radioactivity (Bq/GWh)	
	H-3	Beta/Gamma[1]
BWRX-300 (GEH, maximum)[2]	**1.24E+09**	**1.47E+06**
BWRX-300 (GEH, realistic)[3]	**1.25E+08**	**1.48E+05**
BWRX-300 (OPG)[4]	**1.93E+08**	**1.57E+06**
UK ABWR	**1.70E+07**	**2.60E+02**
Olkiluoto	1.30E+08	2.20E+04
Gundremmigen B+C	1.80E+08	4.50E+04
Isar 1[5]	8.20E+07	9.80E+03
Philippsburg 1[5]	9.70E+07	2.80E+04
Cofrentes	6.50E+07	1.60E+04
Santa Maria de Garona	1.40E+08	9.10E+04
Forsmark	8.10E+07	7.80E+03
Oskarshamn	8.40E+07	1.40E+05
Ringhals 1	1.30E+08	5.30E+05
Leibstadt	2.50E+08	1.40E+04
Clinton-1[6]	NR[7]	NR
Grand Gulf-1	3.1E+08	1.9E+05
LaSalle county 1&2[6]	<LLD[8]	<LLD
Limeric-1&2	2.3E+07	2.8E+03
Nine Mile Point-2[6]	2.0E+07	1.1E+03
Perry-1	1.2E+08	1.8E+05
Susquehanna-1&2	1.4E+08	1.1E+05
Sizewell B PWR	5.00E+09	1.20E+06

[14] The degree to which a comparison may be made between the anticipated radioactive discharges from the BWRX-300 and those of the international NPPs presented is limited at GDA Step 2. This is because 'actual' operational data for the international NPPs (which may be expected to be well below the permitted limits for the selected facilities) is being compared with conservative and bounding estimates of the radioactive discharges from the BWRX-300 (GEH) (which represent the discharge limits for GDA Step 2).

NPP	Normalised Radioactivity (Bq/GWh)	
	H-3	Beta/Gamma[1]
Heysham 2 AGR	3.70E+10	7.40E+06
Rolls-Royce SMR	**2.20E+07**	**1.20E+02**

Notes:

1. Beta/gamma refers to all detectable radionuclides excluding tritium.

2. Conservative bounding case for radioactive aqueous liquid discharges, considered to represent the discharge limit for the purposes of GDA Step 2. This value is anticipated to be reduced when refined EUST data are produced for radioactive aqueous liquid discharges (**FAP.PER7-196**).

3. ‘Realistic’ scenario for radioactive aqueous discharges, described in Subsection 7.5.3.3.

4. Data calculated from an estimate of annual radioactive aqueous liquid discharges from the BWRX-300, produced by OPG for a site-specific BWRX-300 project in Darlington, Ontario, Canada. The radioactive aqueous liquid discharge volume used in OPG’s analysis was not specified.

5. Power generation ceased in 2011.

6. U.S. BWRs that have reported zero release of mixed fission and activation products and tritium via the aqueous liquid pathway between 2012 and 2021 (“Analysis of Environmental Discharge Data for U.S. Nuclear Power Plants,” (Reference 7-50)).

7. NR = No Release, i.e., no releases occurred during this period.

8. LLD = Lower Limit of Detection. No radioactivity was detected and represents the lower limit of detection value for samples within a data set.

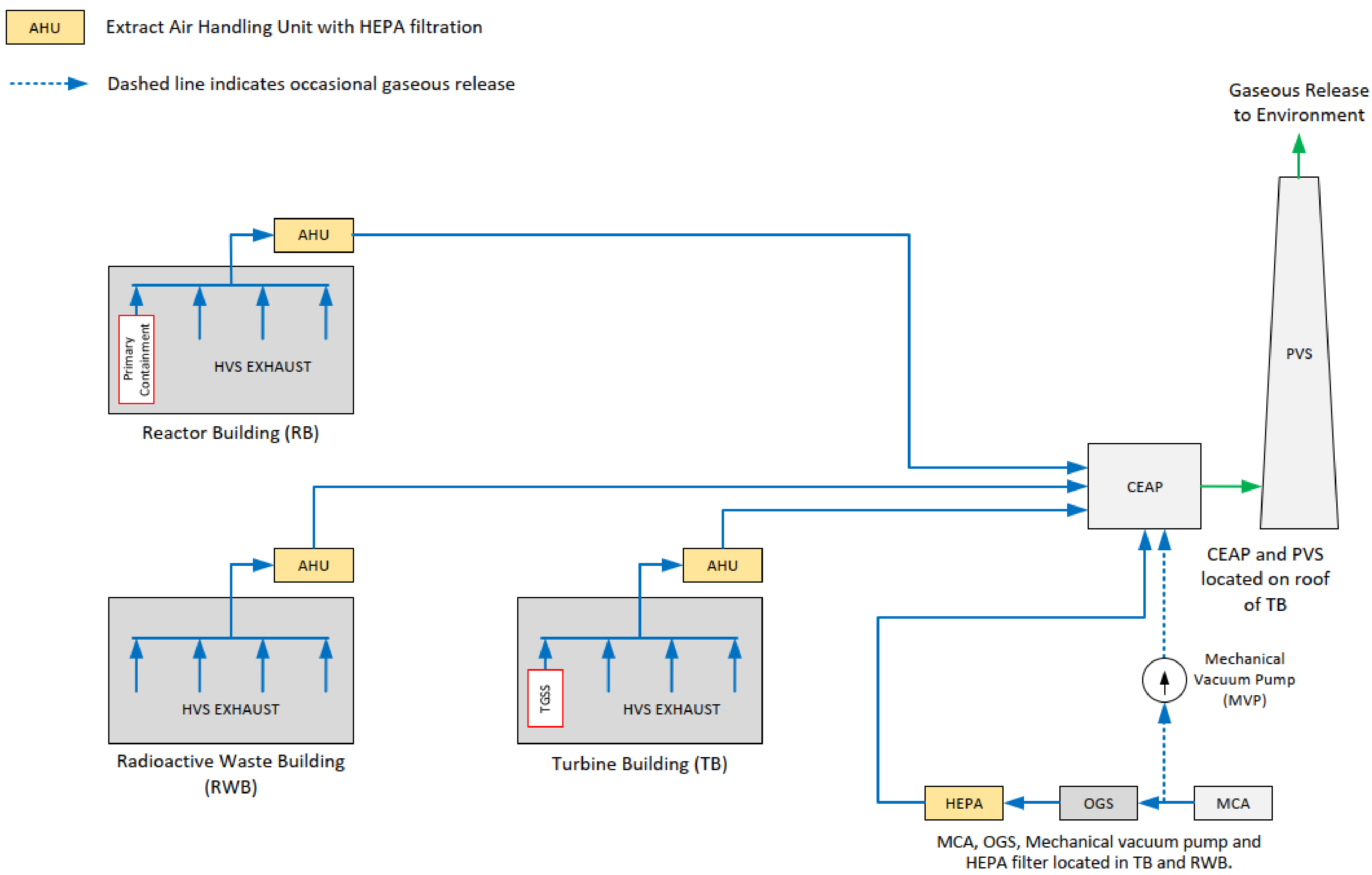

Figure 7-1: Simplified Diagram of **Systems and Buildings Contributing to BWRX-300 Radioactive Gaseous Discharges**

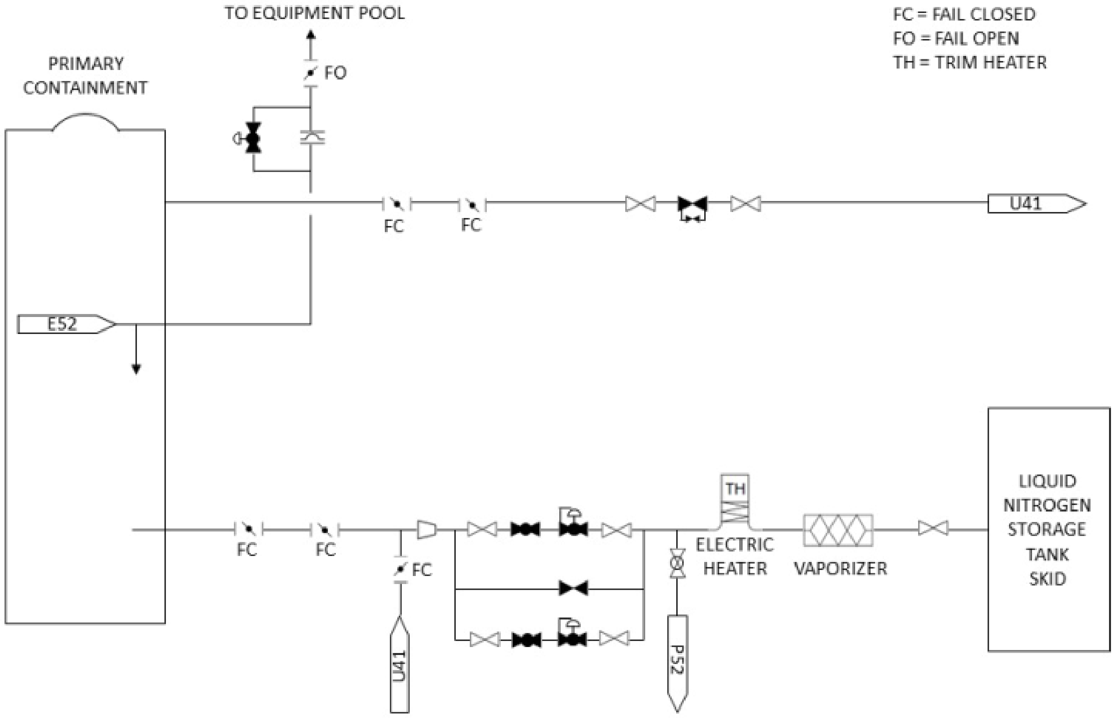

Figure 7-2: CIS Simplified Diagram

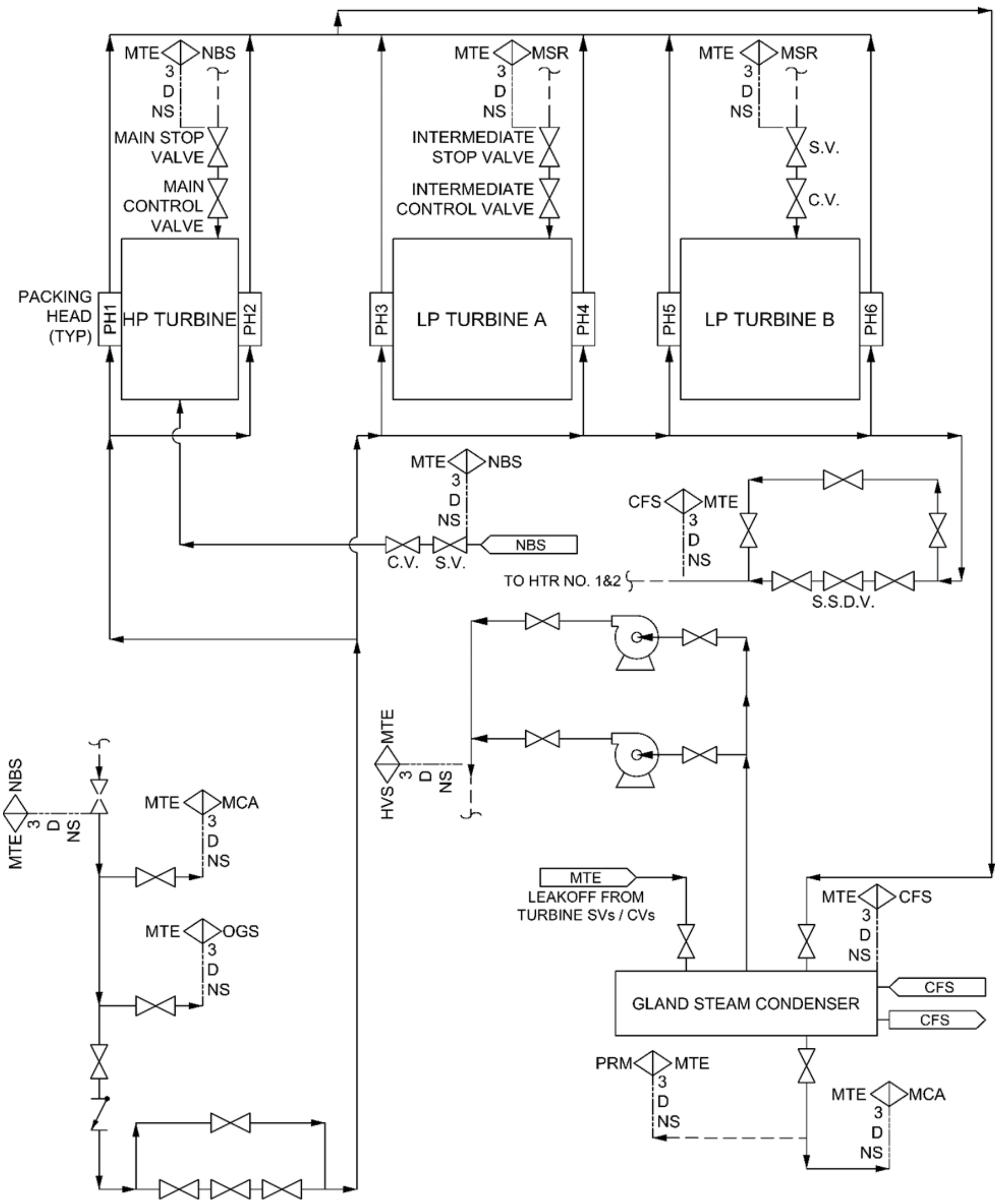

Figure 7-3: TGSS Simplified **Single Line Diagram**

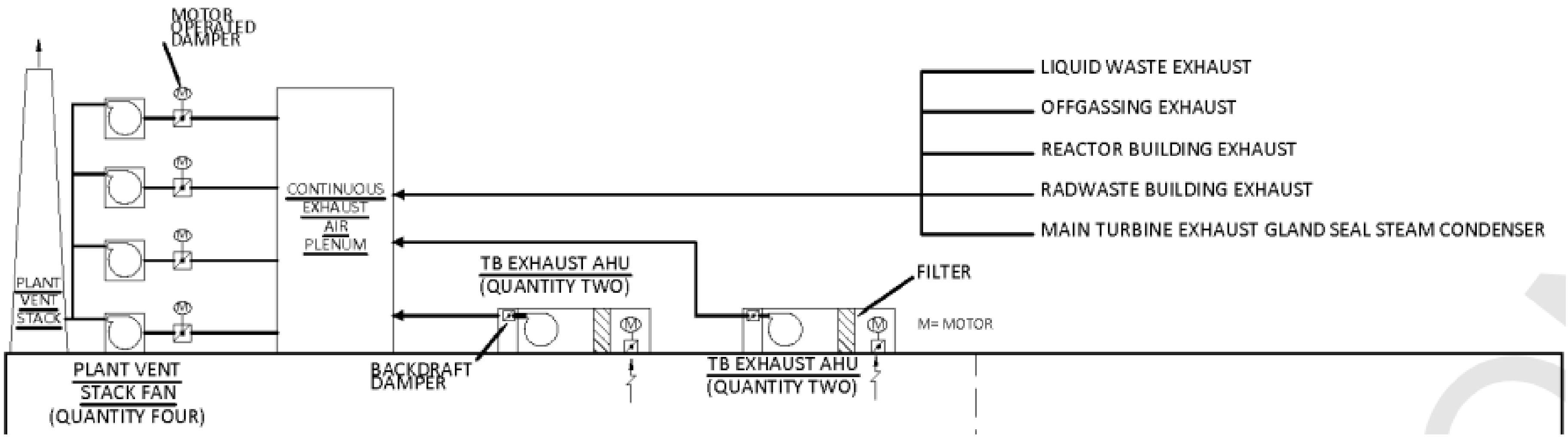

Figure **7-4**: CEAP and PVS Simplified Flow Diagram

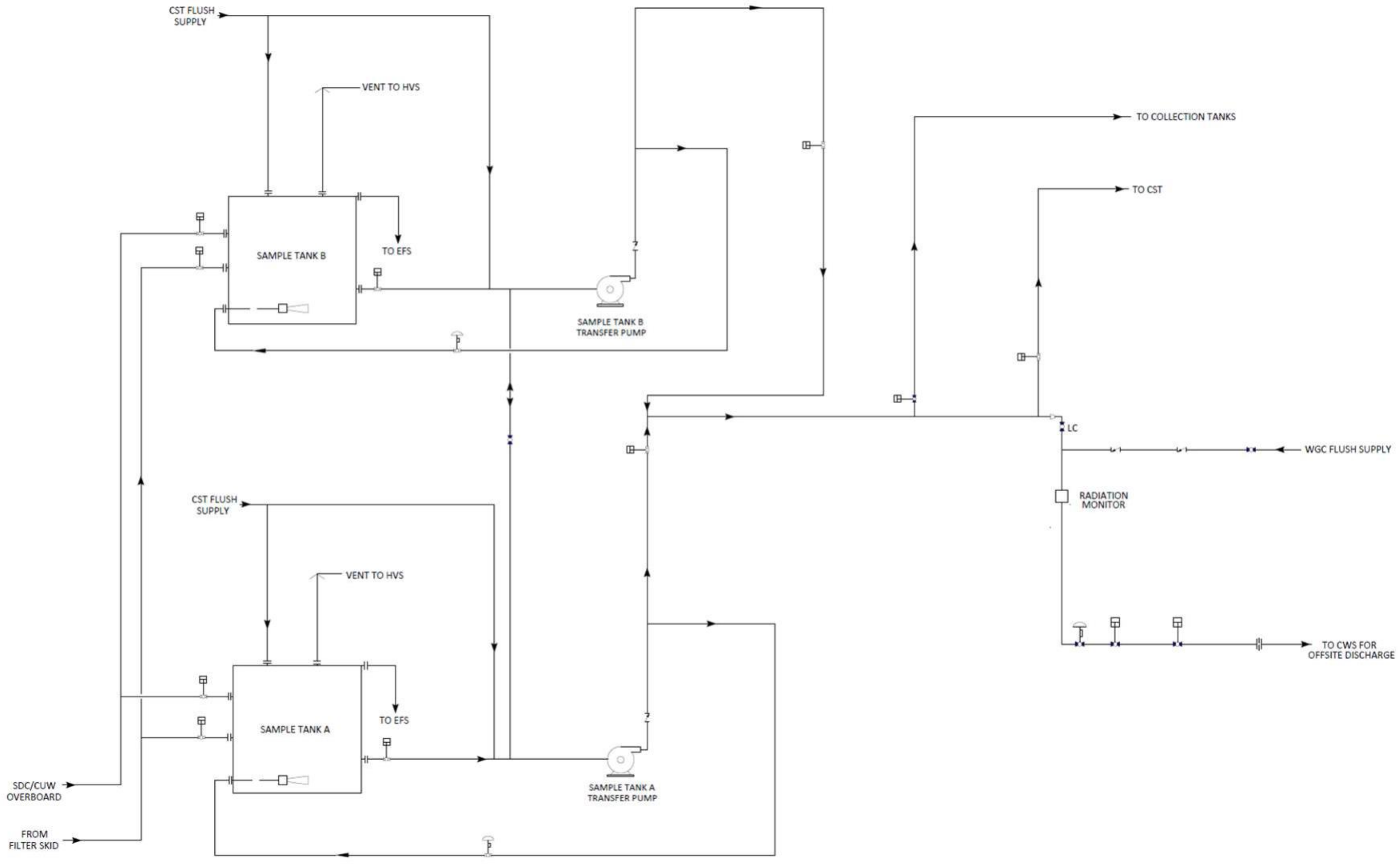

Figure 7-5: Waste Sampling Subsystem Simplified Diagram

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APPENDIX A RADIOACTIVE DISCHARGES FORWARD ACTION PLAN

Table A-1: Radioactive Discharges Forward Action Plan

Action ID	Finding	Forward Actions	Delivery Phase
PER7-194	Any sources of gaseous or aqueous liquid radioactive discharge introduced outside of the power block (i.e., beyond the scope of GDA Step 2) need to be included in future discharge assessments.	Additional sources of gaseous or aqueous liquid radioactive discharges outside of the BWRX-300 power block (e.g., Spent Fuel store) are beyond the scope of GDA Step 2; these sources shall be included in future radioactive discharge assessments at the site-specific design stage.	For Pre-Construction Safety Report (PCSR)/ Pre-Construction Environmental Report (PCER).
PER7-195	The BWRX-300 can be operated according to a 'maximum recirculation' philosophy with minimal discharge of radioactive aqueous liquid waste to the environment. However, site-specific information, including the economics of the required investment, may dictate that discharges during normal operations are the optimal solution. A future BWRX-300 plant developer/operator will need to determine the operational requirements for radioactive aqueous liquid discharges at the site-specific stage. This will allow final radioactive discharge assessments, including discharge limits, to be made to support an environmental permit application.	A future developer/operator shall determine the optimised operational requirements for radioactive aqueous liquid discharges at site-specific stage, including decision-making relating to: • Mode of operation, either employing a 'maximum recirculation' philosophy for management of process water, or with periodic radioactive aqueous liquid discharges during normal operations, taking into account radiological impacts of discharges and economic factors, and relevant OPEX available at the time • Arrangements for management of tritium, with consideration of the relative dose impact via the radioactive gaseous pathway compared to radioactive aqueous liquid releases	Before Site License Application, Environmental Permit Applications and/or Baseline 3 (BL3) Design Phase

PER7-196	The current lack of refined EUST for radioactive gaseous and aqueous discharges[1] means that:
	• The radioactive discharge assessments at GDA Step 2 are conservative and require refinement in order for discharge limits to be established and justifiable headroom factors calculated. This will also enable a refined radiological dose assessment to be performed at the proposed discharge limits, in line with regulator expectations
	• AOOs with environmental consequences are not fully accounted for in the discharge assessments, meaning that monthly and rolling monthly discharge assessments cannot be produced
	• The current BWRX-300 EUST listed radionuclides for radioactive gaseous and aqueous liquid discharges do not exactly match those in the 2004/2/Euratom recommendation. This means that the significant radionuclides discharged from the gaseous and aqueous liquid systems have not yet been fully identified. Identification of the significant radionuclides is required to enable suitable sampling and monitoring equipment to be selected for
		The PST and EUST data for radioactive gaseous and aqueous liquid discharges from the BWRX-300 shall be refined, taking into account:
		• AOOs with environmental consequences (see **FAP.PER5-110**)
		• The 2004/2/Euratom reporting recommendations
		• A review of the assumptions and calculation methodologies to be used, with consideration of relevant OPEX available at the time
		• Consideration of the use of sensitivity analysis to inform prioritisation of effort for ongoing design optimisation
		This will allow more realistic updated radioactive discharge assessments to be produced. These data shall include estimates of:
		• Total radioactive gaseous and aqueous liquid discharges (final discharges)
		• Radioactive discharges by route/source
		• The impact on anticipated radioactive discharges of:
		  ○ Different plant operational modes (e.g., startup and refuelling outages)
		  ○ Expected events (e.g., a fuel pin failure)
		  ○ Short-term releases (e.g., containment purging)
		These data shall then be used to:
			For PCSR/PCER.

Action ID	Finding	Forward Actions	Delivery Phase
	determination of final discharge accountancy • The assumptions and calculation methodologies used for determination of the EUST will need to be reviewed to ensure that they accurately reflect, as far as possible, the design of the BWRX-300, with consideration of relevant OPEX • Sensitivity analysis will need to be considered as a means to inform prioritisation of effort for ongoing design optimisation	• Establish discharge limits, and enable the radiological dose assessment to be performed at the proposed limits • Determine headroom factors • Generate monthly and rolling monthly discharge assessments of the proposed operating cycle • Determine the significant radionuclides that require sampling and monitoring in the radioactive discharges, such that suitable sampling and monitoring equipment can be selected	
PER7-430	Refinement of the radioactive discharge assessments for radioactive gaseous and aqueous liquid discharges from the BWRX-300 will require consideration of relevant OPEX available at the time	A future developer/operator should utilise operational data for radioactive gaseous and aqueous liquid discharges from the first operating BWRX-300 SMR(s), and/or other relevant OPEX available at the time, in order to: • Further refine the radioactive discharge assessments for a BWRX-300 installation in the UK • Provide additional evidence to support the BWRX-300 ‘maximum recirculation’ philosophy for minimisation of radioactive discharges to the aquatic environment	Before Site License Application, Environmental Permit Applications and/or BL3 Design Phase

Note:

A wider action relating to source terms has also been identified in **PSR23-133**, originating from PSR Chapter 23 (Reference 7-11).

APPENDIX B ANNUAL GASEOUS RADIOACTIVITY CONTRIBUTION BY ROUTE

Table B-1 is taken from Annual Average Gaseous Effluent Releases for the BWRX-300 Standard Plant (Reference 7-28). This is the conservative bounding case for normal operations and includes AOOs, as also described in the same document(Reference 7-28). Cells marked with – represent no release.

Table B-1: Annual Gaseous Radioactivity Contribution by Route

Radionuclide	Release Route of Radioactive Gaseous Discharge/Radioactivity in MBq/y[1]							
	RB	PLSA[2]	TB	RWB	MVP	TGSS	OGS	Containment
Kr-83m	-	-	-	-	-	3.30E+05	4.80E-07	3.10E+02
Kr-85m	8.90E+02	2.60E+03	2.20E+04	-	-	8.90E+03	7.80E+00	2.10E+01
Kr-85	-	-	-	-	-	2.20E+03	2.20E+06	3.00E+02
Kr-87	-	1.80E+03	5.20E+04	-	-	6.30E+04	2.70E-14	4.10E+01
Kr-88	8.90E+02	2.60E+03	8.10E+04	-	-	3.40E+04	9.60E-03	5.20E+01
Kr-89	-	1.80E+03	5.20E+05	2.60E+04	-	1.20E+07	-	3.20E+02
Xe-131m	-	-	-	-	-	1.90E+03	3.60E+04	1.60E+02
Xe-133m	-	-	-	-	-	1.10E+03	6.70E-04	3.00E+01
Xe-133	2.40E+04	7.40E+04	1.30E+05	1.90E+05	1.10E+06	1.70E+04	2.40E+03	9.60E+02
Xe-135m	1.30E+04	4.10E+04	3.50E+05	4.80E+05	-	3.00E+05	-	4.10E+01
Xe-135	2.90E+04	8.10E+04	2.90E+05	2.50E+05	4.40E+05	1.70E+05	1.70E-45	8.10E+02
Xe-137	4.10E+04	1.20E+05	8.90E+05	7.40E+04	-	5.60E+05	-	1.90E+01
Xe-138	1.80E+03	5.20E+03	8.90E+05	1.80E+03	-	1.60E+06	-	1.90E+02
I-131	7.00E+00	3.60E+01	2.50E+02	1.60E+01	8.90E+01	2.20E+00	-	1.30E+02
I-132	7.00E+01	3.60E+02	2.50E+03	1.60E+02	-	-	-	2.10E+01
I-133	5.20E+01	2.70E+02	1.90E+03	1.10E+02	-	4.40E+00	-	1.40E+02

Radionuclide	Release Route of Radioactive Gaseous Discharge/Radioactivity in MBq/y[1]							
	RB	PLSA[2]	TB	RWB	MVP	TGSS	OGS	Containment
I-134	2.00E+02	1.00E+03	7.00E+03	4.40E+02	-	-	-	2.30E+01
I-135	1.10E+02	5.60E+02	3.70E+03	2.30E+02	-	-	-	8.90E+01
H-3	4.80E+05	-	4.80E+05	-	-	-	-	-
C-14	-	-	-	-	-	-	4.10E+05	-
Na-24	-	-	-	-	-	-	-	1.40E+00
P-32	-	-	-	-	-	-	-	7.00E-01
Ar-41	-	-	-	-	-	-	3.30E+02	-
Cr-51	4.40E-04	2.00E-03	2.00E-03	1.60E-03	-	-	-	2.00E+01
Mn-54	8.90E-04	2.30E-03	1.30E-03	8.90E-03	-	-	-	1.10E+01
Mn-56	-	-	-	-	-	-	-	4.40E-01
Fe-55	-	-	-	-	-	-	-	2.40E+01
Fe-59	2.00E-04	6.70E-04	2.30E-04	6.70E-04	-	-	-	5.90E+00
Co-58	2.30E-04	4.40E-04	2.30E-03	4.40E-04	-	-	-	5.20E+00
Co-60	2.30E-03	8.90E-03	2.30E-03	1.60E-02	-	-	-	1.10E+01
Ni-63	-	-	-	-	-	-	-	2.40E-02
Cu-64	-	-	-	-	-	-	-	5.90E+00
Zn-65	2.30E-03	8.90E-03	1.30E-02	6.70E-04	-	-	-	4.80E+00
Rb-89	-	-	-	-	-	-	-	4.40E-02
Sr-89	6.70E-05	4.40E-05	1.30E-02	-	-	-	-	6.70E-02
Sr-90	6.70E-06	1.60E-05	4.40E-05	-	-	-	-	3.60E-03
Y-90	-	-	-	-	-	-	-	8.90E-04

Radionuclide	Release Route of Radioactive Gaseous Discharge/Radioactivity in MBq/y[1]							
	RB	**PLSA[2]**	**TB**	**RWB**	**MVP**	**TGSS**	**OGS**	**Containment**
Sr-91	-	-	-	-	-	-	-	1.70E+00
Sr-92	-	-	-	-	-	-	-	1.00E+00
Y-91	-	-	-	-	-	-	-	8.90E-01
Y-92	-	-	-	-	-	-	-	4.10E-01
Y-93	-	-	-	-	-	-	-	1.30E-01
Zr-95	6.70E-04	1.60E-03	8.90E-05	1.80E-03	-	-	-	1.90E+00
Nb-95	2.30E-03	2.00E-02	1.30E-05	8.90E-06	-	-	-	1.80E+00
Mo-99	1.30E-02	1.30E-01	4.40E-02	6.70E-06	-	-	-	2.40E+00
Tc-99m	-	-	-	-	-	-	-	2.30E-01
Ru-103	4.40E-04	8.90E-03	1.10E-03	2.30E-06	-	-	-	4.40E-01
Rh-103m	-	-	-	-	-	-	-	1.90E-03
Ru-106	-	-	-	-	-	-	-	7.40E-02
Rh-106	-	-	-	-	-	-	-	1.00E-02
Ag-110m	-	-	-	-	-	-	-	2.40E-02
Sb-124	4.40E-05	6.70E-05	2.30E-04	1.60E-04	-	-	-	-
Te-129m	-	-	-	-	-	-	-	8.50E-01
Te-131m	-	-	-	-	-	-	-	1.50E-01
Te-132	-	-	-	-	-	-	-	6.70E-02
Cs-134	1.60E-03	8.90E-03	4.40E-04	5.60E-03	-	-	-	6.30E-01
Cs-136	2.30E-04	8.90E-04	2.30E-04	-	-	-	-	3.70E-01
Cs-137	2.30E-03	1.10E-02	2.30E-03	8.90E-03	-	-	-	1.00E+00

Radionuclide	Release Route of Radioactive Gaseous Discharge/Radioactivity in MBq/y[1]							
	RB	PLSA[2]	TB	RWB	MVP	TGSS	OGS	Containment
Cs-138	-	-	-	-	-	-	-	1.10E-01
Ba-140	4.40E-03	4.40E-02	2.30E-02	8.90E-06	-	-	-	7.00E+00
La-140	-	-	-	-	-	-	-	1.60E+00
Ce-141	4.40E-04	1.60E-03	2.30E-02	1.60E-05	-	-	-	4.40E-01
Ce-144	-	-	-	-	-	-	-	7.40E-02
Pr-144	-	-	-	-	-	-	-	8.50E-05
W-187	-	-	-	-	-	-	-	5.20E-01
Np-239	-	-	-	-	-	-	-	1.80E+00

Notes:

1. This scenario represents the conservative bounding case and may be considered to represent the discharge limit for radioactive gaseous discharges for the purposes of GDA Step 2.

2. As a result of ongoing design development during GDA timescales, the PLSA exhaust is no longer considered to contribute to radioactive gaseous discharges from the BWRX-300 (see Subsection 7.2.4.1) and is not routed to the CEAP/PVS at the DRP for GDA Step 2. However, a contribution from the PLSA (comprising 1.4% of the total annual radioactive gaseous discharges) is included in the radioactive discharge assessments generated using the GALE-BWR methodology described in NUREG-0016 (Reference 7-25), which are presented in this chapter.

APPENDIX C REFINEMENT OF BWRX-300 SOURCE TERM

Without prejudice to a future strategy for refinement of BWRX-300 source term data, potential refinements to the EUST for radioactive discharges and radioactive wet solid wastes to provide more realistic estimates are presented in the subsections below.

Radioactive Gaseous Discharge Source Term

There are eight sources of radioactive gaseous discharges in the BWRX-300 (and other BWRs) considered in the BWR-GALE gaseous discharge calculation. These are described in Table C-1 along with the basis for he GALE-BWR calculation and the refinements that can be made to them.

Table C-1: Sources of Radioactive Gaseous Discharges, Basis of GALE-BWR Calculation, and Proposed Refinements

In Plant Contributions to Radioactive Gaseous Discharges	Basis of GALE-BWR Method Calculation	Refinements
RB HVS annual radioactive discharges	Calculated using NUREG-0016, Rev 2 (Reference 7-25) operating data in Tables 4-2 and 4-3 and adjusted for BWRX300 operating parameters. The data in NUREG0016, Rev 2 (Reference 7-25) Tables 4-2 and 4-3 is taken directly from NUREG-0016, “Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from -Boiling Water Reactors”, Rev 1 (Reference 7-58). The NRC has left both revisions of the document in production, but both use the data from 1979.	The radioactive discharges from power block building exhausts can be reduced by performing best estimate analysis based on modern BWR operating data. It is noted the NUREG-0016 data was collected over a period when fuel clad defects were very common so this would represent a significant reduction.
TB HVS annual radioactive discharges		
RWB HVS annual radioactive discharges		
PLSA HVS annual radioactive discharges[15]		
MVP exhaust annual radioactive discharges	Calculated using NUREG0016 Rev 2 (Reference 7-25) operating data in Section 4.1.1.6, and Table 4-23 and adjusted for BWRX300 operating parameters.	If necessary to meet the design objectives, the radioactive discharge from the MVP can be processed through the OGS to remove iodine before release to the environment. This would require a slight design change.[16]

[15] As a result of ongoing design development during GDA timescales, the PLSA exhaust is no longer considered to contribute to radioactive gaseous discharges from the BWRX-300 (see Subsection 7.2.4.1) and is not routed to the CEAP/PVS at the DRP for GDA Step 2. However, a contribution from the PLSA (comprising 1.4% of the total annual radioactive gaseous discharges) is included in the radioactive discharge assessments generated using the GALE-BWR methodology described in NUREG-0016 (Reference 7-25), which are presented in Section 7.5).
[16] No design changes to the BWRX-300 Standard Design are being proposed at GDA Step 2.

In Plant Contributions to Radioactive Gaseous Discharges	Basis of GALE-BWR Method Calculation	Refinements
TGSS exhaust annual radioactive discharges	Calculated using the ANSI/ANS-18.1-2020 (Reference 7-26) normal operation source term and bulk steam flow and applying the GALE-BWR methods in NUREG-0016 Rev 2 (Reference 7-25).	In the BWRX-300 Standard Design, reactor steam containing noble gases and iodine is used to seal the turbine gland. These radioactive discharges can be eliminated entirely by using clean steam (non-radioactive for this system). A Best Available Technology and Techniques Economically Achievable (BATEA) assessment is being conducted now using CNSC requirements and will be completed before the end of Baseline 2[17] design development which may drive a decision to add an auxiliary boiler to the design to provide clean steam for the TGSS. The GEH radiation protection team has provided options and recommendations to the BATEA team that an auxiliary boiler should be added to the design to eliminate radioactive discharges from the TGSS. The decision is pending, and this relaxation will not be implemented until the decision to add an auxiliary boiler is implemented.[18]
OGS annual radioactive discharges	Calculated using the ANSI/ANS18.12020 (Reference 7-26) normal operation source term and bulk steam flow and applying the GALE-BWR methods in NUREG-0016 Rev 2 (Reference 7-25).	There is currently no plan to refine the OGS annual radioactive discharge part of the model. The GEH team does not believe this estimated discharge requires a reduction since it is based on the current OGS and expected operation of the reactor.

[17] Information on GEH’s phased design process is provided in PER Chapter E3 (Reference 7-1).
[18] The BATEA assessment being undertaken in Canada is beyond the DRP for GDA Step 2. The output of the BATEA study, when complete, will form part of the evidence that will be used in the next iteration of the BAT case (PER Chapter E6 (Reference 7-5)).

In Plant Contributions to Radioactive Gaseous Discharges	Basis of GALE-BWR Method Calculation	Refinements
Containment (purging) annual radioactive discharge	Calculated using the ANSI/ANS-18.1-2020 (Reference 7-26) normal operation source term and bulk steam flow and applying the GALE-BWR methods in NUREG-0016 Rev 2 (Reference 7-25).	The GALE-BWR method assumes a containment purging frequency of 24 purges per year. Since the radioactive gaseous discharge analysis was established, additional containment isolation requirements have been established that clarify containment will be maintained dry and nitrogen-inerted, and that it is not practical to continuously purge an inerted containment like a traditional BWR nor is it necessary for the BWRX-300 design. Once inerting is complete, the CIS will provide a small amount of makeup nitrogen to maintain a slightly positive pressure inside the containment. When the radioactive discharge calculation is revised later in 2025 the radioactive gaseous discharge attributed to containment purging will be reduced significantly by replacing the GALE-BWR assumption of 24 purges per year with the assumption of 1 purge per year. In the current analysis of record over 99% of the activated CPs in the radioactive gaseous discharge source term are the results of the GALE-BWR containment purging model. When the aforementioned assumption is modified to align with the expected BWRX-300 purging it will reduce the amount of activated CPs in the radioactive gaseous discharges significantly. Thus, there is a high level of confidence this refinement will be suitable for issue of a Statement of Design Acceptability.

An additional refinement has been developed regarding a reduction in the largest radioactive discharge public dose contributor, carbon-14, which is produced almost entirely in gaseous form (CO_2) in BWRs. The principal source of carbon-14 in a BWR is the thermal neutron reaction with oxygen-17 in the reactor coolant, and the resulting carbon-14 is discharged through the main condenser OGS. The current model based on NUREG-0016 Rev 2 (Reference 7-25) has been found to overpredict the production of carbon-14 compared to other models including the EPRI model presented in “Estimation of Carbon-14 in Nuclear Power Plant Gaseous Effluents,” (Reference 7-23). However, even the EPRI model does not account for a reactor design with natural circulation such as the BWRX-300. GEH has developed a model that more accurately reflects the BWRX-300 core region where the carbon-14 is produced, which is the driver for the higher than expected carbon-14 production. Refinement of the carbon-14 model will reduce the predicted carbon-14 gaseous discharge by roughly 60% when the analysis is updated later in 2025. Current radioactive gaseous discharge dose estimates indicate that carbon-14 contributes more than half of the public dose so this refinement will have a significant impact on doses.

Radioactive Aqueous Liquid Discharge Source Term

With regard to the radioactive aqueous liquid discharge source term, the analysis will be revised in 2025 to apply a recently established water balance for the facility that provides a technical basis to reduce the assumed Percent of Coolant Activity currently credited in the analysis, which will reduce the radioactive aqueous liquid discharge source term.

The BWRX-300 is designed with the flexibility to operate either according to a ‘maximum recirculation’ philosophy with minimal radioactive aqueous liquid discharges, or with periodic discharges. The LWM includes provisions for adequate water storage capacity to ensure that a radioactive aqueous liquid discharge to the environment is rarely needed to avoid a backup of the system. The decision to operate with minimal radioactive aqueous liquid discharges or periodic radioactive aqueous liquid discharges is left to the future developer/operator who has to consider both the environmental and operational impacts (see **FAP.PER7-195**). Several BWRs currently employ the ‘maximum recirculation’ philosophy for operational management of radioactive aqueous liquid discharges due to the associated cost advantages. It is expensive to discharge very high-quality water that could appropriately be recirculated in designated plant systems, and the ‘maximum recirculation’ philosophy conserves natural resources and virtually eliminates radioactive aqueous liquid discharges in BWRs that employ the strategy.

A major consideration for operators deciding to use this flexibility option is the handling of tritium. The tritium in the reactor coolant and steam is a result of the activation of naturally occurring deuterium in the coolant and, to a lesser extent, small amounts of tritium that leak from the fuel. Considerations relating to operational management of tritium are presented in Subsection 7.4.5.

Conservatisms in Radioactive Gaseous and Aqueous Liquid Source Terms

As shown in Table C-1, the driver of conservatisms in the radioactive discharge assessments for gaseous and aqueous liquid discharges is not the ANSI/ANS-18.1-2020 standard (Reference 7-26), but rather the GALE-BWR assumptions and operating data embedded in the method of calculation. Also, the ANSI/ANS-18.1-2020 operational source term has been revised since the last issuance of the radioactive gaseous and aqueous liquid discharge source terms to reduce the nitrogen-16 levels in steam to those of a plant operating with normal water chemistry, based on the HWC maximum injection rate that was reduced through advancement of the chemistry design. Aside from the reduction in nitrogen-16 which greatly reduces the shielding source terms, the GEH radiation protection design team does not plan on making further refinements to the ANSI/ANS-18.1-2020 operational source term.

Revisions to the ANSI/ANS-18.1 standard (Reference 7-26) are developed to apply modern operating data to the table of “reference BWR” water and steam concentrations based on an assumed reference BWR cleanup system configuration. Using the ANSI/ANS-18.1 method, those reference BWR concentrations are then adjusted for a given design based on the thermal power, weight of water in the reactor, cleanup demineraliser flow rate, steam flow rate, and the ratio of condensate demineraliser flow rate to steam flow rate for the plant being analysed, which in this case is the BWRX-300. The 2020 version of the standard included significant reductions to the reference BWR concentrations and the plants providing information for the latest version of the standard are known GEH BWR fleet clients. Several of those BWRs have, over the last three decades, upgraded materials in their reactor coolant pressure boundaries to reduce the amount of activated CPs produced, and/or upgraded their coolant cleanup systems that are not integral to the facility designs. Upgrades to the materials in the facilities providing the data for ANSI/ANS-18.1-2020 could very well drive the reference BWR concentrations to be much closer to the BWRX-300 operational source term than currently anticipated. While the GEH radiation protection design team expects the BWRX-300 to produce less activated CPs, without a complete tabulation of the upgrades and a deep understanding of their impact on the facilities that provided data for the standard, reducing the operational source term based on an assumption that the material in those facilities is the same as when they were built could result in a non-conservative adjustment.

Also, the ANSI/ANS-18.1-2020 standard (Reference 7-26) assumes a reference BWR cleanup configuration that differs from the BWRX-300 cleanup configuration. The BWRX-300 CUW receives blowdown-type flow from the RPV during power operations to cool the reactor water and to minimise flashing and two-phase flow and then direct the flow to the CFD.

Unlike the ANSI/ANS-18.1-2020 reference cleanup configuration, the BWRX-300 CUW does not remove contamination from the blowdown flow but rather conditions the blowdown to levels that are optimal for high efficiency operations of the CFD. The CFD is a full flow system that consists of high efficiency backwash-type filters followed by mixed, deep bed demineralisers with replaceable ion exchange resin. The CUW/CFD system designers have asserted this configuration will outperform the ANSI/ANS-18.1-2020 reference BWR cleanup configuration. However, the radiation protection design team has not yet been able to validate that claim. Until that claim can be validated either with CFD vendor information or operating data collected in an operating BWRX-300, the ANSI/ANS-18.1-2020 standard removal equations have been modified to remove the cleanup that would normally be performed by a traditional CUW. This reduction in the ANSI/ANS-18.1 removal rates for the BWRX-300 does make the coolant concentrations higher than they would be, but until a technical basis is provided to increase the ANSI/ANS-18.1 removal rates they will not be modified.

Radioactive Wet Solid Waste Source Term

The quantification of annual wet solid radwaste generation (comprising spent demineraliser resins and filter backwash sludges) for the BWRX-300 is under development and expected near the start of the BL3[19] design phase. A “normal operations” RM source term will be used for quantification of wet solid radwaste generation going forwards. Up to this point quantification has been based on a DB source term derived using a fuel cladding defect model (see Subsection 7.2.4), used for the purposes of shielding and ventilation design development. FPs are reduced in the “normal operations” RM source term by a factor of over 100 when the fuel cladding defect model is not applied.

Predecessor BWR designs (e.g., the UK ABWR) include dual function filter-demineralisers precoated in powder resin as part of their water treatment systems. The highly active mixed powder resin/sludge waste stream generated by backwashing of these filters contributes approximately 90% of the radioactive waste sludge source term in a typical BWR. However,

[19] Information on GEH’s phased design process is provided in PER Chapter E3 (Reference 7-1).

the BWRX-300 design does not include any precoat filters, and a common approach to water treatment has been adopted throughout the plant, utilising deep bed demineralisation combined with high flow fine filtration. This approach has been demonstrated to provide optimal protection of the fuel from cladding failures as compared to the use of precoat filters (see EPRI 1025190, “Comparison of Effects of Filter Demineralizer and Deep Bed Demineralizer Condensate Polishing on Water Quality,” (Reference 7-59). On this basis, refinement of the source term for BWRX-300 to take account of the elimination of precoat filters is anticipated to reduce the sludge source term by approximately 90%. This will consequently result in additional activity loading of the ion exchange resins; however, this will not increase the anticipated volume of wet solid wastes.

Finally, as described above, the BWRX-300 CUW does not contain any filtration or ion exchange media but serves to optimise the temperature and pressure of the reactor coolant for treatment by the CFD.

Dry Active Wastes

A range of dry solid wastes will be generated through plant operations, maintenance, and repair/refurbishment on an ad hoc basis associated with activities undertaken in the radioactive areas of the plant. Information relating to quantification of these wastes is presented in PER Chapter E5 (Reference 7-6), Appendix F.

Conclusion

In conclusion, the ANSI/ANS-18.1-2020 (Reference 7-26) operational source term is not the reason the radioactive gaseous and aqueous liquid discharge assessments, and radioactive wet solid waste source terms, for BWRX-300 are conservative. The conservatisms in the current estimates arise from:

- Use of the GALE-BWR code for calculation of radioactive gaseous and aqueous liquid discharges
- Use of a DB source term for wet solid wastes to inform plant shielding and ventilation design

A potential reduction in activated CP concentrations may be applied to the ANSI/ANS-18.1-2020 operational source term to account for high efficiency operation of the CFD but will not be applied unless a solid technical basis to do so becomes available which is likely not until the detailed phase of design development.