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PER Chapter 2 Quantification of Effluent Discharges and Limits

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2.1 ACRONYMS AND ABBREVIATIONS

The standard project glossary of terms, abbreviations, and plant systems is provided in SMR-300 Plant Breakdown Structure, Acronyms, and Glossary of Terms [1]. The following additional definitions and abbreviations are used herein:

Table 1 - List of definitions and abbreviations

Term	Definition
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
AP	Activation Products
ActP	Actinide Products
BAT	Best Available Techniques
CA	Cycle Average
CP	Corrosion Products
CVC	Chemical Volume Control System
DB	Design Basis
DF	Decontamination Factors
EA	The Environment Agency
EPR16	Environmental Permitting (England and Wales) Regulations 2016
EPRI	Electric Power Research Institute
FP	Fission Products
GDA	Generic Design Assessment
GRW	Gaseous Radwaste System
IRR17	Ionising Radiation Regulations 2017
HEPA	High-Efficiency Particulate Air
LRW	Liquid Radwaste System
NDAWG	National Dose Assessment Working Group
NRW	Natural Resource Wales
OPEX	Operational Experience
PER	Preliminary Environmental Report
PWR	Pressurised Water Reactor
RCS	Reactor Cooling System
RO/RI	Regulatory Observation/ Regulatory Issue
RP	Requesting Party
RWB	Radioactive Waste Building
SDD	System Design Description
SFAIRP	So Far As Is Reasonably Practicable
SFP	Spent Fuel Pool
SFC	Spent Fuel Pool Cooling System
U.S.NRC	United States Nuclear Regulatory Commission
VRF	Volume Reduction Factors
WCPD	Worst Case Plant Discharge

2.2 INTRODUCTION

This report comprises Chapter 2 of the Holtec SMR-300 Preliminary Environmental Report (PER). The PER forms part of the Generic Design Assessment (GDA) for the reactor.

As a nuclear power plant, the generic SMR-300 will produce radioactive materials as waste throughout its lifetime. This waste will include effluent (aqueous and gaseous) discharges, particularly during the operational stage of the plant's lifetime. This report will consider effluent discharges related to operation of the generic SMR-300, including considerations of the specific radionuclides present and abatement/treatment of waste before discharge.

This report presents an overview of the projected effluent discharges and proposed annual limits to these discharges related to the generic SMR-300, in line with Environment Agency (EA) guidance on discharge limits. The information required for estimates in this chapter and how it is used will be described in the methodology section of this chapter, along with providing context for calculations of effluent discharges and limits, including the use of Operational Experience (OPEX). Where possible, comparisons will be made against other specific nuclear power stations. Information provided on the radioactive waste systems in this revision of this chapter is commensurate to the design maturity at the time of writing. More detail on these systems is available in the System Design Descriptions (SDDs) released as part of the design reference.

In this report 'liquid radioactive wastes' refers to aqueous liquid radioactive wastes only, which excludes non-aqueous liquid wastes such as oils.

2.2.1 Purpose

This chapter aims to provide context and techniques for the calculation of quantitative estimates for effluent (aqueous, gaseous (including aerial discharges with airborne particulates)) discharges of radioactive wastes, and to propose realistic limits for these discharges. These values will be compared to relevant extant power stations with discharges being normalised (in Bq/GWe) to enable relative comparison.

The specific objectives of this Chapter are to:

- Discuss potential normal operations source term(s) associated with operation of the reactor. More detail of the normal operations source term(s) will be provided.
- Provide estimates of quantities and types of aqueous and gaseous discharges to the environment.
- Provide estimates of the effects of radioactive decay and waste treatment on the amount and type of radionuclides that are released to the environment.
- Propose reasonable permit limits for effluent discharges to the environment, based on the above estimates, allowing for uncertainty and potential fluctuations in these discharges. Permit limits are determined in line with Environment Agency, Developing guidance for setting limits on radioactive discharges to the environment from nuclear licensed sites [2] and Environmental Permitting Regulations (England and Wales) Criteria for setting limits on the discharge of radioactive waste from nuclear sites [3]
- Compare these estimated discharges and discharge limits to values from other relevant reactors, recognising and adjusting for different thermal power ratings.
- Outline the methodologies that will be used to calculate effluent discharges (quantities, radionuclides, and release patterns) as well as discharge limits to the environment, using conservative assumptions to ensure that discharges are safe and realistic.

Aqueous effluents will be discharged via a discharge point as part of the main outfall and gaseous effluents will be discharged via a stack.

2.2.2 Scope

This chapter will discuss methods for calculation of radioactive effluent discharges from all modes of normal operation during the operational lifetime of the generic SMR-300.

Normal operation is considered to be routine operation (that is, typically, the design basis or "flowsheet design" and is the minimum level of discharges):

- start-up and shutdown
- maintenance and testing
- infrequent but necessary aspects of operation, for example, plant wash-out
- foreseeable deviations from planned operation (based on a fault analysis) consistent with the use of Best Available Techniques (BAT), for example, occasional fuel pin failures in a reactor.

Precise calculations of discharge rates and resultant doses documented in Holtec SMR-300 GDA PER Chapter 3 Radiological Impact Assessment (RIA) [4] are reliant on specific radionuclide concentrations and forms, however, at this stage, estimates of effluent discharges are not possible due to lack of design maturity. However, the high-level methodology and opportunities for calculating these rates and values for representative isotopes will be discussed in order to present a realistic prediction of the scale of discharges that will be produced.

The discharges considered will only be those from routine/normal operations; discharges from accidents or incidents will not be considered in this report. See Sections 2.4.4 and 2.4.4.1 for discussion of normal operations and 'expected events' of the generic SMR-300.

2.2.3 Chapter Structure

This chapter will firstly cover regulatory context relating to effluent discharges and limits, including the Radioactive Substances Regulations (RSRs) and Regulatory Observations and Issues (ROs and RIs) from previous GDA processes. The process for deriving a source term will then be described, followed by a description of the effluent discharge routes. The method and philosophies for determining effluent discharges will be provided next, and then the methodology for determining proposed limits to these discharges. Future iterations of this report will aim to conclude with a comparison against other relevant Pressurised Water Reactors (PWRs) and the justification as to why these plants were selected for comparison.

2.2.4 Interfaces with other Chapters

To define the interfaces between this chapter and other PER and PSR chapters in order to demonstrate this chapter works together with them to form a strategic environment case.

Table 2 - Interfaces with other chapters

Chapter Title	Interface
Holtec SMR GDA PER Chapter 1 Radioactive Waste Management Arrangements [5]	Chapter 1 presents and provides detail on the management arrangements for solid, liquid and gaseous radioactive waste and spent fuel arising over the lifecycle of the generic SMR-300, providing detail on how the effluents will be generated.
Holtec SMR GDA PER Chapter 3: Radiological Impact Assessment [4]	Radiological Impact Assessment will cover the IRAT2 calculations used for doses from effluent discharges in more detail.
Holtec SMR GDA PER Approach and Application of BAT Demonstration [6]	Best Available Techniques (BAT) will be used to ensure that effluent discharges are controlled effectively and minimised

Chapter Title	Interface
Topic: Sampling and Monitoring	Sampling and monitoring techniques will be used to measure and record effluent discharges, ensuring they are within limits.
Holtec SMR GDA PSR Part B Chapter 2: General Design and Site Characteristics	The fuel and core topic within this chapter will be key to defining the forms of source term, which will be necessary to quantify effluent discharges
Holtec SMR GDA PSR Part B Chapter 10: Radiological Protection [7]	Coolant purification and effluent treatment systems require changeout of spent filter and resin media, presenting dose risks during operation.
Holtec SMR GDA PSR Part B Chapter 11: Environmental Protection [8]	PSR Chapter 11 covers the environmental protection aspects of the generic SMR-300 design. Effluent discharges will affect the environmental impact of the plant and will have to be considered in this chapter.
Holtec SMR GDA PSR Part B Chapter 13: Radioactive Waste Management [9]	PSR Chapter 13 presents and provides detail on the operations and plant arrangements for solid, liquid and gaseous radioactive waste and spent fuel arising over the lifecycle of the generic SMR-300, providing detail on how the effluents will be generated
Holtec SMR GDA PSR Part B Chapter 14: Design Basis Accident Analysis [10]	Chapter B14 presents the deterministic analysis for the generic SMR-300 following accident conditions and presents the basis for demonstration that the risk is ALARP in comparison with the numerical targets introduced in this chapter. Source terms for expected events will be presented in Chapter 14 and used to derive short term discharges in this chapter. This will inform the short-term discharge assessment methodology.
Holtec SMR GDA PSR Part B Chapter 23: Reactor Chemistry [11]	PSR Chapter 23 covers the chemistry regimes across the plant systems, which will influence the volume, radionuclides present, and form of effluent discharges produced

The BAT demonstration for the generic SMR-300 will be developed in line with Holtec SMR GDA PER Approach and Application of the Demonstration of BAT [6] and SMR-300 UK GDA Scope [12], to indicate how the generation and disposal of radioactive waste will be prevented and minimised to reduce the impact on the members of the public and environment As Low As Reasonably Achievable (ALARA). Quantification of Effluent Discharges and Limits will be used to inform the RIA chapter [4], which in turn will be used to identify and aim to demonstrate BAT in the reactor design.

2.2.5 Assumptions

The following assumptions are made to underly the radioactive waste management and radiological discharges arrangements considering the 'Base Case' in the Funded Decommissioning Programme [13]:

- The operational lifetime of a single generic SMR-300 is 80 years.
- The generic SMR-300 is a dual-reactor station that shares a Radioactive Waste Building (RWB) and radioactive waste systems. The regulations, codes and standards applied to radioactive waste management, discharges and decommissioning will be those that are currently in force during the development of site permit applications.
- Dose limits for workers and the public will remain unchanged from those in current use in the UK.
- Definitions of waste categories will remain unchanged from those in current use in the UK.
- The radioactive waste management systems will continue to be used to treat radwaste arisings during the decommissioning stage, if risks to workers, the public and the environment can be reduced So Far As Is Reasonably Practicable (SFAIRP).

2.3 REGULATORY CONTEXT

This section outlines the relevant international and national regulations, obligations, legislation and policy decisions that a new reactor design must adhere to, in order to protect people and the environment from harm resulting from radioactive discharges.

2.3.1 GDA Requirements

The EA/Natural Resource Wales (NRW) guidance for GDAs [14] related to effluent discharges and limits for the whole GDA process are outlined in the table below, alongside the sections of this chapter that individual requirements will be addressed within.

Table 3: Summary of GDA requirements supporting and information to be produced.

GDA Requirement	Information as part of GDA
Quantitative estimates of waste arisings for normal operation of: • **discharges of gaseous and aqueous radioactive wastes**[1]	PER Chapter 2 section 6 provides information on the methodology for calculating and communicating the discharge of gaseous and aqueous radioactive wastes. Quantitative assessment of waste will require the development of source terms.
For gaseous and aqueous radioactive waste, the Requesting Party (RP) must estimate the monthly discharges: • **on an individual radionuclide basis for significant radionuclides**[2] • **on a group basis (for example 'total alpha' or 'total beta') for other radionuclides** • **via each discharge point and discharge route**	PER Chapter 2 sections 4 and 5 cover the methodology for calculating the source terms, and the discharge routes respectively. SDDs for the Liquid and Gaseous Radwaste systems for the generic SMR-300 will be developed.
The radionuclide selection should be consistent with 2004/2/Euratom	Under development
Estimates of discharges and disposals should clearly show the contribution of each constituent aspect of normal operations, including: • **routine operation (typically, the design basis or 'flowsheet design' and the minimum level of disposals)** • **start-up and shutdown** • **maintenance and testing** • **infrequent but necessary aspects of operation, for example, plant start-up, trips, maintenance, shutdown and refuelling.** • **foreseeable (based on a fault analysis), unplanned events during normal operation that remain consistent with using Best Available Techniques (BAT), for example, occasional fuel pin or plant failures**	Under development. Information provided on the rad waste systems in this revision of this chapter is commensurate to the design maturity at the time of writing. More detail on these systems is available in the SDDs released as part of the design reference.

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

[2] Significant radionuclides are those which:

- have a radiological impact on people or non-human species
- are discharged in high quantities of radioactivity
- have long half-lives, may persist or accumulate (or both) in the environment, and may contribute significantly to collective dose
- are indicators of facility performance and process control.

GDA Requirement	Information as part of GDA
The RP must support estimates with performance data from similar facilities, where such facilities exist.	Estimates of discharges will be supported by relevant OPEX and comparison site details will be presented.
The RP must provide proposed limits for: • **gaseous discharges** • **aqueous discharges** • **disposal of combustible waste by on-site incineration (if proposed)**[3]	Once estimates for discharges are available, limits will be presented.
The RP must provide proposals for annual site limits (on a rolling 12-month basis) for gaseous and aqueous discharges and must describe how they derived these limits. They can also propose limits to reflect an operating cycle (campaign limits).	Precise details of the method for calculating site limits will be presented.

2.3.2 RSR Generic Developed Principles

The RSR principles are a set of guidelines published by the EA to protect people and the environment from the effects of radioactive substances Environment Agency, Guidance: Radioactive substances regulation (RSR): objective and principles [15].

The principles relevant to the quantification of effluent discharges and limits are as follows:

Table 4: RSR Principles relevant to Quantification of Effluent Discharges and Limits

RSR Principle	Principle as part of GDA
RSMDP3 – Use of BAT to Minimise Waste [16]: **BAT should be used to ensure that production of radioactive waste is prevented and where that is not practicable minimised with regard to activity and quantity.**	PER Chapter 2 presents the discharge process for the Gaseous Radwaste System (GRW) and Liquid Radwaste System (LRW) for the generic SMR-300. The quantification of discharges for the GRW and LRW of the generic SMR-300 will be provided. Discussion of minimisation of solid wastes and other wastes can be found within PER Chapter 1 Radioactive Waste Management Arrangement [5].
RSMDP12 – Limits and Levels on discharges [16]: **Limits and levels should be established on the quantities of radioactivity that can be discharged into the environment where these are necessary to secure proper protection of human health and the environment.**	PER Chapter 2 presents the methods for calculating these limits. The limits will be confirmed and assessed for whether proper protection has been achieved.
• **RPDP1 – Optimisation of Protection** [17]: **All exposures to ionising radiation of any member of the public and of the population as a whole shall be kept ALARA, economic and social factors being taken into account.**	There will be a BAT process documented for the plant. Implementation of BAT should drive the design to achieve exposures that are ALARA.
• **RPDP4 – Prospective dose assessments for radioactive discharges into the environment** [17]: **Assessments of potential doses to people and to non-human species should be made prior to granting any new or revised permit for the discharge of radioactive wastes into the environment.**	PER chapter 3 [4] presents the methods for assessing exposures to people and non-human species based on discharges at proposed permit levels. Detailed assessments of exposures will be carried out at the site-specific stage, or any future Step 3.
• **ENDP10 – Quantification of discharges** [18]: **Facilities should be designed and equipped so that best available techniques are used to quantify the gaseous and liquid radioactive discharges produced by each major source on a site.**	PER Chapter 2 presents the methodology for quantification of discharges from the GRW and LRW for the generic SMR-300.
• **DEDP4 – Discharges during decommissioning** [19]: **Aerial or liquid radioactive discharges to the environment during decommissioning should be kept to the minimum consistent with the decommissioning strategy for the site.**	Holtec SMR GDA PSR Part B Chapter 26 [20] will present the decommissioning approach and discharges during this stage, with minimisation of waste generation including discharges to be demonstrated.

[3] There is no intention to incinerate on site for the generic SMR-300 design, hence these limits will not be proposed [59].

2.3.3 Other Requirements related to Quantification of Effluent Discharges and Limits

The following key acts, legislations, policies and guidance are relevant to quantification of effluent discharges and limits:

1. Health and Safety at Work etc. Act 1974. [21]
2. The Nuclear Installations Act 1965. [22]
3. Environment Act 1995. [23]
4. Ionising Radiations Regulations 2017. [24]
5. The Environmental Permitting (England and Wales) Regulations 2016. [25]
6. The Environmental Permitting (England and Wales) (Amendment) Regulations 2018. [26]
7. The Environmental Permitting (England and Wales) (Amendment) (No. 2) Regulations 2018. [27]
8. UK policy framework for managing radioactive substances and nuclear decommissioning, May 2024. [28]
9. Department of Energy and Climate Change: Statutory Guidance to the Environment Agency Concerning the Regulation of Radioactive Discharges to the Environment 2009. [29]
10. UK Strategy for Radioactive Discharges 2009 [30]
11. Developing guidance for setting limits on radioactive discharges to the environment from nuclear licensed sites 2005. [31]
12. Environmental Permitting Regulations (England and Wales) Criteria for setting limits on the discharge of radioactive waste from nuclear sites 2010. [32]

The Environmental Permitting Regulation 2016 (EPR16) regulations have specific requirements which are relevant to the quantification of effluent discharges and limits. While dose assessments and evaluations of impact will be covered in PER Chapter 3 Radiological Impact Assessment [4], Holtec SMR GDA PSR Part B Chapter 10 Radiological Protection [7] and Holtec SMR GDA PSR Part B Chapter 11 Environmental Protection [8], this topic will also consider these requirements, namely:

a) All exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable, taking into account economic and social factors;
b) The sum of the doses arising from such exposures does not exceed the individual public dose limit of 1 mSv per year;
c) The individual dose received from any new discharge source does not exceed 0.3 mSv per year; and
d) The individual dose received from the discharges from any single site does not exceed 0.5 mSv per year [25].

The sources of international legislation, codes and standards relevant to effluent discharges and limit setting are also considered in the development of this topic which are regarded as relevant good practice (RGP), are listed (in no particular order) below, including:

1. IAEA, Regulatory Control of Radioactive Discharges to the Environment: General Safety Guide No. GSG-9 [33]
2. IAEA, IAEA-TECDOC-1638 “Setting Authorised Limits for Radioactive Discharges: Practical Issues to Consider” [34]
3. IAEA, International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources [35]
4. Euratom, 2004/2/Euratom Commission Recommendation [36]
5. Euratom, Council Directive 2013/59/Euratom [37]
6. The US NRC, GALE codes [38]
7. The US NRC, NUREG-0017 Revision 2 Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized-Water Reactors [39]
8. ANSI/ANS 18.1 Radioactive Source Term of Light Water Reactors 2020 [40]
9. ANSI/ANS 55.4 Gaseous radioactive waste processing systems for light water reactor plants November 1999 [41]
10. ANSI/ANS 55.6 Liquid radioactive waste processing systems for light water reactor plants May 2007 [42]
11. ICRP, The 2007 Recommendations of the International Commission on Radiological Protection. [43]
12. OSPAR Convention, Convention for the Protection of the Marine Environment of the North-East Atlantic (the UK is a signatory to this convention). [44]

2.3.4 Lessons Learnt and OPEX

Operational Experience (OPEX) on radiological discharges from comparable operations at other PWR facilities have been sourced from the following databases and resources:

Europe:
OPEX from European reactors has been sourced from the European Commission Radioactive Discharges Database (RADD) [45].

US:
OPEX from American reactors has been sourced from the United States Nuclear Regulatory Commission (U.S.NRC) Radioactive Effluent and Environmental Reports database [46], and the Electric Power Research Institute (EPRI) database [47].

UK:
OPEX from UK reactors has been sourced from the EA’s Pollution Inventory [48].

Data from the above sources will be collated and used to support the development and verification of source term data, and eventual comparison of discharges to relevant facilities against the generic SMR-300.

Other OPEX will be used from comparable previous GDA submissions and resulting ROs and RIs, Resolution Plans and EA detailed GDA assessments.

2.3.5 Sustainability

In accordance with the guidance in The UK Policy Framework for Managing Radioactive Substances and Nuclear Decommissioning [49] and the UK Strategy for Radioactive Discharges [50], effluent discharges must be monitored and kept within limits as defined by the regulations above (EPR16 and IRR17), in order to reduce doses to the public and the environment.. Below these limits, further reduction is not sought by regulators, although application of BAT is required [25] to ensure a plant is operating sustainably, in order to protect the environment and current and future generations.

The UN Sustainable Development Goals [51] of most relevance to the generic SMR-300 project have been identified in Holtec SMR GDA PER Chapter 4 Conventional Impact Assessment [52], as the design matures the SDG's identified will be substantiated with evidence from the design, with areas relevant to this chapter presented here in future iterations of this document.

In the development of the environment case in the generic SMR-300 GDA process, application of the waste hierarchy and a risk-informed approach are recognised as key principles in the lifecycle of radioactive waste management, which ensure that the radioactive wastes, including those discharged from the site are managed in a safe, secure, environmental, and sustainable approach. The main aspects from the effluent discharges perspective that contribute to sustainable development in the generic SMR-300 include:

- Implementation of BAT for the generic SMR-300 design as well as consideration of the waste hierarchy principles to prevent and/or minimise the impacts of radioactive discharges on the public and environment.
- In the optimisation process of radioactive effluent discharges (and solid radioactive wastes generated through the filtration of the effluents), all relevant competing factors, such as safety, technical feasibility, environment, and socio-economic benefits, etc., will be considered appropriately to give a single solution through the risk-informed decision-making approach.

2.4 DEVELOPMENT OF A SOURCE TERM FOR ESTIMATING RADIOACTIVE DISCHARGES

2.4.1 Source term definition

The 'source term' of a nuclear reactor refers to the specific magnitude and mix of radionuclides present in the plant within the primary system and associated plant systems during normal operations. The source term is expressed as fractions of the fission product inventory in the fuel and contains information about the physical and chemical form and the release time of each radionuclide [53]. It is key to defining the release of ionising radiation, other radioactive wastes and effluent discharges to the environment.

The discharge source terms will be reliant on the reactor coolant source term and will be derived when information becomes available. The reactor coolant source term is the specific mix of radionuclides present in the reactor coolant and is dependent on the core source terms (core isotopes & decay heat and fission products), as well as activation and corrosion products. The production mechanisms for the radionuclides in these source terms are discussed below.

2.4.2 Radionuclide production mechanism

The primary sources of radionuclide production during normal operation at power are:

- Direct and prompt activation radiation from the core
- Neutron activation in reactor coolant
- Leakage of fission products from defective fuel
- Activated corrosion products in reactor process systems

Actinides such as Americium (Am), Curium (Cu), Neptunium (Np) and Plutonium (Pu) are created by direct or prompt activation by neutron capture of radionuclides (such as Uranium - 238 (U-238)) present in the fuel material, impurities in cladding or trace elements on fuel assembly surfaces deemed tramp uranium.

Neutron Activation of various constituents in the primary reactor leads to the generation of Nitrogen-16 (N-16), Tritium (H-3), Carbon-14 (C-14) and Argon-41 (Ar-41). Although Nitrogen-16 (N-16) from neutron activation of Oxygen-16 (O-16) in the primary coolant is the predominant radionuclide in the steam generator and pressuriser during operations, it has a very short half-life of 7.1 seconds. Therefore, although it is a significant contributor to the radiation field during operation inside the containment building, it is not a concern for off-site dose considerations.

Fission products of fissile material in the reactor core can be present in the primary coolant by leakage of fission products through fuel cladding defects. Key fission products generated are Caesium (Cs), Iodine (I), Krypton, Strontium (Sr) and Xenon (Xe).

Corrosion and wear products in the reactor coolant are generated from neutron activation of non-radioactive corrosion and wear products that are circulated in the primary coolant. Typical corrosion activated products are Sodium-24 (Na-24), Chromium-51 (Cr-51), Manganese-54 (Mn-54), Iron-55 (Fe-55), Iron-59 (Fe-59), Cobalt-58 (Co-58), Cobalt-60 (Co-60), Zinc-65 (Zn-65), Zirconium-95 (Zr-95), Silver-110m (Ag-110m) and Tungsten-187 (W-187).

2.4.3 Planned development of definitive normal operations source term

The majority of information needed to develop a definitive normal operations source term is not available at this stage. This information will be used to generate discharge calculations and ultimately dose calculations. Calculations and analyses for the GDA will be based on the availability of the source term, available OPEX data, current SMR-160 data, and assumptions based on the generic SMR-300 design.

In this section, the process for deriving the normal operations source term, the data needed, and the corresponding philosophies will be described.

2.4.3.1 Source term derivation

A source term will be made available from the RP for Liquid Waste (ANSI/ANS-18.1) [40] and Gaseous Waste derived from the reactor coolant source term. In parallel to receipt of source term data from the RP, development of an OPEX source term from comparable nuclear power stations will also enable verification and sensitivity analysis to be undertaken. An original Core Isotopics and Source Terms Document for SMR-160 describes the design basis neutron and gamma source terms, decay heat values, and quantities of radionuclides available for release which will also provide an input to radionuclide source terms and radionuclide selection.

The aqueous effluent source terms assumes the list of pertinent nuclides, for normal operations, is based on ANS-18.1-2020 “Radioactive Source Term for Normal Operation of Light Water Reactors,” [40] and augmented with some additional radionuclides for completeness. The procedures described in ANSI/ANS 18.1 shall also be used to determine any adjustment factors needed to modify the radionuclide concentrations for reference PWR with once-through steam generators for generic SMR-300.

2.4.3.2 Source term optimisation philosophy

Radionuclide production by-products are unavoidably generated, but the amount and impacts of these products can be reduced through design and maintenance of good chemistry control during normal operation. The quantity of radionuclides produced should be optimised through the application of BAT within the design to ensure that resulting exposures to members of the public are As Low As Reasonably Achievable (ALARA).

PSR Part B Chapter 23: Reactor Chemistry [11] contains claims related to minimisation of radionuclides at source, specifically:

Sub-Claim 2.2.3.5.1 *- The Reactor Coolant System chemistry regime has been optimised to reduce fuel CRUD deposition SFAIRP.*

Sub-Claim 2.2.3.5.2 *- The Reactor Coolant System chemistry regime has been optimised to reduce fuel cladding degradation SFAIRP.*

Sub-Claim 2.2.3.5.4 *- The Reactor Coolant System chemistry regime has been optimised to reduce structural materials degradation.*

As discharge radionuclides cannot be eliminated from the process, it is intended that the BAT demonstration will be used to optimise the amount and activity of radionuclides discharged.

2.4.4 Operating Phases

The generic SMR-300 follows the standard four operating phases. These are the phases that are referred to in the OPEX for PWRs and will be the phases in the OPEX that generic SMR-300 data is compared to. A summary of the four operating phases are:

1. Start-up Operation: The phase between completion of refuelling and power operation at 100% power.
2. Power Operation[4]: Steady-state power operation at 100% power. This will be the phase for most of the time that the generic SMR-300 is in operation.
3. Shutdown Operation: The phase between power operation at 100% power and refuelling outage.
4. Refuelling Operation: The phase in which spent fuel is removed and fresh fuel is loaded.

The generic SMR-300 is also designed to provide flexible power output and perform load following based on grid demand [54]. This means that the generic SMR-300 is capable of operating at less than 100% power based on grid demand, without a plant trip. The plant will produce fewer discharges when operating in a load following operational mode, hence the full power operation mode will be used as a bounding case in the calculation of effluent discharges and limits.

2.4.4.1 Expected events

Derivation of the source term must also include consideration of 'expected events': events that can reasonably be expected to occur during the operational lifetime of a plant. This includes: "infrequent but necessary aspects of operation; and the foreseeable deviations from planned operation (based on a fault analysis) consistent with the application of BAT, for example, occasional fuel pin failures in a reactor" [55].

The contributions of these events will be calculated based on Source Term data. OPEX data will include contributions from most frequent expected events (due to being modelled on existing reactors), but models and theoretical calculations will need adjustments based on consideration of expected events. The impact of expected events and other short-term increases in activity concentration will be assessed in the Radiological Impact Assessment chapter of the PER [4] at the site-specific stage of the GDA. However, the information around expected events will be required at an earlier stage in order to develop appropriate dose assessment methodologies. The appropriate methodology will be adopted depending on how the source term is derived.

Main expected events specific for the generic SMR-300 will be confirmed; however, examples of expected events are listed in section 2.6.7.

[4] Referred to as "Normal Operation" in the plant overview; renamed here to avoid confusion with 'normal operations' as defined by GDA guidelines.

2.5 DISCHARGE ROUTES

2.5.1 Overview

Waste management systems are being developed for both aqueous and gaseous radioactive effluent discharges from the generic SMR-300. These systems will include abatement and analysis of radioisotopes to ensure a minimisation of discharge to the environment. The following section discusses the general management processing systems in place for generic SMR-300 for managing effluent discharges. Detailed generic SMR-300 systems will be presented in future revisions however, information provided on the effluent discharge systems in this revision of the chapter is commensurate to the design maturity at the time of writing. More detail on these systems is available in the SDDs released as part of the design reference. It is anticipated that a site outfall is the discharge point for aqueous waste and main site stack is the discharge point for gaseous radioactive waste. Discharges will be sampled and monitored prior to discharge to ensure permit compliance.

Both the aqueous and gaseous discharges systems will be designed in accordance with ANSI/ANS 55.6 Liquid Radioactive Waste Processing for Light Water Reactor Plants [42] and ANSI/ANS 55.4 Gaseous Radioactive Waste Processing for Light Water Reactor Plants [41].

There is currently no on-site incinerator anticipated for the generic SMR-300.

2.5.2 Gaseous Effluent Discharge Routes

2.5.2.1 Gaseous Radwaste System

GRW is designed to process gaseous waste generated during normal plant operation.

The system provides filtration and holdup for the decay of radioisotopes and transfers the processed gaseous effluent to the Heating, Ventilation and Air Conditioning System (HVAC) for monitoring and release via the stack.

Details of the GRW for processing gaseous effluents are documented in PER Chapter 1 [5] sections 1.5.2.1 and 1.5.2.3.

2.5.3 Aqueous Effluent Discharge Routes

2.5.3.1 Liquid Radwaste System

The LRW is designed to protect plant personnel from radiation exposure and incorporate the basic ALARA objectives and to meet the requirements for radionuclide concentration releases to the environment.

Note: when describing the liquid radwaste system the US use the term liquid (hence LRW), whereas for the UK aqueous would be used. Non-aqueous wastes (e.g. oils and solvents) are not covered in this chapter.

Details of the LRW are documented in section 1.5.1 of PER Chapter 1 [5].

2.6 METHODOLOGY FOR ESTIMATING EFFLUENT DISCHARGES AND LIMITS

2.6.1 Overview of calculational approach

The calculational approach will be based on determining the inputs in the radioactive effluent transfer and applying reductions factors from radioactive decay and processing within the design parameters of the generic SMR-300. Resultant outputs in the form of discharges can then be estimated using a mass activity balance model to calculate the activity of treated effluent streams exiting the aqueous and gaseous radioactive effluent treatment systems.

In simplistic terms, the approach will sum the radioactive inputs from the various aqueous and gaseous sources and subtract the sum of activity retained or decayed (via abatement) to calculate the resulting output in discharges.

Effluent Input examples

Gaseous Effluent Sources

- Degassing of reactor coolant
- Ventilation exhaust air from the plant

Aqueous Effluent Sources

- Effluent radioactive drainage systems
- Degassed reactor coolant from the Chemical Volume Control System

Inputs from the sources (in terms of flow rates and specific activity levels) will be calculated to determine total activities and volumes to be processed by the LRW and GRW. These lists of sources are non-exhaustive.

Processing by treatment and decay (Abatement)

The amount of radioactivity removed via decay during collection and removal by the LRW and GRW can then be determined.

Decay of radionuclides will be modelled with assumptions on hold-up and processing times.

Decontamination Factors (DFs) and Volume Reduction Factors (VRFs) can be applied to standard abatement processes based on design specification, RGP and OPEX.

Outputs

The purpose of the mass and activity balance is to estimate the overall volume and activity of radionuclides discharged.

Mass and Activity Balance Summary

Activity generated will be removed by a combination of decay, purification, discharge and disposal.

The GALE-PWR codes [38] used in NUREG-0017 Revision 2 Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from Pressurized-Water Reactors [39] are based on IAEA guidance may be used to calculate the generic SMR-300 effluent discharges.

2.6.2 Operating conditions

The operating conditions considered in the quantification of discharges and limits are all the constituents of normal operation including start-up, power operation, shutdown and maintenance as well as expected faults. Load following states will also be considered but are likely to produce lower discharges than full power operation, and therefore are unlikely to affect limits or upper bounds of discharge estimates.

2.6.3 Determination of significant radionuclides

EA guidance [55] recommends a series of criteria to select significant radionuclides that:

a) are significant in terms of radiological impact on people (the dose to the most exposed group at the proposed limit exceeds 1 µSv per year);
b) are significant in terms of radiological impact on non-human species (where the impact on reference organisms from the discharges of all radionuclides at the proposed limits exceeds 40 µGy/hour);
c) are significant in terms of the quantity of radioactivity discharged (the discharge of a radionuclide exceeds 1 TBq per year);
d) may contribute significantly to collective dose (where the collective dose truncated at 500 years from the discharges of all radionuclides at the proposed limits exceeds 1 man-sievert per year to any of the UK, European or World populations);
e) are constrained under national or international agreements or is of concern internationally;
f) are indicators of plant performance, if not otherwise limited on the above criteria; and
g) for the appropriate generic categories from the RSR Pollution Inventory (e.g. “alpha particulate” and “beta/gamma particulate” for discharges to air) to limit any radionuclides not otherwise covered by the limits set on the above criteria.

The doses mentioned in criteria a) and b) will be assessed using methods set out in PER Chapter 3 Radiological Impact Assessment [4], principally the EA’s Initial Radiological Assessment Tool (IRAT2) and the reactor coolant source term, to determine significant radionuclides. The reactor coolant source term will be assessed against criterion d at the site-specific stage. Significant radionuclides defined by criteria c, e, f and g will be identified once the source terms has been developed.

2.6.4 General process

The quantification of aqueous and gaseous discharges from generic SMR-300 will be determined by the source term methodology determined in 2.4 The justification for the use of OPEX from the various sources and relevance to generic SMR-300 will be documented in GDA Step 2.

The key high-level steps of the process are:

1) Determine source term for gaseous and aqueous effluent routes (2.4)
2) Determine inputs from gaseous and aqueous sources and fingerprints (2.6.1)
3) Determine significant radionuclides (2.6.3)

4) Determine Decontamination Factors of abatement processes and how key radionuclides will be removed (2.6.1)
5) Determine the specific activities and volumes of resultant aqueous and gaseous discharges (short-term and long-term)
6) Determine the total activity of each significant radionuclide from the discharges
7) Determine limits in accordance with [2]

Normalised OPEX data from comparable PWR plants and previous GDA data, will also be used to compare estimated discharges from the generic SMR-300.

2.6.5 Correction Factors

Although OPEX data used will be selected based on similar plants to the generic SMR-300, there will be discrepancies in discharges – mainly due to design differences. Therefore, a range of correction factors will be defined to be considered in the calculation of discharges. These correction factors will be discussed in the Step 2 document "Methodology for calculating effluent discharge limits".

2.6.6 Headroom Factor

Plant normal operations work on a cycle, so there will be some fluctuations of the levels of gaseous and aqueous discharges within this cycle. Headroom factors will be utilised to ensure that discharge limits are sufficient to allow for normal operation discharge fluctuations without breaching the limits. Due to the fact the generic SMR-300 is a new plant design and there isn't a substantial quantity of directly relevant OPEX data available, considerable uncertainty about the data presented exists therefore greater headroom can be justified when determining headroom factors. They will be utilised to account for uncertainties in discharge estimates that result from using OPEX data to predict plant discharges where possible. The EA permitting requirements recommends that limits are 2 times the expected discharge of a site [2], so this combined with headroom factors should ensure that limits are not breached.

2.6.7 Analysis of expected events

Expected events can result in increased discharges, so representative cases from the list of expected events will be used to quantify these potential increases in a future iteration of this report and ensure they are within limits. Typical expected events that can impact radiological discharges are:

- Small leakage of radioactive systems e.g., steam generator tube leaks
- Unplanned reactor outages causing blowdown and pressure release
- Evaporation from the Spent Fuel Pool (SFP) and other areas
- Coolant and steam leakage from the primary circuit
- Fuel cladding defects or fuel pin failure
- Incorrect chemistry in the primary coolant
- Maintenance activities

The above is by no means an exhaustive list and this list will be fully substantiated in future iterations of this report. It is worth nothing that in many cases the expected events that lead to an increase in gaseous effluent discharges also have an impact on aqueous effluent discharges and vice versa.

2.7 PROSPECTIVE EFFLUENT DISCHARGES

2.7.1 Overview

The RP is required to provide estimates for annual and monthly discharges of significant aqueous and gaseous radionuclides to the environment [14]. Radionuclides that exist in small enough quantities or activities to be grouped, will have their activities grouped under 'total alpha', 'total beta' and 'total gamma', with these groups analysed in the same way as individual radionuclides.

As discussed earlier, design data underpinning the source term and predicted discharges from the generic SMR-300, to allow the derivation of annual discharges, is not yet fully mature. Further, the design of relevant systems that have a bearing on the generation and discharge of radioactive effluent, and frequency of discharges to the environment (including related plant operating philosophies) are currently in development.

Once source terms have been derived, the annual discharges will be listed as follows:

2.7.1.1 Gaseous discharges

The estimated annual discharge of significant gaseous radionuclides will be detailed upon further design development.

2.7.1.2 Aqueous discharges

The estimated annual discharges of significant aqueous radionuclides will be detailed upon further design development.

2.7.2 Monthly discharges

A discharge release schedule has not yet been confirmed for the generic SMR-300 design, so it is not possible at this stage to determine the relationship between the annual discharges and monthly discharges.

Nevertheless, considering the design objective that the generic SMR-300 operates with an overall capacity factor of > 0.95 [54], it can be assumed that the plant can be operated with minimal variation in routine discharges to the environment during power operations. This is on the basis that aqueous effluents are planned to be stored prior to scheduled release and that gaseous discharges are predicted to be relatively uniform, aside from during shutdown (when the reactor coolant is degasified), which will be considered a bounding case for gaseous discharge. A conservative bounding case for aqueous discharges will be that the maximum monthly discharge is equivalent to the maximum annual discharge; this is based on a release schedule of once per year.

The predicted monthly discharges will be re-estimated on completion of the review of predicted discharges and review the list of significant radionuclides, once definitive generic SMR-300 source terms are available.

2.7.2.1 Gaseous discharges

The estimated monthly discharge of significant gaseous radionuclides will be detailed upon further design development.

2.7.2.2 Aqueous discharges

The estimated monthly discharges of significant aqueous radionuclides will be detailed upon further design development.

2.8 PROPOSED DISCHARGE LIMITS

2.8.1 Overview

For an environmental permit application to be duly made for a new nuclear station, the prospective operator must provide proposals for annual site limits for effluent discharges. This is to demonstrate that BAT has been applied to discharge systems to minimise dose to the environment and members of the public, ensuring it is within statutory limits. This section will detail how the discharge limits will be calculated for the generic SMR-300. The proposed discharge limits are usually given for selected radionuclides; as the source terms have not been determined yet, these limits will be provided.

2.8.2 Approach for evaluating proposed limits.

Both normal operations and expected events must be accounted for in the development of proposed discharge limits. Given the unplanned nature of “expected events”, a bounding case approach must be taken for the annual discharge limit, leaving sufficient headroom. As the source terms will be derived, OPEX data is considered to include data from this form of expected event in other PWRs, it will be sufficient to use the source terms together with defined plant processes in order to derive the discharge limits for the stages of operational life for the plant.

Headroom factors as mentioned in 1.6.6 must also be considered in the proposal of annual limits, so that the plant can operate normally while complying with the proposed limits. Previous PWR GDA submissions have used a statistical method for determining these headroom factors, but OPEX data for SMRs is not yet sufficiently detailed to allow this method of determination. Instead, an alternative approach using “worst case plant discharge” (WCPD) will be used, as recommended by the EA [2]. This guidance states that “It is usually appropriate to take the worst case to be a factor of 2 times the best estimate” for determining headroom factors.

2.9 COMPARISON WITH SIMILAR PLANTS

2.9.1 Overview

The GDA guidance that similar plants must be considered relates to the requirement that "radioactive wastes and discharges from any new nuclear power stations in England and Wales are minimised and do not exceed those of comparable stations across the world" [56]. To achieve this, the generic SMR-300 will consider the predicted discharges from other PWR designs submitted for GDA. As these previous designs were also required for the GDA submission to not exceed worldwide comparable stations, it follows that if the generic SMR-300 should not exceed these designs that it also will comply with this requirement.

As these PWRs have different thermal power ratings, the discharges will be normalised to be comparable (given in Bq/GWe).

2.9.2 Comparison with other nuclear power stations

Data for comparison to other plants will be presented. This data will show the normalised predicted annual gaseous and effluent discharges from the GDA submissions of previous PWR designs, and the >5-year average of reported discharge from PWRs globally with inclusion of Sizewell B. Information from the generic SMR-300 will be added and compared.

2.10 SUMMARY

This chapter has presented the methodologies and philosophies that will be used to assess aqueous and gaseous radioactive discharges from the generic SMR-300 design on both a monthly and annual basis. The use of OPEX data from other PWRs, and "worst case" modelling will be key to deriving both best estimates for monthly and annual discharges and limits for effluent discharges from the design. The IRAT2 tool will be used to assess the dose impact of each radionuclide to be released to the public and the environment to aid in determining the list of significant radionuclides.

The method for comparison to other plants (normalisation to Bq/GWe for specific radionuclides) has been demonstrated, and an indicative (but not exhaustive) list of comparable reactors given and justification as to why those plants have been chosen. This comparison will aim to demonstrate that the generic SMR-300 design will be compliant with the requirement to not exceed comparable reactors in terms of effluent discharges.

By the end of the GDA, it is anticipated data to determine source terms will be available, therefore, precise calculations of, discharges, and discharge activity will be possible for generic SMR-300. It will also be possible to determine the discharge limits for the site. This data will then allow for the assessment of the radiological impact of discharges.

At this stage of design, data requirements have been identified in order to be able to conduct the initial impact assessments. Next steps have been determined to ensure a meaningful GDA assessment can be undertaken within this chapter, together with Forward Actions (FA) for detailed assessments to be completed during the site-specific stage. FA have been collated and are managed via the process described in [57].

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