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General Nuclear System

# General Nuclear System Ltd.

## UK HPR1000 GDA Project

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**Title:**

# Pre-Construction Environmental Report

# Chapter 6

# Quantification of Discharges and Limits

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# TABLE OF CONTENTS

**6.1 List of Abbreviations and Acronyms ........ 3**

**6.2 Introduction ........ 4**

6.2.1 Objective ........ 4

6.2.2 Scope ........ 5

**6.3 Regulatory Context ........ 6**

6.3.1 P&ID Requirements ........ 6

6.3.2 Relevant REP ........ 7

6.3.3 Discharge Requirements Related to Dose Limitation ........ 8

**6.4 Discharge Routes ........ 9**

6.4.1 Gaseous Effluent Discharge Routes ........ 9

6.4.2 Liquid Effluent Discharge Routes ........ 11

**6.5 Methodology for Quantification of Discharges and Limits ........ 14**

6.5.1 Operating Conditions ........ 14

6.5.2 Significant Radionuclides ........ 14

6.5.3 General Process ........ 16

6.5.4 Correction Factors ........ 21

6.5.5 Headroom Factor ........ 23

6.5.6 Analysis of Expected Events ........ 25

**6.6 Estimated Discharges and Proposed Limits ........ 28**

6.6.1 Monthly Discharges ........ 28

6.6.2 Annual Discharges ........ 29

6.6.3 Contribution of Expected Events ........ 29

6.6.4 Proposed Annual Discharge Limits ........ 33

6.6.5 Maximum Monthly Discharges ........ 33

**6.7 Comparison with Other Plants around the World ........ 37**

6.7.1 Comparison with International PWR OPEX ........ 37

6.7.2 Comparison with Previous GDA ........ 47

**6.8 Conclusion ........ 54**

**6.9 References ........ 55**

## 6.1 List of Abbreviations and Acronyms

| | |
|---|---|
| APG | Steam Generator Blowdown System [SGBS] |
| BAT | Best Available Techniques |
| BFX | Fuel Building |
| BNX | Nuclear Auxiliary Building |
| BRX | Reactor Building |
| BWX | Radioactive Waste Treatment Building |
| CGN | China General Nuclear Power Corporation |
| CVI | Condenser Vacuum System [CVS] |
| DWK | Fuel Building Ventilation System [FBVS] |
| DWN | Nuclear Auxiliary Building Ventilation System [NABVS] |
| DWQ | Waste Treatment Building Ventilation System [WBVS] |
| EA | Environment Agency (UK) |
| EBA | Containment Sweeping and Blowdown Ventilation System [CSBVS] |
| EDE | Annulus Ventilation System [AVS] |
| EDF S. A. | Électricité de France S. A. |
| HEPA | High Efficiency Particulate Air |
| HPC | Hinkley Point C |
| HPR1000 (FCG3) | Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3 |
| HVAC | Heating, Ventilation and Air Conditioning |
| NRC | Nuclear Regulatory Commission (US) |
| OPEX | Operating Experience |
| P&ID | Process and Information Document for Generic Assessment of Candidate Nuclear Power plant Designs |
| PCER | Pre-Construction Environmental Report |
| PCSR | Pre-Construction Safety Report |
| PSA | Probability Safety Assessment |

| | |
|---|---|
| PWR | Pressurised Water Reactor |
| RADD | European Commission Radioactive Discharges Database |
| RCV | Chemical and Volume Control System [CVCS] |
| REA | Reactor Boron and Water Makeup System [RBWMS] |
| REP | Radioactive Substances Regulation - Environmental Principles |
| RPE | Nuclear Island Vent and Drain System [VDS] |
| SEK | Waste Fluid Collection System for Conventional Island [WFCSCI] |
| SEL | Conventional Island Liquid Waste Discharge System [LWDS (CI)] |
| SRE | Sewage Recovery System [SRS] |
| SSC | Structures, Systems and Components |
| SZB | Sizewell B |
| TEG | Gaseous Waste Treatment System [GWTS] |
| TEP | Coolant Storage and Treatment System [CSTS] |
| TER | Nuclear Island Liquid Waste Discharge System [NLWDS] |
| TEU | Liquid Waste Treatment System [LWTS] |
| UK HPR1000 | UK version of the Hua-long Pressurised Reactor |

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Steam Generator Blowdown System (APG [SGBS]).

## 6.2 Introduction

A nuclear power plant produces by nature radioactive materials during its operation. These materials are minimised at source as far as reasonably practicable, and the unavoidable part produced is treated by physical or chemical processes as and where possible, and ultimately discharged to the environment in form of gaseous or liquid waste or disposed of by relevant approved facilities in form of solid waste.

### 6.2.1 Objective

The aim of this chapter is to present the information on the likely radioactive gaseous and liquid discharges to the environment from the UK version of the Hua-long Pressurised Reactor (UK HPR1000) during normal operation.

The content of this chapter is in line with the requirements on radioactive gaseous and liquid discharges and limits outlined in the *Process and Information Document for Generic Assessment of Candidate Nuclear Power plant Designs (P&ID)*, Reference [1], and the principles from the *Radioactive Substances Regulation - Environmental Principles (REP)*, Reference [2].

The content of this chapter is developed based on Design Reference version 2.1, as described in *UK HPR1000 Design Reference Report*, Reference [3].

### 6.2.2 Scope

This chapter focuses on the identification of the significant radionuclides for which limits should be set and on the quantification of radioactive gaseous and liquid discharges and proposed limits for the UK HPR1000. In this chapter, the radioactive gaseous and liquid effluent streams and discharge routes of the UK HPR1000 are presented, and the estimated discharges and proposed limits for significant radionuclides during normal operation are provided.

The quantification of radioactive solid waste is described in Pre-Construction Environmental Report (PCER) Chapter 4. The quantification of non-radioactive waste is described in PCER Chapter 8.

The demonstration of Best Available Techniques (BAT) on how the radioactive wastes are minimised and reasonably managed and controlled to minimise the radioactive discharges and their impacts on environment during normal operation for the UK HPR1000 is provided in PCER Chapter 3 for the generation, treatment and management of radioactive effluents, and in PCER Chapter 5 for sampling and monitoring.

The interfaces with other PCER chapters are presented in T-6.2-1.

T-6.2-1 Interfaces with Other PCER Chapters

| Chapter | Interface Relationship |
|---|---|
| PCER Chapter 1 Introduction | PCER Chapter 1 provides the summary of each PCER chapter and the P&ID route map. |
| PCER Chapter 3 Demonstration of BAT | PCER Chapter 3 provides the demonstration of BAT on the generation, treatment and management of radioactive wastes for the UK HPR1000. |
| PCER Chapter 4 Radioactive Waste Management Arrangement | PCER Chapter 4 provides information on the radioactive waste management strategy and arrangement for the UK HPR1000.<br>It also provides quantification of solid radioactive waste and proposed disposal routes for the UK HPR1000. |
| PCER Chapter 5 Approach to Sampling & | PCER Chapter 5 provides information on the sampling and monitoring related to radioactive waste and its BAT |

| Chapter | Interface Relationship |
|---|---|
| Monitoring | demonstration for the UK HPR1000.<br>It also provides the list of radionuclides that are to be monitored in the discharges, including the significant radionuclides that are identified in PCER Chapter 6 and for which limits are proposed. |
| PCER Chapter 7 Radiological Assessment | PCER Chapter 6 provides the proposed annual limits and the maximum monthly discharges that are used as inputs for the radiological impact assessment presented in PCER Chapter 7.<br>PCER Chapter 7 provides the radiological impact assessment results based on the maximum monthly discharges and the proposed limits to support the selection of significant radionuclides. |

## 6.3 Regulatory Context

### 6.3.1 P&ID Requirements

The requirements related to the quantification of radioactive gaseous and liquid discharges and limits provided in item 5 of Table 1 in P&ID, Reference [1], are as follows:

***Quantification of radioactive waste disposals***

***Provide quantitative estimates for normal operation of:***

- *discharges of gaseous and aqueous radioactive wastes; 'Normal operation' includes the operational fluctuations, trends and events that are expected to occur over the lifetime of the facility, such as start-up, shutdown, maintenance, etc. It does not include increased discharges arising from other events, inconsistent with the use of BAT, such as accidents, inadequate maintenance, and inadequate operation.*

*For gaseous and aqueous radioactive wastes, you should estimate your monthly discharges:*

- *on an individual radionuclide basis for significant radionuclides;*
- *on a group basis (for example 'total alpha' or 'total beta') for other radionuclides;*
- *via each discharge point and discharge route.*

*'Significant ' radionuclides are those which:*

*- are significant in terms of radiological impact for people or non-human species;*

*- are significant in terms of the quantity of radioactivity discharged (that is,*

*numerically high);*

*- have long half-lives, may persist and/or accumulate in the environment, and may contribute significantly to collective dose;*

*- are significant indicators of facility performance and process control.*

*Your radionuclide selection should be consistent with reference EU, 2004…*

*…Your estimates of discharges and disposals should clearly show the contribution of each constituent aspect of normal operations, including:*

- *routine operation (that is, 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 wash-out; and the foreseeable, undesired deviations from planned operation (based on a fault analysis) consistent with the use of BAT, for example, occasional fuel pin failures.*

*You should support your estimates with performance data from similar facilities and explain, where relevant, how changes in design or operation from those facilities affect the expected discharges and disposals. You should demonstrate that discharges and waste arising will not exceed those of comparable power stations across the world (as required by UK Government policy (GB Parliament, 2008)).*

***Provide your proposed limits for:***

- *gaseous discharges;*
- *aqueous discharges.*

*Provide your proposals for annual site limits (on a rolling twelve months basis) for gaseous and aqueous discharges and describe how these were derived. If desired, additionally propose limits to reflect an operating cycle, that is, 'campaign' limits.*

### 6.3.2 Relevant REP

The REP, Reference [2], contains principles relevant to the quantification of radioactive gaseous and liquid discharges and limits, which are mentioned in Fundamental Principle E (Protecting Human Health and Environment) and Generic REP RSMDP12. All of these principles have been considered in the analysis of radioactive gaseous and liquid discharges and proposed limits for the UK HPR1000, especially the following ones:

*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.*

*Considerations:*

*a) Limits and levels should be established on those radionuclides and/or groups of radionuclides which:*

*1) Are of significance in terms of radiological impact for humans and non-human species, including those which may be taken up in food;*

*2) Are of significance in terms of the quantity of radioactivity discharged;*

*3) Have long half-lives and which may persist and/or accumulate in the environment, and may contribute significantly to collective dose;*

*4) Are significant indicators of facility performance and process control; or*

*5) Provide for effective regulatory control and enforcement.*

*b) The time periods on which limits and levels should be based should be consistent with the intent of the limits or levels. Such periods include annual, quarterly, monthly, weekly and daily. The periods may be calendar or rolling.*

*Limits should be set such that there is minimum headroom between actual levels of discharge expected during normal operation and the discharge limit. "Operation" relates to the current activities at a site including commissioning, operations and decommissioning. "Normal" operation includes maintenance and relevant operational fluctuations, trends and events that are expected to occur over the likely lifetime of the facility.*

### 6.3.3 Discharge Requirements Related to Dose Limitation

*The Environmental Permitting (England and Wales) Regulations 2016 (as amended)*, Reference [4], set the limits and constraints on the annual radiation exposures to members of the public. It is required to ensure that:

a) All exposures to ionising radiation of any member of the public and of the population as a whole resulting from the disposal of radioactive waste are kept as low as reasonably achievable, taking into account economic and social factors;

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 since 13th May 2000 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.

The *Statutory Guidance to the Environment Agency Concerning the Regulation of*

*Radioactive Discharges to the Environment*, Reference [5], states that:

*Where the prospective dose to the most exposed group of members of the public from discharges from a site at its current discharge limits is below 10 µSv/yr the Environment Agency should not seek to reduce further the discharge limits that are in place, provided that the holder of the authorisation applies and continues to apply BAT.*

*It should be noted that the 10µSv/yr figure is not a dose target, a dose limit, threshold or a radiation standard. Instead, it represents an appropriate level of dose, below which discharge limits should not be reduced further if the operator is continuing to apply BAT.*

## 6.4 Discharge Routes

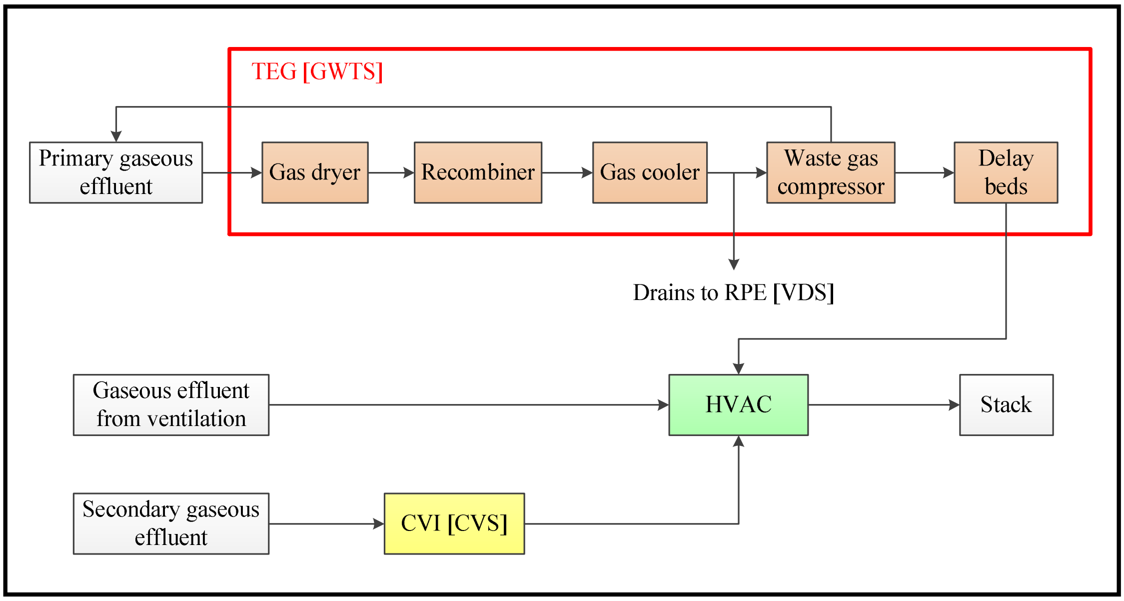
The radioactive gaseous and liquid effluents of the UK HPR1000 are managed throughout the plant, treated by abatement systems, sampled in key locations for effluents characteristics analysis, and monitored in real time by monitoring systems, to ensure that the discharges to environment are reasonable and acceptable.

Discharges from waste incineration are not considered since onsite waste incineration technology is not adopted for the UK HPR1000.

The radioactive gaseous and liquid effluent streams and discharge routes have been identified based on the process and system designs of the UK HPR1000, described in Pre-Construction Safety Report (PCSR) system chapters, Reference [6], [7], [8], [9], [10] and [11], and the radioactive waste management strategy and arrangement, described in PCER Chapter 4.

### 6.4.1 Gaseous Effluent Discharge Routes

The radioactive gaseous effluents from the UK HPR1000 are collected and treated by three systems: the Gaseous Waste Treatment System (TEG [GWTS]), the Heating, Ventilation and Air Conditioning (HVAC) system, and the Condenser Vacuum System (CVI [CVS]). The HVAC system consists of several subsystems in different radioactive buildings: the Containment Sweeping and Blowdown Ventilation System (EBA [CSBVS]) and the Annulus Ventilation System (EDE [AVS]) in Reactor Building (BRX), the Nuclear Auxiliary Building Ventilation System (DWN [NABVS]) in Nuclear Auxiliary Building (BNX), the Fuel Building Ventilation System (DWK [FBVS]) in Fuel Building (BFX), and the Waste Treatment Building Ventilation System (DWQ [WBVS]) in Radioactive Waste Treatment Building (BWX). After the abatement process, all the gaseous effluents are finally discharged through the HVAC system via the main discharge stack. An overview of UK HPR1000 radioactive gaseous effluent streams is provided in F-6.4-1.




F-6.4-1 Radioactive Gaseous Effluent Streams

The radioactive gaseous effluents can be divided into three categories:

a) Primary gaseous effluent. This gaseous effluent comes from the degassing and head spaces of the vessels containing primary coolant or primary effluent. It is collected and processed by the TEG [GWTS] and the DWN [NABVS] before being discharged.

   During steady-state operation, the TEG [GWTS] operates continuously as a closed circuit with the flushing gas being reused and the radionuclides decaying in the closed loop. Only a small quantity of gas goes to the delay beds, where it is delayed to enable decay of noble gases (and, to some extent, of iodine isotopes). During shutdown, start-up and some maintenance transients, a large quantity of gas is produced and collected by the TEG [GWTS] which then switches to an open circuit. The effluent passes through the delay beds for the decay of noble gases (and, to some extent, iodine isotopes).

   After passing through the delay beds, the effluent goes to the DWN [NABVS] for final abatement and controlled discharge. The High Efficiency Particulate Air (HEPA) filters and their pre-filters, as well as iodine traps (if necessary), within the DWN [NABVS] can further reduce the radioactivity of the effluent before its release into the environment via the main discharge stack.

b) Gaseous effluent from ventilation. This gaseous effluent results from possible leakage of radioactive components inside buildings and from evaporation from open water bodies (e.g. the water in spent fuel pool). It is collected by HVAC system in radioactive buildings, sent to the DWN [NABVS] and treated by pre-filters, HEPA filters and iodine traps (if necessary) within DWN [NABVS] before discharge to the environment via the main discharge stack.

c) Secondary gaseous effluent. This gaseous effluent is normally not radioactive except in the case of leakage from the primary circuit to the secondary circuit. It is collected by the CVI [CVS], sent to the DWN [NABVS] and treated by pre-filters, HEPA filters and iodine traps (if necessary) within DWN [NABVS] before discharge to the environment via the main discharge stack.

Thus, during normal operation, all the radioactive gaseous effluents are discharged through a single point, the main discharge stack. At this final gaseous discharge point, sampling and online monitoring of radioactivity are undertaken continuously to obtain information on the gaseous discharges. Further information on sampling and monitoring of discharges is presented in PCER Chapter 5.

### 6.4.2 Liquid Effluent Discharge Routes

The radioactive liquid effluents from the UK HPR1000 are collected, stored, treated and discharged to the environment by the Chemical and Volume Control System (RCV [CVCS]), the Coolant Storage and Treatment System (TEP [CSTS]), the Reactor Boron and Water Makeup System (REA [RBWMS]), the Nuclear Island Vent and Drain System (RPE [VDS]), the Sewage Recovery System (SRE [SRS]), the Liquid Waste Treatment System (TEU [LWTS]), the Nuclear Island Liquid Waste Discharge System (TER [NLWDS]), the Steam Generator Blowdown System (APG [SGBS]), the Conventional Island Liquid Waste Discharge System (SEL [LWDS (CI)]) and the Waste Fluid Collection System for Conventional Island (SEK [WFCSCI]). After passing through the treatment systems, the liquid radioactive effluents are discharged to the environment if they meet the discharge requirements. An overview of the radioactive liquid effluent streams of the UK HPR1000 is provided in F-6.4-2.

The radioactive liquid effluents are divided into three main categories:

a) Reactor coolant effluent. This category is from the letdown of primary coolant to the RCV [CVCS] and part of the drainage or leakage collected by the RPE [VDS]. This effluent passes through purification unit in the RCV [CVCS] and /or in the TEP [CSTS]. The treated effluent is then reused as primary coolant. If the concentration of tritium or chemical impurities exceeding the criteria for reuse, the effluent is routed to the TER [NLWDS] storage/discharge tanks.

b) Liquid waste. This comprises:

   1) The unrecyclable part of the reactor coolant effluent, collected by the RPE [VDS]; and

   2) The effluent from waste management and radioactive area decontamination, collected by the SRE [SRS].

   The liquid waste is divided into four types:

   1) The process drains, coming from the flushing or leakage of tanks or pipelines

containing reactor coolant;

2) The chemical drains, coming from the laboratory and the relevant decontamination operation;

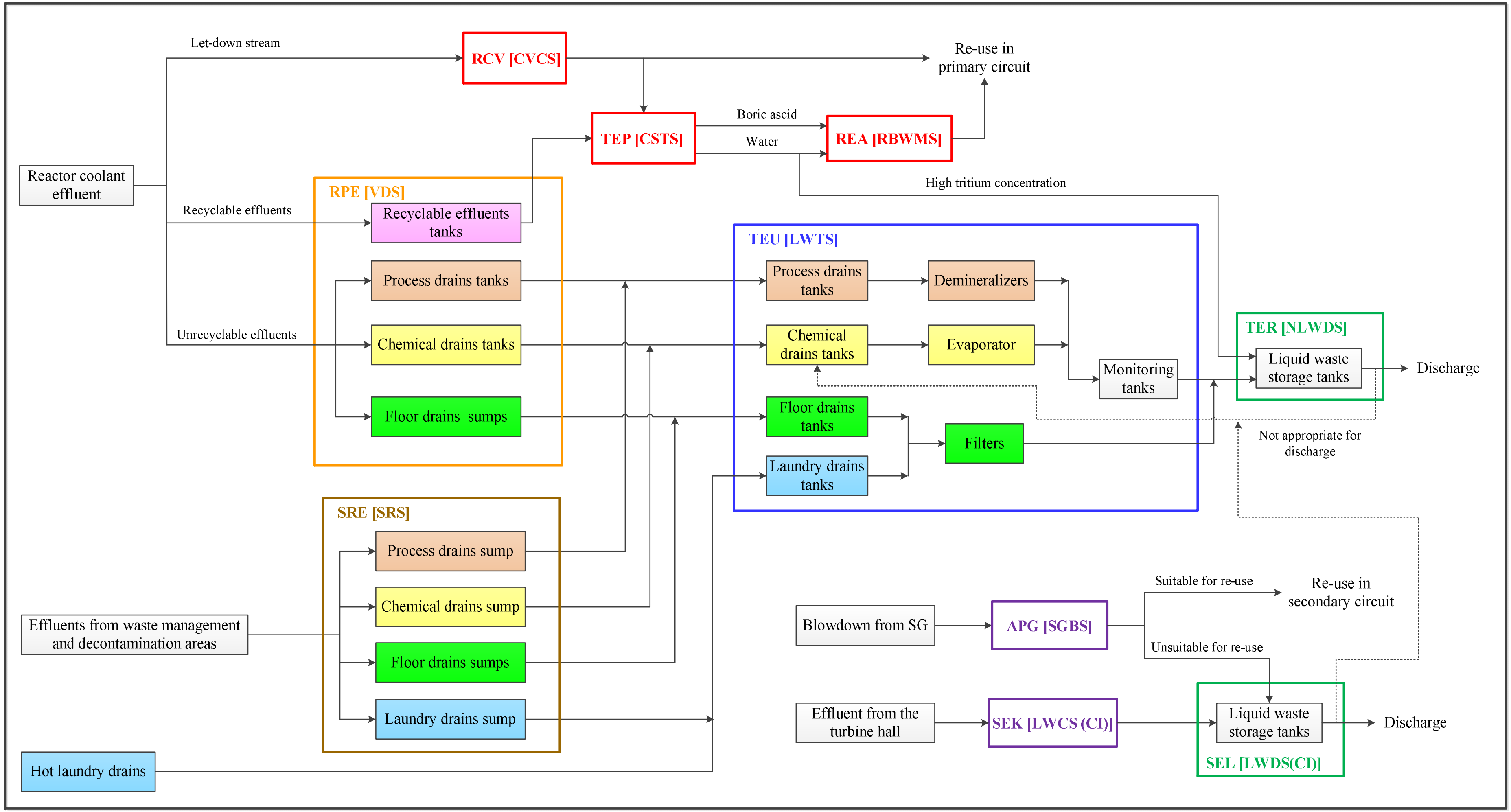
3) The floor drains, coming from the leakage of components or the washing of floors in controlled areas; and

4) Laundry drains, coming from the hot laundry of clothes or gloves.

This liquid effluent is sent to the TEU [LWTS] for abatement. The TEU [LWTS] abatement process includes demineralisation, evaporation and filtration. After treatment, this effluent is sent to the TER [NLWDS] storage/discharge tanks.

c) Secondary circuit effluent. This liquid effluent is normally not radioactive except in the case of leakage from the primary circuit to the secondary circuit. It is made up of blowdown from the steam generator and leakage and drainage from the secondary circuit. The blowdown from the steam generator is treated by APG [SGBS] in the turbine hall and then sent to the main condenser for recycling or to SEL [LWDS (CI)] storage/discharge tanks; while the leakage and drainage from the secondary circuit is collected by the SEK [WFCSCI] and then sent to the SEL [LWDS (CI)] storage/discharge tanks.

During normal operation, all the radioactive liquid effluents are discharged to the environment by the TER [NILWDS] or by the SEL [LWDS (CI)], via the system outfall to which they are connected via a common discharge line. Sampling and monitoring are set throughout the liquid effluent streams to check whether the liquid effluents are appropriate for discharge and whether the systems (in particular the treatment units) are working as anticipated. Further information on sampling and monitoring is presented in PCER Chapter 5.




F-6.4-2 Radioactive Liquid Effluent Streams

# 6.5 Methodology for Quantification of Discharges and Limits

## 6.5.1 Operating Conditions

The operating conditions considered in the quantification of discharges and limits are all the constituents of normal operation, which are:

a) Routine operation (also referred to as power operation);

b) Start-up and shutdown (including outage);

c) Maintenance and testing; and

d) Expected events.

## 6.5.2 Significant Radionuclides

The Environment Agency (UK) (EA) guidance, *Criteria for setting limits on the discharge of radioactive waste from nuclear sites*, Reference [12], recommends a series of criteria to select the significant radionuclides, i.e. radionuclides or groups of radionuclides on which a limit should be set. By following these criteria, the significant radionuclides are those 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);

   The radiological impact to the public is assessed in PCER Chapter 7 based on the calculated discharge limits considering all the radionuclides present in the discharges. According to the dose assessment results, only C-14 is selected as the significant radionuclide under this criterion, since the doses to the public from the gaseous and liquid C-14 discharges exceed 1 μSv per year.

b) Are significant in terms of radiological impact on non-human species (the impact on reference organisms from the discharge of a single radionuclide at the proposed limit exceeds 10 μGy/h);

   According to the results of the non-human species dose assessment presented in PCER Chapter 7, which are based on the calculated discharge limits considering all the radionuclides present in discharges, no radionuclide falls under this criterion.

c) Are significant in terms of the quantity of radioactivity discharged (the discharge of a radionuclide exceeds 1 TBq per year);

   The proposed limits for the UK HPR1000 have been quantified and provided in Sub-chapter 6.6.4 and in report *Estimation of Radioactive Gaseous and Liquid Discharges and Limits for UK HPR1000*, Reference [13]. Based on the calculated limits for all the radionuclides present in the discharges, H-3, C-14, Xe-133 and Xe-135 are selected as the significant radionuclides for the gaseous discharges and H-3 is selected as the significant radionuclide for the liquid discharges under this criterion.

d) May contribute significantly to the collective dose. This only needs to be considered where the collective dose (truncated at 500 years from the discharges of all radionuclides at the proposed limits) exceeds 1 man.Sv per year to any of the UK, European or World populations;

According to the collective dose to the UK, European or World populations assessed in PCER Chapter 7 at UK HPR1000 calculated proposed limits considering all the radionuclides present in the discharges, the gaseous C-14 can have significant contribution to the collective dose of EU and World populations, considering the first past and global circulation together. The predicted dose from gaseous C-14 discharge (at proposed limits) for EU and World population groups exceeds 1 man.Sv. Thus, C-14 is selected as the significant radionuclide for gaseous discharges under this criterion.

For liquid discharges, none of the radionuclides are selected since their contributions to the collective dose do not exceed the 1 man.Sv threshold.

e) Are constrained under national or international agreements or are of concern internationally;

No radionuclide falls under this criterion.

f) Are indicators of plant performance, if not otherwise limited on the above criteria;

Xe-133, Xe-135 and I-131, I-133 are possible indicators for the fuel reliability as they can come out of the fuel easily once there is any fuel cladding defect. Based on international practice (including UK, French and Chinese practice), Xe-133 and Xe-135 are used by Pressurised Water Reactor (PWR)s operators as indicators for fuel reliability as they will be released from the fuel failure more quickly than I-131 and I-133, are therefore better early indicators.

In addition, the total gamma and total beta are also measured for the gaseous discharges to indicate the performance of the gaseous waste abatement systems, i.e. the HVAC system and the TEG [GWTS], while the total gamma is measured for the liquid discharges to indicate the performance of the liquid waste treatment system, i.e. the TEU [LWTS].

Since Xe-133 and Xe-135 are already identified as significant radionuclides under criterion c) above, the additional radionuclides selected under this criterion are:

1) Beta/gamma emitters other than those identified in previous criteria, for gaseous discharges; and

2) Gamma emitters other than those identified in previous criteria, for liquid

discharges.

g) Are not covered by the limits set in the above criteria, but for the appropriate generic categories from the Radioactive Substances Regulation Pollution Inventory (e.g. “alpha particulate” and “beta/gamma particulate” for discharges to air).

There are no additional radionuclides needed to be selected under this criterion.

Therefore, the selected significant radionuclides are as summarised in T-6.5-1.

T-6.5-1 Significant Radionuclides

| No. | Definition Criteria | Gaseous Discharge | Liquid Discharge |
|---|---|---|---|
| a) | Dose to most exposed person (greater than 1 μSv/yr) | C-14 | C-14 |
| b) | Dose to non-human species (greater than 10 μGy/h for exposure from a single source ) | - | - |
| c) | Discharged activity (greater than 1 TBq/yr) | H-3, C-14,<br>Xe-133, Xe-135 | H-3 |
| d) | Collective Dose (greater than 1 man.Sv) | C-14 | - |
| f) | Plant performance indicators | a) Xe-133, Xe-135<br>(Fuel reliability indicators)<br>b) Other gamma / beta emitters<br>(Performance of gaseous waste abatement system (HVAC system and TEG [GWTS])) | Other gamma emitters (Performance of liquid waste treatment system (TEU [LWTS])) |

### 6.5.3 General Process

In line with UK regulations and guidance, a methodology mainly based on Operating Experience (OPEX) data has been developed. The process of quantification of radioactive gaseous and liquid discharges and proposed limits for the UK HPR1000 is as follows:

a) Collection of OPEX data

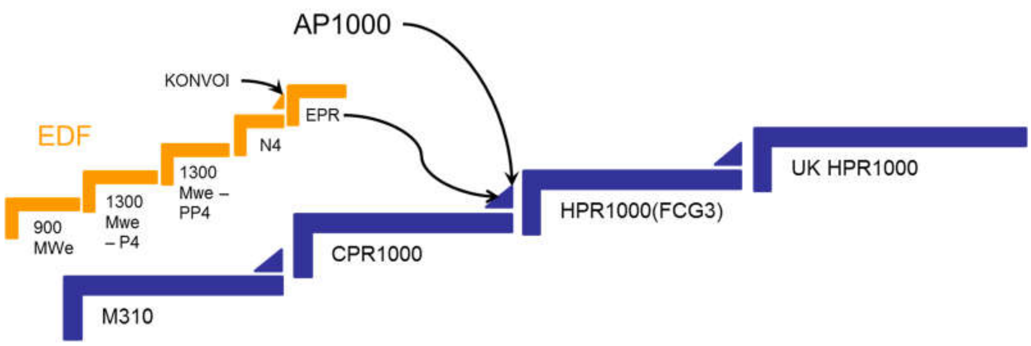
The OPEX data for discharges can be divided into the following two categories:

1) Basic OPEX data

The basic OPEX data serve as the basis for quantifying discharges and proposed limits for the UK HPR1000.

Since the UK HPR1000 and its reference plant, which is Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3 (HPR1000 (FCG3)), have not yet been operated (as of the time of submission), the OPEX data of UK HPR1000 or its reference plant are not yet available.

However, as shown in F-6.5-1, the reference plant of UK HPR1000, HPR1000 (FCG3), is developed from China General Nuclear Power Corporation (CGN) fleet units and their OPEX feedbacks, considering the advanced design features of EPR and AP1000. Thus, the OPEX data from the CGN fleet units are considered to be relevant to underpin the quantification of discharges and limits for the UK HPR1000. Almost 100 reactor-years of OPEX data from the CGN fleet have been selected as the basic data in accordance with the OPEX data selection criteria.




F-6.5-1 Summary of Design Evolution of UK HPR1000

Since most of CGN OPEX units[1] are still at early stage in their operational lifetime while the UK HPR1000 proposed limits should reflect the whole lifetime, it is necessary to understand how plant ageing impact the discharges and, if any increase trend due to plant ageing is identified, to take it into account to ensure the UK HPR1000 discharge estimates and proposed discharge limits are representative of the whole lifetime.

To understand the impact of plant ageing on discharges, a trend analysis has been carried out for radioactive discharges from a nuclear power plant over its whole lifetime[2] based on relevant available international OPEX data.

[1] "OPEX units" means the units from which the OPEX data have been selected.
[2] It is noted that 'whole lifetime' does not fully cover the whole operational period as most PWR units for which OPEX is available and can be analysed (as sufficiently understood) have not yet reached their end of life.

This trend analysis indicates no obvious increase trend due to plant ageing. Instead, the discharges of noble gases, iodine and other radionuclides tend to decrease during the plant lifetime. Hence, the OPEX data selected from CGN units are considered appropriately bounding for the radioactive discharges across the whole lifetime of the plants. The CGN OPEX data are therefore appropriate to underpin the discharge quantification and limit setting for the UK HPR1000, for the 60-year lifetime of this plant.

More detailed information on trend analysis is presented in the report *Trend Analysis of Radioactive Discharges of Nuclear Power Plant During the Whole Life-time*, Reference [14].

2) Comparison OPEX data

Comparison OPEX data are used to verify that UK HPR1000 discharges will not exceed those of comparable PWRs across the world. These data have been collected from public databases for relevant PWRs in the United Kingdom, France, Germany and the United States of America.

More detailed information on OPEX data, including the details on scope, selection, appropriateness and applicability is provided in the report *OPEX Data Selected for Quantification of Discharges and Limits for UK HPR1000*, Reference [15].

b) Identification of discharge routes and effluent streams

The radioactive gaseous and liquid discharge routes and effluent streams have been identified based on the radioactive waste management strategy and arrangement, and the process and system design of the UK HPR1000, as shown in Sub-chapter 6.4.

c) Establishment of the expected events list

The operating conditions considered in the quantification of the radioactive gaseous and liquid discharges and limits are all the constituents of normal operation (as listed in Sub-chapter 6.5.1). Expected events are constituent of normal operation that needs to be taken into account when setting limits so as not to unduly constrain the operator.

The establishment of expected events list is divided into the following steps:

1) Identification of the Structures, Systems and Components (SSC) along each effluent stream from source to discharge;

2) Identification of the expected events to establish the preliminary list according to the production, transportation and abatement process of the radionuclides and the functions and performance of the SSC; and

3) Verification the preliminary expected events list based on expert judgement and insight from OPEX to obtain the final list.

   Expert judgement and insight from OPEX have been provided by CGN experts from Mechanical Engineering, Radiological Protection, Environmental, Fault Study, Probability Safety Assessment (PSA), BAT, Cross Cutting, Radwaste Management and Reactor Chemistry disciplines and experts from Électricité de France S. A. (EDF S. A.), Hinkley Point C (HPC), Sizewell B (SZB) and General Nuclear System Limited to verify and finalise the expected events list.

   Those events from the final list, which can have the most significant contribution on discharges have been identified and defined as the representative cases to envelop all the other cases of expected events.

Detailed information on expected events, including definition, methodology and establishment of the preliminary and final list of expected events, is provided in the report *Expected Event List for UK HPR1000*, Reference [16].

d) Quantification of discharges and limits

The quantification of discharges and limits consist of the following steps:

1) Quantification of discharges and limits based on the basic OPEX data

   - Quantification of discharges based on the basic OPEX data

     When quantifying the discharges and proposed limits based on OPEX data from plants that are similar (but not strictly the same) as the UK HPR1000, correction factors and headroom factors are defined to reasonably adjust the basic OPEX data to avoid over or under quantification of discharges and limits.

     - The correction factors are defined to quantify the differences in discharges resulting from the differences in design schemes between the UK HPR1000 and the OPEX units;
     - The headroom factors are defined to quantify the uncertainty of the OPEX data to provide appropriate margins for the 60-year normal operation of the plant.

     The definition and consideration of the correction factors and the headroom factors are described respectively in Sub-chapter 6.5.4 and 6.5.5.

   - Quantification of the contribution of expected events and proposed limits

     Expected events are constituent of normal operation that needs to be taken into account when setting limits to ensure that operators have sufficient flexibility to operate the plant and are not unduly constrained. To set reasonable limits, representative cases[3] are established from the expected events in the final list considering their contributions to discharges based on qualitative analysis and expert judgement.

The quantification of the contributions of expected event representative cases is based on OPEX data and theoretical analysis. The consideration of representative cases and their quantification are described in Sub-chapter 6.5.6.

2) Quantification of discharges and proposed limits for those radionuclides for which OPEX data are not available

   It has been identified that there are a number of radionuclides potentially present in discharges for which OPEX data are not available. This is because their levels are below the detection limits or their measurements are not feasible (difficult or impossible to measure) or not required.

   For these radionuclides without OPEX data, the radionuclides with OPEX data, which have similar physical and chemical characteristics and share the same effluent streams and discharge routes with them are selected as their indicators. Theoretical analysis is applied based on the similar behaviours between these radionuclides and their indicators, and on the primary coolant source term, to establish the correlation factors (or scaling factors) between them and then estimate the discharges of the radionuclides without OPEX data.

More detailed information on the quantification of discharges and limits, including the considerations of key factors (correction factors and headroom factors) and the selection and analysis of expected event representative cases, is provided in Reference [13].

The UK HPR1000 discharge and proposed limit values are provided in Sub-chapter 6.6.

e) Comparison with discharges from international plants

   The radioactive gaseous and liquid discharges from the UK HPR1000 are compared with the comparison OPEX data to verify that the UK HPR1000 discharges do not exceed those of comparable power stations across the world. Explanation is provided if they do. The details for this comparison and its outcomes are provided in Sub-chapter 6.7.

f) Update of the discharges and limits by the future operator

[3] "Representative cases" refers to the cases of expected events whose contribution can envelop the contribution of all the other cases of expected events.

Since the OPEX data of the UK HPR1000 is not available during the GDA process, the estimated discharges and limits of the UK HPR1000 are based on the OPEX data from similar units.

Once the OPEX data of the UK HPR1000 itself are available and sufficient, the discharges and limits will be verified and updated if necessary based on the UK HPR1000 (and HPR1000 as relevant) OPEX data.

### 6.5.4 Correction Factors

Even though the OPEX units are selected for their similarities with the UK HPR1000, there are still some differences in design features, which may have effects on discharges. It is important to quantify these effects and to adjust the OPEX data as relevant to ensure that discharges from the UK HPR1000 are appropriately defined and quantified. Correction factors are therefore defined for that purpose. They are quantified considering the main differences influencing discharges in all relevant aspects of production, abatement and discharge management by comparing these relevant factors between the UK HPR1000 and the OPEX units.

a) H-3

Considering the way H-3 is produced, transported throughout the plant, abated and discharged (which has been demonstrated BAT in PCER Chapter 3) for the UK HPR1000, the only difference that could influence H-3 discharges is the difference in power between the UK HPR1000 and the OPEX units. This will influence the production of H-3, thence the resulting discharges of H-3, as H-3 cannot be abated in PWRs.

Thus, a correction factor defined by power ratio is applied to the OPEX data of H-3 that are used to quantify discharges from the UK HPR1000.

b) C-14

Considering the way C-14 is produced, transported throughout the plant, abated and discharged (which has been demonstrated BAT in PCER Chapter 3) for the UK HPR1000, the following differences have been identified as potentially influencing the discharges of C-14:

1) The cover and purge gas of the primary circuit and auxiliary systems tanks and vessels (notably the RCV [CVCS] Volume Control Tank) for the UK HPR1000 is nitrogen, while that for the CGN OPEX units is hydrogen. Nitrogen can dissolve in the primary coolant and be carried into the reactor core, where it can be activated into C-14. Thus, the use of nitrogen may increase the quantity of C-14 produced;

2) The difference in power between the UK HPR1000 and the OPEX units can also influence the production of C-14 in the primary coolant as C-14 is

primarily produced from neutron activation of O-17 and N-14 that are present in the primary coolant.

These differences influencing the C-14 production will affect its discharges as C-14 cannot be abated in PWRs.

Thus, theoretical calculation focusing mainly on C-14 production is applied to correct/adjust the OPEX data for discharges of C-14.

c) Noble gases

Considering the way noble gases is produced, transported throughout the plant, abated and discharged, the following identified differences may influence the discharges of noble gases:

1) The difference in power between the UK HPR1000 and the OPEX units may influence the production of noble gases slightly. However, this difference in the production of noble gases can be offset by the effective abatement of noble gases by the TEG [GWTS] for both the UK HPR1000 and the OPEX units;

2) The TEG [GWTS] design scheme, including its abatement process and discharge management scheme is different in the UK HPR1000 and the OPEX units. The UK HPR1000 adopts delay beds for the TEG [GWTS] abatement process while the OPEX units adopt the decay storage tanks. In addition, the TEG [GWTS] of the UK HPR1000 operates as a closed circuit (where the flushing gas, which contains the radionuclides, is reused) during steady-state operation and as an open circuit (with the effluent and the radionuclides being routed to delay beds and discharged to the atmosphere) during shutdown and start-up transients. The TEG [GWTS] of OPEX units operates as an open circuit during all the cycle (with the effluent and the radionuclides being routed to decay tanks and discharged to the atmosphere after the defined decay period).

By comparison and analysis of these two schemes for the TEG [GWTS], their effects on discharges of noble gases are anticipated to be negligible because:

1) During steady state operation, there are no important water movements in the primary circuit and auxiliary systems that create an increase of gas volume in the TEG [GWTS]. Therefore, for both UK HPR1000 and OPEX units, there are little discharges during this period. So the effect on discharges of noble gases of the closed circuit is negligible;

2) During shutdown and start-up transients, when most of the water movements happen, the primary circuit is degassed to remove the noble gases present. Important volumes of the noble gases are then routed to the TEG [GWTS]. The TEG [GWTS] of the UK HPR1000 and the OPEX units both operate in

the same way (i.e. open circuit) and the decay effects for both systems are broadly the same, considering the half-life of the noble gases.

Overall, the discharges of noble gases from the UK HPR1000 and the CGN OPEX units will be almost the same. The correction of OPEX data is therefore deemed not necessary for noble gases.

d) Others (except H-3, C-14 and noble gases) (including halogen)

For other radionuclides (except H-3, C-14 and noble gases), considering the way they are produced, collected, transported throughout the plant, abated and discharged, the only identified difference that may influence their discharges is the difference in power between the UK HPR1000 and the CGN OPEX units. Whilst this difference may influence slightly their production, this can be neglected for the discharges as these radionuclides can be effectively abated for both the UK HPR1000 and the OPEX units. Therefore, correction of OPEX data is deemed not necessary for these radionuclides.

The correction factors for different radionuclides/groups are provided in T-6.5-2.

T-6.5-2 Correction Factors for Different Radionuclides

| Phase | Radionuclide | Correction Factor |
|---|---|---|
| Gaseous Effluents | H-3 | 1.09 |
| | C-14 | 1.62 |
| | Noble Gases | None |
| | Halogen (including iodine and bromine) | None |
| | Others<br>(except H-3, C-14, noble gases and halogen) | None |
| Liquid Effluents | H-3 | 1.09 |
| | C-14 | 1.62 |
| | Others (except H-3 and C-14) | None |

The detailed information on definition and quantification of correction factors is provided in Reference [13].

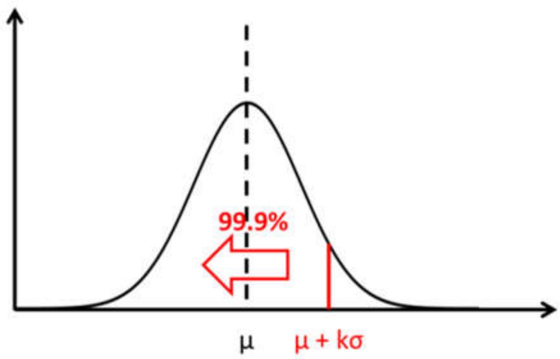
### 6.5.5 Headroom Factor

During normal operation, there will be some fluctuations of gaseous and liquid discharges between different cycles notably due to variations, from one cycle to another, of plant parameters or system operation within the normal operation range. In addition, as presented in Sub-chapter 6.5.3, OPEX data used for quantifying the discharges from UK HPR1000 are not from UK HPR1000 or from its reference plant as these plants have not yet been in operation (at the time of submission). The OPEX data are from plants that have been selected for their similarities with the UK HPR1000 in terms of design and operation, but that still present some differences.

As such, to provide appropriate margin for the 60-year plant lifetime (normal operation), headroom factors are defined to account for the uncertainty and variability of the OPEX data used to quantify the UK HPR1000 discharges.

To determine the UK HPR1000 headroom factors, statistical analysis of the CGN OPEX data has been carried out. The distribution of the CGN OPEX data seems to follow a normal distribution or log-normal distribution, verified by Q-Q plots[4].

Considering that the headroom factors are used to determine the UK HPR1000 proposed limits (i.e. the upper limit of discharges), and to be appropriately conservative and ensure the variation of discharges are appropriately covered, a one-side normal distribution is adopted to quantify the headroom factors, with a 99.9% confidence of coverage for 60-year lifetime (totally 720 months) of normal operation, as shown in F-6.5-2.




F-6.5-2 One-side Normal Distribution

The headroom factors for different radionuclides/groups calculated using the one-sided normal distribution with 99.9% confidence of coverage are provided in T-6.5-3.

T-6.5-3 Headroom Factors for Different Radionuclides

| Phase | Radionuclide | Headroom Factor |
|---|---|---|
| Gaseous Effluents | H-3 | 4.55 |
| | C-14 | 3.40 |
| | Noble Gases | 5.30 |
| | Halogen (including iodine and bromine) | 6.40 |
| | Others (except H-3, C-14, noble gases and halogen) | 2.89 |
| Liquid Effluents | H-3 | 2.58 |
| | C-14 | 2.94 |
| | Others (except H-3 and C-14) | 3.11 |

Detailed information on definition and quantification of headroom factor is provided

[4] Q-Q plot is an effective way to verify if a data set follows a normal distribution or log-normal distribution.

in Reference [13].

### 6.5.6 Analysis of Expected Events

In order to quantify the potential increase in discharges due to expected events, representative cases are determined from the list of expected events, considering their contributions to discharges (based on a qualitative analysis and expert judgement), as explained in Sub-chapter 6.5.3. The representative cases considered for different radionuclides/groups are provided in T-6.5-4.

The detailed information on the consideration and analysis of the representative cases is provided in Reference [13].

T-6.5-4 Consideration for Representative Cases of Expected Events

| Phase | Radionuclide | Representative Case | Note |
|---|---|---|---|
| Gaseous Effluents | H-3 | 1) Increase of the open water evaporation | It will impact the gaseous discharges. |
| | | 2) Small leakage of the radioactive systems | It will impact the gaseous discharges since the leaked H-3 can evaporate. |
| | C-14 | Increase of nitrogen concentration in the primary coolant | It will impact C-14 production, thence the discharges. |
| | Noble Gases | 1) Fuel pin cladding defect | It will impact the concentration of noble gases in primary coolant and therefore the discharges. |
| | | 2) Small leakage of the radioactive systems | It will impact the gaseous discharges since the leaked noble gases will not go through the abatement by TEG[GWTS]. |
| | Halogen | 1) Fuel pin cladding defect | It will impact concentration of halogen in the primary coolant and therefore the discharges. |
| | | 2) Small leakage of the radioactive systems | It will impact the gaseous discharges since the leaked halogen can gasify. |
| | Others | None | |
| Liquid Effluents | H-3 | Change of H-3 management strategy in the primary coolant [a] | It will impact the liquid discharges. |
| | C-14 | Increase of nitrogen concentration in the primary coolant | It will impact C-14 production and therefore the discharges. |
| | Others | None | |

Note:

a) "Change of H-3 management strategy in the primary coolant" is not actually an expected event. The H-3 management strategy that will be adopted by the future operator will influence the annual and 12-rolling month tritium discharge and therefore needs to be considered when setting limits. This is even more relevant as the UK HPR1000 design provides flexibility to a future operator to adopt any of the two existing management strategies, namely the Continuous Dilution Strategy and the End-cycle Dilution Strategy.

   "Continuous Dilution Strategy" means the concentration of H-3 in the primary coolant is monitored and controlled. Once the concentration of H-3 exceeds the control values, the distillate will not be recycled but discharged to environment.

   "End-cycle Dilution Strategy" means that there is no control value for H-3 concentration in the primary coolant and normally H-3 will be kept in the primary coolant during power operation without being discharged until shutdown for refuelling at the end of fuel cycle.

## 6.6 Estimated Discharges and Proposed Limits

### 6.6.1 Monthly Discharges

The monthly discharges from UK HPR1000 for power operation and shutdown for refuelling are taken as the average values of the basic OPEX data (CGN fleet OPEX data), for power operation and shutdown for refuelling, with appropriate corrections as presented in Sub-chapter 6.5.4, as follows:

a) Monthly discharges during power operation, including routine operation as well as maintenance and testing carried out during power operation:

$$M_{UK\ \ HPR1000,\ i}^{Power} = \frac{1}{2}\left(\overline{m_{OPEX\,Units,\ i}^{Power}}\right) \times CF_i \tag{6.6-1}$$

b) Monthly discharges during shutdown for refuelling, including shutdown and outage for refuelling, preparatory activities, start-up as well as maintenance and testing carried out during shutdown:

$$M_{UK\ \ HPR1000,\ i}^{Shutdown} = \left(\overline{m_{OPEX\ \ Units,\ i}^{Shutdown}} - \frac{1}{2}\overline{m_{OPEX\ \ Units,\ i}^{Power}}\right) \times CF_i \tag{6.6-2}$$

With,

$M_{UK\ \ HPR1000,\ i}^{Power}$: Monthly discharge of radionuclide i from the UK HPR1000 during power operation (Bq);

$M_{UK\ \ HPR1000,\ i}^{Shutdown}$: Monthly discharge of radionuclide i from the UK HPR1000 during shutdown for refuelling (Bq);

$\overline{m_{OPEX\ \ Units,\ i}^{Power}}$: Average monthly discharge of radionuclide i from the OPEX units during power operation (Bq). The monthly discharges from the OPEX units during power operation are data from two units, with both units under power operation;

$\overline{m_{OPEX\ \ Units,\ i}^{Shutdown}}$: Average monthly discharge of radionuclide i from the OPEX units during shutdown for refuelling (Bq). The monthly discharges from the OPEX units during shutdown are data from two units, with one unit under power operation and one under shutdown for refuelling;

$CF_i$ : Correction factor of radionuclide i, presented in Sub-chapter 6.5.4.

The monthly discharges from the UK HPR1000 during power operation and those during shutdown for refuelling are provided in T-6.6-2.

### 6.6.2 Annual Discharges

The annual discharges from the UK HPR1000 are calculated from the monthly discharges from the UK HPR1000 quantified in Sub-chapter 6.6.1.

According to the reference plant design HPR1000 (FCG3), the minimal duration of the shutdown for refuelling is 14 days covering only refuelling operations without any maintenance and testing being undertaken. Based on experience from the CGN fleet, the shutdown for refuelling generally lasts between 1 and 2 months (covering shutdown preparatory activities, maintenance and testing usually carried out during shutdown for refuelling, the refuelling operation themselves and start-up). So the duration of shutdown for refuelling of the UK HPR1000 is considered to be two calendar months to account for all the necessary operations to be carried out during shutdown for refuelling (which is the common case). This should provide the future operator with sufficient flexibility for undertaking proper shutdown and not unduly affecting the operator's ability to operate and maintain/test/inspect the plant.

Thus, the annual discharges from the UK HPR1000 are quantified by accounting for ten months of power operation and two months of shutdown for refuelling, as follows:

$$A_{UK\ \ HPR1000,\ i} = M_{UKHPR1000,i}^{Power} \times 10 + M_{UKHPR1000,i}^{Shutdown} \times 2 \qquad (6.6\text{-}3)$$

With,

$A_{UK\ \ HPR1000,\ i}$: Annual discharge of radionuclide i from the UK HPR1000 (Bq);

$M_{UK\ \ HPR1000,\ i}^{Power}$: Monthly discharge of radionuclide i from the UK HPR1000 during power operation (Bq), quantified as presented in Sub-chapter 6.6.1;

$M_{UK\ \ HPR1000,\ i}^{Shutdown}$: Monthly discharge of radionuclide i from the UK HPR1000 during shutdown for refuelling (Bq), quantified as presented in Sub-chapter 6.6.1.

The annual discharges from the UK HPR1000 are provided in T-6.6-2.

### 6.6.3 Contribution of Expected Events

To quantify the potential increase in discharges due to expected events, representative cases are established as described in Sub-chapter 6.5.6. The contributions of representative cases are then quantified based on CGN OPEX data and theoretical analysis as follows:

a) Gaseous Discharges:

1) H-3

- Increase of the open water evaporation

  Sensitivity analyses have been carried out to assess the influence, on the gaseous discharge of H-3, of changes of water / air temperature, air velocity and humidity. Based on the results of these sensitivity analyses, the temperature of the water is the parameter that impacts the most on the water evaporation rate and can have about 38% increase in the evaporation of the spent fuel pool water from the expected temperature to the maximal temperature, thence slightly conservatively assumed 38% increase in the final gaseous H-3 discharges.

- Small leakage of the radioactive systems

  The impact on gaseous discharges of H-3 from small leak during normal operation has already been covered in the CGN OPEX data. It is therefore deemed not appropriate to add a complementary contribution for this expected event.

2) C-14

- Increase of nitrogen concentration in the primary coolant

  Sensitivity analyses have been carried out to assess the influence, on C-14 production, of a change of the nitrogen concentration in the primary coolant. These sensitivity analyses show that the annual production of C-14 would increase by about 33% when the atomic concentration of nitrogen in the primary coolant increases from the expected value to maximal value. This increase would be reflected in the discharges as C-14 is not abated in PWRs.

3) Noble Gases

- Fuel pin cladding defect

  The discharges of noble gases are sensitive to fuel pin cladding defect since they will be released easily from the fuel pin through the defect of the cladding. The contribution of fuel pin cladding defect to noble gases discharges are quantified based on CGN OPEX data with slightly conservative assumption due to the young age of the CGN fleet.

- Small leakage of the radioactive systems

  The impact on noble gas discharges from small leak during normal operation has already been covered in the CGN OPEX data. It is deemed not appropriate to add a complementary contribution for this expected event.

4) Halogen

- Fuel pin cladding defect

  The discharges of halogens are sensitive to fuel pin cladding defect since they will be released easily from the fuel pin through the defect of the cladding. The contribution of fuel pin cladding defect to noble gases discharges are quantified based on CGN OPEX data with slightly conservative assumption due to the young age of the CGN fleet.

- Small leakage of the radioactive systems

  The impact on halogen discharges from small leak during normal operation has already been covered in the CGN OPEX data. It is therefore deemed not appropriate to add a complementary contribution for this expected event.

5) Others

- None

b) Liquid Discharges:

1) H-3

- Change of H-3 management strategy in primary coolant (from Continuous Dilution Strategy to End-cycle Dilution Strategy)

  As explained in Sub-chapter 6.5.6, this is more relevant as the UK HPR1000 design provides flexibility to a future operator to adopt either of the two existing management strategies, namely the Continuous Dilution Strategy and the End-cycle Dilution Strategy. As such, a change in the H-3 management strategy is assimilated to an expected event so as to simplify the presentation of information.

  Tritium discharges over a cycle will be the same for the two H-3 management strategies but the annual or 12-rolling month discharges will differ. Indeed, for the continuous dilution strategy, discharges of tritium (liquid discharges) are made throughout the cycle, in a more or less regular way depending on the set target value for tritium concentration in the primary coolant. For the end-cycle dilution strategy, discharges of tritium (liquid discharges) are made in one batch, generally over one month, during the month preceding the outage for refuelling (before the reactor pressure vessel head lift). As a result, the annual liquid discharges for a calendar year or for 12 rolling month with shutdown for refuelling will correspond to:

- the maximal tritium production over 12 months (i.e. the production over the 12 first months of the cycle) for the Continuous Dilution Strategy, as tritium is continuously discharged throughout the cycle;
- the total production of tritium over the cycle for the End-cycle Dilution Strategy, as all the tritium is discharge in one batch over one month.

2) C-14

- Increase of nitrogen concentration in the primary cycle

  Same as the analysis for gaseous C-14 discharge mentioned above.

3) Others

- None

The outcomes are summarised in T-6.6-1.

T-6.6-1 Contributions of Expected Event Representative Cases

| **Phase** | **Radionuclide** | **Contribution of Expected Events (Bq)** | **Representative Case** |
|---|---|---|---|
| Gaseous Effluents | H-3 | 1.44E+12 | 1) Increase of the open water evaporation;<br>2) Small leakage of the radioactive systems. |
| | C-14 | 4.19E+11 | 1) Increase of nitrogen concentration in the primary coolant. |
| | Noble Gases | 9.15E+12 | 1) Fuel pin cladding defect;<br>2) Small leakage of the radioactive systems. |
| | Halogen | 1.10E+08 | 1) Fuel pin cladding defect;<br>2) Small leakage of the radioactive systems. |
| | Others | - | None. |
| Liquid Effluents | H-3 | 3.46E+13 | Change of H-3 management strategy in the primary coolant (from Continuous Dilution Strategy to End-cycle Dilution Strategy). |

| Phase | Radionuclide | Contribution of Expected Events (Bq) | Representative Case |
|---|---|---|---|
| | C-14 | 1.46E+10 | Increase of nitrogen concentration in the primary coolant. |
| | Others | - | None. |

### 6.6.4 Proposed Annual Discharge Limits

The proposed annual discharge limits (12 rolling months) are defined based on the annual discharges (as presented in Sub-chapter 6.6.2), headroom factors (as presented in Sub-chapter 6.5.5) and the contribution of expected events during normal operation (as presented in Sub-chapter 6.6.3), as follows:

$$A_{UK\ HPR1000,i}^{max} = A_{UK\ HPR1000,i} \times HF_i + C.O.E.E_i \qquad (6.6\text{-}4)$$

With,

$A_{UK\ HPR1000,i}^{max}$: Proposed limit (maximal annual discharge) of radionuclide i for the UK HPR1000 (Bq);

$A_{UK\ HPR1000,i}$: Annual discharge of radionuclide i from the UK HPR1000 (Bq), quantified in Sub-chapter 6.6.2;

$HF_i$: Headroom factor of radionuclide i, presented in Sub-chapter 6.5.5;

$C.O.E.E_i$: Contribution of expected events for radionuclide i (Bq), presented in Sub-chapter 6.6.3.

The proposed limits of the UK HPR1000 are provided in T-6.6-2.

### 6.6.5 Maximum Monthly Discharges

The maximum monthly discharges from the UK HPR1000 are taken as the maximum monthly discharges of the basic OPEX data with appropriate corrections as presented in Sub-chapter 6.5.4, as follows:

$$M_{UK\ HPR1000,i}^{max} = \left( m_{OPEX\ Units,i}^{max} - \frac{1}{2}\overline{m_{OPEX\ Units,i}^{Power}} \right) \times CF_i \qquad (6.6\text{-}5)$$

With,

$M_{UK\ HPR1000,i}^{max}$: Maximal monthly discharge of radionuclide i from the UK HPR1000

(Bq);

$m_{OPEX\ units,i}^{max}$ : Maximal monthly discharge of radionuclide i from the OPEX units (Bq).

The maximum monthly discharges from the OPEX units appear during shutdown for refuelling and they are data from two units, with one unit being under power operation, the other one under shutdown for refuelling;

$m_{OPEX\ units,i}^{Power}$ : Monthly discharge of radionuclide i from the OPEX units during power operation (Bq). The monthly discharges from the OPEX units during power operation are data from two units: with both units being under power operation;

$CF_i$ : Correction factor of radionuclide i, presented in Sub-chapter 6.5.4.

The maximum monthly discharges from the UK HPR1000 are provided in T-6.6-2.

Detailed information on the quantification of discharges and proposed limits is provided in Reference [13].

T-6.6-2 Radioactive Discharges and Proposed Limits for the UK HPR1000

| Phase | Radionuclide | Monthly Discharge During Power Operation [a] (Bq) | Monthly Discharge During Shutdown [b] (Bq) | Maximum Monthly Discharge (Bq) | Annual Discharge (Bq) | Proposed Limit (Bq) |
|---|---|---|---|---|---|---|
| Gaseous Effluents | H-3 | 4.71E+10 | 1.82E+11 | 9.31E+11 | 8.34E+11 | 5.23E+12 |
| | C-14 | 1.75E+10 | 9.91E+10 | 3.44E+11 | 3.74E+11 | 1.69E+12 |
| | Noble Gases | 6.69E+10 | 2.71E+11 | 2.83E+12 | 1.21E+12 | 1.56E+13 |
| | Xe-133 | 5.00E+10 | 2.02E+11 | 2.12E+12 | 9.04E+11 | 1.16E+13 |
| | Xe-135 | 1.48E+10 | 5.99E+10 | 6.28E+11 | 2.68E+11 | 3.45E+12 |
| | Halogen | 4.79E+05 | 6.33E+06 | 6.93E+07 | 1.75E+07 | 2.21E+08 |
| | Others | 3.15E+05 | 3.58E+05 | 1.62E+06 | 3.86E+06 | 1.12E+07 |
| Liquid Effluents | H-3 | 1.63E+12 | 5.27E+12 | 9.39E+12 | 2.69E+13 | 1.04E+14 |
| | C-14 | 7.67E+08 | 3.71E+09 | 9.21E+09 | 1.51E+10 | 5.90E+10 |
| | Others | 1.84E+07 | 7.49E+07 | 2.94E+08 | 3.33E+08 | 1.04E+09 |

Note:

a) "Power Operation" consists of the following:

1) Routine operation (i.e. power operation); and

2) Maintenance and testing carried out during power operation.

b) "Shutdown" consists of the following:

1) Shutdown and outage for refuelling (including the preparation for outage);

2) Start-up; and

3) Maintenance and testing during shutdown.

## 6.7 Comparison with Other Plants around the World

### 6.7.1 Comparison with International PWR OPEX

The international PWR OPEX data including discharges from PWRs in United Kingdom, France, Germany and the United States of America from 2002 to 2016 have been collected respectively from the *European Commission Radioactive Discharges Database (RADD)*, Reference [17], and the *United States Nuclear Regulatory Commission (US) (NRC) Radioactive Effluent and Environmental Reports*, Reference [18]. Those data from representative European fleet and American fleet units have been selected as comparison OPEX data. The annual averages of the selected international OPEX data and the annual discharges from the UK HPR1000 have been normalised to 1000MWe and compared as shown in T-6.7-1 and F-6.7-1~F-6.7-7.

When analysing the comparison of discharges from UK HPR1000 with those from comparable power stations across the world, it is important to consider the following points:

a) The UK HPR1000 annual discharges reflect a full (100% contribution of) shutdown for refuelling (defined in Sub-chapter 6.6.2). However, the annual discharges of international OPEX data are average values of 14-year operation, meaning that the contribution of shutdown for refuelling is averaged as most plants use an 18-month fuel cycle. As such, the UK HPR1000 annual discharges are “overestimated averages” compared to international OPEX data which are actual averages;

b) Differences in the reporting approaches can also have an influence on the discharge OPEX data. In the UK, France and China, the conservative reporting approach is adopted, which consists in reporting half of the detection limit for the main radionuclides when the measurement values are below the detection limits. In the United States of America and Germany, the measurement-based reporting approach is adopted, which consists in only reporting the measurement values that are above the detection limits. Therefore, the discharges from the UK HPR1000, UK fleet and French fleet are “overestimates” of the actual discharges for the main radionuclides compared to those of American fleet and German fleet due to the different reporting approach;

c) Driven by safety improvements, the UK HPR1000 adopts nitrogen as the cover and purge gas for the primary circuit and the auxiliary systems tanks and vessels instead of hydrogen. This enables significant reduction in the risk of explosion as well as the doses to workers induced by the heavy maintenance and testing requirements on the equipment carrying hydrogen while slightly increases the doses to the public (less than 14% of low doses) from the additional C-14 produced from the activation of nitrogen. The use of nitrogen is therefore considered BAT (as demonstrated in PCER Chapter 3). This safety improvement has been adopted on the German Konvoi plants (the Emsland and the Isar 2) and is also adopted on the EPR design, notably on HPC. The UK HPR1000 annual discharges of gaseous C-14 is therefore expected to be close to those of the German Emsland Plant and the Isar 2 Plant but higher than those of other comparable plants which use hydrogen.

The comparisons of the annual discharges from the UK HPR1000 with those from comparable plants across the world are presented in T-6.7-1 and F-6.7-1~F-6.7-7 and summarised as follows:

a) The gaseous C-14 annual discharge from the UK HPR1000 is higher than those from comparable plants using hydrogen (as expected as explained presented previously) but close to those from plants using nitrogen (the German Emsland Plant and the Isar 2 Plant);

b) The gaseous annual discharges of H-3, noble gases, halogen and other radionuclides and liquid annual discharges of H-3 are higher compared to discharges from some plants and lower compared to discharges from other plants. As explained previously, the discharges from the UK HPR1000 are "overestimated averages" while those from the other plants are actual averages due to different considerations of shutdown for refuelling which contributes to an important part of the annual discharge;

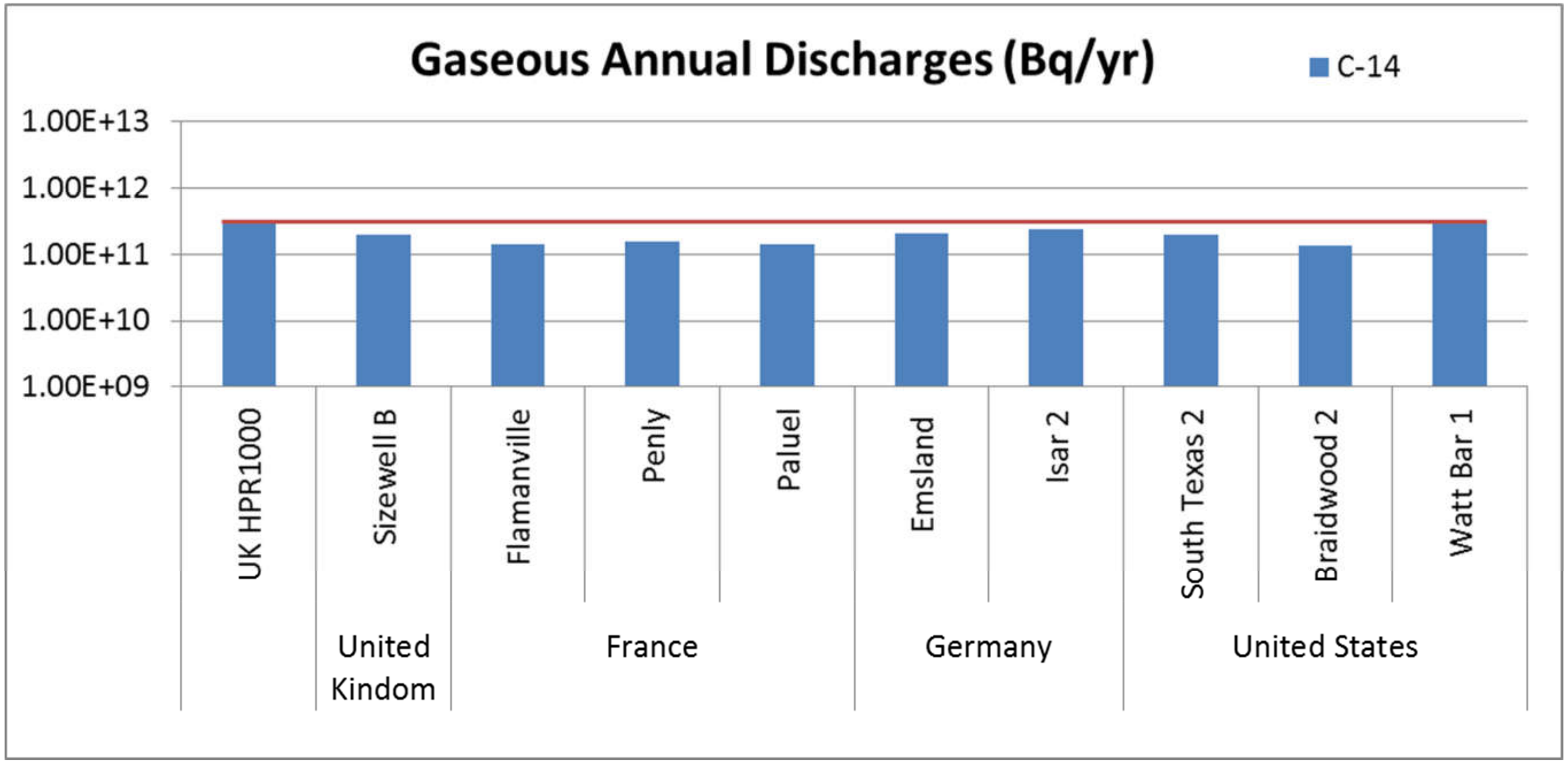
c) The liquid annual discharge of other radionuclides (including C-14) is slightly higher than those of comparable plants using hydrogen but close to those of plants using nitrogen (the German Emsland Plant and the Isar 2 Plant). This is due to C-14 being the main constituent/contributor among other radionuclides, which is as expected (as explained previously).

Overall, considering the points mentioned above, it can be concluded that the predicted annual discharges from the UK HPR1000 are reasonable and within the range of discharges from international PWRs.

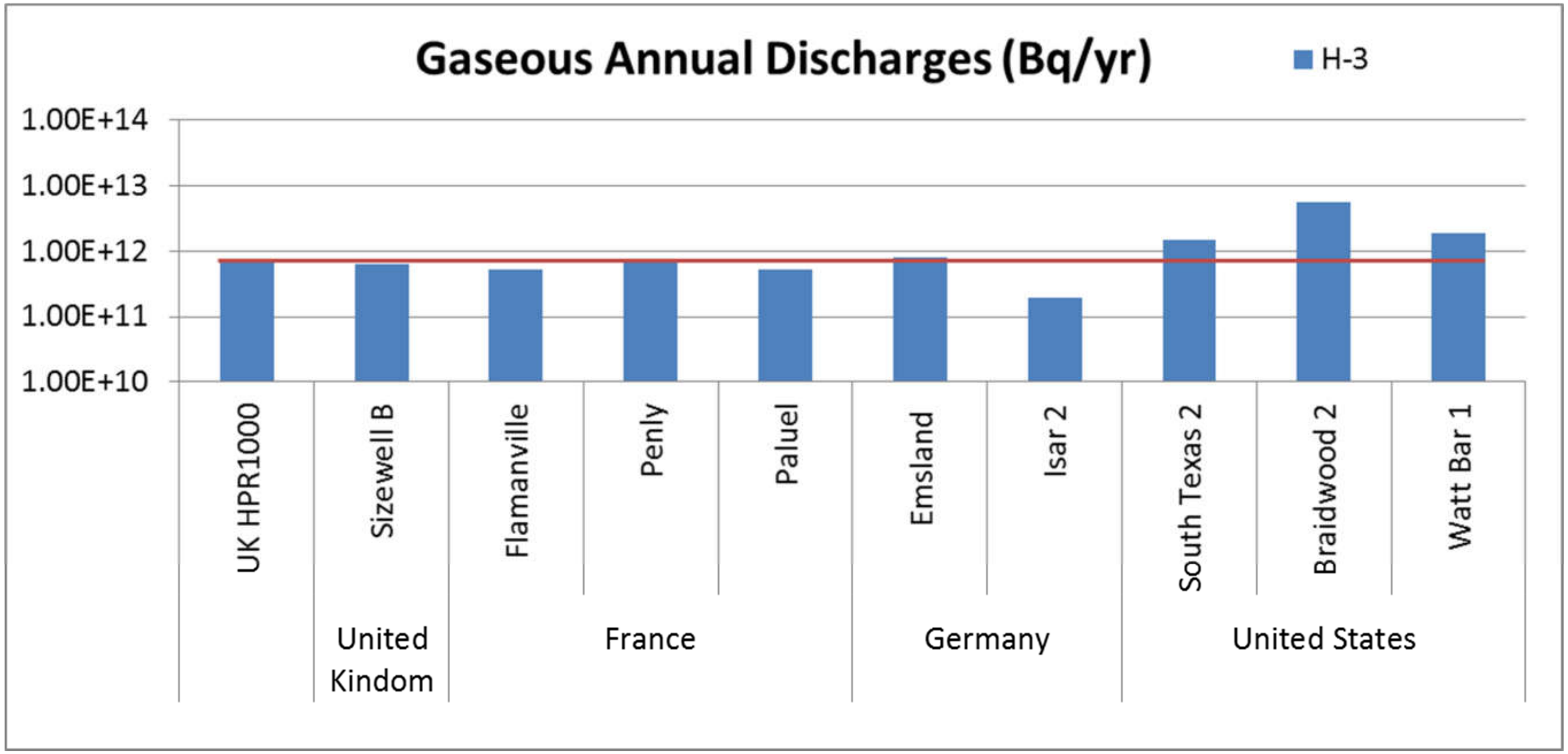
More detailed information on the international OPEX data, including the scope and the selection of the OPEX data, is provided in Reference [15]. The detailed information on the demonstration of BAT for H-3 and C-14 is provided respectively in the reports *Minimisation of the Discharge and Environment Impact of Tritium,* Reference [19] *and Minimisation of the Discharge and Environment Impact of Carbon-14,* Reference [20].

T-6.7-1 Comparison of the UK HPR1000 Annual Discharges with International OPEX Data _Normalised to 1000MWe (Reference [21])

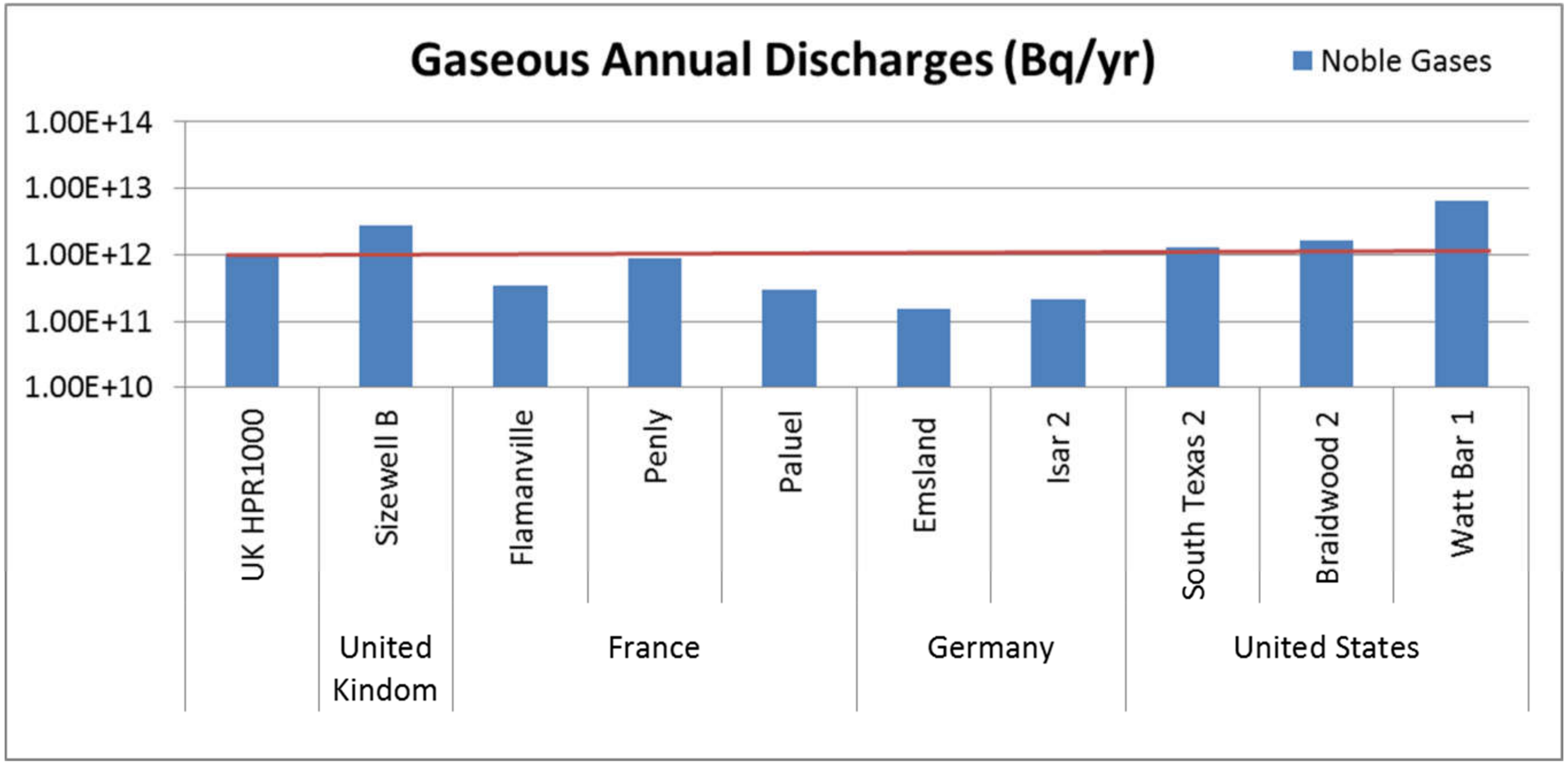
| No. | Country | Site/Unit | Gross Electrical Power (MWe) | Nomalised Gaseous Discharge (Bq/(unit•yr)) | | | | | Nomalised Liquid Discharge (Bq/(unit•yr)) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | C-14 | H-3 | Noble Gases | Iodine | Others | H-3 | Others |
| 1 | — | UK HPR1000 | 1180 | 3.17E+11 | 7.07E+11 | 1.03E+12 | 1.48E+07 | 3.27E+06 | 2.28E+13 | 1.31E+10 |
| 2 | United Kingdom | Sizewell B | 1250 | 1.96E+11 | 6.45E+11 | 2.77E+12 | 1.22E+08 | 1.63E+07 | 3.28E+13 | 1.13E+10 |
| 3 | France | Flamanville | 1382 | 1.40E+11 | 5.20E+11 | 3.37E+11 | 1.48E+07 | 1.34E+06 | 1.93E+13 | 1.13E+10 |
| 4 | | Penly | 1382 | 1.56E+11 | 7.70E+11 | 9.02E+11 | 2.31E+07 | 1.78E+06 | 1.97E+13 | 1.26E+10 |
| 5 | | Paluel | 1382 | 1.39E+11 | 5.34E+11 | 2.91E+11 | 1.15E+07 | 2.04E+06 | 1.72E+13 | 1.05E+10 |
| 6 | Germany | Emsland | 1406 | 2.07E+11 | 8.15E+11 | 1.50E+11 | 6.79E+05 | 5.09E+04 | 1.26E+13 | 6.55E+04 |
| 7 | | Isar 2 | 1485 | 2.38E+11 | 1.97E+11 | 2.12E+11 | NA | 4.02E+05 | 1.41E+13 | 8.41E+05 |
| 8 | United States | South Texas 2 | 1354 | 1.99E+11 | 1.48E+12 | 1.29E+12 | 6.19E+06 | 2.01E+07 | 2.64E+13 | 8.61E+09 |
| 9 | | Braidwood 2 | 1230 | 1.32E+11 | 5.61E+12 | 1.61E+12 | 2.81E+07 | 1.30E+06 | 3.72E+13 | 1.45E+09 |
| 10 | | Watt Bar 1 | 1210 | 3.16E+11 | 1.85E+12 | 6.43E+12 | 8.70E+07 | 2.72E+07 | 5.08E+13 | 1.71E+10 |



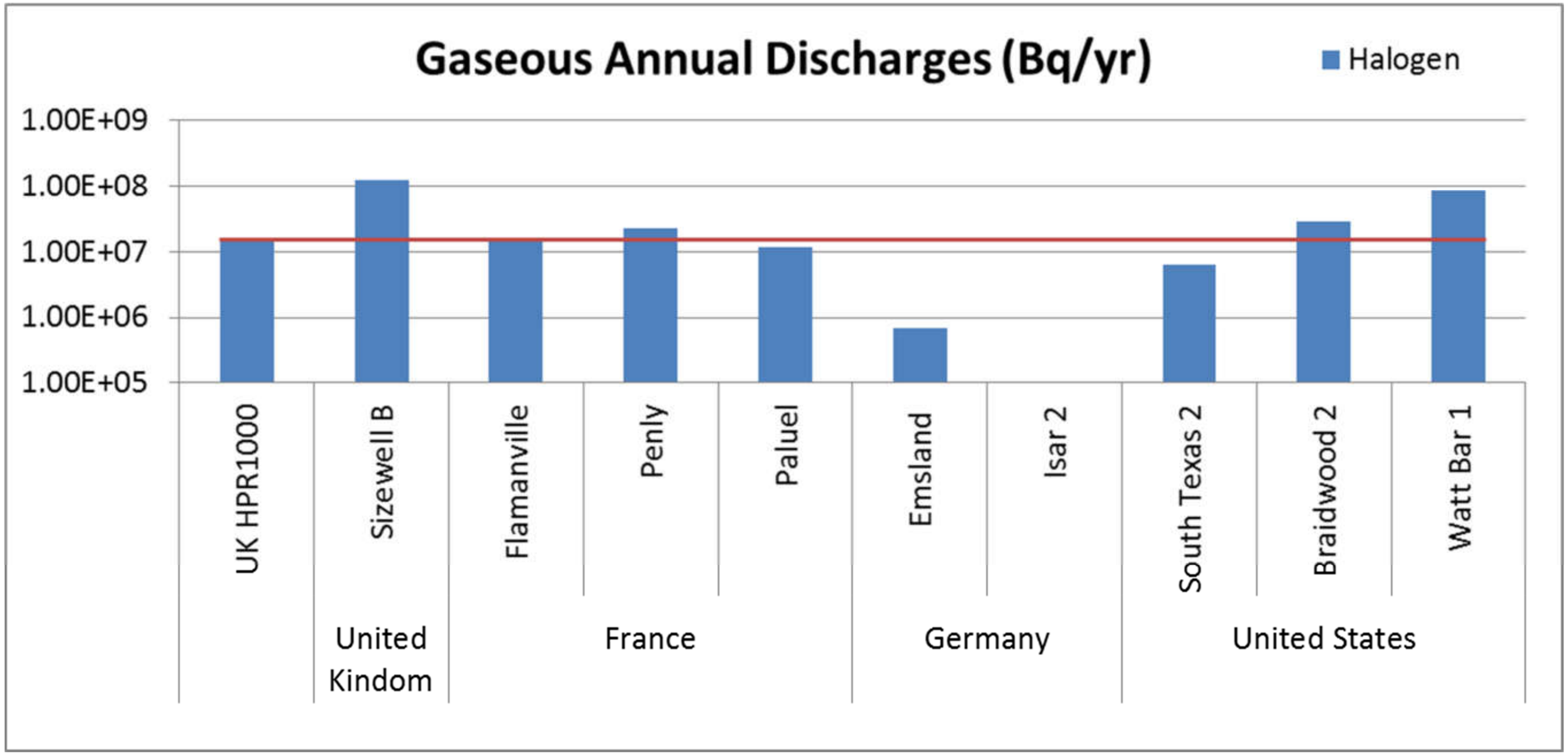

F-6.7-1 Comparison of the UK HPR1000 Gaseous Annual Discharges with International OPEX Data _ C-14 (Normalised to 1000MWe)



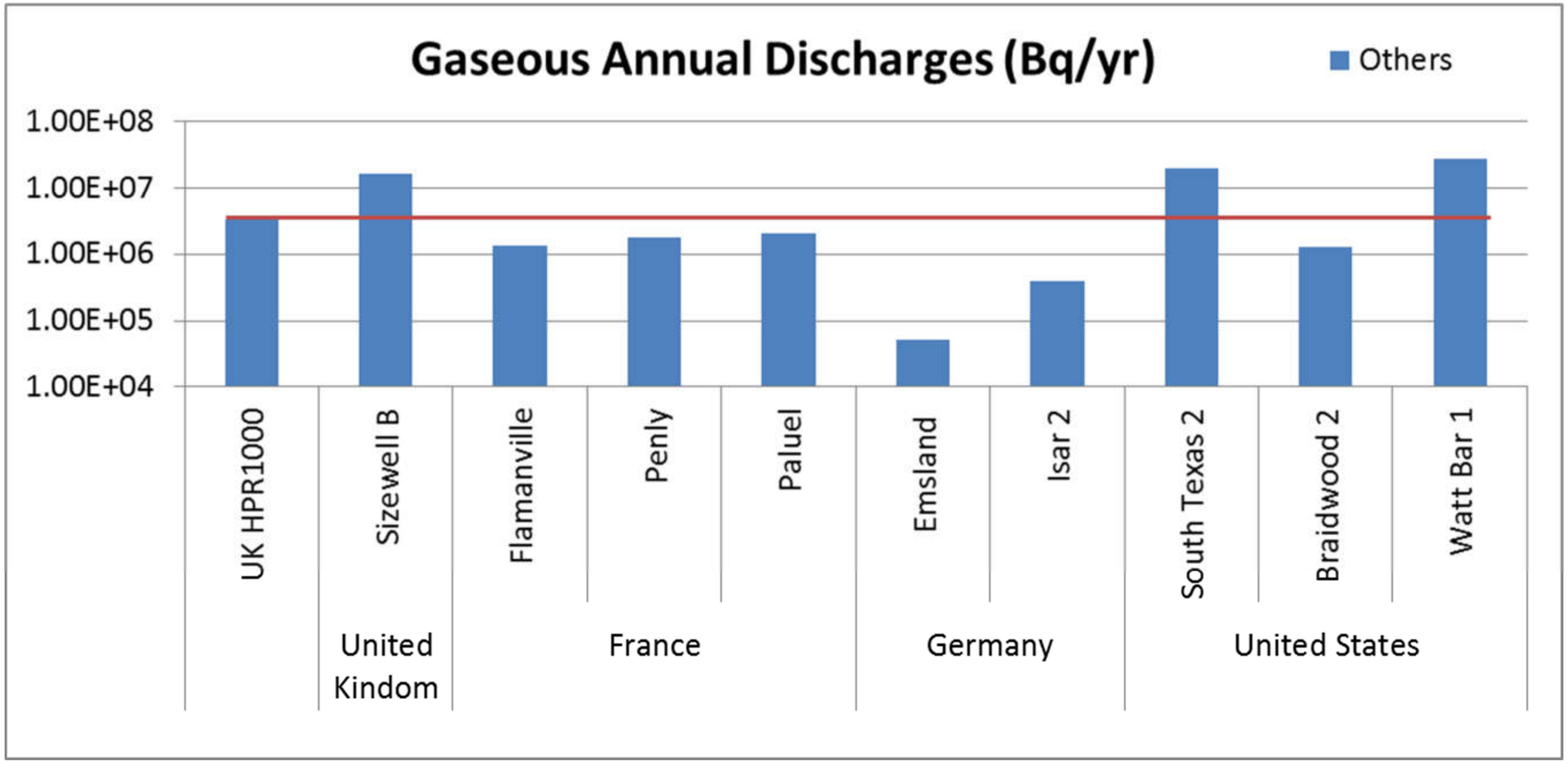

F-6.7-2 Comparison of the UK HPR1000 Gaseous Annual Discharges with International OPEX Data _ H-3 (Normalised to 1000MWe)



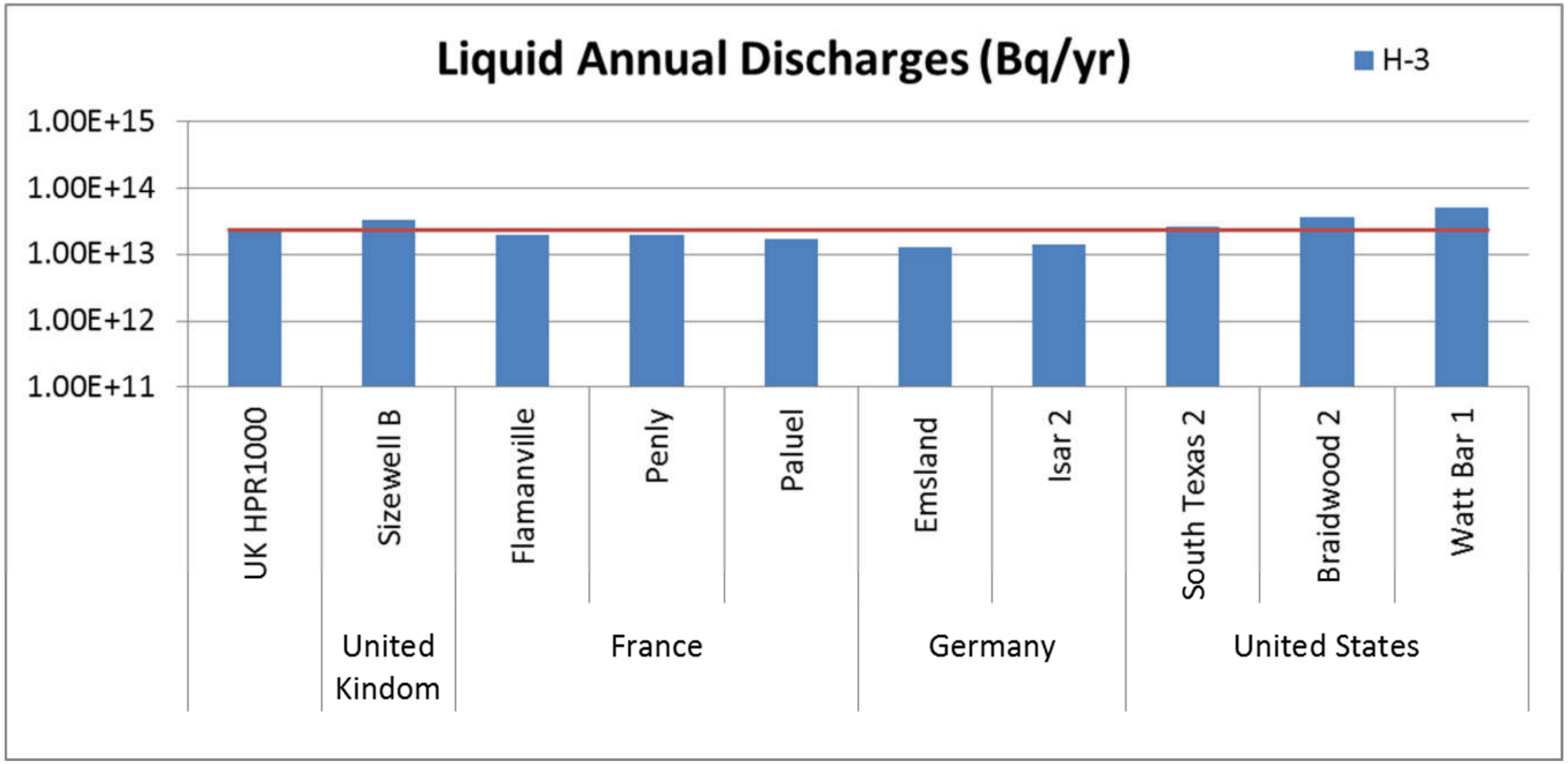

F-6.7-3 Comparison of the UK HPR1000 Gaseous Annual Discharges with International OPEX Data _ Noble Gases (Normalised to 1000MWe)



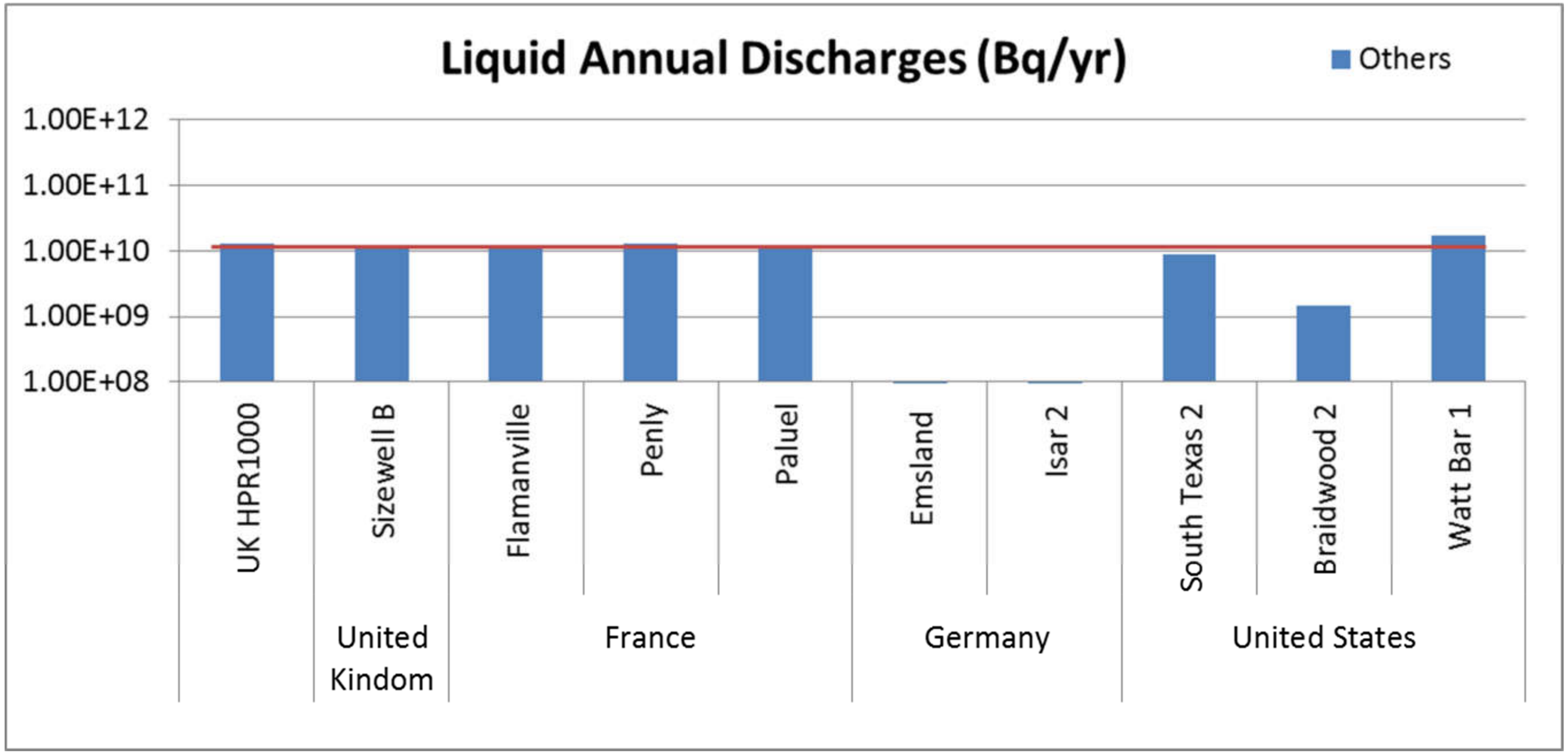

F-6.7-4 Comparison of the UK HPR1000 Gaseous Annual Discharges with International OPEX Data _ Halogen (Normalised to 1000MWe)




F-6.7-5 Comparison of the UK HPR1000 Gaseous Annual Discharges with International OPEX Data _ Others (Normalised to 1000MWe)




F-6.7-6 Comparison of the UK HPR1000 Liquid Annual Discharges with International OPEX Data _ H-3 (Normalised to 1000MWe)




F-6.7-7 Comparison of the UK HPR1000 Liquid Annual Discharges with International OPEX Data _ Others (Normalised to 1000MWe)

### 6.7.2 Comparison with Previous GDA

Even though the design scheme and the methodology for the quantification of discharges and limits are different for the UK HPR1000, the UK EPR and the UK AP1000[5], the annual discharges and proposed limits for the UK EPR and the UK AP1000 have been collected from their respective PCER publically available versions and normalised to 1000MWe to be compared with those of the UK HPR1000 (also normalised to 1000MWe). This comparison is purely indicative. The comparisons are provided in T-6.7-2 and illustrated in F-6.7-8 ~ F-6.7-15.

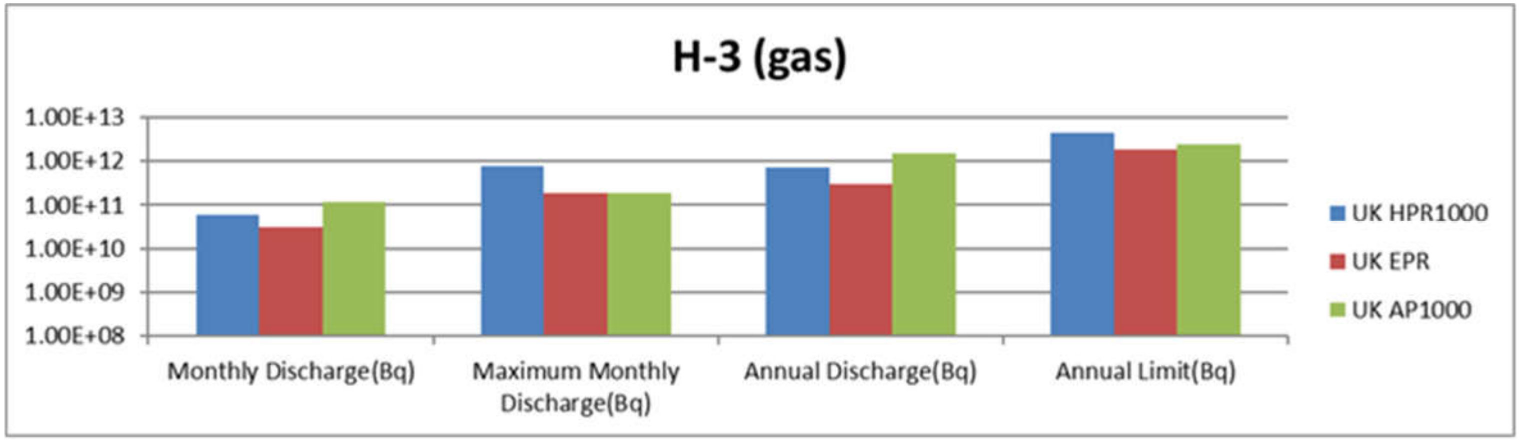
As can be seen in F-6.7-8 ~ F-6.7-15, the gaseous and liquid discharges (monthly/annual discharges and proposed limit) of most radionuclides (except for gaseous H-3 and C-14 and liquid H-3) from the UK HPR1000 are at the same level (relatively lower) compared with those from the UK EPR and the UK AP1000.

The monthly discharges and annual discharges of H-3 and C-14 from the UK HPR100 are at the same level as those from the UK EPR and the UK AP1000, but the proposed limits and the maximum monthly discharges of gaseous H-3 and C-14 and liquid H-3 for the UK HPR1000 are slightly higher than those for the UK EPR and the UK AP1000. These differences are mainly due to the differences in the methodology adopted by the different Requesting Parties and the assumptions made, e.g. considerations of the headroom factor for uncertainty and variety and the contribution of expected events. The methodology for the UK HPR1000 has been developed in accordance with EA guidance for setting limits, Reference [12].

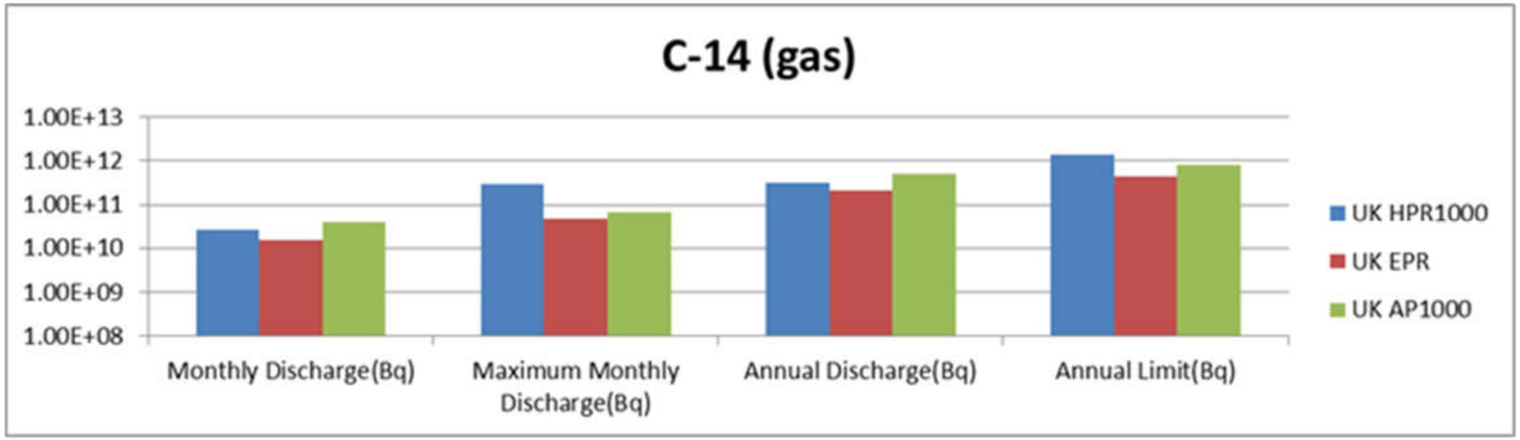
[5] The UK ABWR is not considered since it is a boiling water reactor, not comparable with the UK HPR1000.

T-6.7-2 Comparison of Discharges and Limits between UK HPR1000 and Previous GDA _ Normalised to 1000MWe

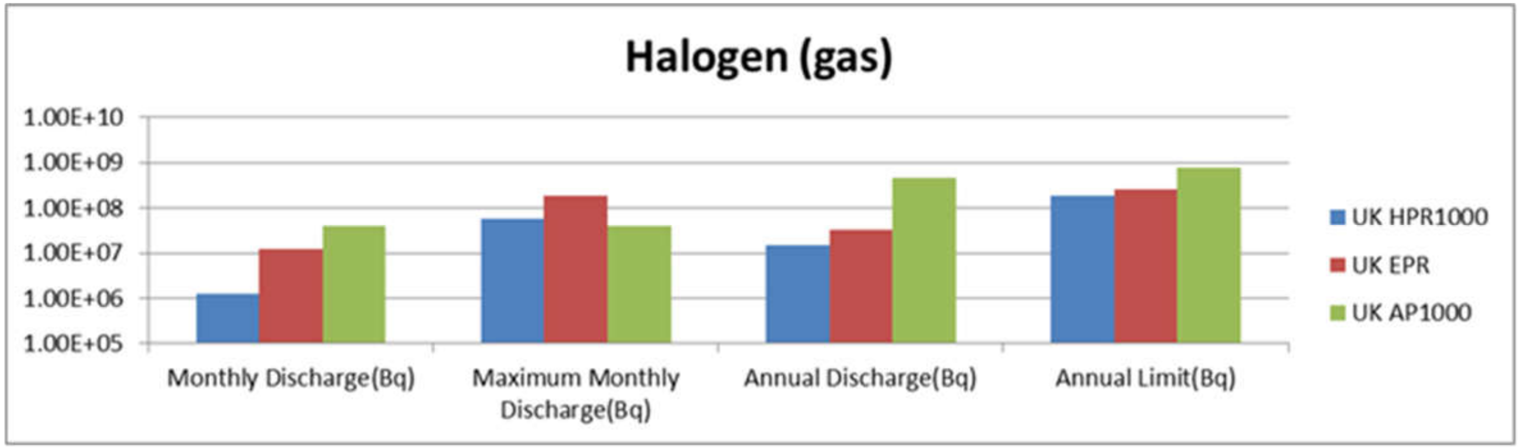
| **Phase** | **Radionuclide** | **Average Monthly Discharge (Bq)** | | | **Maximum Monthly Discharge (Bq)** | | |
|---|---|---|---|---|---|---|---|
| | | **UK HPR1000*** | **UK EPR** | **UK AP1000** | **UK HPR1000** | **UK EPR** | **UK AP1000** |
| Gaseous Effluent | H-3 | 5.90E+10 | 3.13E+10 | 1.18E+11 | 7.89E+11 | 1.88E+11 | 1.94E+11 |
| | C-14 | 2.64E+10 | 1.56E+10 | 4.05E+10 | 2.92E+11 | 4.69E+10 | 6.64E+10 |
| | Noble Gases | 8.55E+10 | 2.50E+11 | 4.45E+11 | 2.40E+12 | 3.13E+12 | 1.62E+12 |
| | Iodine | 1.23E+06 | 1.25E+07 | 3.97E+07 | 5.87E+07 | 1.88E+08 | 3.97E+07 |
| | Others | 2.73E+05 | 5.00E+05 | 8.16E+05 | 1.37E+06 | 3.75E+07 | 8.16E+05 |
| Liquid Effluent | H-3 | 1.90E+12 | 8.13E+12 | 2.22E+12 | 7.96E+12 | 1.17E+13 | 3.64E+12 |
| | C-14 | 1.07E+09 | 3.59E+09 | 2.22E+08 | 7.81E+09 | 1.50E+10 | 1.12E+09 |
| | Others | 2.36E+07 | 1.88E+08 | 1.65E+08 | 2.49E+08 | 6.28E+09 | 8.24E+08 |
| * The average monthly discharges from the UK HPR1000 are taken as 12 months' average from the annual discharges. | | | | | | | |
| **Phase** | **Radionuclide** | **Annual discharge (Bq)** | | | **Proposed Limit (Bq)** | | |
| | | **UK HPR1000** | **UK EPR** | **UK AP1000** | **UK HPR1000** | **UK EPR** | **UK AP1000** |
| Gaseous Effluent | H-3 | 7.07E+11 | 3.13E+11 | 1.50E+12 | 4.44E+12 | 1.88E+12 | 2.40E+12 |
| | C-14 | 3.17E+11 | 2.19E+11 | 5.10E+11 | 1.43E+12 | 4.38E+11 | 8.00E+11 |
| | Noble Gases | 1.03E+12 | 5.00E+11 | 6.48E+12 | 1.32E+13 | 1.41E+13 | 1.04E+13 |
| | Iodine | 1.48E+07 | 3.13E+07 | 4.76E+08 | 1.87E+08 | 2.50E+08 | 8.00E+08 |
| | Others | 3.27E+06 | 2.50E+06 | 1.38E+07 | 9.49E+06 | 7.50E+07 | 2.40E+07 |
| Liquid Effluent | H-3 | 2.28E+13 | 3.25E+13 | 2.81E+13 | 8.81E+13 | 4.69E+13 | 4.80E+13 |
| | C-14 | 1.28E+10 | 1.44E+10 | 3.54E+09 | 5.00E+10 | 5.94E+10 | 5.60E+09 |
| | Others | 2.82E+08 | 3.79E+08 | 2.62E+09 | 8.81E+08 | 6.28E+09 | 4.32E+09 |



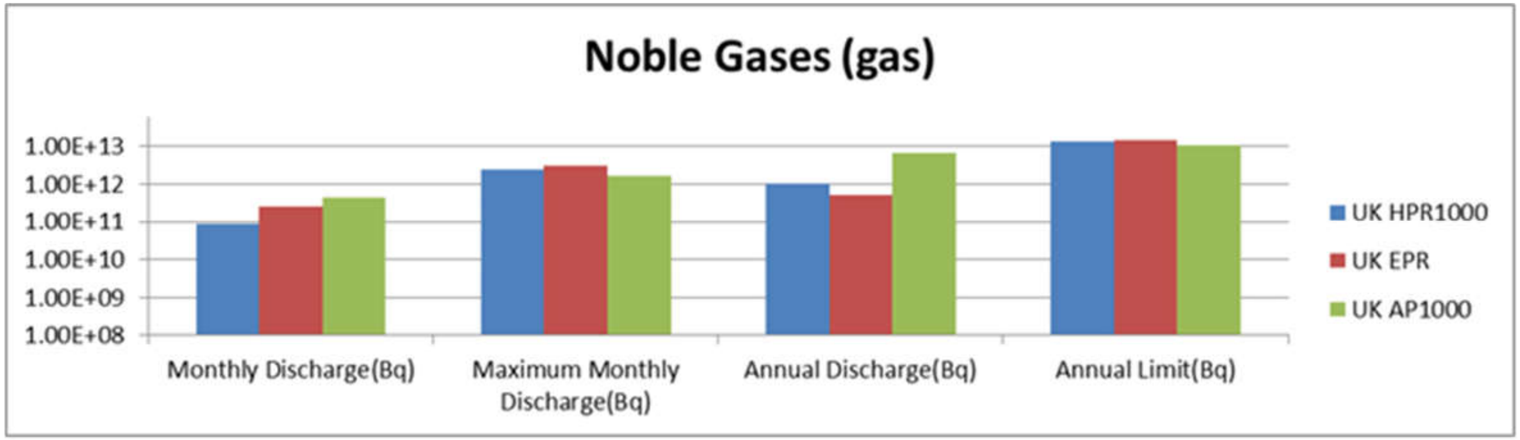

F-6.7-8 Comparison of Gaseous Discharges and Limits between UK HPR1000 and Previous GDA _ H-3 (Normalised to 1000MWe)



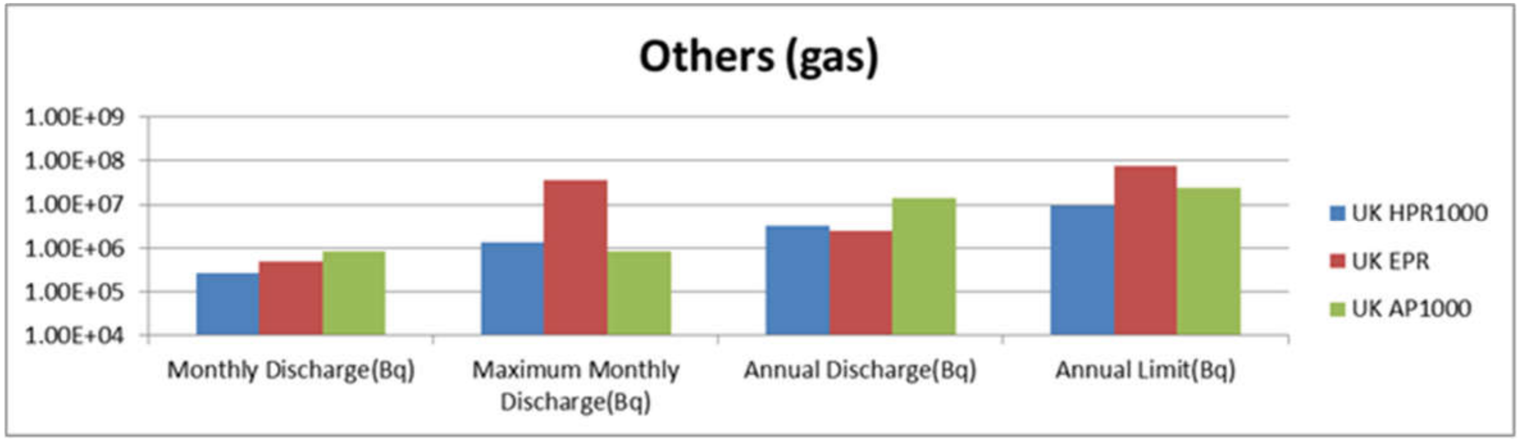

F-6.7-9 Comparison of Gaseous Discharges and Limits between UK HPR1000 and Previous GDA _ C-14 (Normalised to 1000MWe)



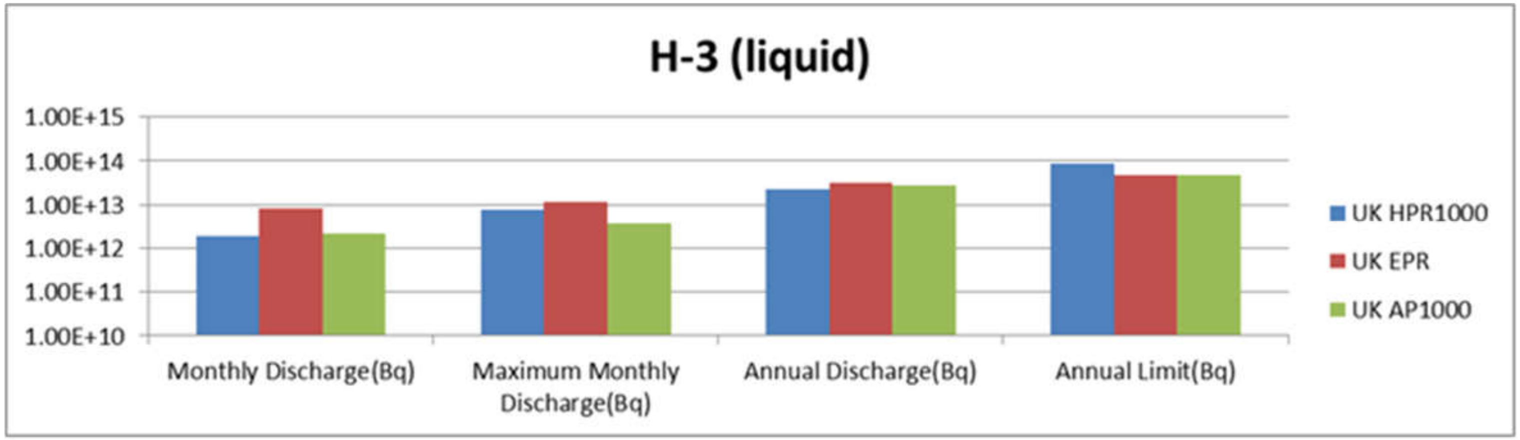

F-6.7-10 Comparison of Gaseous Discharges and Limits between UK HPR1000 and Previous GDA _ Noble Gases (Normalised to 1000MWe)



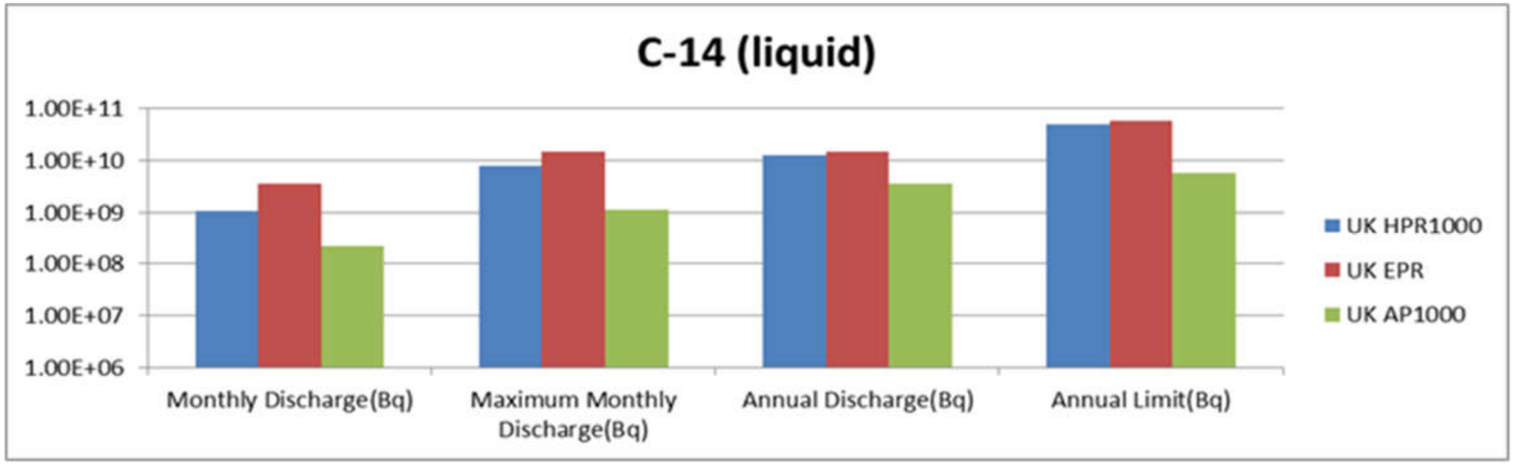

F-6.7-11 Comparison of Gaseous Discharges and Limits between UK HPR1000 and Previous GDA _ Halogen (Normalised to 1000MWe)



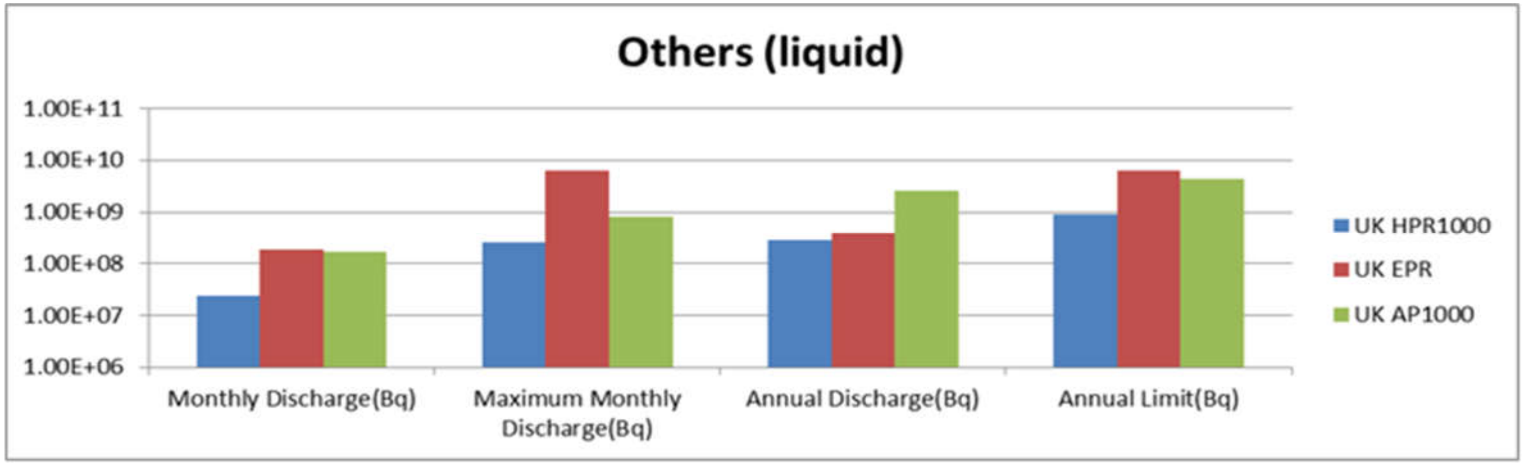

F-6.7-12 Comparison of Gaseous Discharges and Limits between UK HPR1000 and Previous GDA _ Others (Normalised to 1000MWe)




F-6.7-13 Comparison of Liquid Discharges and Limits between UK HPR1000 and Previous GDA _ H-3 (Normalised to 1000MWe)




F-6.7-14 Comparison of Liquid Discharges and Limits between UK HPR1000 and Previous GDA _ C-14 (Normalised to 1000MWe)




F-6.7-15 Comparison of Liquid Discharges and Limits between UK HPR1000 and Previous GDA _ Others (Normalised to 1000MWe)

## 6.8 Conclusion

This chapter presents the methodology for the quantification of the radioactive gaseous and liquid discharges and limits for the UK HPR1000, in line with the relevant P&ID requirements, REP principles and other related requirements.

The discharge routes and effluent streams are identified according to the system and process design and the radioactive waste management arrangement strategy.

On the basis of CGN OPEX data, considering all possible discharge routes and effluent streams, the radioactive gaseous and liquid discharges and limits for the UK HPR1000 during normal operation have been quantified. The annual discharges from the UK HPR1000 are compared with the international OPEX data and proved not to exceed the discharges of comparable international plants.

The estimated discharges and limits are used as inputs for the environmental impact assessment in PCER Chapter 7.

## 6.9 References

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