The Application of Best Available Techniques (BAT) and Best Environmental Practice (BEP) in Nuclear Facilities in the United Kingdom 8th round

OSPAR Agreement 2018-01

Radioactive Substances Series

2023

Summary of Radioactivity in Food and the Environment (2004–2021)

Department for Business, Energy & Industrial Strategy

Environment Agency

Food Standards Agency
food.gov.uk

Food Standards Scotland

Cyfoeth Naturiol Cymru
Natural Resources Wales

NIEA
www.daera-ni.gov.uk
Northern Ireland Environment Agency

SEPA
Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. The Contracting Parties are: Belgium, Denmark, the European Union, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Convention OSPAR

La Convention pour la protection du milieu marin du Nord-Est de l'Atlantique, dite Convention OSPAR, a été ouverte à la signature durant la réunion ministérielle des anciennes commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. Les Parties Contractantes sont: l'Allemagne, la Belgique, le Danemark, l'Espagne, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède, la Suisse et l'Union Européenne.

Acknowledgement

This report has been prepared by Cefas, on behalf of the UK, who would also like to thank numerous contributors for their valuable input.

Contents

Summary 7
Résumé 9
Structure of the combined report 12
1 Introduction 13
2 Nuclear fuel production and reprocessing 16
2.1 Introduction 16
2.2 Sellafield 17
2.2.1 Sources of liquid effluent 19
2.2.2 Liquid effluent treatment and abatement 20
2.2.3 Trends in liquid discharges over the 2017–2021 period 21
2.2.4 Gaseous discharges relevant to the marine environment 25
2.2.5 Radiological impact of gaseous and liquid discharges 25
2.2.6 The application of BAT 26
2.2.7 Comparison with performance of similar plants world-wide 28
2.3 Capenhurst 29
2.3.1 Sources of liquid effluent 29
2.3.2 Liquid effluent treatment and abatement 29
2.3.3 Trends in discharges over the 2017 to 2021 period 30
2.3.4 Radiological impact of gaseous and liquid discharges 32
2.3.5 The application of BAT 32
2.3.6 Comparison with performance of similar plants world-wide 34
2.4 Springfields 34
2.4.1 Sources of liquid effluent 34
2.4.2 Liquid effluent treatment and abatement 35
2.4.3 Trends in discharges over the 2017 to 2021 period 35
2.4.4 Radiological impact of gaseous and liquid discharges 37
2.4.5 The application of BAT 37
2.4.6 Comparison with performance of similar plants world-wide 38
3 Research and development 39
3.1 Introduction 39
3.2 Dounreay 41
3.2.1 Sources of liquid effluent 42
3.2.2 Liquid effluent treatment and discharges 42
3.2.3 Trends in discharges over the 2017 to 2021 period 43

3.2.4 Radiological impact of gaseous and liquid discharges 45
3.2.5 Particles on the Dounreay foreshore 46
3.2.6 The application of BAT 47
3.2.7 Comparison with performance of similar plants world-wide 48
3.3 Harwell 49
3.3.1 Sources of liquid effluent 49
3.3.2 Liquid effluent treatment and discharges 49
3.3.3 Trends in discharges over the 2017 to 2021 period 50
3.3.4 Radiological impact of gaseous and liquid discharges 51
3.3.5 The application of BAT 51
3.3.6 Comparison with performance of similar plants world-wide 52
3.4 Winfrith 53
3.4.1 Sources of liquid effluent 53
3.4.2 Liquid effluent treatment and discharges 54
3.4.3 Trends in discharge over the 2017 to 2021 period 54
3.4.4 Radiological impact of gaseous and liquid discharges 56
3.4.5 The application of BAT 56
3.4.6 Comparison with performance of similar plants world-wide 57
4 Nuclear power generation 58
4.1 Introduction 58
4.2 Operational power stations 59
4.2.1 Sources of liquid effluent for AGRs and PWR 59
4.2.2 Management of liquid effluents for AGRs and PWR 60
4.2.3 Liquid effluent treatment and abatement from AGRs and PWR 62
4.2.4 Trends in discharges over the 2017 to 2021 period 63
4.2.5 Radiological impact of gaseous and liquid discharges for AGRs and PWR74
4.2.6 The application of BAT for AGRs and PWR 74
4.2.7 Comparison with performance of similar plants world-wide 77
4.3 Decommissioning power stations 78
4.3.1 Sources of liquid effluent 81
4.3.2 Liquid effluent treatment and abatement 81
4.3.3 Trends in discharges over the 2017 to 2021 period 83
4.3.4 Radiological impact of gaseous and liquid discharges for Magnox 96
4.3.5 The application of BAT (decommissioning sites) 96
4.3.6 Comparison with performance of similar plants world-wide 103
5 The development and application of BAT 104

5.1 Introduction..104
5.2 Technologies in use or under development in the UK..............................107
5.2.1 Filtration..107
5.2.2 Caustic scrubbers 108
5.2.3 Ion exchange and adsorption..108
5.2.4 Hydrocyclone centrifuge...109
5.2.5 Electrochemical and electrophysical processes.....................................109
5.3 Conclusions...110
5.3.1 Nuclear fuel production and reprocessing 110
5.3.2 Power Generation (operational)...110
5.3.3 Power Generation (decommissioning) 111
5.3.4 Research and development 111
5.3.5 Overall conclusion...111
Foreword..115
Introduction 117
6 Overview of 'total dose' and environmental indicators near the UK's nuclear sites 118
6.1 'Total dose' assessment 118
6.2 Environmental indicators close to and away from nuclear sites 123
6.3 Doses to the public away from nuclear sites 124
7 Nuclear fuel production and reprocessing 125
7.1 Public's exposure to radiation due to discharges of radioactive waste 126
7.2 Sellafield, Cumbria...128
7.2.1 Discharges of radioactive waste 128
7.2.2 Concentrations of radionuclides in food and the environment 130
7.3 Capenhurst - 132
7.4 Springfields - 134
7.5 Summary...135
8 Research and development 136
8.1 Public's exposure to radiation due to discharges of radioactive waste 137
8.2 Dounreay – 139
8.3 Harwell - 140
8.4 Winfrith –...142
8.5 Summary...144
9 Nuclear power generation 145
9.1 Public's exposure to radiation due to discharges of radioactive waste 146
9.2 Discharges of radioactive waste from nuclear power stations...................149

9.3 Concentrations of radionuclides in food and the environment 150
9.4 Trawsfynydd - Discharges of radioactive waste and concentrations of radionuclides in the environment..153
9.5 Summary...154
10 Defence 155
10.1 Public's exposure to radiation due to discharges of radioactive waste..156
10.2 Aldermaston, Devonport, Faslane and Coulport, and Rosyth –.............157
10.3 Defence establishments – 160
10.4 Summary...161
11 Radiochemical production 161
11.1 Public's exposure to radiation due to discharges of radioactive waste..162
11.2 Amersham –...163
11.3 Cardiff - 165
11.4 Summary...167
12 Summary and Conclusions 168
Appendix 1 Bibliography 170
Appendix 2 Acronyms 171

Summary

This report (Parts 1 and 2) has been prepared for the Radioactive Substances Committee of the Oslo and Paris Convention (OSPAR) Commission as the UK statement on the implementation of OSPAR Recommendation 2018/1 on Radioactive Substances, related to the application of Best Available Technology[1] (BAT) to minimise and, where appropriate, eliminate radioactive discharges from the nuclear industry (excluding defence and medical facilities) into the marine environment.

Policy and strategy

The UK laid out its initial strategy to implement the agreements reached at the 1998 OSPAR Ministerial Meeting, and subsequent OSPAR Commission meetings on radioactive substances, in its UK Strategy for Radioactive Discharges 2001-2020, which was issued in 2002. The UK government and devolved administrations published the revised UK Strategy for Radioactive Discharges in 2009. This revised strategy expanded its scope to include gaseous, as well as liquid discharges, from decommissioning as well as operational activities, and from the non-nuclear as well as the nuclear industry sectors. It also includes considerations of uncertainties associated with discharges from new nuclear power stations, the possible extension of the operational lives of some of the existing nuclear power reactors, and discharges arising from decommissioning activities. The permitting and authorisation processes applied in the UK, particularly the conditions relating to periodic review, ensure that BAT will continue to be implemented in accordance with the discharge strategy and associated statutory guidance.

Regulation

Radioactive waste disposal by UK nuclear installations is governed by national legislation, most notably the Environmental Authorisations (Scotland) Regulations 2018 (EASR18)[2] in Scotland, and the Environmental Permitting (England and Wales) Regulations 2016 (EPR16)[3].

The UK authorities responsible for the regulation of radioactive discharges and radioactive waste disposal from nuclear sites are the Environment Agency in England, the Scottish Environment Protection Agency (SEPA) and Natural Resources Wales (NRW).

In England and Wales, the application of Best Available Techniques (BAT) is the means to achieve compliance with the radiological protection principle of optimisation. The use of BAT was one of the principles adopted in the 2009 UK Strategy on radioactive discharges. In Scotland, the terms of Best Practicable Means (BPM) and Best Practicable Environmental Option (BPEO) continue to be used by SEPA. The UK environment agencies consider that the terms BPM and BPEO taken

---

[1] In OSPAR Recommendation 2018/1, the term BAT is related to 'technology'. However, in the UK the term 'techniques' is more commonly used in this context, to include both equipment and management practices. This broader interpretation of BAT is applied throughout this report.

[2] On 1 September 2018, the new Environmental Authorisations (Scotland) Regulations came into force [22], replacing the Radioactive Substances Act 1993 [23]

[3] On 1 January 2017, the new Environmental Permitting (England and Wales) Regulations 2016 came into force (United Kingdom - Parliament, 2016), replacing the Environmental Permitting (England and Wales) Regulations 2010 (EPR10).

together are equivalent to the requirement to use BAT and that the obligations on waste producers are the same. The use of BAT, BPM and BPEO in the UK delivers a level of discharge control that is at least consistent with that implied by BAT as defined by OSPAR.

Review of BAT

In this report, current practices and the application of BAT are reviewed at each relevant site and facility. This review is grouped by the following nuclear industry sectors: nuclear fuel production and reprocessing, research and development and nuclear power generation. The practices, and impacts, of operational and decommissioning nuclear power stations are presented separately.

Radiochemical production is considered to be a non-nuclear sector and is included in the non-nuclear reports submitted to OSPAR. The implementation of OSPAR Recommendation 2018/1 is not appropriate to UK defence establishments (OSPAR only relates to civil nuclear industries). However, the environmental impacts of both radiochemical production and defence sectors are assessed and provided in Part 2 of this report. Sites involved in the treatment and management of low-level radioactive wastes (such as landfill sites that accept solid low levels wastes) and other non-nuclear sectors (for example, hospitals and universities) are considered to be outside the required scope and have not been included in this report.

In addition to the review of the application of BAT, based on current practices, technologies that are under development in the UK and elsewhere have been identified and comparisons with performance of similar plants world-wide have been made where appropriate.

The UK government and devolved administrations believe the procedures and techniques applied in the UK nuclear industry are consistent with the implementation of BAT, BPEO and BPM. Furthermore, the review process for radioactive waste disposal and discharge permits and authorisations requires that technological developments continue to be reviewed and implemented where appropriate.

Progress in the application of BAT in the UK's nuclear facilities is clearly demonstrated in this report. Specific examples of processes and waste management activities which occurred during the reporting period are described and summarised for each of the nuclear sectors.

Conclusion

The application of BAT in the UK brought about, for example, by stringent regulation, considerable investment in abatement plant, process optimisation and better application of the waste management hierarchy (including waste minimisation) has been effective in reducing discharges. The UK will continue to apply BAT rigorously.

Further substantial reductions in discharges may be increasingly difficult to achieve in some areas; in recent years we have seen fluctuations in discharges in line with operational throughputs and essential work to reduce hazards and decommission redundant facilities.

Résumé

Le présent rapport (parties 1 et 2) a été préparé pour le Comité des Substances Radioactives de la Commission OSPAR à titre de Royaume Uni de Grande Bretagne et d'Irlande du Nord sur la mise en œuvre de la recommandation 2018/1 sur les substances radioactives, portant sur l'application des meilleures technologies disponibles[4] (MTD) dans le but de minimiser ou éliminer les rejets radioactifs des industries nucléaires dans le milieu marin (à l'exception des installations militaires et médicales).

Politique et stratégie

Le Royaume Uni de Grande Bretagne et d'Irlande du Nord a exposé sa stratégie initiale de mise en œuvre des accords conclus lors de la réunion ministérielle OSPAR de 1998, puis lors des réunions suivantes de la Commission OSPAR sur les substances radioactives, dans sa Stratégie pour les Rejets Radioactifs 2001-2020, publiée en 2002. Le gouvernement britannique, appuyé par ses administrations décentralisées, ont ensuite publié une mise à jour de cette Stratégie en 2009. Cette nouvelle version étendit sa portée afin d'inclure les rejets gazeux et liquides issus de sites nucléaires en opération ainsi que d'opérations de démantèlement, et également de produits provenant des secteurs industriels non nucléaires. Elle prit également en compte les incertitudes liées aux rejets de nouvelles centrales nucléaires, de centrales en opération prolongée ainsi que les rejets issus des activités de démantèlement. Les procédures d'octroi de permis en vigueur au Royaume-Uni de Grande Bretagne et d'Irlande du Nord, et en particulier les conditions liées aux examens périodiques, garantissent que les Meilleures Technologies Disponibles continueront d'être mises en œuvre conformément à la Stratégie en matière de rejets et d'autres réglementations en vigueur.

Réglementation

L'élimination des déchets radioactifs provenant des installations nucléaires au Royaume Uni de Grande Bretagne et d'Irlande du Nord est régie par différentes législations nationales, en l'occurrence, l'«Environmental Authorisations (Scotland) Regulations 2018 (EASR18)[5] » en Écosse, et l' «Environmental Permitting (England and Wales) (Amendment) (EU Exit) Regulations 2016» en Angleterre et au Pays de Galles EPR16)[6].

---

[4] Dans la recommendation 2018/1, le terme MTD porte sur les technologies. Cependant, le terme « techniques » est utilisé plus couramment au Royaume-Uni de Grande Bretagne et d'Irlande du Nord dans ce contexte, pour couvrir aussi bien le matériel que les pratiques de gestion. Cette interprétation plus large des MTD s'applique à l'ensemble du rapport.

[5] Le 1er September 2018, les nouveaux règlements l'«Environmental Authorisations (Scotland) Regulations 2018 (EASR18) sont entrés en vigueur, remplaçant les règlements sur Radioactive Substances Act 1993.

[6] Le 1er janvier 2017, les nouveaux règlements de 2016 sur les permis environnementaux (Angleterre et Pays de Galles) sont entrés en vigueur (Royaume-Uni - Parlement, 2016), remplaçant les règlements sur les permis environnementaux (Angleterre et Pays de Galles) de 2010 (EPR10).

Les autorités britanniques responsables de la réglementation des rejets radioactifs et de l'élimination des déchets radioactifs provenant des sites nucléaires et industriels non-nucléaire sont l'Agence de l'Environnement en Angleterre, l'Agence Ecossaise pour la Protection de l'Environnement (SEPA) et Ressources Naturelles du Pays de Galles (NRW).

En Angleterre et au Pays de Galles, l'application des Meilleures Technologies Disponibles (MTD) permet de se conformer au principe d'optimisation de la protection radiologique. L'utilisation des MTD a été l'un des principes adopté dans la Stratégie du Royaume-Uni de Grande Bretagne et d'Irlande du Nord de 2009. En Écosse, les termes de Meilleures Techniques Existantes (BPM) et Meilleure Option Environnementale Applicable (BPEO) sont toujours utilisés par la SEPA. Les agences britanniques de protection de l'environnement considèrent que les termes BPM et BPEO pris ensemble équivalent à l'utilisation des MTD et que les obligations pour les producteurs de déchets sont les mêmes. L'utilisation des MTD, BPM et BPEO au Royaume-Uni de Grande Bretagne et d'Irlande du Nord permet un niveau de contrôle des rejets en accord avec celui des MTD définis par OSPAR.

Bilan des MTD

Dans ce rapport, les pratiques actuelles et l'application des MTD sont examinées pour chaque site et installation concernés. Ce bilan s'articule autour des secteurs industriels nucléaires suivants : production et traitement du combustible nucléaire, recherche et développement et production d'énergie nucléaire. Les pratiques et les incidences de l'exploitation et du démantelement des centrales nucléaires sont présentées séparément.

La production de composés radiochimiques est considérée comme un secteur non nucléaire et figure dans les rapports non nucléaires soumis à OSPAR. La mise en œuvre de la Recommandation 2018/1 d'OSPAR n'est pas appropriée pour les établissements de défense présents au Royaume-Uni de Grande Bretagne et d'Irlande du Nord. Toutefois, les effets sur l'environnement provenant de la production de composés radiochimiques et du secteur de la défense sont évalués et présentés dans la deuxième partie de ce rapport. Les sites impliqués dans le traitement et la gestion des déchets solides faiblement radioactifs (par exemple les sites de décharge acceptant les déchets solides faiblement radioactifs) et autres secteurs non nucléaires (hôpitaux, universités, etc.) sont considérés comme étant en dehors du champ requis et n'ont donc pas été couverts dans ce rapport.

En plus de la révision de l'application des MTD, fondée sur les pratiques actuelles, les technologies en cours de développement au Royaume-Uni de Grande Bretagne et d'Irlande du Nord et ailleurs ont aussi été recensées, et des comparaisons avec les performances d'installations similaires dans le monde entier ont été faites.

Le gouvernement britannique et ses administrations décentralisées sont convaincus que les procédures et techniques en vigueur dans le secteur nucléaire au Royaume Uni de Grande Bretagne et d'Irlande du Nord sont compatibles avec la mise en œuvre des MTD, BPEO et BPM. Par ailleurs, en vertu des exigences du processus d'examen pour l'évacuation des déchets radioactifs et l’octroi de permis et d’autorisations de rejets, les développements technologiques doivent continuer d’être révisés et mis en œuvre le cas échéant.

Les progrès réalisés dans l’application des MTD dans les installations nucléaires au Royaume Uni de Grande Bretagne et d’Irlande du Nord sont clairement démontrés dans ce rapport. Des exemples de processus et d’activités de gestion des déchets déployés au cours des cinq dernières années sont décrits et résumés pour chacun des secteurs nucléaires.

Conclusion

L’application des MTD au Royaume-Uni de Grande Bretagne et d’Irlande du Nord, entraînée notamment par une réglementation stricte, des investissements considérables dans les installations de réduction de la pollution, l’optimisation des procédés, et une meilleure classification des déchets (dont la minimisation des déchets) a permis de réduire les rejets au cours des dernières années. Le Royaume-Uni de Grande Bretagne et d’Irlande du Nord continuera d’appliquer avec rigueur les MTD dans les prochaines années.

Réduire davantage de manière substantielle les rejets risque de s’avérer de plus en plus difficile dans certains domaines. Ces dernières années, des fluctuations au niveau des rejets ont été constatées conformément aux débits de production et aux travaux essentiels visant à réduire les risques et à démanteler les installations redondantes.

Structure of the combined report

This combined report has been prepared for the Radioactive Substances Committee (RSC) of the Oslo and Paris Convention (OSPAR) Commission as the UK statement on the implementation of OSPAR Recommendation 2018/01 on Radioactive Substances, related to the application of Best Available Technology (BAT) to minimise and, where appropriate, eliminate radioactive discharges from the nuclear industry into the marine environment.

The report has been prepared in accordance with RSC guidelines, providing the required general information, site specific information of discharges, relating to UK civil nuclear licensed sites. This report provides a summary of the public's exposure (doses) to radiation to people living around nuclear licensed sites in the UK. It also gives more detail of trends on discharges of radioactivity to the environment and concentrations of radionuclides in food and the environment over the same period for each of the nuclear industry sectors.

This UK report is presented in 2 parts:

Part 1. Report on application of Best Available Techniques (BAT) in UK civil nuclear facilities (2017 to 2021)

In Part 1, the BAT current practices for each relevant site or type of facility are provided and reviewed, the detailed application of BAT (or the equivalent Best Practicable Means (BPM) and Best Practicable Environmental Option (BPEO), applied in Scotland) is discussed and an assessment of liquid radioactive discharged to the marine environment is provided over the period of the evaluation (2017 to 2021). A summary document (country profile) detailing the organisation of nuclear safety and radiation protection within the national regulatory and legislative framework is available on the UK's implementation reporting webpage: https://www.ospar.org/work-areas/rsc/bat-bep/implementation-reporting/united-kingdom.

Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004 to 2021)

In Part 2, information is provided that is relevant to specific nuclear licensed sites. The environmental impact from discharges on the marine environment is determined using BAT indicators. The environmental data are presented to indicate the overall trends in activity concentrations and public exposure (doses) over a period of more than a decade (2004 to 2021).

PART 1. UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2017 to 2021)

1 Introduction

The Oslo and Paris Convention (OSPAR) Radioactive Substances Committee has established ‘Guidelines for the submission of information on the assessment of the application of Best Available Technology (BAT) in nuclear facilities’ (Reference number 2018–01e), referred to hereafter as ‘the Guidelines’.

The combined UK report (Parts 1 and 2), is submitted as part of an examination of the implementation of OSPAR Recommendation 2018/01 on radioactive discharges, concerning which the contracting parties agreed:

“To respect the relevant Recommendations of the competent international organisations and to apply the Best Available Technology to minimise and, as appropriate, eliminate any pollution caused by radioactive discharges from all nuclear industries, including research reactors and reprocessing plants, into the marine environment.”

The combined UK report has been prepared in accordance with these Guidelines, providing the required general information, the implementation of BAT, characteristics of nuclear licensed sites (as part of the country profile), together with information relevant to specific sites of discharges and environmental impact (monitoring data and doses to the general public), relating to UK civil nuclear licensed sites as given in Figure 1.1. The previous report, submitted to RSC in 2018 [1] (and predecessor reports) were prepared on the basis of the previous Guidelines (2004–03) and covered the period 2012–2017. The present report provides an update on the implementation of BAT over the period 2017 to 2021 (Part 1), together with environmental activity concentration data and the public’s exposure (doses) to radiation for the period 2004 to 2021 (Part 2), in accordance with the Guidelines.

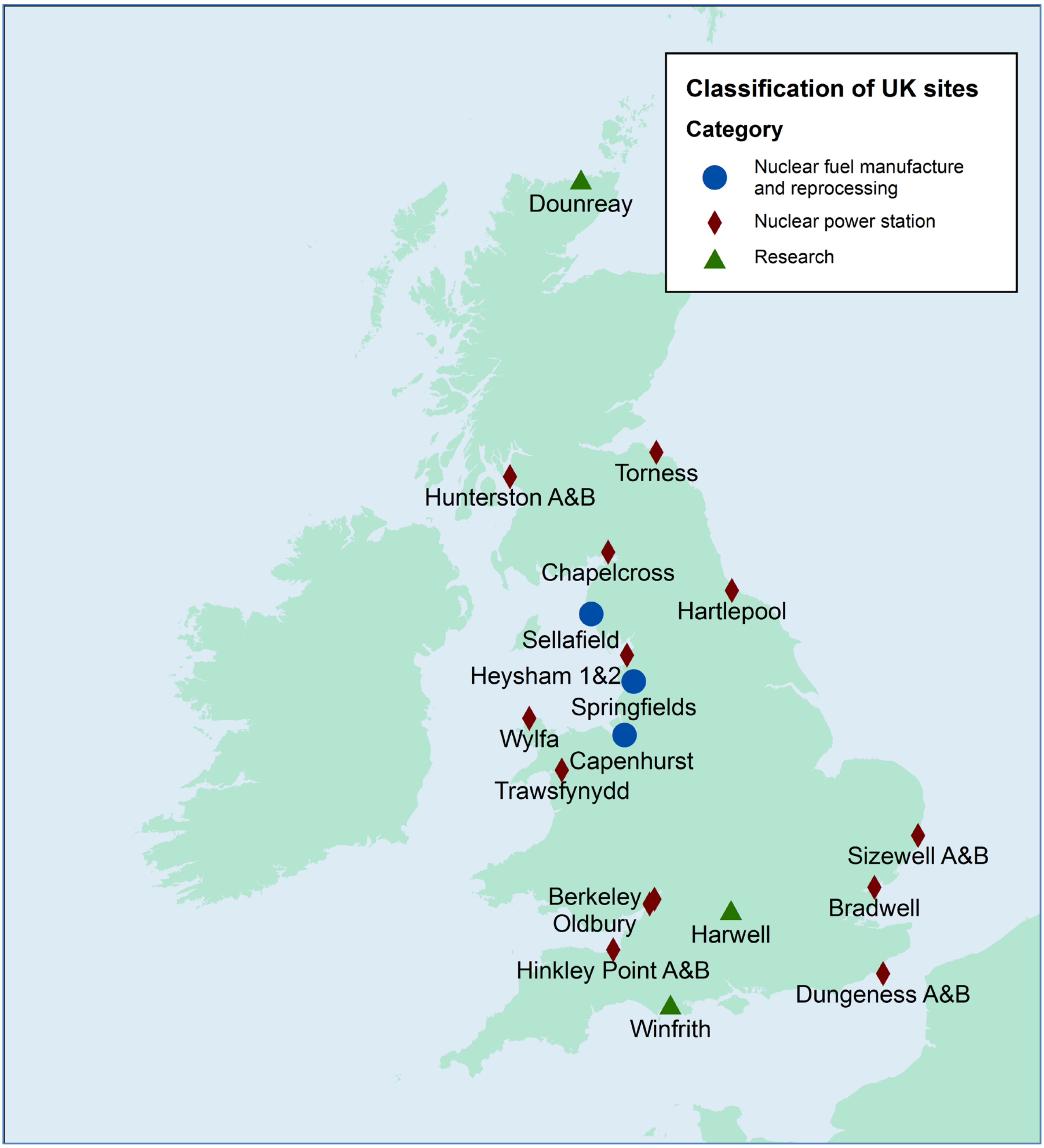


Figure 1.1 UK nuclear licensed sites (excluding radiochemical production and defence)

Information is provided for the following nuclear industry sectors: nuclear fuel production and reprocessing, research and development and nuclear power generation. Radiochemical production is considered to be a non-nuclear sector, and is included in the non-nuclear reports submitted to OSPAR. The implementation of OSPAR Recommendation 2018/01 is not appropriate to UK defence establishments (OSPAR only relates to civil nuclear industries). However, the environmental impacts of both radiochemical production and defence sectors are assessed and provided in Part 2 of this report. Sites involved in the treatment and management of low-level radioactive wastes (such as landfill sites that accept solid low levels wastes) and other non-nuclear sectors (for example, hospitals and universities) are considered to be outside the required scope and have not been included in the combined report.

In Part 1 of this combined report, current practices for each relevant site or type of facility are provided and reviewed, the detailed application of BAT (or the equivalent Best Practicable Means (BPM) and Best Practicable Environmental Option (BPEO), applied in Scotland [2,3]) is discussed and an assessment of liquid radioactive discharged to the marine environment is provided over the period of the evaluation (2017–2021)[7]. It is noted that the term BAT relates to 'technology' in Paris Commission (PARCOM) Recommendation 91/4. However, in the UK, the term 'techniques' is more commonly associated with BAT. This is a more inclusive term that explicitly embraces both equipment and management practices. This broader interpretation of BAT is applied throughout the remainder of this report. A summary of key advances in the application of BAT and some concluding remarks related to the application of BAT in nuclear facilities in the UK are also given in Part 1 (Section 5). Information on implementation of BAT, detailing the organisation of nuclear safety and radiation protection within the national regulatory and legislative framework and general nuclear licensed site characteristics is provided in the UK's country profile (https://www.ospar.org/work-areas/rsc/bat-bep/implementation-reporting/united-kingdom).

In Part 2, information is provided that is relevant to specific nuclear licensed sites. The environmental impact from discharges on the marine environment is determined by presenting environmental data to indicate the overall trends in activity concentrations (BAT indicators) over a period of more than a decade (2004 to 2021). These data allow a broad interpretation of the trends. These trends together with overall trends of public exposure (doses) are provided to demonstrate the impact of discharges from UK civil nuclear facilities. The environmental information in Part 2 is taken from more detailed data published in the annual Radioactivity in Food and the Environment (RIFE) report series. The RIFE reports give analytical results from independent monitoring carried out by the Food Standards Agency, Environment Agency, Scottish Environment Protection Agency, Food Standards Scotland, Natural Resources Wales, and the Northern Ireland Environment Agency.

In addition to the review of the application of BAT based on current practices, technologies that are under development in the UK and elsewhere have been identified and comparisons with performance of similar plants world-wide have been made where appropriate.

This report addresses the marine environment and therefore focusses on liquid radioactive discharges direct to the marine environment; however, the UK is also mindful of the interaction between liquid and atmospheric discharges, and of the need to maintain a holistic view including consideration of:

- the balance of radioactive and non-radioactive discharges
- the relative environmental impacts of discharges to the aquatic and terrestrial environments

[7] In some trend plots, multipliers have been applied to allow the y-axis scales to be the same to permit simpler comparisons of trends, and small changes may be exaggerated in some cases.

- the preferred use of 'concentrate and contain' in the management of radioactive waste over 'dilute and disperse' in cases where there would be a definite benefit in reducing environmental pollution, provided that BAT is being applied and worker dose is taken into account

Within the power generation sector, information on the practices and impacts arising from operational and decommissioning nuclear power stations are presented separately. In this report, sites that have permanently ceased operating (including those that are at the stage of defueling) are considered under the 'decommissioning' heading. Complex sites, where individual plants may be operational while others are undergoing decommissioning, are considered according to the sector and status of their original purpose (for example, the Sellafield site is addressed as an operational reprocessing site, although a number of individual facilities are currently undergoing decommissioning). The Sellafield site also contains facilities (Calder Hall and Windscale) that were previously associated with power generation and research/defence, respectively. Sellafield, Calder Hall and Windscale are managed by Sellafield Limited and share a single radioactive substances permit (under Environmental Permitting Regulations (EPR)16). The activities of all 3 entities are therefore included within Section 2 (Part 1) and 7 (Part 2) of the report.

The sites within the research and development sector are now concerned primarily with decommissioning and land remediation but are presented under the heading for their original purpose for the sake of consistency with previous reports.

2 Nuclear fuel production and reprocessing

2.1 Introduction

The licensed sites in the UK involved with the civil production and reprocessing of nuclear fuel are at: Sellafield (Cumbria), Capenhurst (Cheshire) and Springfields (Lancashire).

The main operations on the Sellafield site are fuel storage, decommissioning and clean-up of redundant nuclear facilities, and materials and waste treatment and storage (fuel reprocessing ended in 2018 (Thorp) and 2022[8] (Magnox)). However, as reprocessing has ceased, the emphasis is shifting towards remediation, decommissioning and clean-up of the historical legacy. The Sellafield site includes the Calder Hall nuclear power station the former Windscale site. All Sellafield operations are carried out under a single Nuclear Site License and EPR-RSR (Radioactive

[8] Magnox reprocessing ceased during preparation of this report

Substance Regulations) environmental permit. The National Nuclear Laboratory (NNL) also carry out activities on the site, including research and development.

The Capenhurst site is owned partly by Urenco UK Limited (UUK) and partly by the Nuclear Decommissioning Authority (NDA). The major operators at the site are UUK, Urenco Nuclear Stewardship (UNS) and Urenco ChemPlants Limited (UCP). UUK operates 3 plants producing enriched uranium for nuclear power stations. UNS manages assets owned by NDA, comprising uranic material storage facilities and activities associated with decommissioning. UCP is currently building a new facility (Tails Management Facility, which is currently undergoing commissioning). This facility will de-convert Uranium Hexafluoride (UF_6), or 'Tails' to Uranium Oxide (U_3O_8) to allow the uranium to be stored in a more chemically stable oxide form for potential future reuse in the nuclear fuel cycle and will recover hydrofluoric acid for reuse in the chemical industry.

The Springfields site is leased long-term to Springfields Fuels Limited under the management of Westinghouse Electric UK Limited. The site is used to carry out nuclear fuel manufacture and other commercial activities. Springfields Fuels Limited also have a contract with NDA to decommission legacy facilities on the site.

Both the Springfields and Sellafield sites are owned by NDA.

All the aforementioned sites are certificated to the international Environmental Management Standard ISO 14001 and the international Quality Management Standard ISO 9001. In addition, analytical services, accredited under the UK Accreditation Service (UKAS), is also certified under ISO 17025:2017.

2.2 Sellafield

The Sellafield site is the largest nuclear complex in the UK and, amongst other activities, undertook the reprocessing of spent Magnox and oxide fuels during this reporting period (2017–2021) [9] connected with the UK nuclear electricity generation programme and spent oxide fuel from other countries.

Operational liquid and gaseous discharges are projected to reduce substantially as reprocessing activities are completed. In particular, tritium discharges are dominated by operational activities and will virtually cease when reprocessing Post-Operational Clean Out (POCO) is completed.

During the reporting period, the main process activities on this site were:

- storage of irradiated Magnox, Advanced Gas-cooled Reactor (AGR) and Light Water Reactor (LWR) fuels in water-filled ponds
- consolidation and transfer of fuels to other ponds for interim storage

[9] Sellafield Limited held contracts for the reprocessing of all spent Magnox fuel arising from the UK nuclear electricity generating programme.

- reprocessing of Magnox spent fuels
- reprocessing of oxide fuels (completed in 2018)
- storage of uranium and plutonium recovered through reprocessing.
- processing and storage of High-Level Waste (HLW) and Intermediate Level Waste (ILW)
- processing and disposal of Low-Level Waste (LLW) through optimised disposal route including disposal to an on-site landfill facility and appropriate off-site facilities
- clean up and decommissioning of redundant facilities, including the retrieval, treatment, and conditioning of inventories of liquid and solid wastes
- research and development (including activities carried out by the NNL).
- management of non-radioactive solid waste (including re-use, recycling and disposal)
- care and maintenance of facilities that will be decommissioned in later years

The reprocessing of spent fuel was a major activity at Sellafield for the reporting period, noting that oxide fuel reprocessing ended in 2018 and Magnox reprocessing has since also ended (July 2022), see Figure 2.1. There has been an increased focus in recent years on the high hazard and risk reduction, involving the retrieval and conditioning of legacy waste, decommissioning of redundant facilities, remediation activities and management of radioactive wastes. At this point remaining AGR fuel, and new receipts, will remain in storage ponds for the duration of interim storage.

Following completion of reprocessing, the reprocessing plants enter a period of run-down operations, prior to entering POCO.

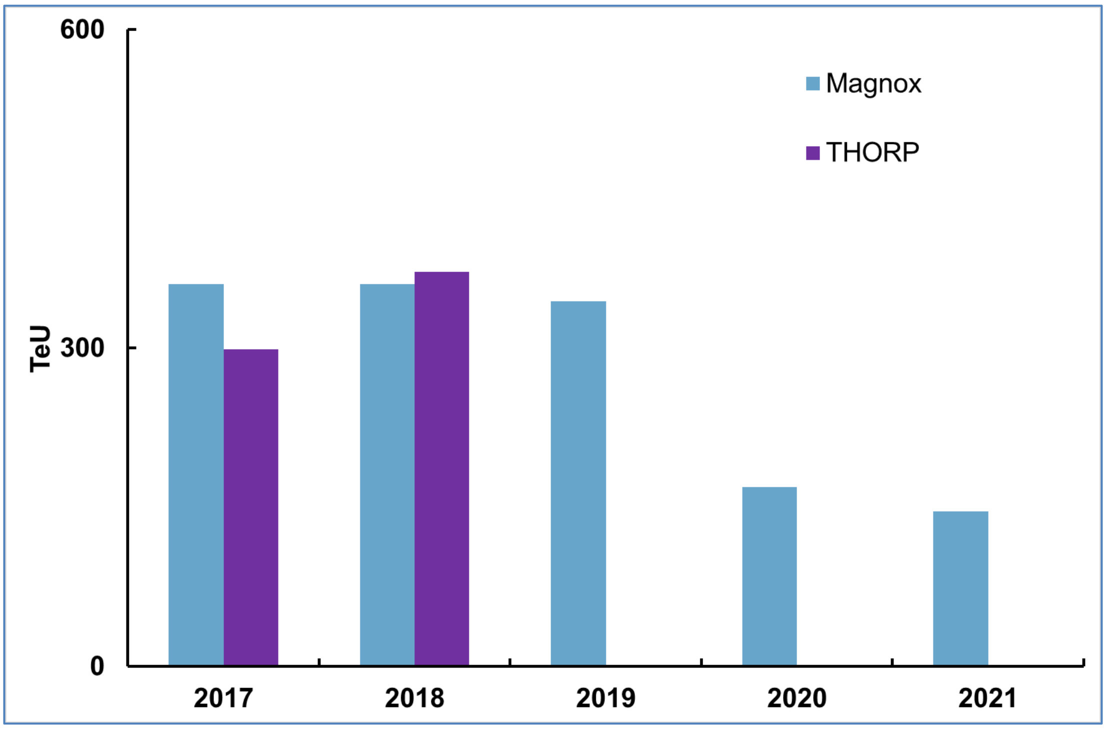


Figure 2.1 Sellafield Reprocessing Rates

Progress has been made since 2017 on the clean-up of legacy facilities and decommissioning activities. This includes removal of legacy wastes from old ponds and silos and decommissioning activities on stacks which were no longer required. The work in these areas helps reduce the likelihood and magnitude of potential faults, hence reduces risk of impacts on the environment.

2.2.1 Sources of liquid effluent

Radioactive liquid effluents arise from fuel reprocessing, materials and waste storage, decommissioning, processing of legacy wastes and research and development activities. Those reprocessing liquid effluents, which contain the highest levels of activity, are concentrated through evaporation and decay stored in the High Active Liquor Evaporation and Storage plant and then treated in the Waste Vitrification Plant through incorporation into a solid glass waste form. Medium active liquid effluents are separated into a number of waste streams, evaporated, decay stored and further treated in the Waste Vitrification Plant or in Enhanced Actinide Removal Plant (EARP), depending upon their composition and activity.

Radioactive liquid effluents from the Sellafield site are discharged via pipelines which extend approximately 2 kilometres off the coast. Some surface water is also discharged via the Factory Sewer which runs through the site and contains very low levels of radioactivity, and through the Calder Interceptor Sewer, where an environmental permit allows discharge of low-active effluents which improves operational flexibility and application of BAT. There are a number of other minor catchment surface water drainage systems which discharge non-active effluent to the local rivers and the Irish Sea.

A range of radionuclides are present in liquid effluents produced on the Sellafield site and some key radionuclides are outlined below:

- Tritium: In terms of dose to the representative person, tritium gaseous discharge typically gives rise to a higher dose than discharge to the marine environment. The main tritium discharge from Sellafield is liquid effluent to sea resulting from the scrubbing of Thermal Oxide Reprocessing Plant (THORP) and Magnox reprocessing gaseous discharges, noting that reprocessing at THORP ceased in 2018.
- Carbon-14: The main discharge routings from Sellafield are liquid effluents to sea resulting from the caustic scrubbing of gaseous streams associated with Magnox reprocessing and HLW Plants.
- Cobalt-60: Over 99% of these arisings in spent fuel from the Sellafield site are routed to solid waste. Discharges are related to the amount of ‘fuel crud’ deposited on the fuel elements, dependent on the individual reactor type, design, and operating characteristics. Insoluble corrosion products, including cobalt-60, are released into the fuel pond water during fuel handling and hence discharged to the marine environment following treatment.
- Strontium-90: Discharges occur from various activities, though the majority of strontium-90 at Sellafield is routed to storage as solid radioactive waste.
- Ruthenium-106: Most of the potential arisings are routed to long-term storage prior to

final disposal, primarily as vitrified product, but also some as an encapsulated waste form via the Waste Product Encapsulation Plant.

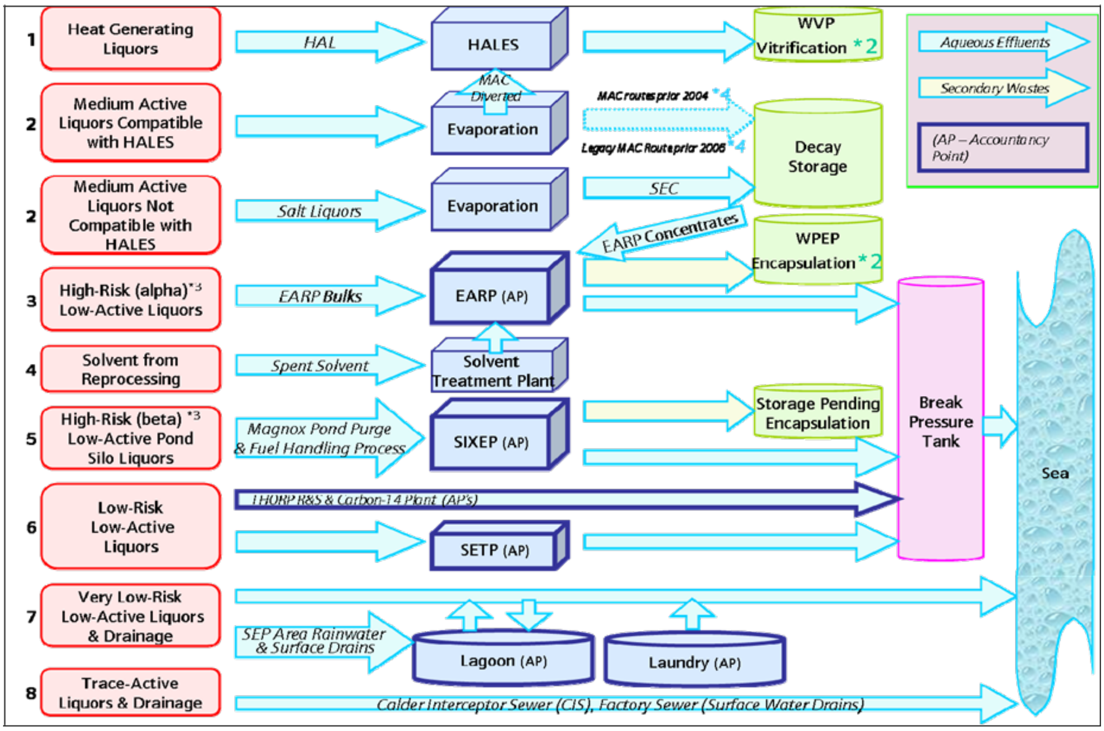
- Iodine-129: In terms of dose to the representative person iodine-129, the dose from gaseous discharge is assessed to be greater than the discharge to the marine environment. Discharges to sea arise from the caustic scrubbing of gaseous discharges, much of which is associated with reprocessing
- Caesium-137: Discharges occur from various sources, such as from processing of historical wastes. Greater than 99% of caesium-137, arising from reprocessing operations, is routed to long-term storage and final disposal in the form of vitrified product or cemented waste, with less than 1% routed via streams resulting in final discharges to sea. Effluents from fuel pond purges are treated primarily in Site Ion Exchange Effluent Plant (SIXEP). Clean-up of legacy facilities will result in different effluent feed challenges over coming years, including but not limited to caesium-137.
- Plutonium and Americium: When fuel is reprocessed at Sellafield, over 99% of the available plutonium is routed to plant product lines for separation and subsequent storage. Of the residual waste streams that contain plutonium isotopes and americium-241, over 99% is directed to site facilities and routed for treatment, and then storage in solid form prior to eventual disposal.

2.2.2 Liquid effluent treatment and abatement

Main (site-wide) treatment plants

The major liquid effluent treatment facilities operating on the site are described in previous iterations of this report [4,5]. In terms of future liquid effluent treatment developments, a project is proceeding to build the SIXEP Continuity Plant, which will provide additional resilience for the site in terms of liquid effluent management.

Figure 2.2 below provides a schematic representation of the Sellafield liquid effluent treatment system showing the routings of the different liquid waste arisings.



*2 Effluents generated for encapsulation and storage.
*3 The Low-Active streams labelled as High-Risk because the stream content is routinely low in activity but carries the risk (due to the donor plants involved) of raised levels of radionuclides during fault conditions.

Figure 2.2 Liquid Effluent Management System

Future waste treatment and storage facilities

A range of new process plants and stores are being developed for Sellafield, which will assist in the management of radioactive wastes and materials, helping reduce the hazard associated with them, with much of the waste planned to be disposed of in a national repository.

2.2.3 Trends in liquid discharges over the 2017–2021 period

The discharges from Sellafield's main site pipeline have remained generally constant throughout the reporting period, as shown by the trends of liquid discharges for a number of the permitted radionuclides over time (given in Figure 2.3). Small variations between years reflect the rates of spent fuel reprocessing operations the intensity of clean-up of the legacy facilities. Discharges of total beta activity, which is an overall indicator, remained generally constant during most of the period.

The trends of radionuclides in liquid discharges, over a longer timescale, are also presented in Part 2, Section 7 (Figure 7.2). Between 2004 and 2016, all liquid discharges followed a pattern of overall reduction and low levels were maintained during this reporting period (2017 to 2021).

Liquid discharges of alpha, beta and tritium from the site are also permitted via the Factory Sewer and Calder Interceptor Sewer. These are minor outlets, with annual plant notification levels much lower than other plants on-site (for example, SETP, SIXEP, EARP) and discharges via these routes are far lower than overall site discharges.

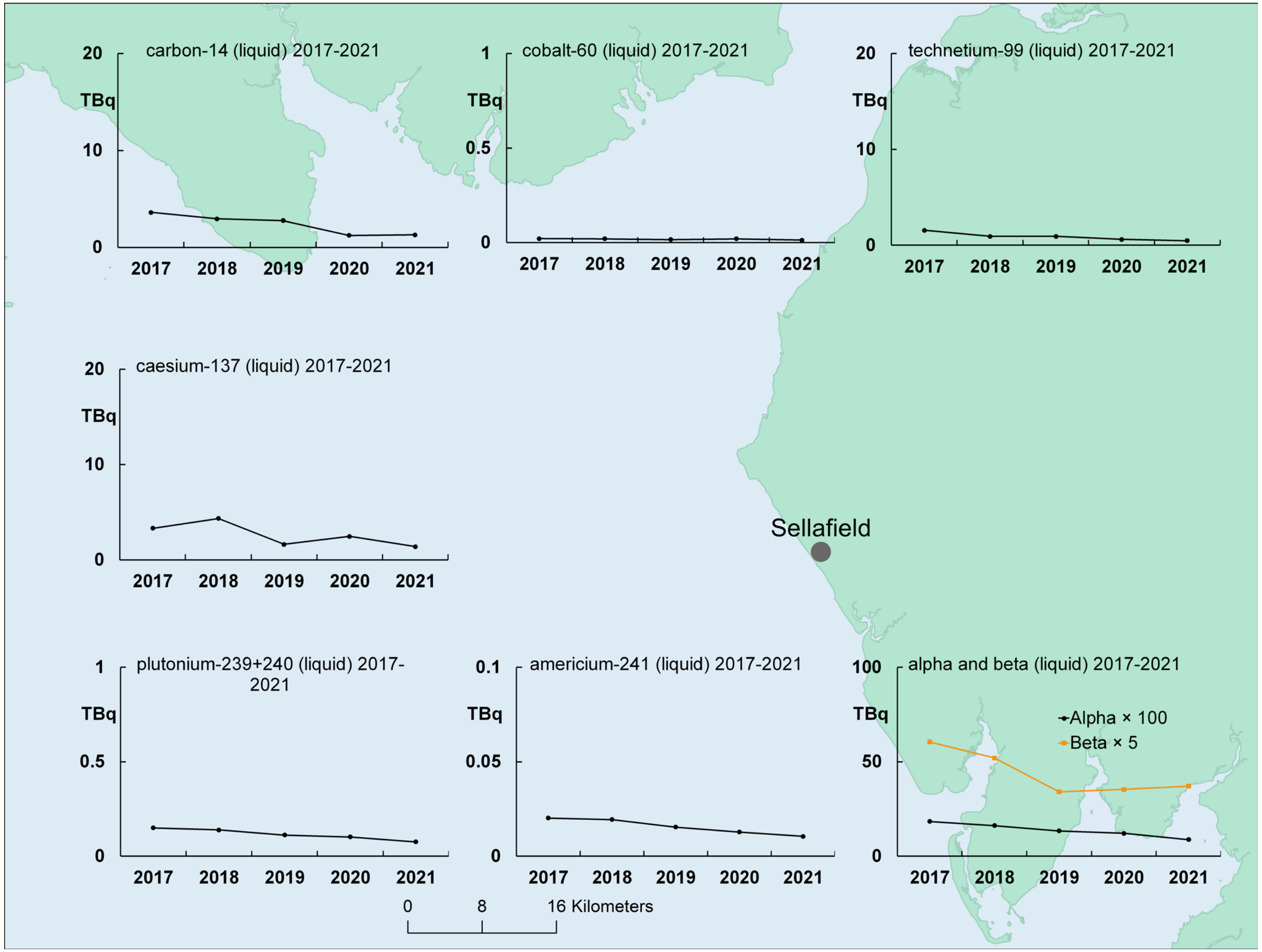


Figure 2.3 Liquid discharges of key permitted radionuclides, Sellafield (2017 to 2021)

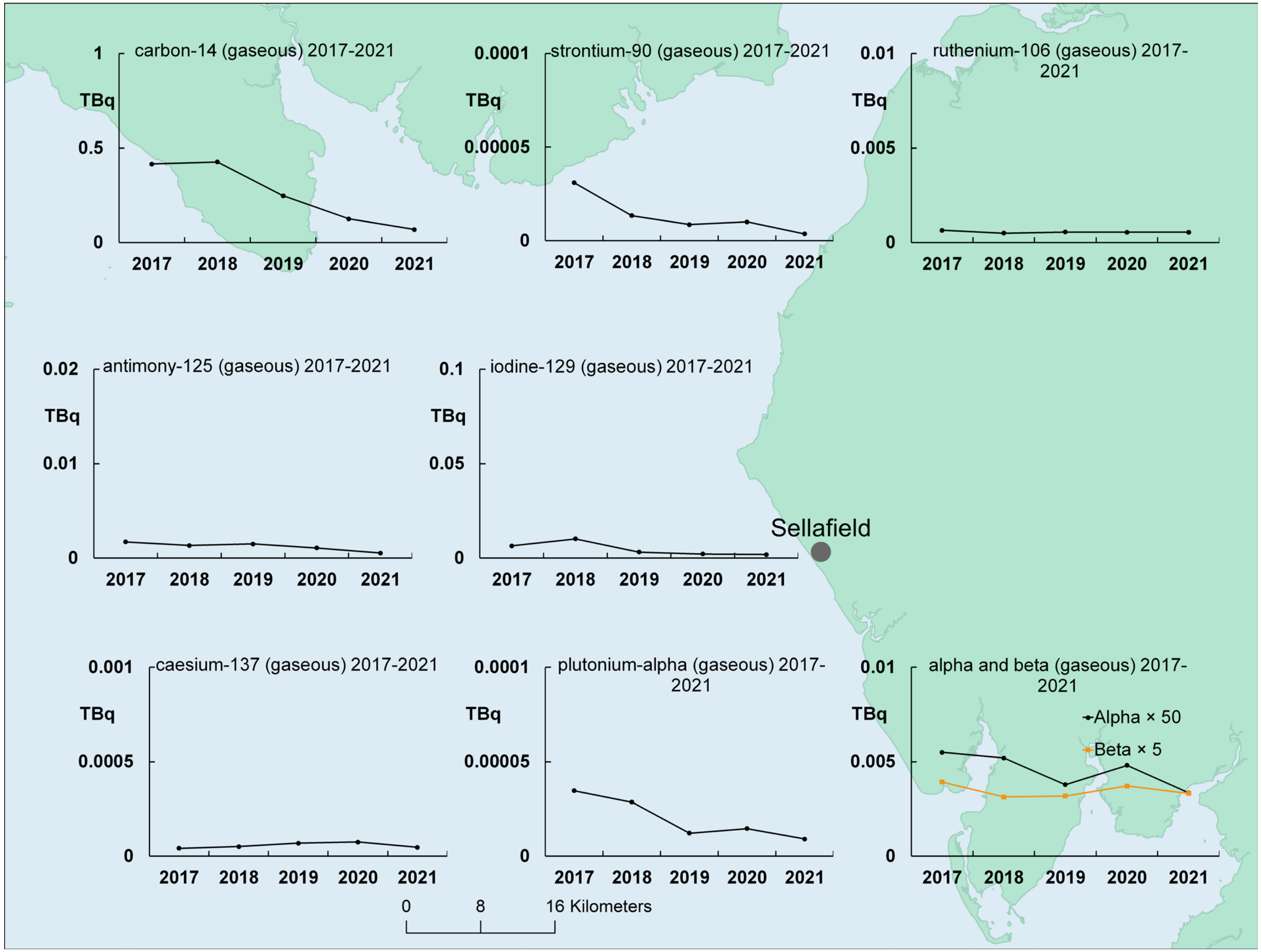


Figure 2.4 Gaseous discharges of key permitted radionuclides, Sellafield (2017 to 2021)

2.2.4 Gaseous discharges relevant to the marine environment

Radioactive gaseous discharges arise from ventilation air from process plants during operations associated with the receipt, storage, reprocessing and management of spent nuclear fuels, waste storage and processing, retrievals of legacy wastes, decommissioning, remediation and research and development activities.

Discharges to the atmosphere are minimised by the application of BAT, through the use of:

- Process and equipment designed to minimise arisings to gaseous streams.
- High Efficiency Particulate Air filtration (to abate particulate activity).
- Wet scrubbers to divert activity from the gaseous to the aqueous stream (both water and caustic type) on streams where significant volatile activity is present.
- Other abatement equipment such as electrostatic precipitators (ESPs), condensers and pre-heaters (to prevent condensation, which affects performance of the filters).

The trends of gaseous discharges of radionuclides (2017 to 2021) are also given in Figure 2.4 and over a longer period (2004 to 2021) in Part 2, Section 7 (Figure 7.2). Over both periods, gaseous discharges of radionuclides either decreased or remained relatively stable (except for antimony-125).

Variations in the emission of some radionuclides, such as tritium and krypton-85, are largely influenced by reprocessing rates on the site.

2.2.5 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series RIFE. The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 7.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 7.2)
- a summary of trend data for nuclear fuel production and reprocessing sector (2004 to 2021) (Part 2, Section 7.5)

2.2.6 The application of BAT

Overarching management arrangements at Sellafield provide the framework through which the application of BAT is demonstrated in facilities and activities that are undertaken at the site. These arrangements operate in a tiered approach, to ensure that environmental issues are considered at all levels of decision making. This includes the following components:

- development and implementation of Environment Cases for all operating plants and new project developments. Environment Cases are generated by a process that requires assessment of significant environmental aspects, which ensures that any associated discharges are minimised in line with BAT. Environment Cases are maintained by periodic review
- modifications to existing plant are also subject to full assessment of environmental issues such as how to minimise discharges through the application of BAT
- formally established committees are in place to identify and share environmental best practice (for example, the Aqueous and Gaseous Waste Strategy Steering Group). Sellafield Limited also tracks developments in the application of BAT on other sites and in other industries, for example, the Environment Agency Requirements Working Group to share and understand learning from experience
- Sellafield has updated its effluent management strategy, taking into account current and future operations, with the aim of ensuring government policy is implemented in the form of a deliverable plan. This is supported by the Sellafield effluent management strategy and a discharge forecasting tool, developed to model the impacts of different strategies on discharges to air and water. It will be of increasing importance in predicting discharges and identifying associated BAT discharge control arrangements as more of the site activities move to POCO, decommissioning and clean-up of the historical legacy waste

This discharge forecasting model deals with a complex and varying set of interacting source terms and is of increasing importance in forward predictions. There has been significant and continual improvement in source data and forward predictions that better reflect expected operational outcomes. Operational outcomes are based on assumptions about future activities contained within detailed plans which contribute to differences between predictions. It should be noted that as further clarity is obtained on timescales and waste arisings from POCO and decommissioning activities, these predications may change in future. The emphasis at Sellafield is shifting to environmental remediation, decommissioning and clean-up of the historical legacy waste with an increasing degree of uncertainty. Such uncertainty will remain until progress has been made and experience is incorporated into discharge modelling. A structured lead and learn approach is in-place.

Sellafield Limited also supports a range of research and development work, to facilitate improved management of effluents.

Examples of the technological application of BAT in Sellafield's management of liquid discharges are given in Section 3.2.2, in terms of major treatment facilities (e.g., SIXEP). Notable improvements over the reporting period also include:

- Sellafield has been proactively managing metal fuel through containerisation within its Fuel Handling Plant. This has successfully reduced pond water activity levels down to historically low levels. The ponds are one source of radioactive discharges to sea, hence reduction at source has assisted the site to better manage its overall discharges
- Sellafield has formulated a strategy regarding the potential to reduce water volume usage in its Fuel Handling Plant, in recognition of the lower pond water activity levels which have been achieved. This work is now in flight to ascertain how/when to enact the reduction in water usage. Reduction in levels of 'process water' used on site can enable subsequent opportunities in future, in terms of reducing the challenge on downstream abatement plant
- Sellafield has developed a strategy for management of 'failed' oxide fuel to determine how to prevent, detect and hence better manage it. These measures should result in benefits in future years, in terms of reducing further already low pond discharges
- within Sellafield, application of research into actinide precipitation pathways has allowed optimisation of acid dosing within the abatement plant EARP, to minimise alpha discharges in line with BAT. This knowledge is of particular value as the site moves away from reprocessing operations which typically provide the acid feed to EARP
- at Sellafield, preparation work regarding effluent treatment has been carried out in advance of the end of Magnox Reprocessing and is now in position to be deployed. This will allow control of the process during a period of variable feeds to ensure BAT is being applied. This builds on 5 years of research and development to prepare for post-reprocessing activities at the site
- Sellafield have developed an 'Active Effluent Programme', incorporating coordination meetings between operational areas, which has improved the predictions of future effluent arisings allowing better assessments of how to deploy the capacity and capability of the effluent facilities
- optimisation of SIXEP performance has continued with mass balance monitoring, the ongoing review of feed controls, Ion-Exchange bed change triggers, feed blending and optimisation. This continues to lead to improved discharge management, reduced secondary waste and maximises treatment capability to support donor plant hazard reduction progress
- work has begun on construction of the SIXEP Continuity Plant project (SCP). This new effluent treatment plant is planned to replace the SIXEP plant at the end of its design life. The new plant design also provides greater flexibility to support the minimisation of discharges associated with the decommissioning of legacy plants at Sellafield
- Research and Development studies have been carried out to improve SIXEP performance and ensure that it will be able to deal with future feed challenges from decommissioning and clean-up activities. These studies include:

    - tests on the use of settling aids to reduce the particulate and alpha activity challenge to SIXEP during Magnox Swarf Storage Silo (MSSS) retrieval operations
    - development of new test methods to quantify the performance of candidate Ion-Exchange materials
- in 2019 a programme of work to implement flow smoothing on the SIXEP plant was completed. Modelling assessment using a validated Dynamic model recommended changes to the flow control system. Plant performance reviews have indicated each change to be successful in reducing flow fluctuations with no adverse impact on plant operability. The benefits and long term expected outcomes from the project include:
    - reduced cyclic loading on SIXEP leads to an extended plant lifetime
    - improved plant performance over the long-term operations of the plant
- at Sellafield, the operation of a Local Effluent Treatment Plant to treat Pile Fuel Storage Pond water prior to discharge via the site low activity effluent treatment and discharge system, significantly reduces discharges to sea from this facility. Since 2017, the Local Effluent Treatment Plant has prevented the discharge to sea of over 10.6TBq of beta activity
- at Sellafield since 2017, Liquor Activity Reduction operations have resulted in the transfer and treatment of over 2,700m^3 of liquor from the MSSS to the SIXEP for processing. This ensures that these liquid effluent arisings are routed through an abatement plant at Sellafield, providing appropriate treatment for these type of effluents prior to discharge and hence appropriately minimising discharges, whilst supporting High Hazard reduction activities on site and assisting in the clean-up of legacy facilities
- at Sellafield, the First-Generation Magnox Storage Pond (FGMSP) is a legacy facility, which generates low levels of liquid radioactive discharges on an ongoing basis. Over the time period covered in this report, 195m^3 of radioactive sludge has been successfully retrieved from the FGMSP and transferred to the Sludge Packaging Plant (SPP1) for storage prior to further management. This reduces the amount of radioactive material from the pond which can potentially be mobilised, hence assists in reducing lifetime liquid discharges from this facility

2.2.7 Comparison with performance of similar plants world-wide

Due to the complex nature of operations and decommissioning activities on the Sellafield site and recognising that many of the process plants are bespoke, it is difficult to draw direct comparisons with other sites. The reprocessing operations at Sellafield are often considered alongside those of Cap de la Hague in France and in the past broad comparisons have been made when undertaking major permit reviews. However, due to the different processes involved, it is not practicable to make direct comparisons between liquid discharges from Sellafield and La Hague, particularly as Sellafield transitions from reprocessing to decommissioning. At both sites the higher activity effluents are transformed using vitrification into solid waste and the lower activity effluents are treated prior to discharge to sea.

In accordance with permit requirements, Sellafield continually reviews its effluent treatment techniques through management system processes, undertaking research and development and by maintaining a ‘watching brief’ on national and international best practice and innovative and emerging techniques. Sellafield has also been involved in the development of the Aqueous Waste Management Good Practice Guide, which details the principles, processes, and practices during the management of aqueous waste that is contaminated, or potentially contaminated, with radioactivity. Nuclear site operators are not mandated to follow the guidance, although it is recommended to do so.

2.3 Capenhurst

In 2012, NDA completed the transfer of its Capenhurst site with the transition of Sellafield Limited activities to Capenhurst Nuclear Services Ltd (CNS), creating one nuclear licensed site owned and managed by UUK. The major operators at the site are UUK, UNS and UCP.

During the reporting period, the main process activities were:

- uranium enrichment for fuel production
- uranic material storage facilities and activities associated with decommissioning

2.3.1 Sources of liquid effluent

The main activities undertaken on this site giving rise to effluent discharges were:
- decommissioning operations
- operation of the centrifuge enrichment plants
- UUK laboratories, the laundry facilities and liquid discharges arising from the operation of wet scrubbers in the older centrifuge plants

Only small amounts of liquid wastes are discharged from the site. The primary source of liquid effluents is the UUK centrifuge operations.

2.3.2 Liquid effluent treatment and abatement

Waste streams from the decontamination plant, which supports the operation of the enrichment plant, contain uranium radionuclides and very small amounts of technetium-99 and neptunium-237 (associated with historic enrichment activities).

These streams are segregated and held in delay tanks for sampling and subsequent discharge to Rivacre Brook. Decommissioning activities do not generally lead to the generation of significant amounts of liquors and any such arisings are kept in storage for settling, sampling and eventual permitted discharge.

The BAT for the management of liquid waste streams was identified in the documents submitted in support of the improvement conditions [6], specified in the UUK environmental permit. The following technologies are summarised:

- treatment of bulk aqueous waste by conventional wastewater processes on the Capenhurst site, as far as the treatment works will allow decontamination, removal of degradation products and other contaminants and reuse where possible of fluorinated and other hydrocarbons. This involves physical cleaning, scraping and removal of breakdown residues, citric acid wash, hot water rinse and, if required, blasting with carbon dioxide pellets
- removal and recovery of uranium from uranium-contaminated aqueous liquors in an off-site facility, thus minimising the volume of radioactive waste
- a number of measures are in place to minimise the arisings and transfer of liquid radioactive waste, including; counter-flow system in the UUK Decontamination Facility which allows decontamination rinse water to be re-circulated into the process; the use of dry ice gun for removal of surface contamination which reduces the requirement for liquid decontaminants; electrical heating of Product and Feed Cylinders in a Centrifuge Plant to eliminate the potential for radioactive liquid effluent associated with steam heating; recovery of residues from decontamination processes (for example, citric acid and degreaser water) by a third party off-site; use of disposable paper overalls, where there is a significant potential for contamination to reduce the amount of material requiring to be laundered and the amount of liquid effluent arising from laundry operations

No abatement measures are fitted to laundry or laboratory effluents due to the small quantities and low activity concentrations involved.

Notwithstanding the fact that these management processes are considered to be BAT, UUK installed dry Gaseous Effluent Ventilation Systems into the E22 enrichment plant in 2008. This system replaces a wet venturi scrubber system. As a consequence, contamination will be captured on High Efficiency Particulate Air filters and liquid effluents will be reduced.

2.3.3 Trends in discharges over the 2017 to 2021 period

Trends of liquid and gaseous discharges from Capenhurst during the reporting period (2017–2021) are given in Figure 2.5 and Figure 2.6. Figure 7.5 (in Part 2, Section 7) also shows time trends of discharges over a longer period (2004 to 2021).

Liquid discharges of technetium-99, uranium alpha activity and uranium daughters from the Capenhurst site have decreased considerably since 2006. Since then (and continuing throughout this reporting period), liquid beta and other discharges have been generally similar and remained low (at the reduced levels). Gaseous discharges of uranium were all low and alpha discharges declined in most recent years.

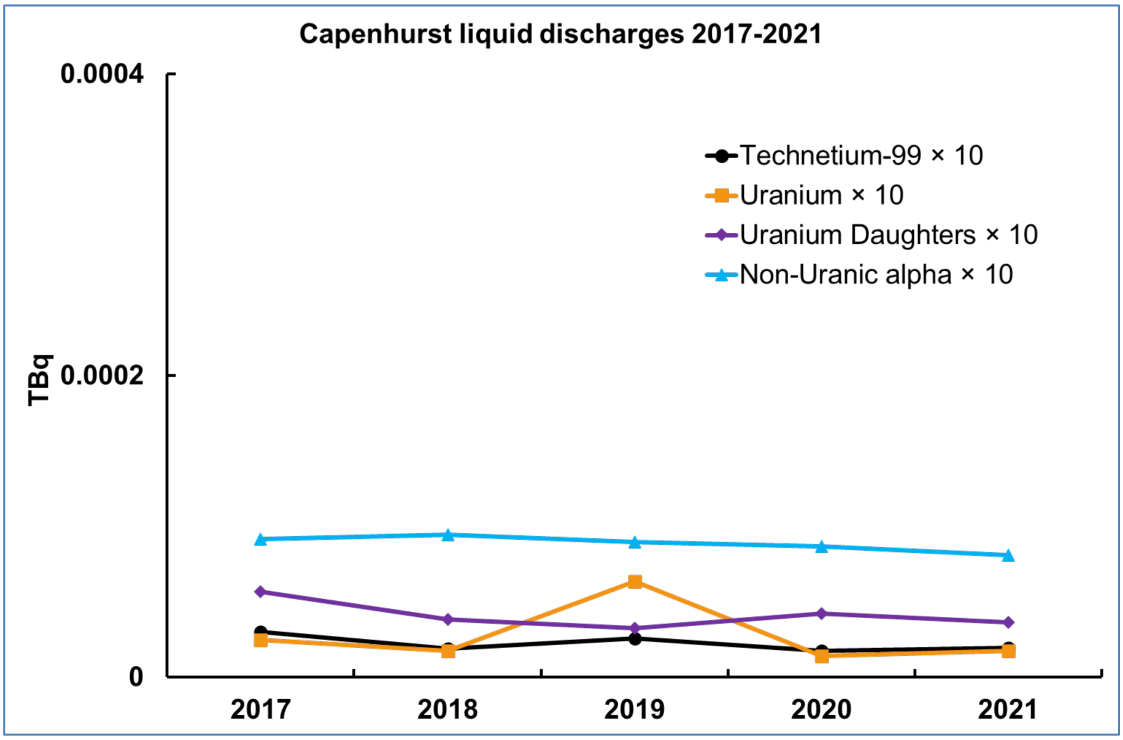


Figure 2.5 Liquid discharges, Capenhurst (2017 to 2021)

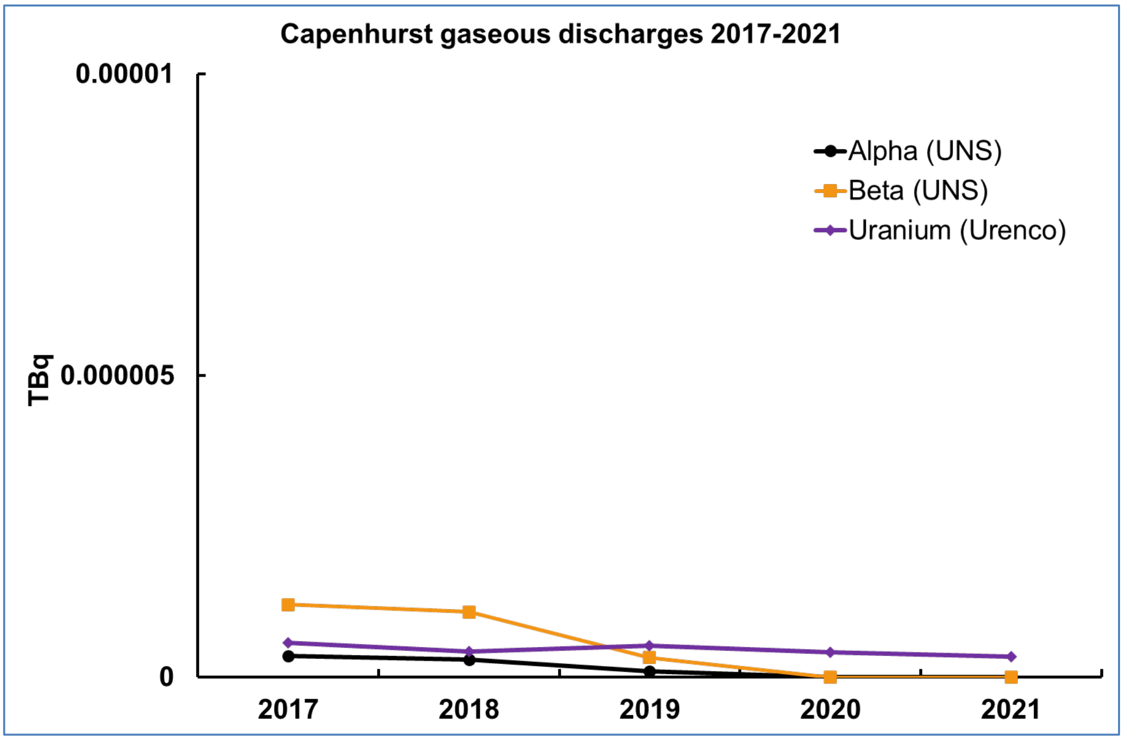


Figure 2.6 Gaseous discharges, Capenhurst (2017 to 2021)

2.3.4 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series RIFE. The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of KMEIs (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 7.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 7.3)
- a summary of trend data for nuclear fuel production and reprocessing sector (2004 to 2021) (Part 2, Section 7.5)

2.3.5 The application of BAT

The Capenhurst site does not discharge directly to the marine environment but into Rivacre Brook, a surface water tributary of the River Mersey. The discharges and the environmental impact of this site continue to be very low. While there are no specific treatment systems in place for radionuclides of uranium, technetium-99 or neptunium-237, the site sewage treatment plant removes material through filtration and sludge settlement processes in advance of discharge. Sample analyses and compliance checks are also undertaken in advance of discharge.

UUK operates enrichment facilities which process uranium hexafluoride (hex) to increase the isotopic concentration of 235U. The enrichment process results in two outputs, enriched hex (or product) which is supplied to customers worldwide as part of the civil nuclear fuel cycle and a low enriched by-product known as tails that can be re-enriched if economically viable. Enrichment operations at Capenhurst are anticipated to continue.

In addition, UUK are considering carrying out the following activities in the future:

- enrichment of recycled uranium, subject to market demand and regulatory approval
- enrichment of uranium to higher levels for future generations of nuclear power stations
- potential expansion of existing enrichment plants
- possible repurposing of old centrifuge enrichment plants
- possible decommissioning of old centrifuge enrichment plants

There are two other Urenco subsidiaries that operate at the Urenco Capenhurst Site, UCP and UNS. Both companies are tenants on the UUK nuclear licensed site but operate under their own environmental permits.

UCP operates a newly commissioned Tails Management Facility (TMF). The TMF de-converts the uranium hexafluoride tails to a more stable uranium oxide which is stored pending potential future re-use in the nuclear fuel cycle. The process generates hydrofluoric acid which is recovered for re-use in the chemical industry. The TMF also has ancillary facilities comprising of cylinder washing, residue recovery and decontamination and maintenance.

UNS plays a leading role in providing responsible stewardship of nuclear materials through waste management, long term storage and decommissioning services.

In compliance with the UUK environmental permit and nuclear industry guidance for BAT, a BAT assessment process is used by all operators at Capenhurst to identify the best available methods and techniques to minimise waste, discharges, and emissions. This is especially important for decommissioning/waste management, where BAT is used to minimise creation of leaks, discharges or secondary waste during storage and processing. Available techniques and methods are aligned with the waste hierarchy and assessed via transparent, logical, systematic, and auditable processes that balance the benefits of the process/activity on the environment, workforce and public health against the cost and practicability of implementing the option.

2.3.6 Comparison with performance of similar plants world-wide

The operators of the Capenhurst site maintain a periodic review of national and international developments in best practice for minimising waste disposals and a strategy for reducing discharges and carry out research and development programme to review BAT.

UUK has a well-established, standardised approach for the design of centrifuge plants, which is used in the UK, the Netherlands and Germany. A new centrifuge plant is being constructed in the USA, which will also follow this model. This design produces no radioactive liquid discharges, and all gaseous discharges are abated using a combination of absorbers and High Efficiency Particulate Air filtration in series. The newest centrifuge plant at Capenhurst, which has been operating since 1997, is also based on this design.

2.4 Springfields

The Springfields site has provided fuel fabrication services since the mid-1940s. During the reporting period, the main process activities were:

- manufacture of oxide fuels for Advanced Gas-cooled and Light Water Reactors, as well as intermediate fuel products, such as powders, granules and pellets
- processing of current and historical natural and enriched residues for recovery of uranium and return to the fuel cycle
- management of cylinders containing Hex (UF_6)
- decommissioning and demolition of redundant plants and buildings

2.4.1 Sources of liquid effluent

The sources of liquid effluent include those from commercial operations, residue processing (including recovery of uranium) and treatment of legacy material. Examples of liquid waste are:

- liquors from off-gas scrubbers used to minimise gaseous discharges
- spent production process liquors
- liquors arising as secondary waste from decontamination processes
- effluent from the site laundry
- rainwater run-off from potentially contaminated areas

Storm water and trade effluent are routed via a site-wide drain network to the site effluent complex. Twenty-four-hour flow proportional samples are taken from both the trade and the storm water drain. The trade effluent and storm water are then combined before being discharged via one of two pipelines to the Ribble Estuary. The flow proportional samples are analysed for a variety of radionuclides.

2.4.2 Liquid effluent treatment and abatement

The Natural and Enriched Uranium Residues Processing Plants are used to recover uranium (to be fed back into the fuel fabrication process) from waste liquors. Liquors are recycled and reused, where possible, thus effectively minimising the level of uranium in the liquid waste stream and the activity in liquid effluents. The following chemical and physical processing technologies are applied:

- precipitation and flocculation technologies: selective reagents are used to remove uranium species from solution. For example, the addition of sodium hydroxide forms a precipitate of sodium diuranate, which can be readily separated using physical separation techniques
- physical separation technologies: centrifugation of flocculation treated process liquid effluents to remove particulates; decontamination liquors are passed through a hydrocyclone to remove entrained solids, while evaporation is used to allow recycling of distillate in the UO_3 plant as backwash
- filtration techniques: process effluents and slurry from precipitation of process effluents are filtered using frame and press filters; a basket filter is used for laundry effluents and oil separators are used to separate oil from aqueous liquids. These simple processes are suitable for the efficient removal of uranium particulates encountered at Springfields

2.4.3 Trends in discharges over the 2017 to 2021 period

Trends of liquid and gaseous discharges from Springfields during the reporting period (2017 to 2021) are given in Figure 2.7 and Figure 2.8. Figure 7.6 (in Part 2, Section 7) also shows time trends of discharges over a longer period (2004 to 2021).

A considerable decline in alpha, beta and thorium-230 liquid discharges occurred as a consequence of the cessation of Uranium Ore Concentrate (UOC) purification in 2006. Since 2007 (and continuing throughout this reporting period), liquid beta and other discharges have been generally similar and remained low (at the reduced levels). Gaseous discharges were generally similar and were all low.

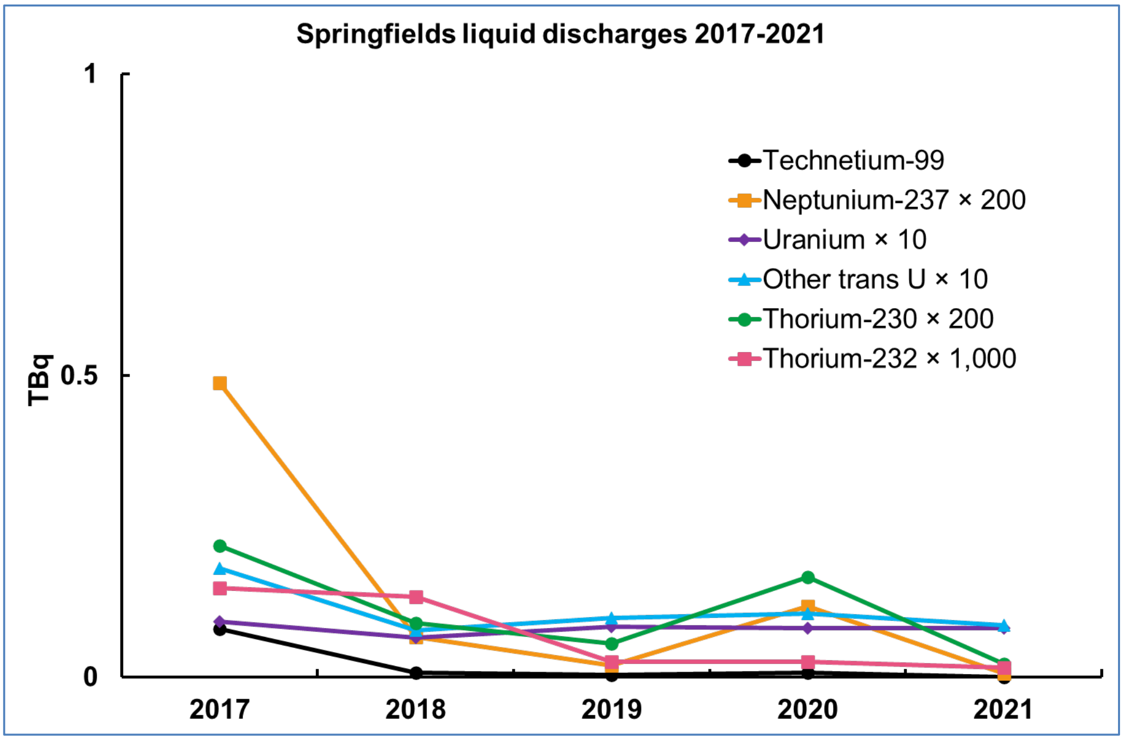


Figure 2.7 Liquid discharges, Springfields (2017 to 2021)

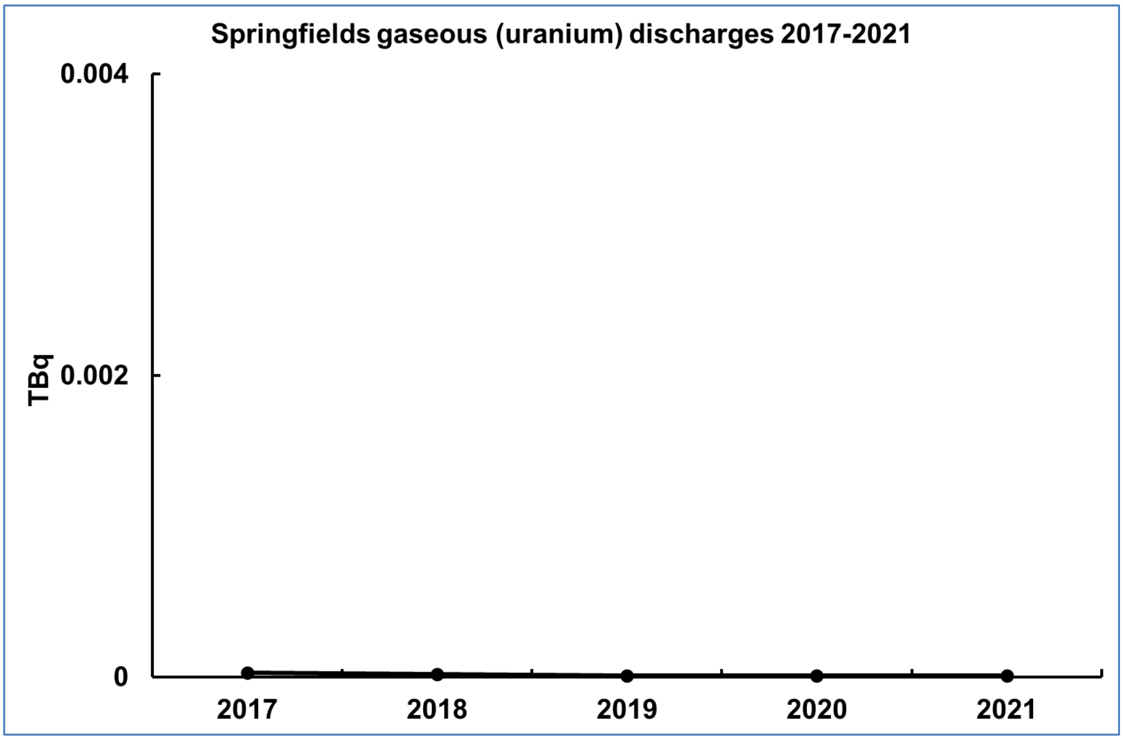


Figure 2.8 Gaseous discharges, Springfields (2017 to 2021)

2.4.4 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004–2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series RIFE. The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of KMEIs (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 7.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 7.4)
- a summary of trend data for nuclear fuel production and reprocessing sector (2004–2021) (Part 2, Section 7.5)

2.4.5 The application of BAT

Springfields Fuels Limited operate in a tiered approach and ensure that BAT is considered at all levels of decision making and that BAT is applied to all activities carried out on site. There are essentially 2 separate elements associated with BAT assessments:

- 'Optioneering element' – which is focussed on ensuring that the right 'strategic' option is chosen for implementation when looking at the impacts on the environment as a whole
- 'Operational BAT' – is about optimising the chosen 'option', in other words, deciding how to implement the option to ensure it is carried out in the best way to minimise impact on the environment, ensuring that once the option is in place it continues to represent BAT

For existing processes, the overall optioneering/strategic element has already been completed, all plants have operational BAT assessments. These are subject to regular review to ensure that plants continue to apply BAT and keep abreast of new developments.

For all new processes (and/or modifications to existing ones), a BAT assessment in some form is required. For minor changes, a simple optioneering assessment and a BAT justification is required, endorsed by a member of the Corporate Radioactive Waste Advisor Forum. Higher impact projects require a multi-disciplined team to carry out a strategic BAT optioneering assessment. BAT assessments and equipment, identified in the assessment as being essential to deliver effective optimisation, are incorporated into the plant environmental safety cases.

A new site wide committee, the Corporate Radioactive Waste Advisor Forum has been set up alongside existing committees (such as the waste strategy group) to identify and share environmental best practice and to review all BAT assessments across the site.

Springfields Fuels Limited also tracks developments in the application of BAT at other sites in the UK through active participation in the Environment Agency Requirements Working Group (EARWG). Springfields Fuels Limited also works closely with other plants operated by Westinghouse Electric Company to share and understand best practice and learning from experience.

There have been a number of initiatives aimed at reducing radioactive waste arisings on site, for example a successful trial was carried out in the decontamination centre to allow metal from cylinders previously destined for LLW disposal to be recycled. Other successful projects have allowed oil contaminated materials to be processed and the uranium recovered. Springfields Fuels Limited have reviewed monitoring equipment and procedures to allow better characterisation of wastes to meet the reduced clearance values for uranium.

2.4.6 Comparison with performance of similar plants world-wide

The details of operation and impact may differ between sites and the activities currently being undertaken at Springfields do not easily lend themselves to comparisons with other plants world-wide. However, a number of improvement programmes, including the one outlined above, require Springfields Fuels Limited to review their activities against national and international developments to keep abreast of, and continue to review, development of new techniques. Springfield Fuels Limited continue to take an active part in the EARWG and other industry forums, exchanging technical information and promoting best practice in radioactive waste management and other topics related to the regulatory control of radioactive substances. Springfield Fuels Ltd is in the process of establishing links to share best practice with other sites in the Westinghouse group, notably Västerås, the UF_6 to UO_2 conversion plant in Sweden and the Columbia (UO_2) Fuel Manufacturing plant in the United States.

3 Research and development

3.1 Introduction

There are six sites associated with research reactors that are currently authorised/permitted to discharge radioactive waste in the UK. The main sites are Dounreay in Highland, Harwell in Oxfordshire, and Winfrith in Dorset. Other smaller research sites include the experimental fusion reactor at Culham (Oxfordshire), the Imperial College Reactor Centre (Berkshire) (now closed and de-licensed) and Windscale (Cumbria) which is on the Sellafield site. These latter smaller sites make small discharges overall and are not considered further here.

The reactors located at Dounreay, Harwell and Winfrith have been closed down and are at different stages of decommissioning. NDA has ownership of these sites. In 2012, Babcock Dounreay Partnership (BDP), which was subsequently renamed as the Cavendish Dounreay Partnership, was awarded the contract to manage the decommissioning and clean-up of the Dounreay site and became the Parent Body Organisation for Dounreay. Dounreay Site Restoration Limited (DSRL) is the responsible site licence company, however DSRL officially transitioned ownership to the NDA in 2021. In 2015, Harwell and Winfrith sites, previously operated by Research Sites Restoration Limited merged to be part of Magnox Limited, also a wholly owned subsidiary of the NDA, however Tradebe Inutec acquired buildings and land at Winfrith and hold their own environmental permit.

A number of companies are tenants on some of these sites and hold separate authorisations/permits to discharge radioactivity. The discharge arrangements for these companies are outlined in the relevant sections below.

Over the coming years, the main activities leading to discharges of radioactivity into the environment from these sites will be associated primarily with the decommissioning of redundant nuclear facilities. Future discharges will, therefore, depend on the decommissioning programme for each site, which is itself dependent on NDA funding for these sites.

BAT (or BPM in Scotland) is applied at all research sites by taking steps to ensure that the effluent management systems and controls are implemented effectively. These include:

- acceptance criteria: The operator requires producers of liquid effluents on site to minimise arisings and to control their disposals via the active drainage system. This is achieved through compliance with the requirements of site instructions which set out the acceptance conditions for disposal of radioactive and non-radioactive liquid effluents, including the specification of limits on total activity of radionuclides in effluent streams

- audits/checks for compliance: Mandatory procedures are enforced through audits of the system to ensure that compliance by consignors, including tenants, is being achieved
- maintenance and inspection: Components of the active effluent discharge systems, for example, tanks, drains, discharge pipelines and associated monitoring equipment are subject to programmes of regular inspection and maintenance, and improvements made where necessary
- minimising arisings at source: At a local facility level, the managers of facilities in which liquid radioactive wastes are produced are responsible for ensuring that liquid waste arisings are kept to a minimum through appropriate implementation of local working practices and instructions, and for undertaking regular management review of working practices

There are a number of key elements in minimising effluent arisings at source, including the design of operations and implementation of processes. Ensuring that operations are well controlled is one of the best ways of minimising waste arisings. Where practicable, operations which could give rise to liquid wastes are avoided by using ‘dry’ techniques, for example, dry swabbing. Waste liquors generated in laboratories are treated, where practicable, to precipitate radioactive materials which are concentrated into a solid form. These are disposed of as solid wastes.

The operators each have an integrated management system in place, which satisfies the requirements of national and international standards. Each of the research sites have an environmental management system certified to ISO 14001 and work within quality assurance procedures that are ISO 9001 certified and are regularly audited both internally and externally. All work, including record keeping and management of processes, is carried out in accordance with these procedures. Internal and external analytical laboratories are used for the analyses performed in support of discharge measurements and environmental sample analysis.

Significant milestones achieved during the reporting period at the research sites are summarised in Table 3.1.

Table 3.1 Summary of Progress in the Decommissioning of Research Sites

Site	Decommissioning status
Dounreay	Destruction of the bulk liquid coolant at the Dounreay Fast Reactor was completed in March 2012. In 2013, SEPA granted DSRL's authorisation for a Low-Level Radioactive Waste disposal facility adjacent to the site. The facility began accepting waste for disposal in April 2015. Dounreay Site Restoration Limited (DSRL) is the responsible site licence company. In 2021, ownership of DSRL transitioned from the Parent Body Organisation to the NDA.
Harwell	The second Retrieval Machine (RM2) was commissioned and put in operation in 2009 and has been used to speed up the rate at which waste cans from storage holes can be recovered. Work continues at Building 462 Post Operational Clean-Out of tube stores#. The project to transfer nuclear materials away from the site is expected to be completed by 2025. Phase 1 of the construction of the Harwell ILW Box Store is complete. During 2021, the final remediation work was completed for the decommissioned Liquid Effluent Treatment Plant (LETP) and radiological sampling is now underway to support the permit surrender for this area and the old sewage treatment plant. Over the next period, work will re-commence on decommissioning the British Experimental Pile Zero (BEP0) reactor in Hangar 10. A significant milestone was achieved when the decommissioning of the last active drains on the site was completed. Whilst the plan for the Offsite Discharge Pipeline is to defer removal until after 2021; in 2016 Magnox were approached by offsite stakeholders to complete work on the Backhill Lane section. A project was completed to remove the sections of the pipeline under the busy link road to Didcot and under the mainline railway. The RSR EPR permit for the Sutton Courtenay section of the Offsite Discharge Pipeline was removed after a case was submitted to the Environment Agency.
Winfrith	Primary Containment Deplanting at the Steam Generating Heavy Water Reactor (SGHWR) is underway. Detailed design and build for segmentation of the reactor core at the Steam Generating Heavy Water Reactor has begun. A number of the deliverables have been achieved to identify the site end state, however work is still to be completed. Optioneering work is underway to determine the preferred decommissioning option for the Active Liquid Effluent sea pipeline.

Harwell's tube stores hold the legacy intermediate level waste discarded from decades of nuclear research and civil use.

3.2 Dounreay

This site was previously concerned with research and development of fast reactor technology, including reprocessing of fast reactor fuel. There are now no reactors operating. The Prototype Fast Reactor (PFR), the last of the 3 reactors, ceased operation in March 1994. The reprocessing facilities ceased operation in 1996, with reprocessing formally terminated in 2001. The focus for the site is now on decommissioning and waste handling (including irradiated fuel), operation and further construction of waste treatment and storage facilities and, finally, site restoration. There have been reductions in the amount of radioactivity discharged into the environment. In March 2019, DSRL received a new Environmental Authorisations (Scotland) Regulations 2018 (EASR) permit which replaced the multi-media Radioactive Substances Act (RSA) authorisation issued in April 2014. There was no change to the site discharge limits. In 2021, radioactive waste discharges from the Dounreay site were made by DSRL under an EASR radioactive substances permit granted by SEPA.

The management of decommissioning activities is via the sites Near Term Work Plan and Lifetime Plan. These set out the sequence of activities and are the basis by which the permitted limits for discharges are set. This ensures that limits within the sites permits are required for work that is planned and therefore in itself ensures radioactive waste (in all phases) is minimised.

3.2.1 Sources of liquid effluent

The principal radionuclides discharged are: alpha, all other non-alpha, tritium, strontium-90and caesium-137. Liquid alpha and all other non-alpha discharges are mainly associated with the decommissioning of the reprocessing facilities and fuel cycle areas. Liquid tritium discharges are mainly from the dissolution and destruction of the alkali metals formerly used as fast reactor coolant.

3.2.2 Liquid effluent treatment and discharges

As previously stated DSRL applies BPM at the consigning facilities to minimise both the production of and the subsequent concentration of radionuclides in its low-level radioactive effluents, for disposal via the Low-Level Liquid Effluent Treatment Plant (LLLETP). The waste treatment philosophy at Dounreay for aqueous liquid waste is abatement at source (the consigning facilities), for example, through the use of filtration and ion exchange. Higher active liquid wastes are immobilised for subsequent disposal as solid intermediate level waste.

The design and operation of LLLETP allows for the settlement of entrained particulate, with the effluent being pumped through a 50µm filter and representatively sampled before discharge to sea.

Consignment of effluent to the site active drainage system and subsequently to the Low-Level Liquid Effluent Treatment Plant (LLLETP) is controlled through management procedures. These procedures include sampling, analysis, and approval of effluent consignments whether they are sentenced or unsentenced. This analysis allows trending of cumulative discharges and comparison with internal limits, which forms part of the demonstration of BPM in aqueous effluent management and disposal.

The aqueous low level liquid effluent discharged from LLLETP arises as follows:-

- contaminated ground water pumping schemes - 65 %
- the Low-Level Waste Pits –Solid) - 30 %
- other Decommissioning activities – 5 %

DSRL has undertaken a strategic options assessment of how it will manage the drainage networks (Radioactive and Non-Radioactive) through to the interim end point of the site. DSRL are currently working towards implementing the drainage strategy and will apply BPM throughout this process.

In parallel DSRL are finalising the design for upgrading the treatment afforded to the non-radioactive effluent, which will complement the drains strategy.

3.2.3 Trends in discharges over the 2017 to 2021 period

Trends of liquid and gaseous discharges from Dounreay during the reporting period (2017-2021) are given in Figure 3.1 and Figure 3.2. Figure 8.2 (in Part 2, Section 8) also shows time trends of discharges over a longer period (2004 to 2021).

Liquid discharges have remained low and within permitted limits. Where comparisons can be made, radionuclides were generally similar (for example, tritium) or declined (for example, caesium-137) over the period. Variations in discharges between years were related to specific decommissioning activities.

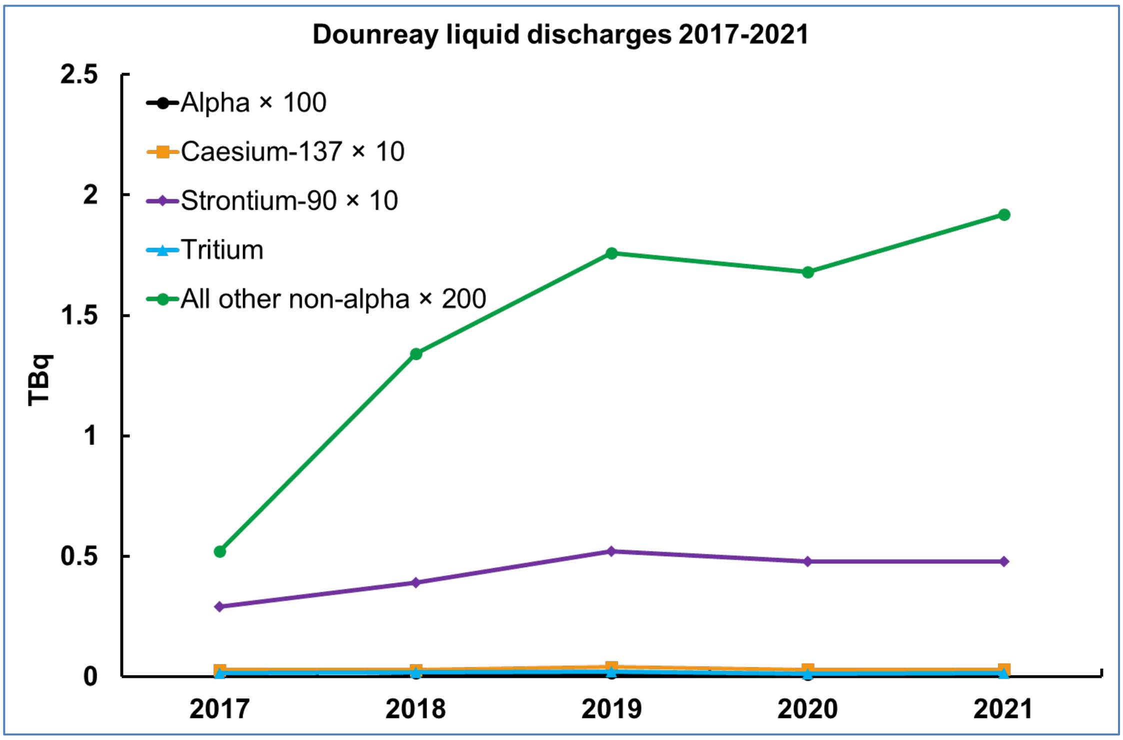


Figure 3.1 Liquid discharges, Dounreay (2017 to 2021)

Gaseous discharges (where comparisons can be made) generally declined or remained low over the reporting period.

Gaseous emissions management

Emissions to atmosphere are only permitted through authorised discharge points i.e., the site stacks.

Where there are releases or discharges from outwith the authorised stacks (which are of sufficiently small volume that they meet the requirements of EASR standard permit conditions) the authorised stack these are quantified and managed by the site.

Each facility and building is required to produce an emissions agreement which provides an internally derived gaseous limit which is well below the site's permitted limit.

The management of gaseous discharges is embedded within the sites BAT (BPM) processes such that by following the internal process, BAT is achieved.

Monitoring of Gaseous emissions

Monitoring of gaseous emissions is via statutory samplers within the sites authorised stacks and occurs continuously. As required by the site permit the results of statutory monitoring is provided to the SEPA as part of the on-going compliance monitoring.

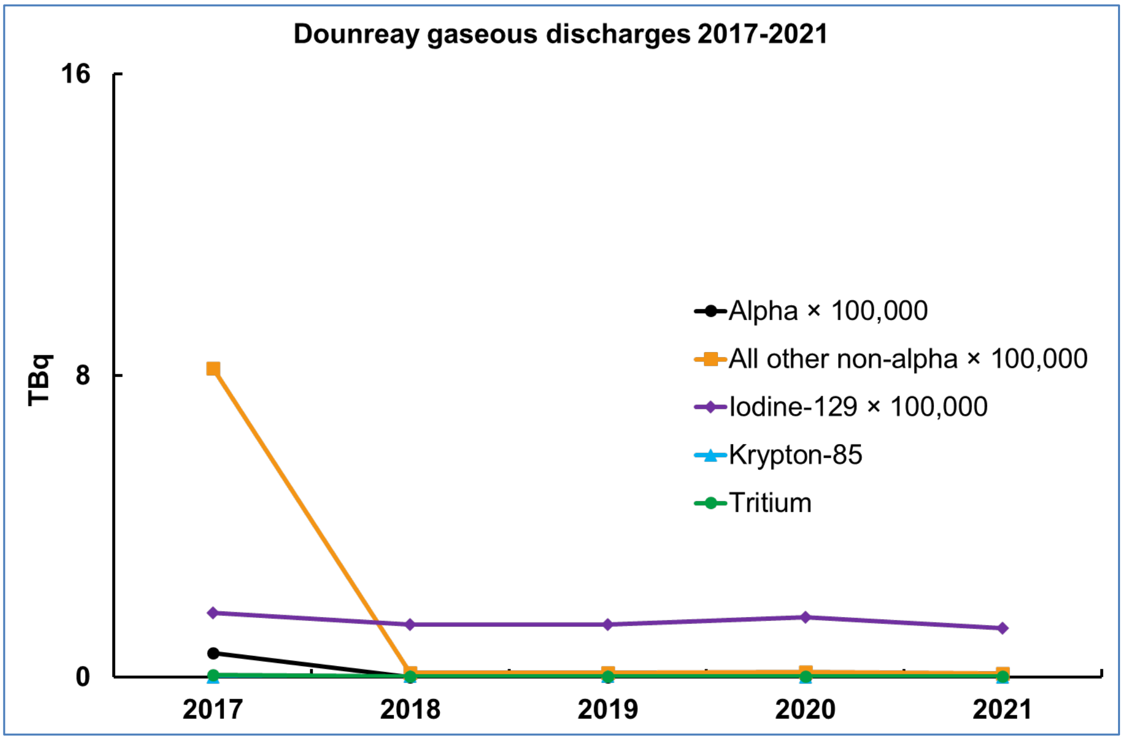


Figure 3.2 Gaseous discharges, Dounreay (2017 to 2021)

3.2.4 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series 'Radioactivity in Food and the Environment' (RIFE). The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 8.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 8.2)

- a summary of trend data for research and development sector (2004-2021) (Part 2, Section 8.5)

Both the operator (Dounreay Site Restoration Limited (DSRL)) and SEPA undertake separate comprehensive environmental monitoring programmes in the vicinity of the Dounreay site. These programmes measure activity concentrations in a number of foodstuffs, environmental media, and dose rates across various locations. Results from the regulatory programme are published annually in the RIFE report. Reported values can reflect the impact of current and past discharges as well as other sources of radioactivity in the environment, for example fall-out. DSRL provides the regulator a review of its programme and assessment of trends that demonstrate the effectiveness of systems that enable optimisation of discharges to the environment.

3.2.5 Particles on the Dounreay foreshore

The previously conducted offshore survey work provided data on repopulation rates of fragments of irradiated nuclear fuel particles to areas of the seabed previously cleared of particles. This work has improved the understanding of particle movements in the marine environment. The Dounreay Particles Advisory Group (DPAG) completed its work following the production of its Fourth Report [7]. Since the work of DPAG was concluded, the Particles Retrieval Advisory Group (Dounreay) (PRAG (D)) has published reports in March 2010 and March 2011 [8,9]. In March 2016, PRAG (D) published a further report into the retrieval of offshore particles. This was produced following an extensive research and monitoring programme in 2012 [10]. The report considers the extent and effectiveness of the offshore recovery programme to reduce the numbers of particles. The report concludes that any noticeable change in the rate or radioactive content of the particles arriving on the nearest publicly accessible beach (Sandside Bay) will take a number of years to assess and recommends that in the interim the monitoring of local beaches be continued. In response to the detection of an alpha rich particle, the regulator requested that the site operator undertook monitoring to determine the likelihood of a large population of such fragments being present on publicly accessible beaches. During July and August 2021, DSRL performed a beach monitoring trial at the west foreshore and Sandside Beach using the FIDLER (Field Instrument for the Detection of Low Energy Radiation) monitoring system which is in operation at Sellafield. PRAG(D) concluded that the monitoring with the FIDLER detectors indicated that there could not be a large population of alpha rich fragments present on the upper sediment on the beach which could pose a realistic risk to health and therefore there is no need for changes to be made to DSRL’s beach monitoring arrangements.

The management of the particles and their associated risks is an ongoing programme of assessment. It is necessary to understand the nature of arrival on local beaches in relation to marine dispersion and in response to offshore events (e.g., winter storms). The changing nature of the hazard, due in part to radioactive decay and also particle fragmentation is being kept under review. Future management options will be kept under regulatory review with consideration of potential hazards and assessment of risks to the public.

3.2.6 The application of BAT (BPM in Scotland)

The demonstration of BAT (BPM applies in Scotland [2,3]) requires a comprehensive understanding of processes or projects and any associated radioactive wastes (i.e., solid, liquid, and gaseous wastes) that are or will be generated during the lifetime of the process/project. Activities which generate radioactive wastes are identified as part of the aspects assessment process and BAT/BPM assessment identifies the engineered and managerial controls required to minimise discharges of radioactivity to the environment. Modifications to environmental protection equipment (EPE), statutory equipment (STAT-E), environmental management requirements or environmental operating rules are also subject to BAT/BPM assessment. The application of BAT/BPM and the ongoing reduction of site inventories as decommissioning advances mean that radioactive discharges from the Dounreay site are several orders of magnitude lower than historic discharges.

Solid waste management

DSRL applies the waste hierarchy and has an extant waste Best Practicable Environmental Options study (BPEO). which has been reviewed several times over the past 18 years. This BPEO set the key direction for the site with respect to its waste management practices. The subsequent reviews have only resulted in a limited number of changes to proposed waste management streams. Those reviews considered the availability of new technologies as part of a review of national and international best practice for waste minimisation and DSRL continues to monitor emerging opportunities.

Building on the Site Waste BPEO, the Dounreay Integrated Waste Strategy document was updated in 2020. This provides an update as to the current waste management strategies and starting to communicate some of the improvements being delivered through the Waste Optimisation Programme. The document also introduced the integrated waste strategy (IWS) dashboard which aims to provide an at-a-glance view on the availability of waste routes on the Dounreay site through to the site Final End State

BPM is embedded into the processes and is demonstrated in different ways throughout the project lifecycle. For radioactive waste disposal, a demonstration of BPM for the scope of waste generating activities is a pre-requisite for permissioning of the generation of waste under the Project Specific Waste Plan (PSWP) process i.e., a project must have demonstrated that they have applied BPM prior to generating radioactive waste. This is summarised in Figure 3.3.

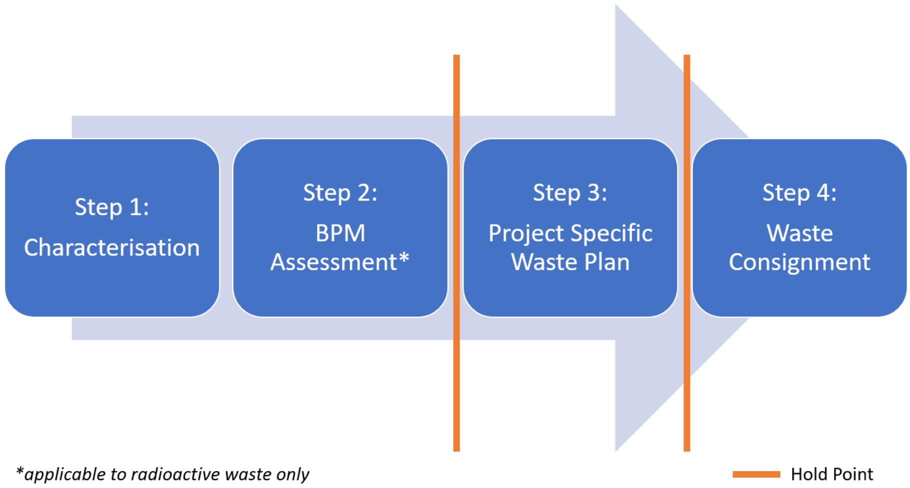


Figure 3.3 The PSWP process

The Dounreay site is also continuing to develop a Waste Management Plan which aims to demonstrate how waste management is being optimised all the way through to achieving a defined end state. This is a requirement of the published regulatory guidance on the management of radioactive waste from the decommissioning of nuclear sites (also known as GRR). It is recognised that the IWS and waste management plan (WMP) are complementary, and work is ongoing to ensure that these are integrated efficiently.

3.2.7 Comparison with performance of similar plants world-wide

Although the activities currently being undertaken at Dounreay do not easily lend themselves to comparisons with other plants world-wide, DSRL maintains contact with relevant plants in Europe and the US, to share experience and information regarding international best practice. The details of operation and impact may differ between sites. For example, the PFR and, more significantly, the Dounreay Fast Reactor (DFR) bulk liquid coolant contained more caesium-137 (due to fuel and coolant contact as a result of fuel pin cladding failure) than similar plants elsewhere such as the US Department of Energy's Experimental Breeder Reactor-II operated by Argonne National Laboratory; and the French fast breeder reactors Phenix and SuperPhenix.

Due to the often highly specialized requirements, new systems are determined by various means of optioneering (for example, in the form of Hazard and Operability Studies).

3.3 Harwell

The site at Harwell was established in 1946 as Britain's first Atomic Energy Research Establishment. The Harwell nuclear licensed site forms part of Harwell Campus, a science, innovation, and business campus. The nuclear licensed site originally accommodated 5 research reactors of various types. The last of these reactors ceased operation in 1990. Current activities include: decommissioning of research reactors; a radiochemical facility and auxiliary facilities; and the management of low and intermediate level wastes arising from decommissioning. Since April 2015, the Harwell site has been operated by Magnox Limited on behalf of the NDA.

3.3.1 Sources of liquid effluent

At Harwell, liquid effluents are produced from several buildings on the nuclear licensed site and arise as a result of waste management in support of decommissioning operations, from commercial tenants on the Harwell nuclear licensed site and some liquid waste is received from neighbouring research and development organisations on the Harwell Science and Innovation Campus. A few buildings on the site still house active operations associated with waste treatment, which is discharged to the Magnox active drainage system. During 2021, the final remediation work was completed for the decommissioned Liquid Effluent Treatment Plant (LETP) and radiological sampling is now underway to support the permit surrender for this area and the old sewage treatment plant.

Discharges from Harwell are released to sewers serving the Didcot Sewage Treatment Works and treated effluent subsequently enters the River Thames at Long Wittenham. Discharges to the River Thames at Sutton Courtenay ceased in 2013, thereafter the decommissioning of the effluent discharge point was completed in 2014. Discharges of surface water effluent from the Harwell site are made via the Lydebank Brook, north of the site, which is a permitted route.

3.3.2 Liquid effluent treatment and discharges

Effluent management on the Harwell site has changed significantly in recent years with the closure of the Liquid Effluent Treatment Plant. The plant was considered to be oversized for the volume and activity of wastes that it received. An alternative strategy was developed to discharge low activity effluent to the Didcot Sewage Treatment Works via 3 onsite locations (B462, B220 and Low Liquid Effluent Treatment Plant).

The most significant new system being installed at B462 is known as the Replacement Effluent Treatment Plant. This plant is compact in size and consists of an evaporator. The resulting concentrate will be cemented ready for storage and disposal. The effluent held in delay tanks at B220, and the Liquid Effluent Treatment

Plant is filtered and stirred to ensure homogeneity. In all cases the effluent in tanks are:

- sampled prior to discharge to assess and ensure that the effluent is compliant with Magnox written arrangements for authorisation of discharge
- sampled post discharge to calculate the radioactivity in the discharge which is used for regulatory reporting requirements

As a consequence of these reduced operations, discharge volumes are much lower than in previous years. The tanks at B220 and B462 only discharge ~ 60m^3 of effluent per year. At the Liquid Effluent Treatment Plant, a large tank (Tank 9) of around 1,000m^3 has recently been commissioned, this has only been used once to date to make a discharge of mainly rainwater.

3.3.3 Trends in discharges over the 2017 to 2021 period

Trends of liquid and gaseous discharges from Harwell during the reporting period (2017–2021) are given in Figure 3.4 and Figure 3.5. Figure 8.3 (in Part 2, Section 8) also shows time trends of discharges over a longer period (2004 to 2021).

Discharges arise mainly from active showers (for example, from staff decontamination procedures) and collection of rainfall within active areas. The volume of liquid effluents discharged from Harwell has decreased significantly over the reporting period. Consequently, discharges have remained very low, and all radionuclides have generally declined over time, particularly in recent years. Gaseous discharges were generally similar over the reporting period and were all low.

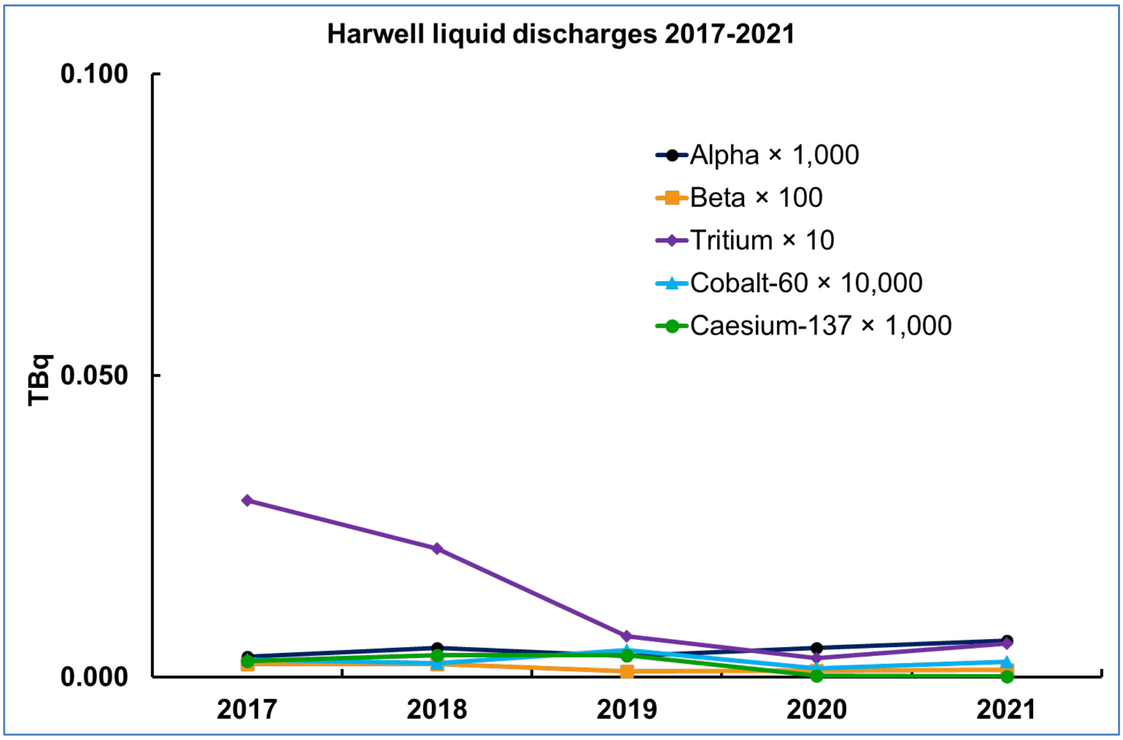


Figure 3.4 Liquid discharges, Harwell (2017 to 2021)

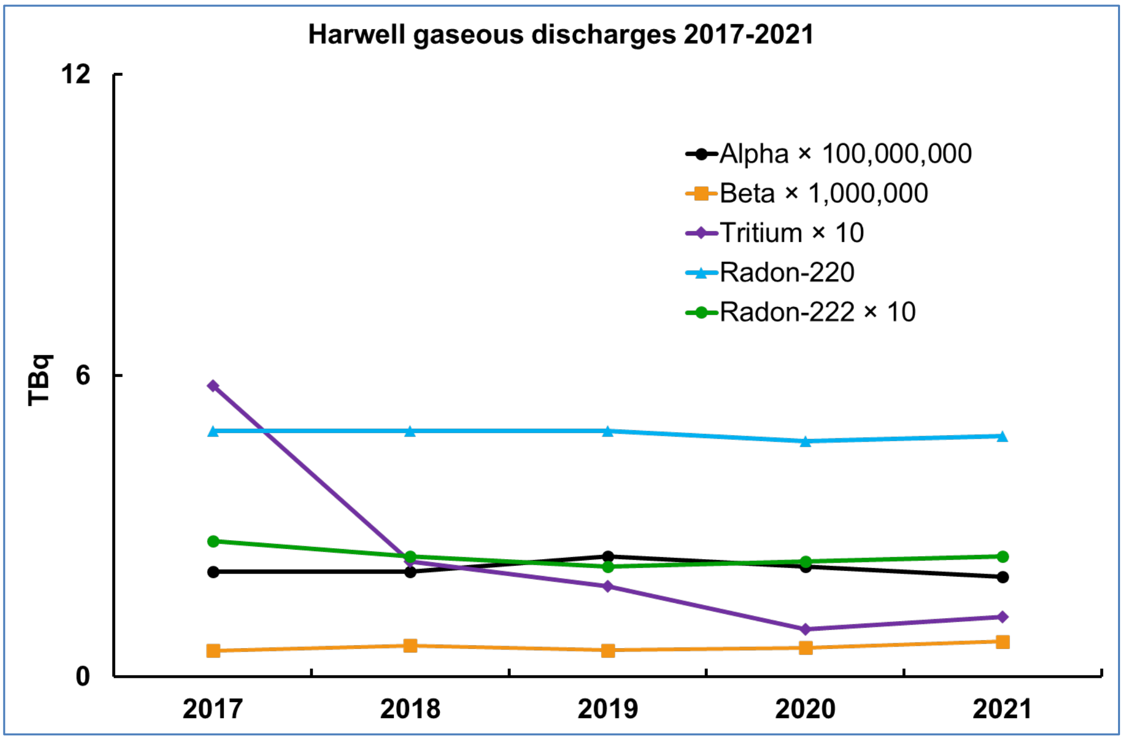


Figure 3.5 Gaseous discharges, Harwell (2017 to 2021)

3.3.4 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series RIFE. The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of KMEIs (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 8.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 8.3)
- a summary of trend data for research and development (2004 to 2021) (Part 2, Section 8.5)

3.3.5 The application of BAT

There are a number of management processes and controls that help achieve BAT. These include the optioneering process that underpins the way waste and discharges are managed. This process helps to identify the option that:

- avoids or reduces the generation of radioactive waste
- results in the lowest amount of radioactivity being released into the environment
- provides the least impact on people and the environment
- performs best under permit/authorisation conditions and limits, and whether an option results in the final end-state for a facility or land being reached sooner than other options

Magnox sites have a plant labelling system which identifies equipment required to protect the environment and that which is used to assess and monitor discharges made under the site environmental permit. This plant is managed through the execution of the appropriate maintenance schedule. The associated maintenance strategy ensures an appropriate frequency of testing, calibration, and maintenance.

Work planning and approval ensures that due consideration is given to environmental impacts and permit compliance through the application of the Estate Development Control Form and Safety Case Modification process. In addition, "Suitably Qualified and Experienced Persons", supported by Providers of Radioactive Substance Legislation Advice, are in key roles supervising and controlling operations. The Asset Management Database, supported by scheduled review via local maintenance committees, ensure that the plant is appropriately maintained and refurbished or upgraded (where appropriate).

The Magnox corporate Radioactive Waste Advisors arrangements ensures that there are appropriate experts providing advice on all aspects on the environmental permit/authorisation, including BAT.

Discharges of radioactivity to sewer are small in comparison to historic discharge levels, around 200m^3 per year; nonetheless Magnox Limited continue to apply BAT. Volumes of discharges have remained consistently low during the reporting period.

The Liquid Effluent Treatment Plant has been decommissioned, and a much smaller evaporator-based Replacement Effluent Treatment Plant has been put in place. This system became operational in early 2014. The development of this plant was substantiated through BAT assessment and analysis data is regularly reviewed to ensure plant efficiency and permit compliance.

3.3.6 Comparison with performance of similar plants world-wide

There are difficulties in comparing the performance of the treatment plant at Harwell with other plants since decontamination factors achieved are highly dependent on input concentrations. However, the general techniques applied are consistent with those used at other facilities.

Comparisons of the performance of the evaporator at Harwell with equivalent evaporators in nuclear applications elsewhere are not readily available. However, the choice of evaporator was made after reviewing those in use elsewhere in the nuclear industry (for example, the Atomic Weapons Establishment (AWE) evaporator) and some industrial evaporators from the non-nuclear sector.

3.4 Winfrith

The Winfrith site was established in 1957 as an experimental reactor research and development site. There have been 9 research and development reactors. The last operational reactor at Winfrith closed in 1995. Seven of the reactors have been decommissioned and dismantled. The final two; Steam Generating Heavy Water Reactor (SGHWR) and 'Dragon' (high temperature gas-cooled) reactor, and supporting site facilities, are in the process of being decommissioned.

Since 2015, the Winfrith site has been operated by Magnox Limited, which is a wholly owned subsidiary of the NDA. The current focus of Magnox's work on the site is the decommissioning of remaining reactors and associated waste management operations.

The Tradebe Inutec site is a radiological waste processing facility for the wider nuclear industry, located adjacent to the main Winfrith site. In February 2019, Tradebe Inutec acquired buildings and land at Winfrith from the NDA and the Office for Nuclear Regulation (ONR) and Environment Agency granted a new nuclear site licence and environmental permit transfer (respectively) to Inutec Limited (who trade as Tradebe Inutec). Prior to this, Tradebe Inutec had been operating as a tenant of Magnox Limited up to 2019 and this reporting period covers the period of transition from tenant to independent nuclear operator.

3.4.1 Sources of liquid effluent

Current Magnox operations at Winfrith are concerned primarily with decommissioning activities. Discharges from this site therefore depend on the decommissioning programme. Liquid wastes, from the Magnox Winfrith site, are disposed through its Active Liquid Effluent System (ALES) via a pipeline to deep water in Weymouth Bay.

Liquid wastes from Tradebe Inutec are transferred off site and discharged into Southampton water (English Channel) under a non-nuclear permit. The process for Tradebe Inutec discharging liquid effluent via Winfrith ALES ended in 2019.

3.4.2 Liquid effluent treatment and discharges

In accordance with Magnox Limited procedures, the volume and radioactive content of its waste arisings are minimised at source by the application of BAT. There is some minor pre-settlement treatment of liquid wastes entering the ALES system. Monitoring and pH adjustment take place prior to discharge.

Active process effluent is isolated in a tank and sampled for pre-discharge analysis. The pH level is modified to fall within the permitted range. Repeat sampling and analysis is carried out until the pH criterion is met. Additional analysis is carried out to measure: gross alpha, gross beta, and tritium activities, free chlorine content, suspended solids content and chemical oxygen demand. If the results are acceptable, the effluent is mixed. Prior to discharge, additional samples are taken for post discharge analysis.

3.4.3 Trends in discharge over the 2017 to 2021 period

Trends of liquid and gaseous discharges from Winfrith during the reporting period (2017–2021) are given in Figure 3.6 and Figure 3.7. Figure 8.4 (in Part 2, Section 8) also shows time trends of discharges over a longer period (2004 to 2021).

Liquid discharges were broadly consistent over the reporting period. The principal radionuclide was tritium. Until 2019, a significant component of the tritium liquid wastes originated from operations of Tradebe Inutec (TI) as the on-site tenant. TI processes a wide range of wastes (with different radionuclide fingerprints). Consequently, activity concentrations from the site during the reporting period have been variable, difficult to predict and not solely representative of Magnox's activities.

The majority of liquid arisings discharged from the ALES system from Magnox's activities are from non-radioactive groundwater that enters the drainage system and change facilities within active area. The earliest part of this reporting period covered decommissioning work including primary containment dismantling operations at SGHWR, where circuits were flushed with water to transfer tritium into the liquid phase. This resulted in an increased contribution to the total tritium activity discharged through ALES. The bulk of the operational clean-up of the primary containment has been completed and impact from liquid discharges is now relatively insignificant, given the small volumes discharged.

Work is now being undertaken to prepare for the future cessation of discharges to sea from Winfrith, in order to decommission the Active Liquid Effluent System and the Sea Pipeline. The dismantling of ALES and associated pipeline is not expected until the late 2020s. A route for future discharges is currently being identified.

Gaseous discharges were generally similar over the reporting period. Variations in particulate discharges can be attributed to phases of decommissioning operations (including, cutting operations).

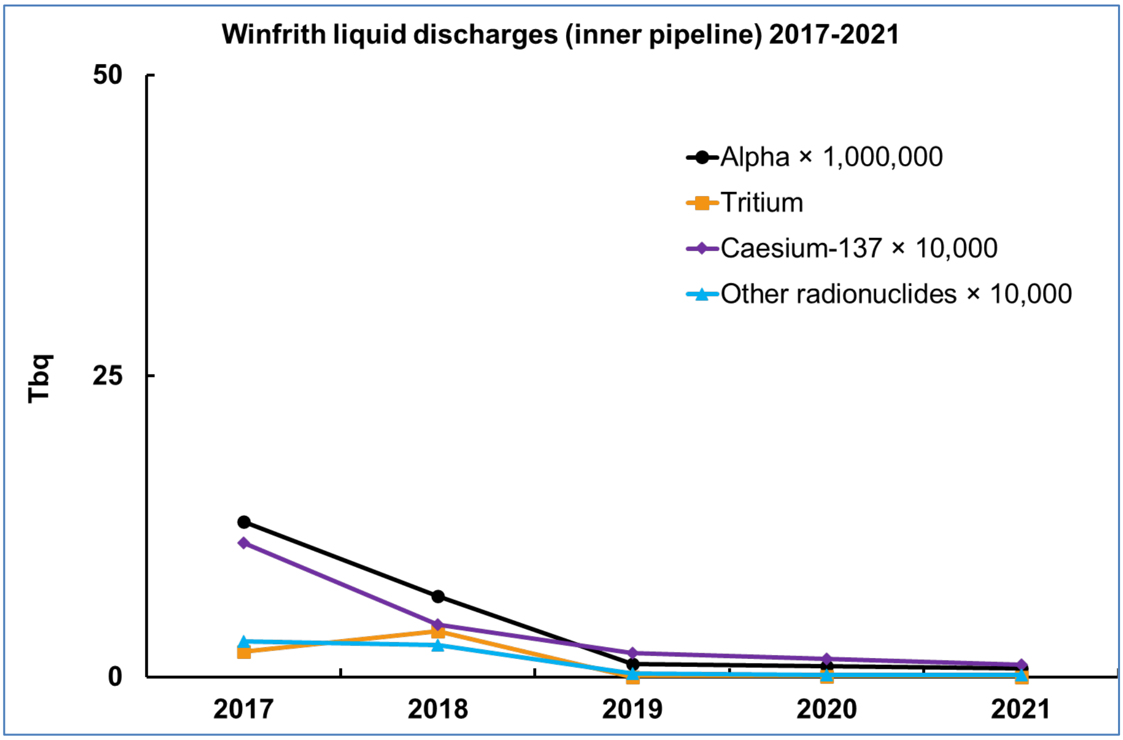


Figure 3.6 Liquid discharges, Winfrith (2017 to 2021)

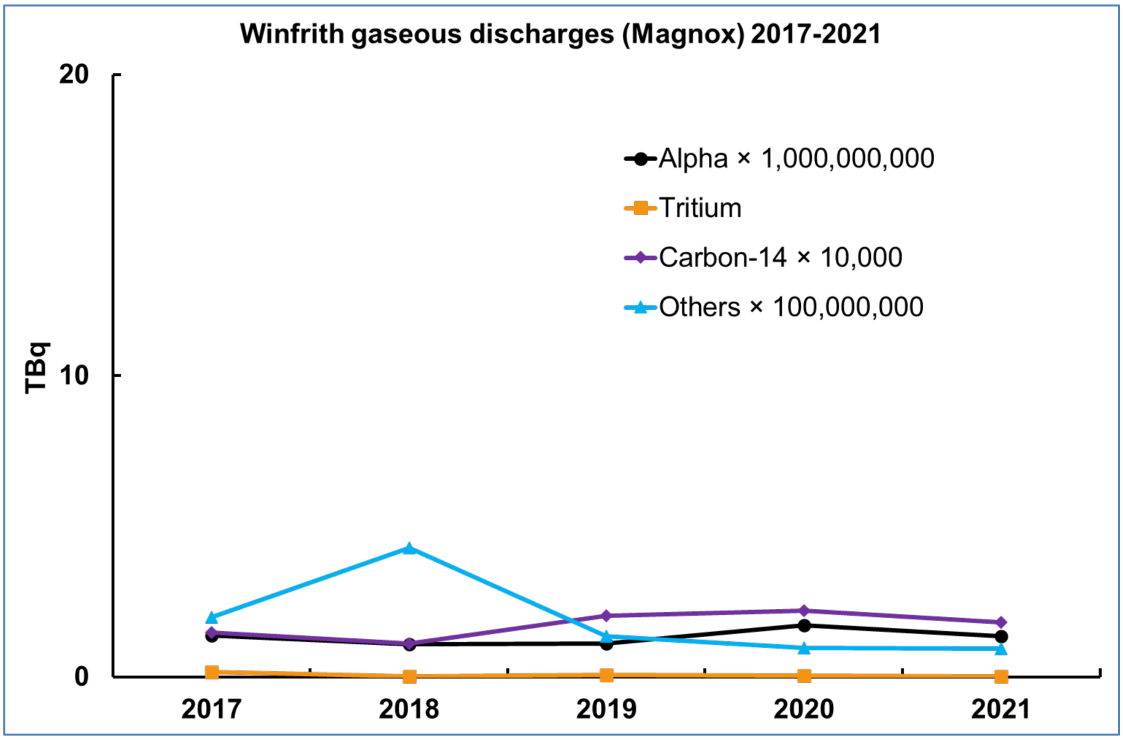


Figure 3.7 Gaseous discharges, Winfrith (2017 to 2021)

3.4.4 Radiological impact of gaseous and liquid discharges

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series RIFE. The information is provided in Part 2 of this report, as follows:

- time trends of ‘total dose’ (Part 2, Section 6.1)
- time trends of KMEIs (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 8.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 8.4)
- a summary of trend data for research and development sector (2004 to 2021) (Part 2, Section 8.5)

3.4.5 The application of BAT

BAT at Winfrith is achieved through similar processes and controls at other Magnox sites, as given in Section 3.3 for Harwell.

Discharges of radioactivity to sea are very small and have remained so throughout the reporting period; nonetheless Magnox Limited continue to apply BAT. Volumes of discharges have decreased significantly decreased and most is groundwater.

The discharge strategy for the site is set to significantly change over the coming period with the anticipated closure of the Active Liquid Effluent System (ALES). The site is currently identifying an alternative discharge route following the BAT process.

During the reporting period, the site's foul system which previously discharged via ALES, has been replaced with a transient foul system which discharges to the local sewer network, reducing the discharge volumes through ALES.

Given the wide range of decommissioning tasks at Winfrith, the importance of BAT in terms of a compliance and improvement tool remains an integral part of our arrangements.

3.4.6 Comparison with performance of similar plants world-wide

The activities currently being undertaken at Winfrith do not easily lend themselves to comparisons with other plants worldwide. Magnox Limited does, however, maintain a watching brief on international best practice in this field.

Magnox Limited management procedures are periodically reviewed and updated to reflect learning and good practice within the Magnox fleet and practices from other organisations. There are numerous fora through which the company reviews performance. Internally, the company applies optioneering (for example, BAT assessments), strategy development, research and development programmes through environment and waste peer groups. Externally, Magnox Limited supports and participates in EARWG (an industry forum which reviews BAT as it is applied to waste management). Subject Matter Experts take part in British Standards Institute and International Standards Institute working groups in developing standards and industry working groups such as the Ventilation Working Group sponsored by the Nuclear Safety Directors Forum. Magnox Limited also participates in a number of NDA working groups (for example, Characterisation, NDA Technical Baseline and Underpinning Research and Development Requirements (TBuRD) Working Group). the Magnox TBuRD defines the scope of a number of development areas where they seek to improve radioactive waste management. Given where Magnox sites are in their lifecycle, the focus on abatement options has been guided by having solutions that are appropriate and where possible using proven technology (from within and outside the nuclear industry) to balance the need to progress with decommissioning in a proportionate manner given the low radiological impact.

4 Nuclear power generation

4.1 Introduction

In the UK, there are a total of 19 nuclear power stations at 14 locations; 9 in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), 3 in Scotland (Chapelcross, Hunterston and Torness) and 2 in Wales (Trawsfynydd and Wylfa):

- 11 are first generation Magnox power stations (Magnox design gas cooled reactors).
- 7 are more recent advanced gas-cooled reactor (AGR) power stations.
- 1 is a pressurised water reactor (PWR) power station.

Ten Magnox power stations are currently managed by Magnox Limited, under the ownership of the NDA, while Calder Hall is being decommissioned by Sellafield Limited on behalf of the NDA. The 7 AGR power stations and 1 Pressurised Water Reactor (PWR) power station are owned and operated by EDF Energy Nuclear Generation Limited; these are Dungeness B, Hartlepool, Heysham 1 and 2, Hinkley Point B and Sizewell B power stations (in England), and Hunterston B and Torness power stations (in Scotland). All these power stations generated electricity during 2017 to 2021.

No Magnox Power stations were operating over the 5 year-period of this report (2017-2021). De-fuelling of Magnox Power stations was completed during the period of this report.

Section 4 has been divided according to the operational status of the power stations during the reporting period (2017 to 2021). Information is provided under the appropriate headings for 2 categories of site:

- operational sites – those that were operational throughout the reporting period
- decommissioning sites – those that permanently ceased operation and began de-fuelling or decommissioning before 2021

The nuclear licensed sites included under each category are set out in Table 4.1.

Table 4.1 Operational status of UK power stations in 2021

Operational		Decommissioning*	
Dungeness B# (AGR)	Sizewell B (PWR)	Berkeley (Magnox)	Hunterston A (Magnox)

Hartlepool (AGR)	Torness (AGR)	Bradwell (Magnox)	Sizewell A (Magnox)
Heysham 1 (AGR)		Calder Hall (Magnox)	Trawsfynydd (Magnox)
Heysham 2 (AGR)		Chapelcross (Magnox)	Oldbury (Magnox)
Hinkley Point B (AGR)		Dungeness A (Magnox)	Wylfa (Magnox)
Hunterston B (AGR)		Hinkley Point A (Magnox)	

*Calder Hall, which ceased operation during 2003, is considered separately in Section 3.
Dungeness B power station was operational until June 2021, when EDF decided to move the station into the defueling stage and therefore will be reported under the operational sites.

4.2 Operational power stations

There were 7 AGRs and 1 PWR in operation during the reporting period. During the reporting period (2017 to 2021), Dungeness B power station was operational until June 2021 and therefore is reported under this section.

4.2.1 Sources of liquid effluent for AGRs and PWR

The main sources of radioactive liquid effluent from AGR stations are:

i) Reactor gas dryers, which remove water from the gas coolant to prevent the build-up of moisture. The water is then drained from the dryers to the tritiated water storage tanks
ii) Pond water treatment plants, which may contain radionuclides as a consequence of corrosion of cladding material, leaching from graphite sleeves surrounding the fuel during storage in the pond, contamination on the fuel cladding surfaces or fuel pin cladding failure and contamination brought into the pond with the fuel transport flask
iii) Drainage from radiation-controlled areas, which comprises wastewater from plant areas, flask decontamination, drainage from change rooms, circulator maintenance areas, waste void sumps, radiochemistry laboratory, active workshops, fuel route maintenance and sumps
iv) Activity from storage tanks that contain soluble activation and fission products from solid waste such as sludge or resin from the treatment plant

The main sources of radioactive liquid effluent from the PWR station are:

i) Reactor coolant system/boron recycling system, which contains activity as a result of fission and activation processes, and which may be transferred to the Liquid Radioactive Waste System. During each fuel cycle, borated water is processed by the Chemical and Volume Control System into the Boron Recycle System

ii) Reactor coolant drainage tank, which contains radioactivity from the borated reactor grade water. Its contribution to the overall radioactivity is relatively small
iii) Fuel storage pond cooling and clean-up system. Activity in this system originates from the ponds and is mainly due to fuel-cladding corrosion and fuel contamination
iv) Resin transfer, storage and encapsulation plant contains the soluble radionuclides from the supernatant liquid from spent resin storage tanks.
v) Active drains from radiation-controlled areas as a consequence of plant decontamination washings, drainage from the reactor building/support buildings and plant areas, and from change rooms, radiochemistry laboratory, active workshops, and sumps
vi) Leaks from 'secondary-side' plant that may sometimes contain traces of some radionuclides

Sources i – v inclusive, from the PWR station contain most of the radioactivity and their effluent is usually discharged via the Liquid Radioactive Waste System.

Other sources of liquid effluent include the turbine steam and feed water systems. The volume of wastewater is 10 times greater than the volume discharged from the Liquid Radioactive Waste System, but this effluent normally contains no more than traces of radioactivity. It is discharged via a dedicated system, which can be redirected to the Liquid Radioactive Waste System if it is found to contain significant amounts of radioactivity.

Secondary neutron sources used to provide essential control information when a PWR reactor is returned to power (following a period of shut down) are also known to produce tritium as a by-product. These were removed in 2015 and significantly reduced gaseous tritium discharges.

4.2.2 Management of liquid effluents for AGRs and PWR

All AGR and PWR sites are certified to the international Environmental Management Standard ISO 14001 and are therefore subject to external audit. There is also an internal quality management system for all sites.

All AGRs have an Active Effluent Treatment Plant, or equivalent system. The function of the plant is to deal with potentially active effluent by various treatment processes leading to separation of oils, particulate, and treated liquids. It comprises filter vessels, pumps, pipes, valves, and indicators. The output of these active treatment plants is fed into the final monitoring and delay tanks. The plant is almost totally duplicated, either through secondary stand-by plant or plant currently undergoing maintenance.

The Active Effluent Treatment Plants process the liquid waste by separation to remove oil and filtration to remove particulates. Treatment includes using non-regenerable ion exchange units, to reduce the dissolved activity as far as reasonably practicable.

AGR Systems and Processes

Fuel pond water is usually the most radioactive contributor to the effluents transferred to the Active Effluent Treatment Plants.

On the rare occasion that a defective or leaking fuel element is detected within the reactor, it would normally be held for an extended period in dry buffer storage pending a decision regarding off-site disposal. The leaking element(s) would then be placed in a separate water-tight container before entering the fuel cooling ponds. The residence time in the cooling ponds, and release of radionuclides to pond water, are thereby minimised. Priority is given to minimising the release of radioactivity to fuel storage ponds.

Other measures taken to minimise liquid discharges from the pond are as follows:

- the pond water treatment system is a closed system and the discharge route to the sea is only used for small quantities of liquid following treatment in the Active Effluent Treatment Plant (AETP)
- pond water is continuously recirculated through deep bed sand filters, funda filters and ion exchange resin beds
- chloride ion concentration is controlled in order to minimise the incidence of stress corrosion of the stainless-steel cladding of the fuel, so reducing the chance of fuel corrosion in the pond
- pond radiochemical factors are monitored through a process of routine sampling and analysis
- pond water is monitored for caesium-137 and its levels are controlled using specialist ion exchange media, as required, before the water is discharged into the Active Effluent Treatment Plant

In addition, boron is added to eliminate as far as practicable any possibility of a criticality event in the pond. This increases levels of boron in the discharge effluent. Boron is a listed hazardous substance and therefore its introduction into the water environment, via pond water, should be minimised.

PWR Systems

The PWR at Sizewell is designed to minimise the production of radioactive wastes and liquid effluents. There are a number of design features and operating practices which assist in minimising either the generation of radioactive liquid wastes or the quantities of radionuclides present in them. For example:

- use of the hard-facing material Stellite was limited as far as possible in metalwork within the reactor cooling system, because of its high cobalt content
- the Chemical and Volume Control System and the Boron Recycle System act to decontaminate the reactor coolant (keeping radionuclide concentrations low) and to control the rate of the nuclear reaction inside the reactor core, respectively. Both comprise demineraliser and filters, so the wastewater has already been treated before it reaches the Liquid Radioactive Waste System. The Boron Recycle System holds the let-down reactor coolant in one of two large (300m^3) tanks before it is fed forward to the Liquid Radioactive Waste System, so that short-lived radionuclides decay before transfer
- the Fuel Storage Pond Cooling and Clean-up System is designed to control contamination of Fuel Storage Pond and to ensure that the heat from the fuel is removed. The water is almost entirely recycled, thereby reducing the level of radioactivity discharged to the environment, since only a relatively small amount is routed to the Liquid Radioactive Waste System. The ponds are also managed to ensure minimisation of waste. For example, the fuel storage pond water chemistry is controlled to minimise corrosion of the fuel-cladding
- Reactor Coolant System. The radioactivity in this system is the result of fission and activation processes. Some of this activity is transferred to the Liquid Radioactive Waste System and collected on resins in the Liquid Radioactive Waste System. Where possible, resin beds are changed with sufficient frequency to ensure that they can be disposed of as Low-Level Waste (LLW)
- Solid Radioactive Waste System contains 2 low level waste spent resin storage tanks and 3 Intermediate Level Waste (ILW) spent resin storage tanks. Supernatant liquid from these tanks is decanted to the Resin Transfer System Storage Tank. Excess water in this system is filtered by cartridge filters or demineralisers within the Liquid Radioactive Waste System prior to discharge

4.2.3 Liquid effluent treatment and abatement from AGRs and PWR

AGR and PWR stations employ a number of particulate filters. For example, liquid effluents are generally passed through a sand pressure filter and a back-up filter that is provided to trap any loose sand particles.

Ion exchange resins are used to remove soluble radioactivity from the cooling ponds. This process is optimised by pre-filtration of insoluble particulate materials to maximise the lifetime of the resins.

The active effluent treatment system collects all radioactive or potentially radioactive liquid effluent arisings in a series of tanks, in preparation for being treated and filtered for final disposal. During the collection and treatment stages, sludge is left as a residue in the tanks. This sludge is generally directed to long-term storage for subsequent specialist disposal. Additional effluent management systems have been put in place to eliminate (so far as is practicable) discharges of organic material containing organic bound tritium.

4.2.4 Trends in discharges over the 2017 to 2021 period

The discharges from operational sites have generally been similar throughout the reporting period and most of the apparent variations can be associated with changes in power output (including shutdowns for maintenance operations). In this Section, Figure 4.1 to Figure 4.16 illustrate the variations in discharges over the reporting period (2017 to 2021) for each site. Figure 9.3 (in Part 2, Section 9) also shows time trends of discharges over a longer period (2004 to 2021).

Dungeness B: Liquid and gaseous discharges started to decrease between 2019 and 2021 due to extensive production outages to deal with a range of technical issues. In June 2021, EDF Energy Nuclear Generation Limited decided to move Dungeness B nuclear power station into the de-fuelling phase, with immediate effect.

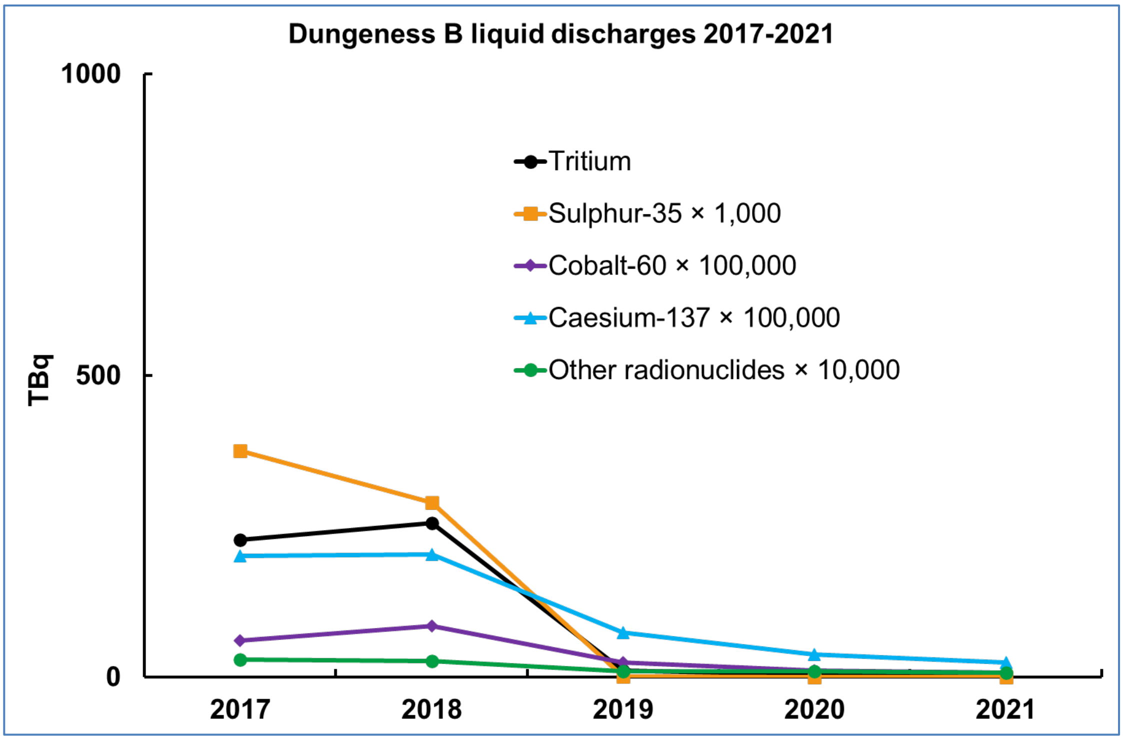


Figure 4.1 Liquid discharges, Dungeness B (2017 to 2021)

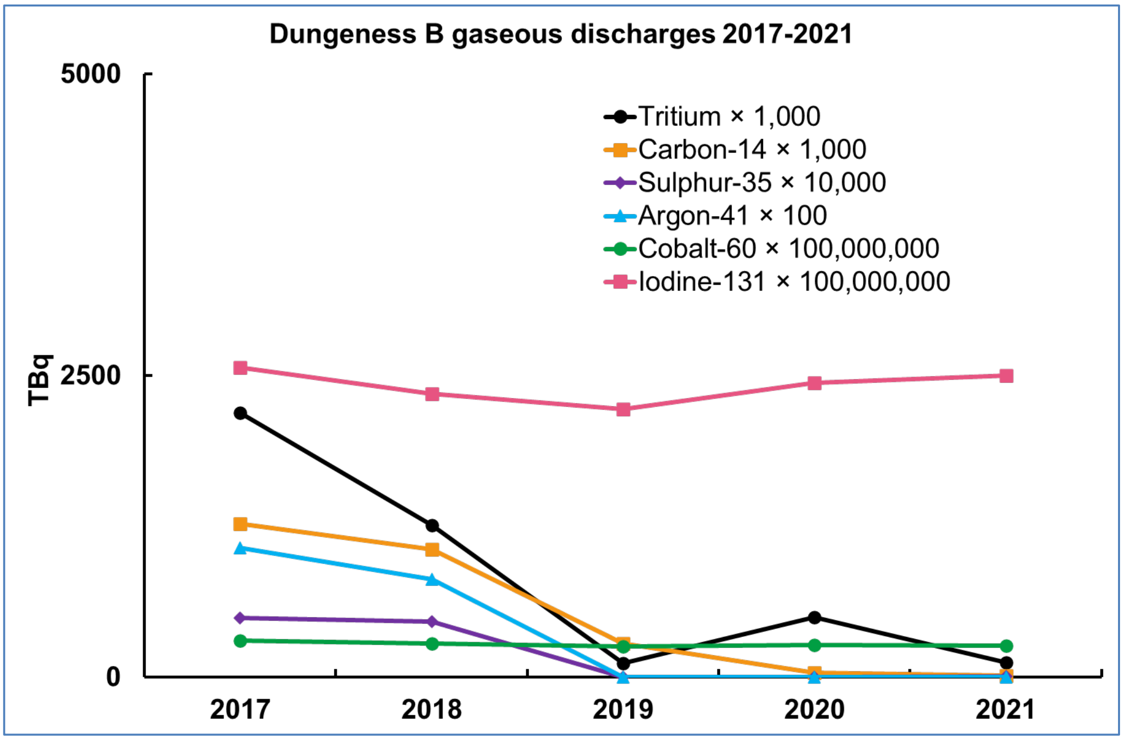


Figure 4.2 Gaseous discharges, Dungeness B (2017 to 2021)

Hartlepool: Liquid and gaseous discharges were generally similar each year over the reporting period. Variations observed between and within years in activity discharged are associated largely with power output and maintenance outages. Over the last period (2017 to 2021), sulphur-35 discharges show a decreasing trend due in part to the use of less carbonyl sulphide (COS) in the reactor circuit to manage carbon deposition. Levels in discharges remain well below the corresponding permitted discharge limits.

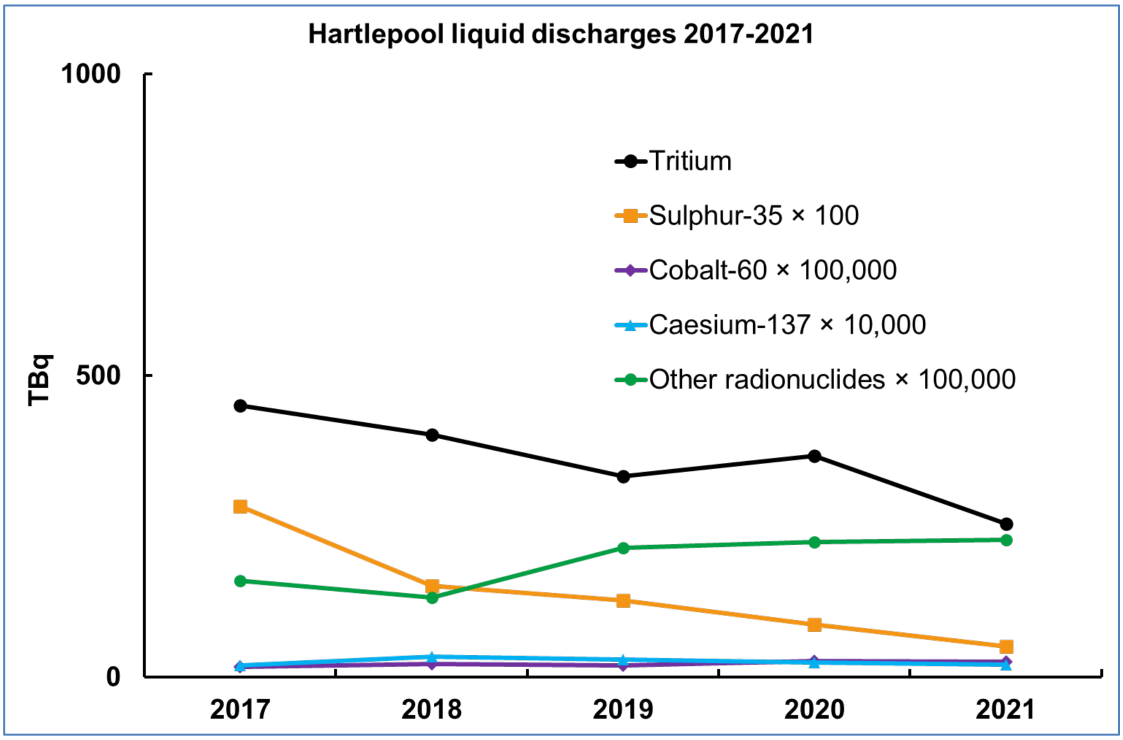


Figure 4.3 Liquid discharges, Hartlepool (2017 to 2021)

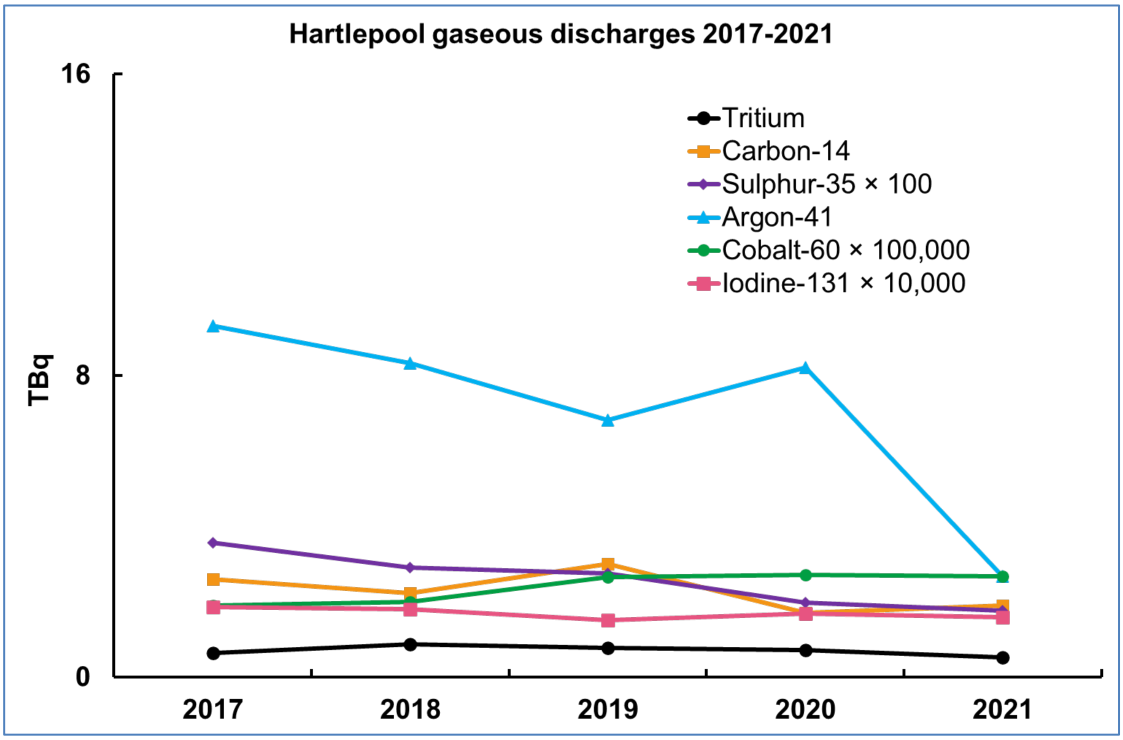


Figure 4.4 Gaseous discharges, Hartlepool (2017 to 2021)

Heysham 1: Liquid and gaseous discharges were generally similar each year over the reporting period, with variations related to power generation and operational activities.

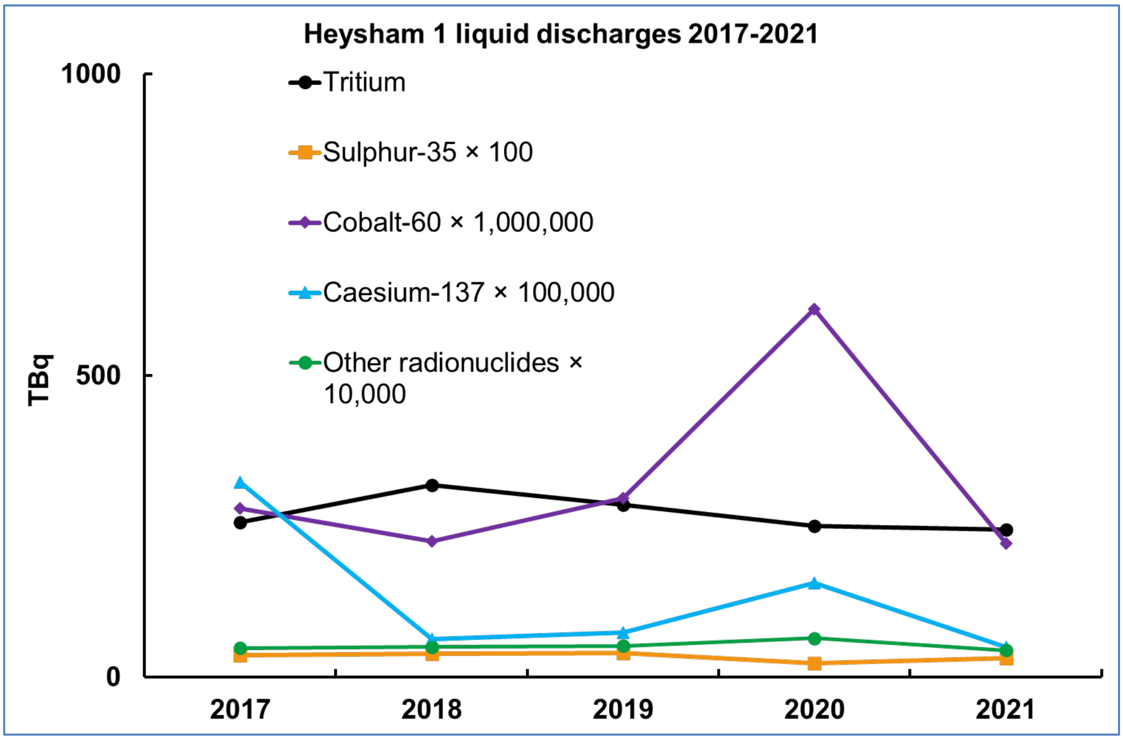


Figure 4.5 Liquid discharges, Heysham 1 (2017 to 2021)

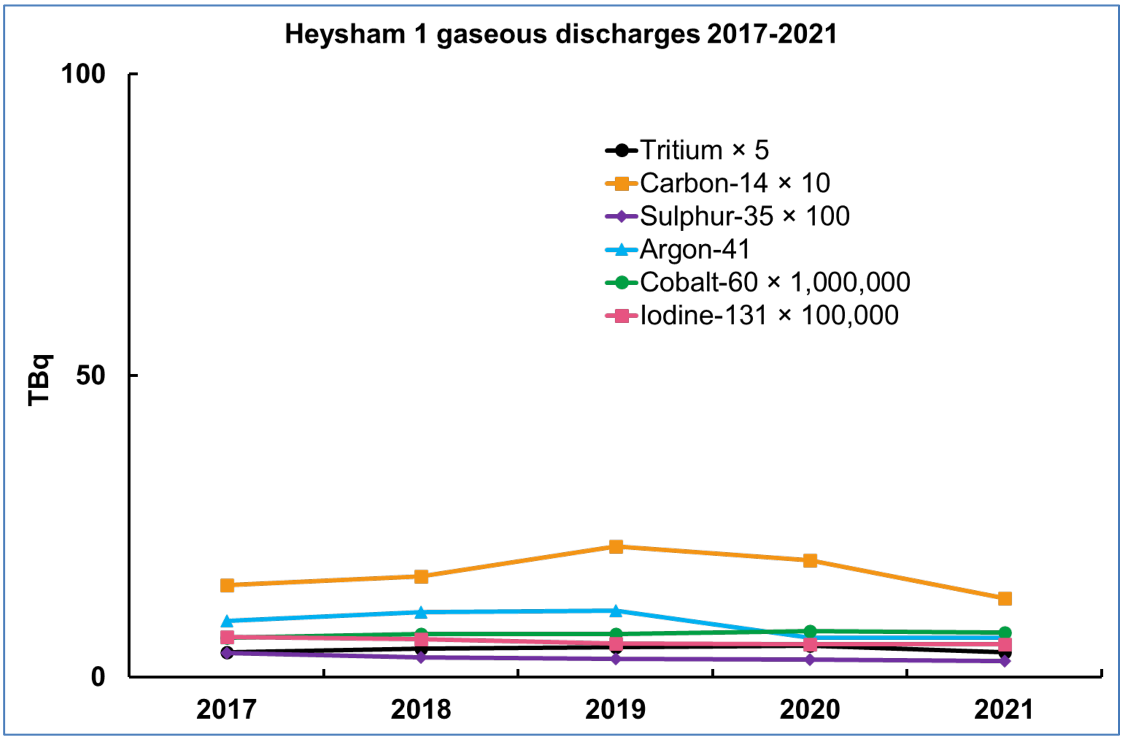


Figure 4.6 Gaseous discharges, Heysham 1 (2017 to 2021)

Heysham 2: Liquid and gaseous discharges were generally similar each year over the reporting period, with small variation related to power generation.

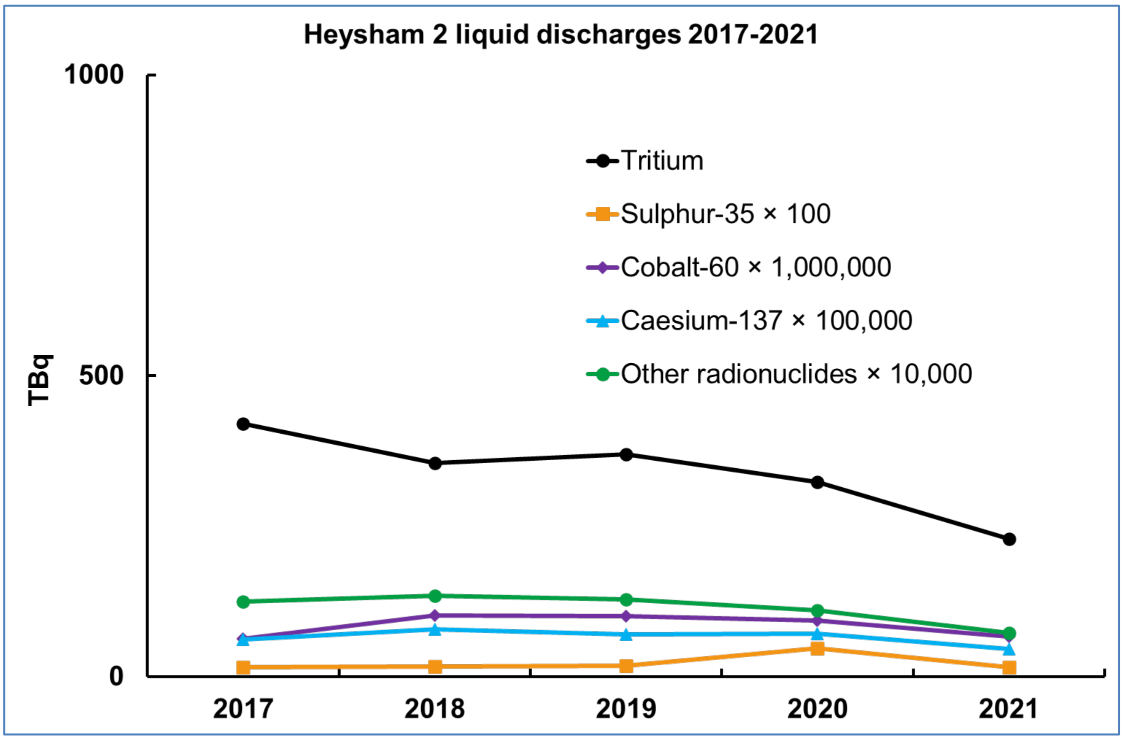


Figure 4.7 Liquid discharges, Heysham 2 (2017 to 2021)

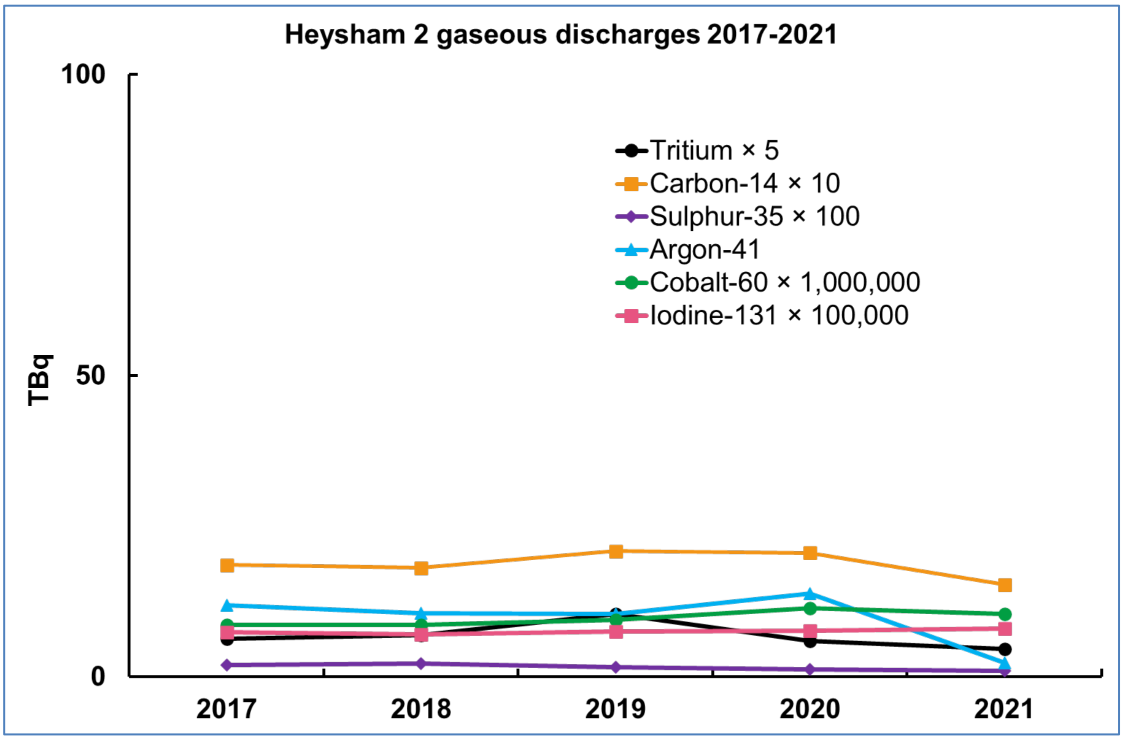


Figure 4.8 Gaseous discharges, Heysham 2 (2017 to 2021)

Hinkley Point B: Liquid and gaseous discharges were generally similar each year over the reporting period, with small variation related to power generation.

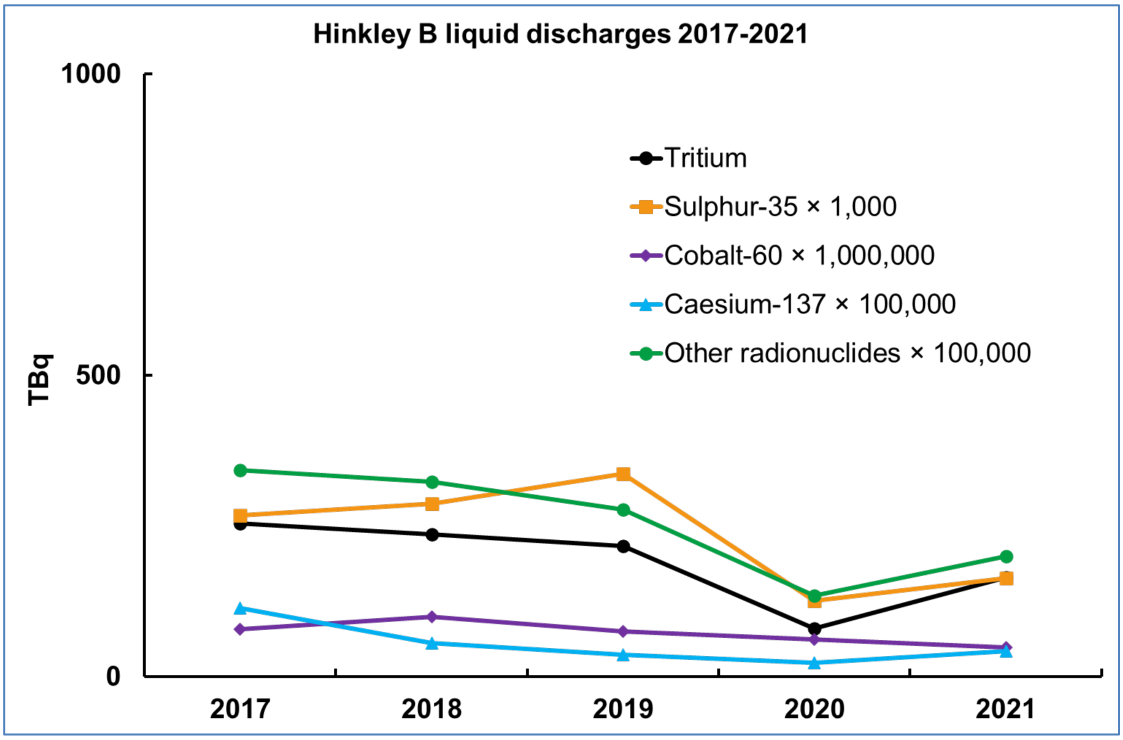


Figure 4.9 Liquid discharges, Hinkley Point B (2017 to 2021)

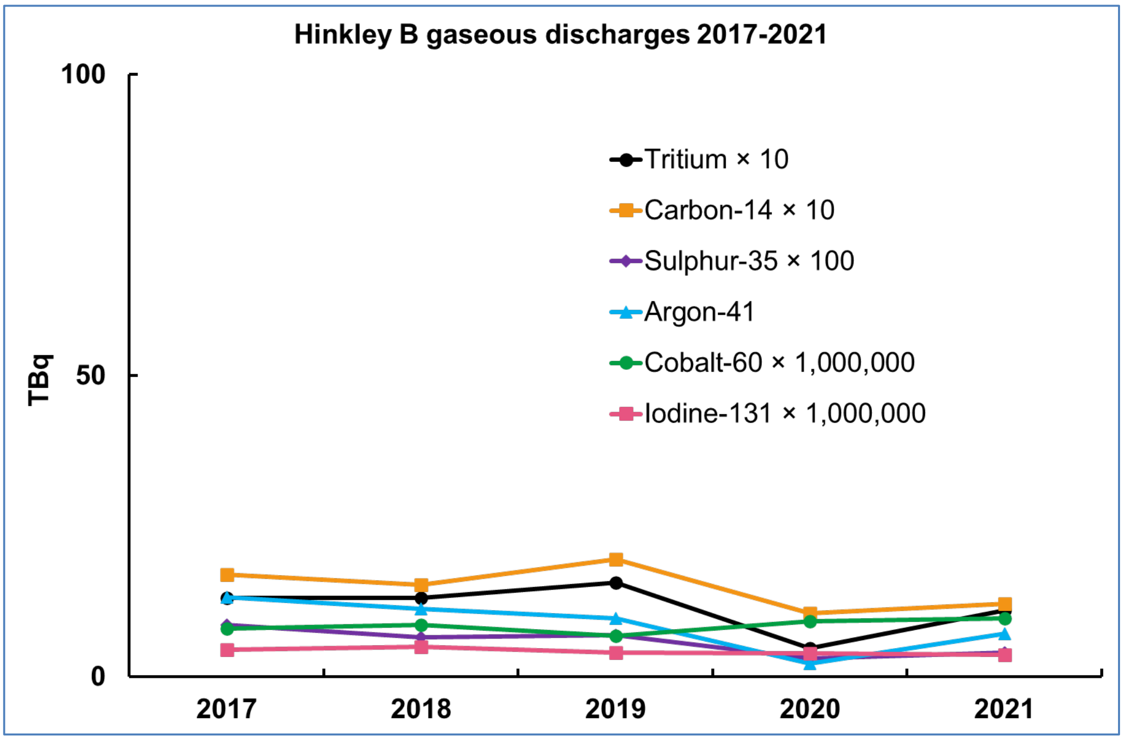


Figure 4.10 Gaseous discharges, Hinkley Point B (2017 to 2021)

Hunterston B: Liquid and gaseous discharges were generally similar each year over the reporting period. Any variation between years in activity discharged are associated with power output and maintenance outages.

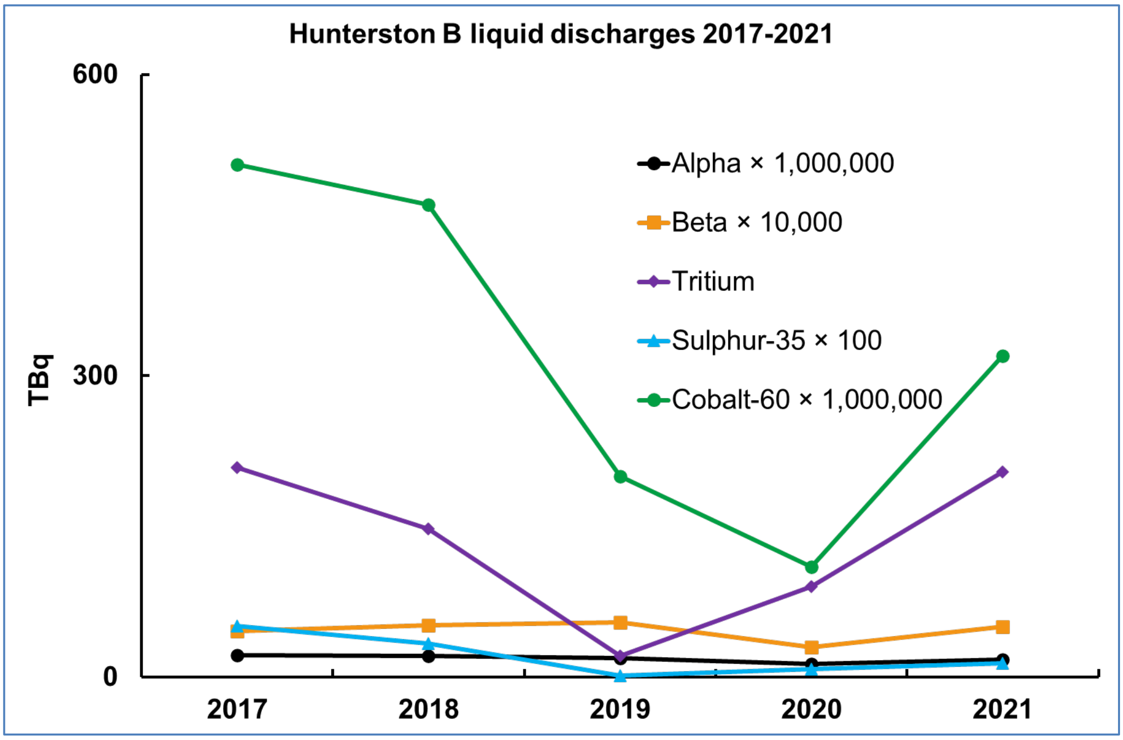


Figure 4.11 Liquid discharges, Hunterston B (2017 to 2021)

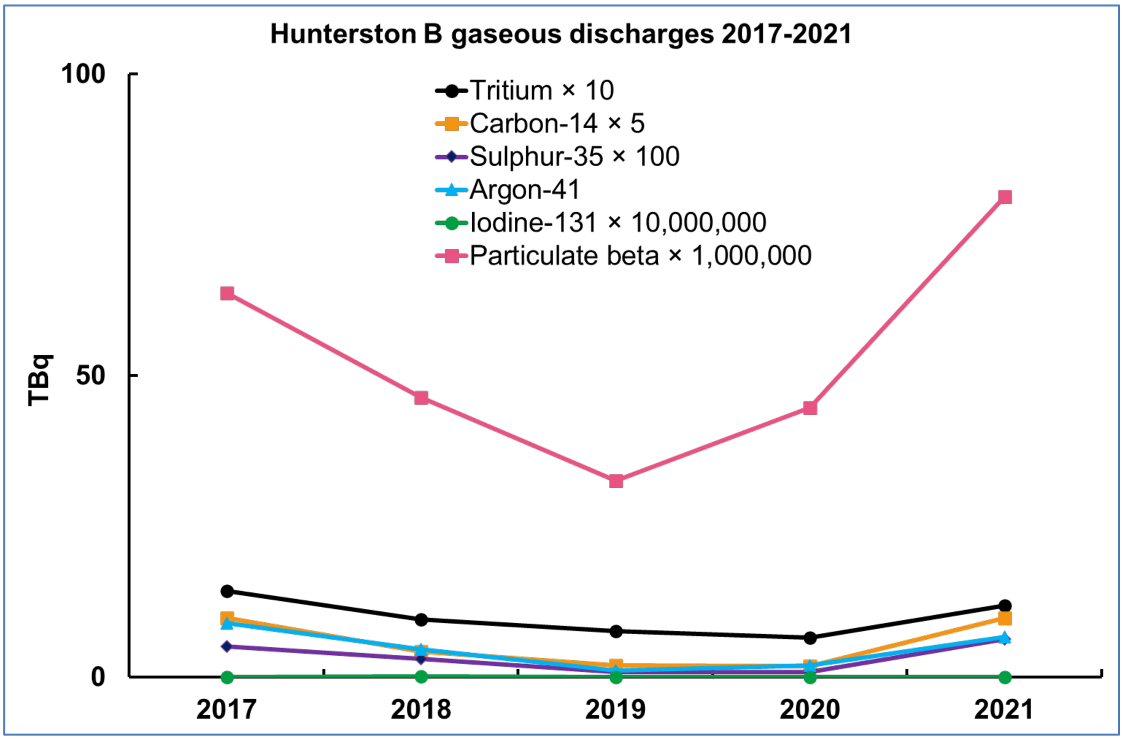


Figure 4.12 Gaseous discharges, Hunterston B (2017 to 2021)

Torness: Liquid and gaseous discharges were low and generally similar over the reporting period, with some minor variation from year to year.

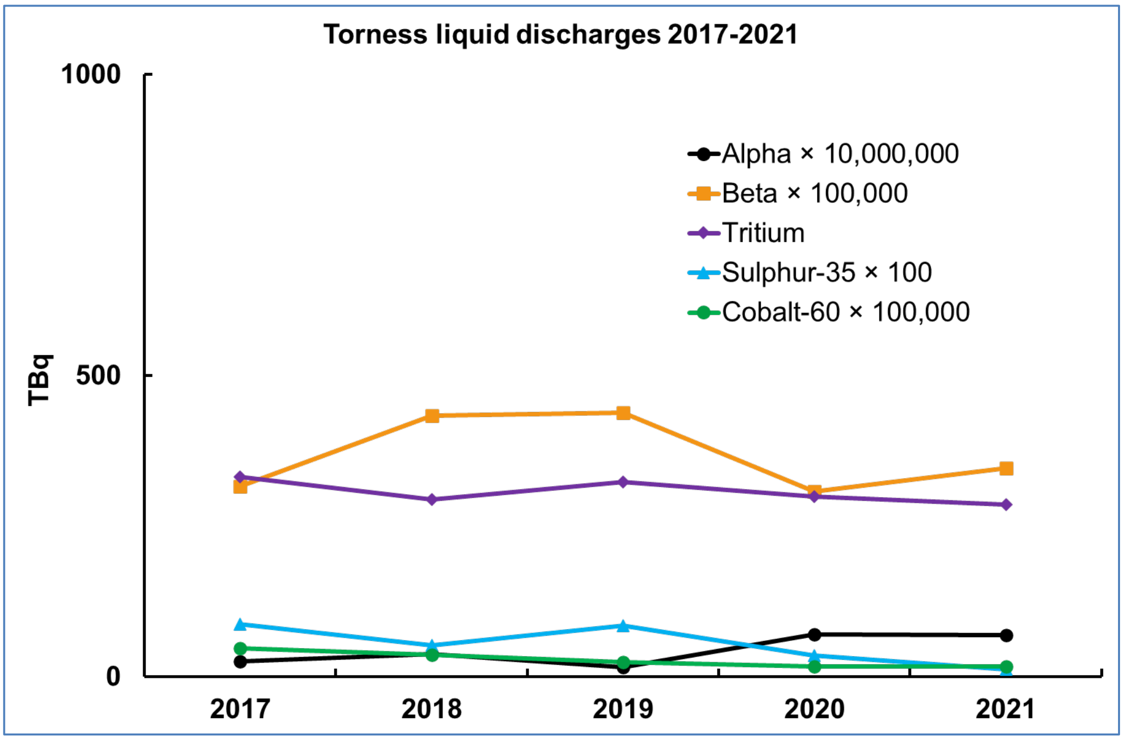


Figure 4.13 Liquid discharges, Torness (2017 to 2021)

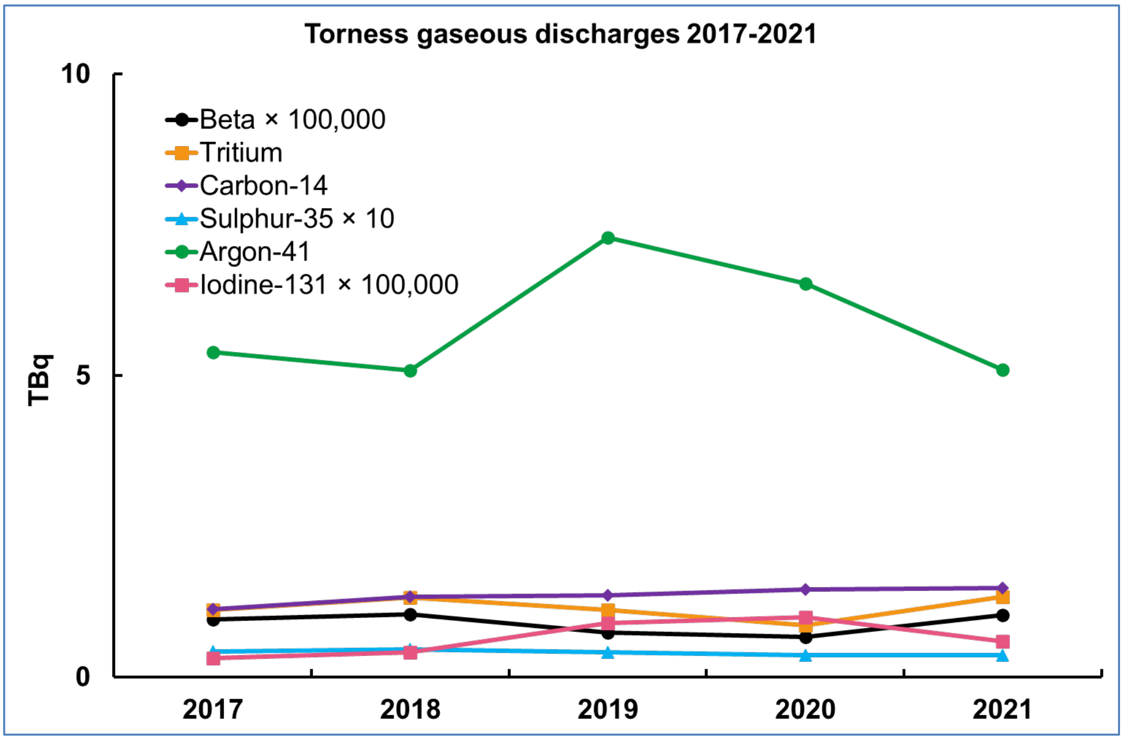


Figure 4.14 Gaseous discharges, Torness (2017 to 2021)

Sizewell B: Liquid discharges were generally similar over the reporting period, with some changes due to variations in power output discharges from year to year. Liquid tritium discharges were below 50% of the annual discharge limit between 2017 and 2021. Similarly, gaseous discharges were generally similar and were all low, however, carbon-14 discharges have increased due to extended periods of operation at full power.

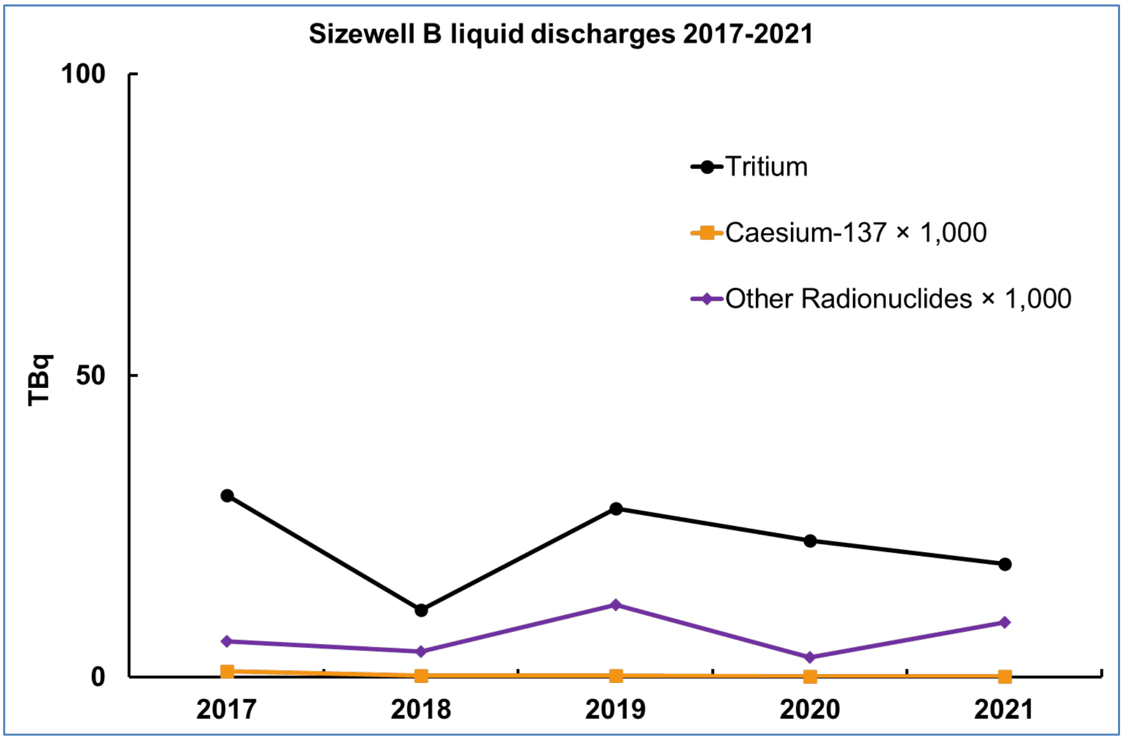


Figure 4.15 Liquid discharges, Sizewell B (2017 to 2021)

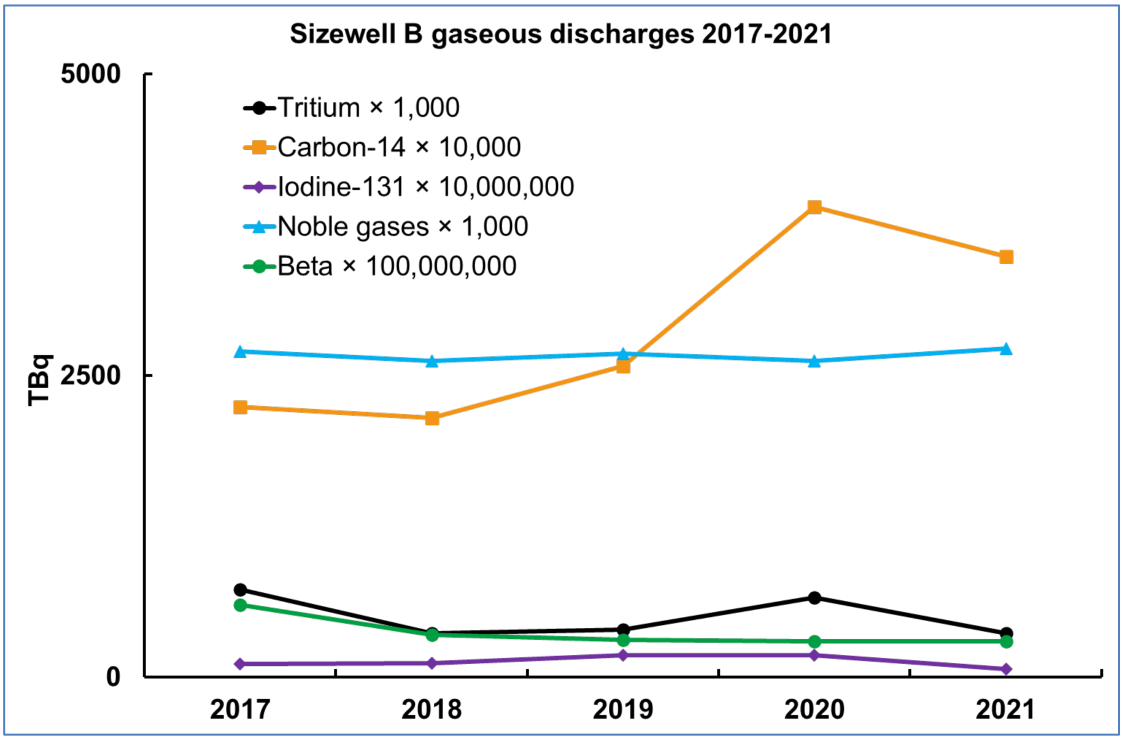


Figure 4.16 Gaseous discharges, Sizewell B (2017 to 2021)

4.2.5 Radiological impact of gaseous and liquid discharges for AGRs and PWR

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series 'Radioactivity in Food and the Environment' (RIFE). The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 9.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 9.3)
- a summary of trend data for power generation sector (2004 to 2021) (Part 2, Section 9.5)

4.2.6 The application of BAT for AGRs and PWR

EDF Energy Nuclear Generation Limited's environmental operational rules (referred to as Environmental Specifications or ESpecs) identify:

a) which plant should be in service at any time to protect the environment
b) what action should be taken if that plant is not available
c) appropriate investigation and action levels for radioactivity in effluent

Maintenance of environmentally sensitive plant is controlled via an Environmental Maintenance, Inspection and Testing Schedule (EMITS). The ESpecs and EMITS are based on documents that are required for nuclear safety purposes by the nuclear site licences and also for protection of the environment in accordance with Radioactive Substances Regulations.

Nuclear fuel is a source of fission products, and a management objective is applied to ensuring that fuel delivered to the power station is of high quality and that fission products are contained. The abatement techniques commonly employed at operational AGR and PWR stations are summarised in Table 4.2.

Table 4.2 Operational AGR and PWR Power Station Abatement Techniques

Station	Liquid Abatement	Gaseous Abatement
AGRs and PWR	Fuel integrity Delay Tanks Ion exchange Filtration Oil separation Reactor coolant chemistry Spent Fuel Ponds chemistry	Fuel integrity High Efficiency Particulate Air filtration Sintered metal filters Charcoal adsorption Reactor coolant chemistry

AGR Approach

Once an aqueous effluent has reached the Active Effluent Treatment Plant, there is further capability to remove particulate and soluble radioactivity in the supernatant water (if required). Particulate filtration and oil separation is normally used but the plants also contain ion exchange units, which are used as appropriate. Since the normal wastes from the Active Effluent Treatment Plant contain relatively low levels of radioactivity, the routine use of these units is not considered to constitute BAT as it would lead to the production of associated solid waste. Furthermore, the high ionic strength of the liquids in the plant reduces the effectiveness of these units in reducing radioactivity levels. However, these ion exchange units are available to use if there were a significant increase in the level of radionuclides in the liquid effluent.

Since spent fuel cooling ponds are a potentially significant source of liquid radioactivity arising in the Active Effluent Treatment Plant, the radioactivity present in these fuel ponds is reduced in a number of ways:

- bottling of fuel that has been found to be defective in-reactor, thus guarding against the release of significant quantities of fission products into the fuel pond water
- buffer storage of irradiated fuel stringers, which reduces the time that fuel is held in the cooling ponds, and so reduces the time over which radioactivity is released into the pond water.
- controlling the pond water chemistry to minimise corrosion of fuel cladding
- carrying out an intensive monitoring and cleaning programme on fuel flasks before they are placed into the pond and filled with spent fuel to prevent any cross-contamination from the site supplying the flasks
- pond water filtration
- pond water ion exchange

All these measures minimise the concentrations of loose particulate and soluble radioactivity in the pond water and hence waste transfers to the Active Effluent Treatment Plant. In addition, the caesium abatement strategy for AGR cooling ponds has been improved through deployment of an additional cation ion exchange resin with improved caesium selectivity.

There are additional measures to reduce the concentrations of radioactivity released in liquid effluents, including the retention of liquids in the Tritiated Water Storage Tanks to retain organic compounds floating on the water surface. Also at some stations, additional filtration has been installed to retain particulate organic material found in some of the Tritiated Water Storage Tanks. This filtration reduces the discharge of organically bound tritium.

The discharge control management system applied at AGR sites has evolved over the years and is appropriate for the discharges and the plants. Its aim is to ensure that the technology is reliable, currently available and meets regulatory requirements. Current discharges are believed to be as low as reasonably achievable, although measures to further reduce discharges are continuously reviewed and remain under consideration.

Several AGR reactors exhibit carbon deposition on internal reactor surfaces, including the fuel. This inhibits efficient heat transfer and can result in the fuel over-heating and leaking fission products into the coolant, which can then be discharged. A revised fuel design (robust fuel) has been implemented to minimise the risk of fuel failure through over-heating. Robust fuel has been introduced into reactors through their normal refuelling programme and now some AGRs are completely fuelled with robust fuel. Although the introduction of robust fuel may result in a small increase in discharges, an assessment by the AGR operator concluded that the benefits of robust fuel (e.g. reducing the chance of fuel failures) outweigh the detriments (e.g. the increase in discharges).

The approach presented above has been assessed to demonstrate that the consequent discharges are consistent with BAT.

In addition to the above and prior to discharge to the environment, aqueous effluents are held in a Final Monitoring and Delay Tank. A pre-discharge sample is taken from these tanks, then analysed and if activity levels exceed any action level, the effluent can be recirculated for further treatment / abatement. A discharge is only made when all criteria detailed on a ‘quality plan’ are met and signed off by suitably qualified and experienced personnel.

PWR Approach

At Sizewell B, reliable systems are also in place to manage discharges. Discharges are filtered, and ion exchange is used when the activity of effluent is such that significant reductions can be achieved. The quality of resins has been improved over time to reduce the amount of ILW generated.

Sizewell B was constructed with 2 evaporators: one for recycling boric acid from the reactor coolant system, and one for abatement of liquid radioactive waste. However, evaporation of liquid for either purpose is not currently considered BAT, primarily because the consequent reduction of public dose is much less than the increased operator doses associated with the use of these systems. In addition, the small reduction in public dose is not considered sufficient to justify the cost of processing (evaporator and encapsulation) and the production of sufficient high-quality steam to run the evaporators.

The chemical conditions within the Reactor Coolant System are designed to reduce steel corrosion. The optimisation of coolant chemistry has been pursued at PWRs throughout the world. Organisations such as the Electric Power Research Institute (EPRI), to which Sizewell B subscribes, have made significant contributions on this topic. Therefore, the optimum coolant chemistry for each fuel cycle is reviewed and improvements are made accordingly.

Following refuelling, the Reactor Coolant System is filled with a boric acid solution made from demineralised water. The presence of dissolved gases (oxygen and nitrogen) in the demineralised water is strictly controlled in order to reduce production of carbon-14 and nitrogen-16 within the system.

Secondary neutron sources used to provide control information when the reactor is returned to power following a period of shut down are known to produce tritium. After a review of their continued use, comparing the nuclear safety risks versus the reduction in activity, it was decided to remove them completely to eliminate that source of tritium from discharges. This work has now been completed, such that there are no secondary sources within the reactor anymore.

In addition to the above, the same controls are applied at Sizewell B as those applied at the AGR sites for managing the release of effluent to the environment (i.e., pre-discharge sampling, analysis and recirculation of effluent as required to further minimise the radioactivity discharged).

4.2.7 Comparison with performance of similar plants world-wide

There are no directly comparable AGR installations outside the UK, but the dose impact is comparable to that from other types of power stations.

PWRs are the most common type of reactor in the western world. However, many reactors are inland and discharge to rivers, whereas Sizewell B discharges to the marine environment. This is established practice in the UK and is acknowledged to represent BAT.

Table 4.3 shows the estimated normalised discharges from global PWRs for 2010, taken from the most recent UNSCEAR report [11], compared with the normalised discharges from the Sizewell B power station, averaged between 2010 to 2021.

Table 4.3 Estimated normalized discharges from Global PWRs (in 2010) and Sizewell B (2010-2021)

	Normalized discharges (TBq/GWh)						
	Gaseous					Liquid	
	Noble gases	Tritium	131I	14C	Particulates	Tritium	Other
Global PWRs (2010)*	6.62 x 10-4	1.71 x 10-4	9.13 x 10-9	9.47 x 10-6	4.11 x 10-9	2.05 x 10-3	4.33 x 10-7
Sizewell B (2010-2021)**	3.89 x 10-4	8.86 x 10-5	2.21 x 10-9	3.58 x 10-5	6.06x 10-10	4.13 x 10-3	1.30 x 10-6

*UNSCEAR (2017) PWR data normalized to 'per hour' using 8766 hours per year.
** Sizewell B data normalised to 'per hour' using data from https://www.iaea.org/pris/

A comparison of the 2 normalised discharges shows many of the Sizewell B values are below the average 2010 global normalised PWR values. Values for some Sizewell B discharges, namely gaseous carbon-14 and liquid discharges are higher, but are generally comparable to the average global values.

4.3 Decommissioning power stations[10]

All Magnox power stations are defueled and are at different stages of decommissioning. Decommissioning strategies for Magnox stations and other UK civil nuclear facilities are the responsibility of the NDA.

Current reactor decommissioning plans are based on the following phases:

- defueling: Sites will be de-fuelled as soon as practicable after cessation of electricity generation. All of the Magnox nuclear power stations have been defueled and the fuel reprocessed at Sellafield. Spent fuel from AGR nuclear power stations will be transferred to interim storage on the Sellafield site, prior to final transfer to a Geological Disposal Facility
- Care and Maintenance (C&M) preparations: The majority of facilities and buildings except the reactor buildings will be decontaminated and demolished.

[10] This category of sites comprises all power stations that have permanently ceased to operate and includes those in all stages of decommissioning.

The reactor buildings will be put into 'Safestore[11],' in other words, weather, and intruder resistant for the extended C&M period. Low Level Waste (LLW) is processed and disposed. A large proportion of the operational ILW, will be retrieved, packaged for safe interim storage until a ILW Geological Disposal Facility is available. Miscellaneous Activated Components will be safely contained within storage locations inside concrete vaults, (except at Trawsfynydd, see Table 5.6). In the future, Miscellaneous Activated Components will be retrieved for disposal during reactor dismantling. In the case of Chapelcross, Miscellaneous Activated Components are currently stored in ponds, where they will be size reduced and then packaged as ILW

- C&M: During this period, reactor sites will remain in a state of passive safety for about 85 years from cessation of generation. Sites will continue to be monitored and maintained to ensure they remain in a passively safe and secure state
- Final Site Clearance: This phase involves the final decommissioning activities whereby the remaining facilities (for example, Safestore, Interim Storage Facility) are demolished and the necessary work is undertaken to leave the site fit for its defined end-state and to release it from regulatory control

It is recognised that short-term increases in discharges may arise during decommissioning processes. This will be due to the associated processing of radioactive waste.

The current status of decommissioning power stations discussed in this section is summarised in Table 4.4.

Table 4.4 Status of Decommissioning Sites

Site	De-fuelling status	Decommissioning status
Berkeley	De-fuelled	Berkeley Safestores (previously reactors) 1 and 2 are now in their passive state for the Care and Maintenance phase. Projects are underway to retrieve and encapsulate waste currently stored in vaults (referred to as MILWEP and R4). The waste will be packaged and then stored on site within an Intermediate Storage Facility for ILW pending movement to the Geological Disposal Facility once it becomes available.
Bradwell	Defueled	The site is now in the Care and Maintenance phase. LLW and ILW retrieval treatment and processing, including dissolution of Fuel Element Debris (FED) has been

[11] 'Safestore' is a component of the preferred strategy for the decommissioning of UK Magnox and AGR. It refers to the period following defueling of reactors and C&M preparation, during which intruder-proof and weather-proof structures are constructed around the remaining site buildings housing the active reactors. The structure is left in a passive-safe state with minimum maintenance (other than routine surveillance) for around 85 years to allow for radioactive decay, after which the remaining structures on site are dismantled and the site restored and delicensed.

		completed. The reactor buildings and Ponds/Active Effluent Treatment plant have been closed and made into safe stores. The ILW store is operational. Bradwell site is now managed via Sizewell A.
Chapelcross	Defueled	All reactors were de-fuelled by early 2013 and is now undergoing decommissioning activities to reach the Care and Maintenance phase. Activities have been focussed on the retrieval, packaging and conditioning of ILW radioactive wastes for storage in the on-site Interim Storage Facility which has now been actively commissioned and is receiving packages.
Dungeness A	Defueled	Site decommissioning commenced in 2007. Activities have focused on the dismantling, demolition of structures and the retrieval, processing, and disposal of wastes. Divers have been used in the ponds to carry out clean-up activities (a first for the UK, taking experience from the US). The fuel cooling pond is expected to be drained between 2017 and 2018.
Hinkley Point A	Defueled	The site was de-fuelled prior to 2005 and is now undergoing decommissioning. Decommissioning activities have focused on the retrieval and disposal of wastes from the fuel cooling ponds to prepare for draining. Draining, partial decontamination and passivation of the 2 fuel cooling ponds was completed in 2016. Works are on-going for the retrieval, processing, and storage of ILW.
Hunterston A	Defueled	Hunterston A is undergoing decommissioning, having been defueled prior to 2005. Activities are on-going for the retrieval, processing, and storage of ILW wastes. The Fuel cooling pond was decontaminated and drained in 2019. The ILW store is operational.
Oldbury	Defueled	Oldbury ceased generation in February 2012 and achieved fuel free status early in 2016 and Post Operational Clean-Out began during the reporting period.
Sizewell A	Defueled	Defueling was completed in 2014. Post Operational Clean-Out activities are underway.
Trawsfynydd	Defueled	An ILW Store was constructed in 2008 and both Miscellaneous Activated Components Vaults were emptied by 2009. Pond lane decontamination is almost complete and 16 FEDEPS $3m^3$ boxes; 23 x $3m^3$ sludge drums and approximately $1500m^3$ of conditioned effluent treatment resins have been retrieved and stored in the ILW store in July 2017. All orphan# Low Level Waste (LLW) has been removed from the Active Waste Vaults and 13 FED boxes have been retrieved. The Reactor 2 vessel was purged in 2011 to reduce moisture levels. A capping roofing has been installed in both reactor buildings.

Wylfa	Defueled	Defueling operations were completed in 2019.

#No underpinned disposal route or agreed transfer established.

4.3.1 Sources of liquid effluent

Radioactive liquid effluents arise from reactor and fuel handling operations, and from practices such as removal of fuel cooling pond liquor and the retrieval and processing of wastes. The principal decommissioning sites are:

- spent fuel ponds management (where irradiated fuel is stored under water before being despatched for reprocessing)
- reactor defueling and decommissioning operations
- laundry operations
- ILW and LLW waste management

During de-fuelling, the most radiologically significant source of liquid effluents is the spent fuel storage pond water. Subsequently, the retrieval and processing of wastes and activities such as draining pond water become the major contributors to aqueous effluents from decommissioning sites. At decommissioning stations, site dryer liquors and spent fuel are no longer a source of activity.

Effluents produced as a result of reactor de-fuelling and decommissioning activities were considered as part of a BAT (or BPM) study and minimised accordingly.

4.3.2 Liquid effluent treatment and abatement

Discharges associated with decommissioning projects are assessed in advance to define the appropriate procedures to minimise the amount of radioactivity released to the environment. If a project or plant modification is identified as having a potential impact on discharges, then a BAT (or BPM, which applies in Scotland) assessment is carried out and the outputs are included in process planning and controls. In most cases liquid effluent from decommissioning projects is treated through existing treatment plants, however, new bespoke plants are sometimes required.

For these Magnox decommissioning sites, a Pond Water Treatment Plant is used to control the chemical environment of the fuel cooling ponds (this minimises the corrosion of the fuel elements stored in the ponds). For sites where the fuel has been removed the plant is also important for managing the wastes generated during the clean-up of the ponds. The Pond Water Treatment Plant contains ion exchange beds for the removal of radioactive species such as caesium, and sand pressure filters for the removal of particulates. Discharges occur only if chemical and radioactivity levels are within annual limits. Other aqueous effluents arising on site are passed through sand pressure filters in the Active Effluent Treatment Plant to remove residual particulate matter. Effluents are then accumulated in delay tanks, sampled and, if their activity content is acceptable, are discharged at optimum times (typically around high water) to avoid high local concentrations near the discharge outfall. Also at Oldbury, filter catchpots[12] have been introduced to prevent sediment input into the Active Effluent Treatment Plant.

On most Magnox sites, an Active Effluent Treatment Plant receives radioactive effluent from routine processes on sites, such as hand and floor washings. The plant effluent is generally filtered via sand pressure filters and in some case also through ion exchange resins, prior to discharge. Ion Exchange Plants consist of a cation unit and/or an anion unit. The cation ion exchange unit removes sodium ions, and some soluble metal ions (for example, caesium). The resin in the cation bed can be regenerated using sulphuric acid. The anion exchange unit removes sulphate, silica, chloride, and other non-metallic elements. The anion is regenerated with sodium hydroxide. The ion exchange units are efficient at removing strontium-90 and sulphur-35, as well as caesium-137. Sand pressure filters reduce the amount of radioactive particulates discharged; their efficiency varies between individual radionuclides and depends upon particle size distribution in waste stream. There are a number of particulate filter systems used at the Magnox stations, which include fine filters (5 to 10μm), often used in conjunction with coarse filters (15μm), to remove particulate from the effluent waste stream.

To support decommissioning of the Pond Water Treatment Plant and the Active Effluent Treatment Plant, a new temporary Modular Active Effluent Treatment Plant may be installed, or modifications made to existing treatment processes, to serve the same functions. Furthermore, some waste treatment plants may also have their own specific Active Effluent Treatment Plant to deal with effluent wastes that are generated during processing (for example, Bradwell had a specific plant for dissolution of fuel element debris (FED), as well as general site radioactive effluents). Treated effluents are accumulated in delay tanks and sampled to confirm that they are suitable for discharge. Historically, most Magnox sites discharged their effluent with the stations cooling water, but this does not occur during decommissioning as cooling water is no longer being discharged. Decommissioning sites may install a new active effluent pipeline for the decommissioning phase, where this is considered appropriate, to ensure effluent (which is no longer subject to large dilution from cooling water) is distributed appropriately in the environment.

As described above, a Modular Active Effluent Treatment Plant is being used at some sites (for example, Hunterston A) to abate radioactive liquid arisings during

[12] A catchpot is a vessel inserted in a pipeline to remove solid particles which may be entrained in an effluent stream.

the more advanced decommissioning stages. This is a generic modular design that consists of oil removal, particulate filtration, and ion exchange stages (as required), in addition to reception and monitoring, and delay tanks. The design has enough flexibility not to install the ion exchange stage for sites not requiring this type of abatement due to the composition of the effluent. Reviews are being undertaken to determine appropriate Modular Active Effluent Treatment Plant configuration for effluent treatment at other sites (for example, Chapelcross, Hinkley, Oldbury and Dungeness) and to show these configurations are BAT. Where required, additional trials will be undertaken to prove the technology is appropriate, given the range of effluent compositions.

4.3.3 Trends in discharges over the 2017 to 2021 period

The variation in discharges is primarily associated with the phasing, nature and scale of operations and decommissioning projects. In this Section, Figure 4.17 to Figure 4.34 illustrate the variations in discharges over the reporting period (2017-2021) for each site. Figure 9.3 and Figure 9.5 (in Part 2, Section 9) also show time trends of discharges over a longer period (2004 to 2021).

Berkeley: For liquid discharges, the slight increase in other radionuclides over the period 2018-2021 was attributed to a range of decommissioning work.

Gaseous discharges of beta radiation appear to have increased over the reporting period but are still relatively low.

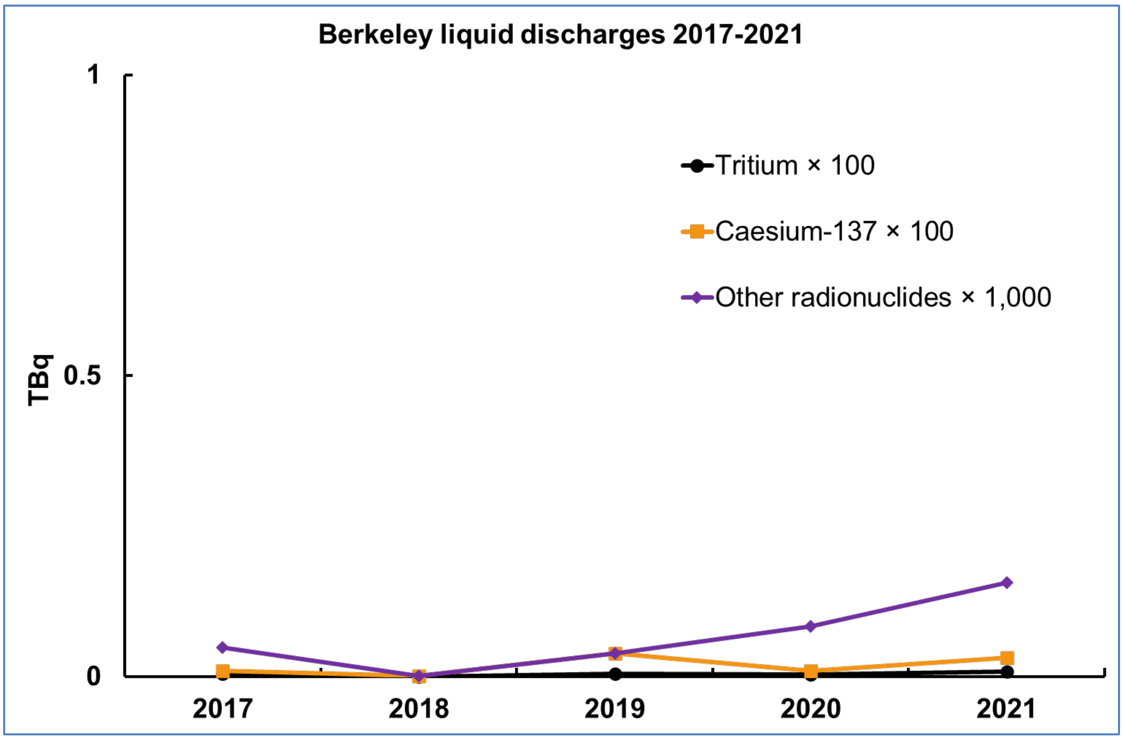


Figure 4.17 Liquid discharges, Berkeley (2017 to 2021)

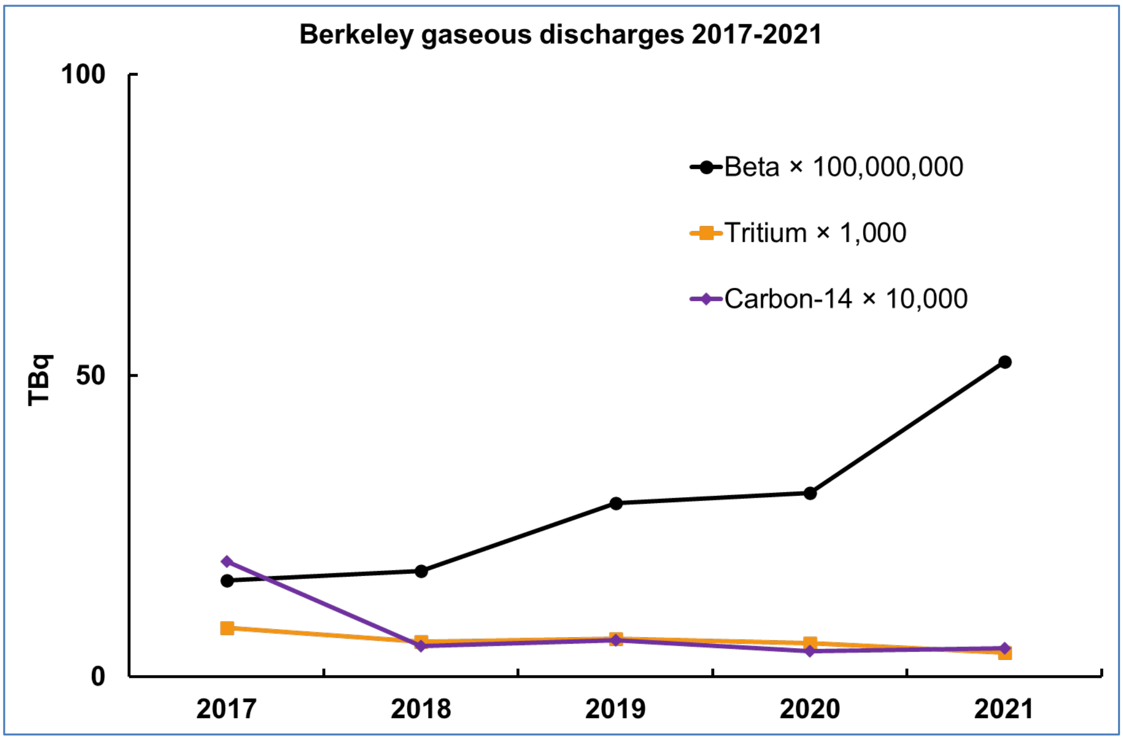


Figure 4.18 Gaseous discharges, Berkeley (2017 to 2021)

Bradwell: In 2018, Bradwell became the UK's first Magnox site to reach the interim end-stage of passive Care and Maintenance, following an accelerated decommissioning programme.

As a consequence, liquid and gaseous discharges dropped from 2018 and remained very low until the end of the reporting period.

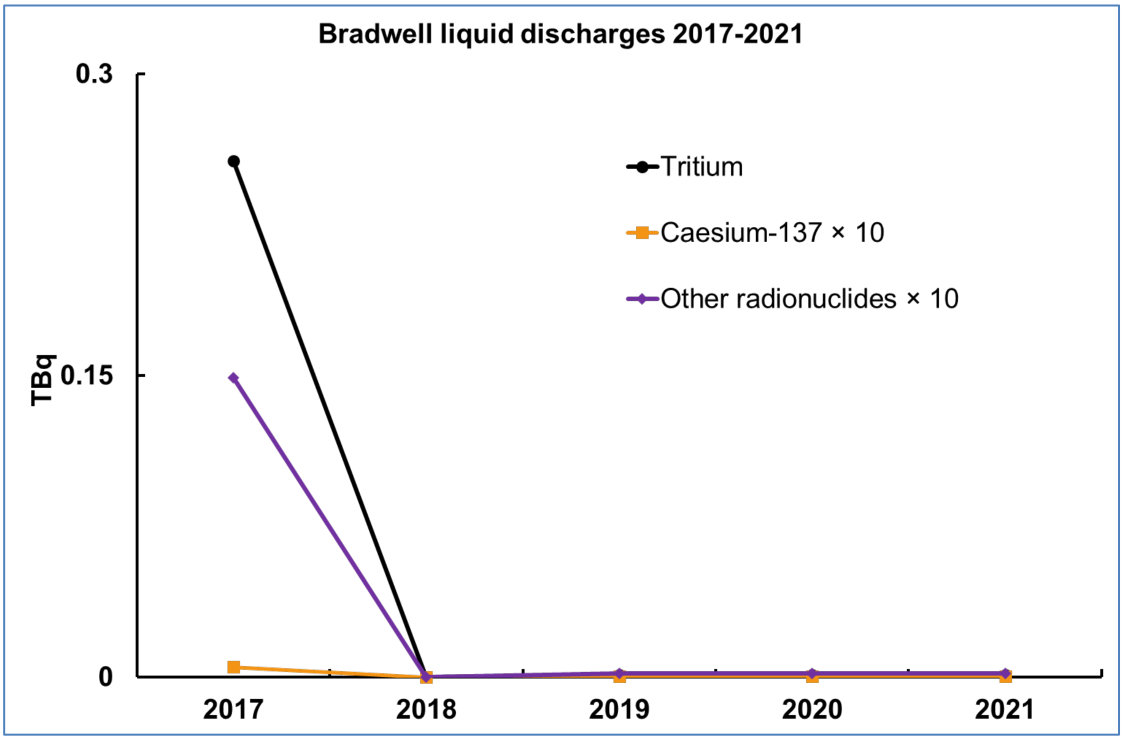


Figure 4.19 Liquid discharges, Bradwell (2017 to 2021)

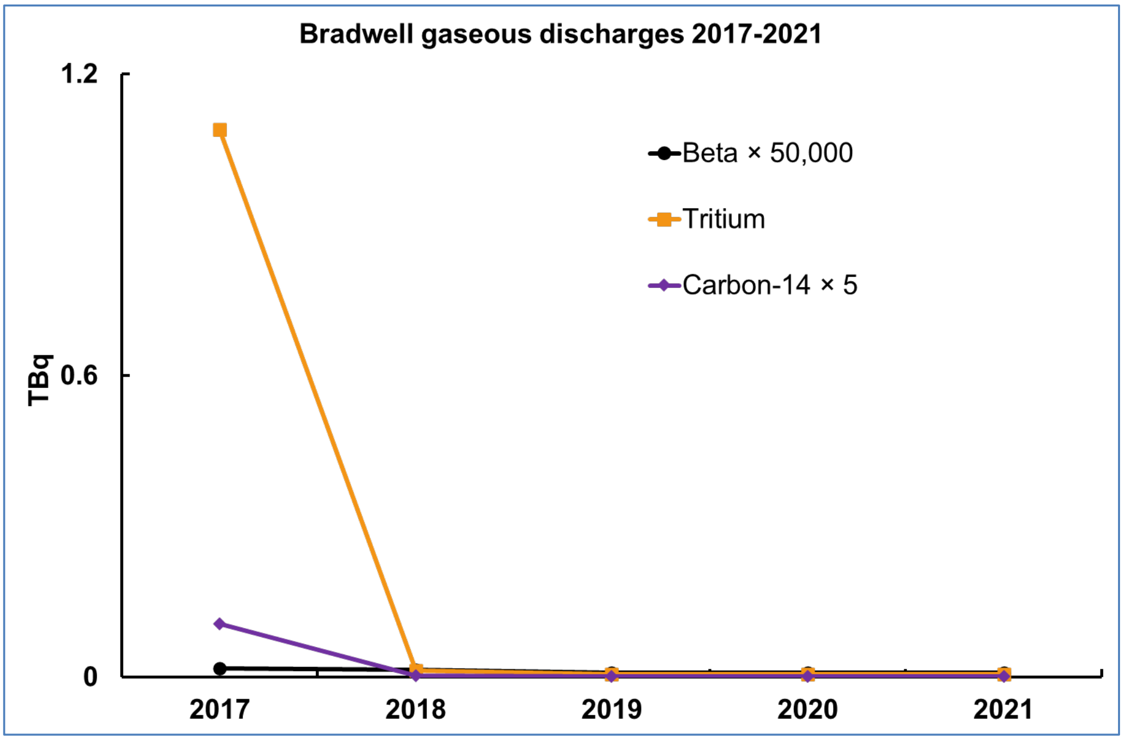


Figure 4.20 Gaseous discharges, Bradwell (2017 to 2021)

Chapelcross: Liquid and gaseous discharges were similar over the reporting period and remain low. Discharges have been operating on a campaign basis, with disposals occurring approximately once per year, rather than occurring throughout the year. There was no disposal campaign for liquid radioactive waste in 2019 and 2020.

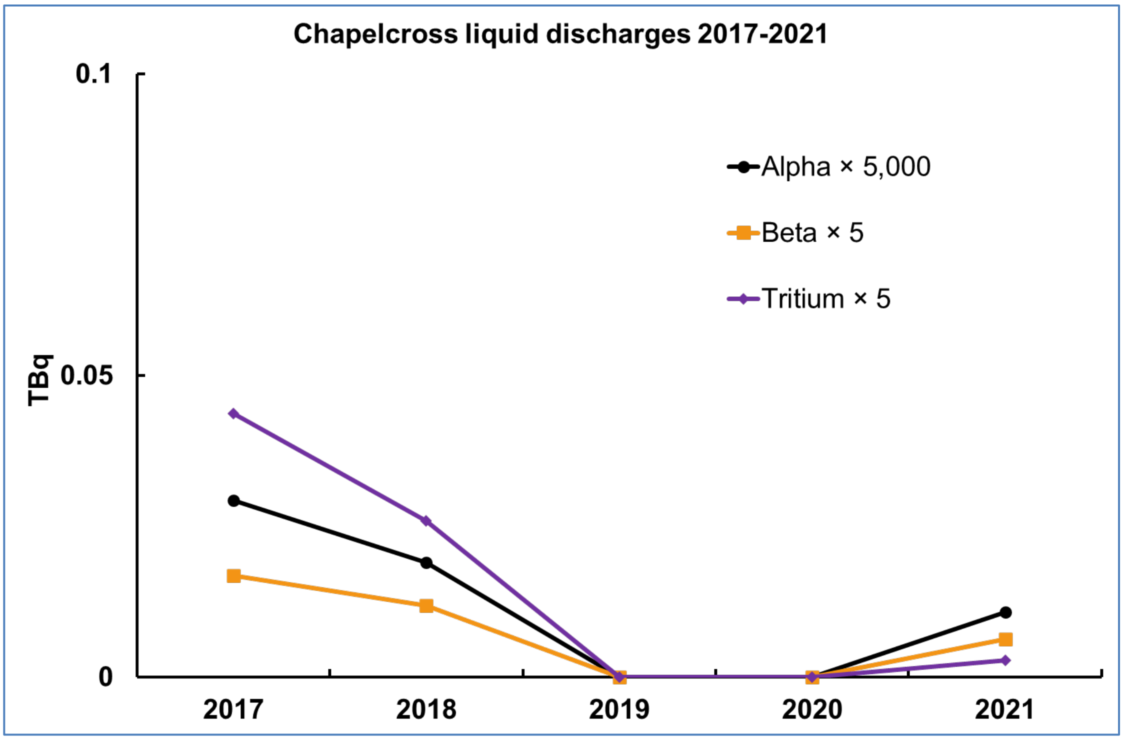


Figure 4.21 Liquid discharges, Chapelcross (2017 to 2021)

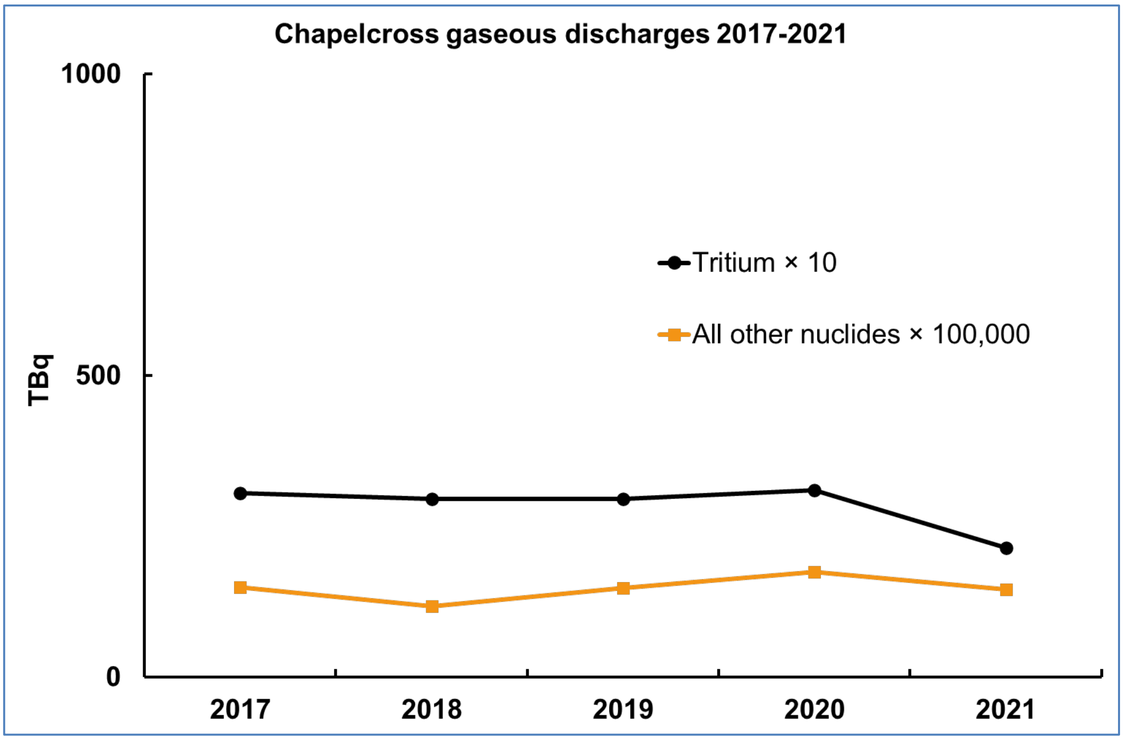


Figure 4.22 Gaseous discharges, Chapelcross (2017 to 2021)

Dungeness A: An increase in liquid discharges of other radionuclides was observed in 2019 but remained low. The gaseous discharges of tritium have generally increased overall by the end of the reporting period but remained low.

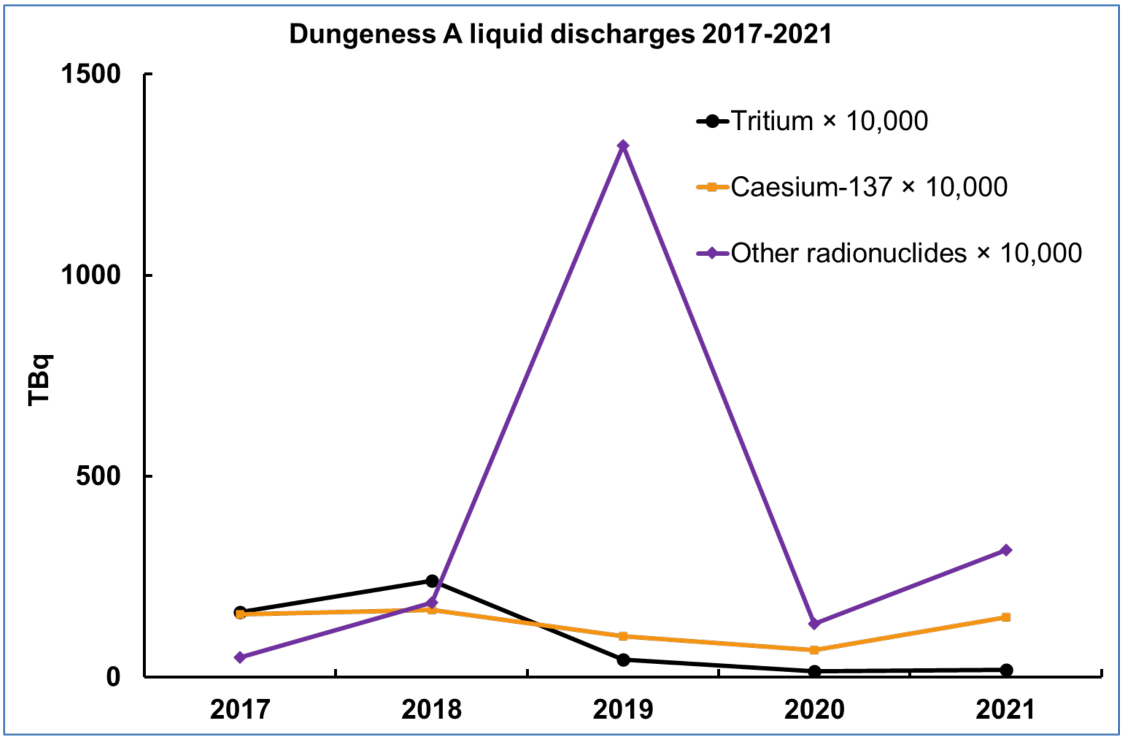


Figure 4.23 Liquid discharges, Dungeness A (2017 to 2021)

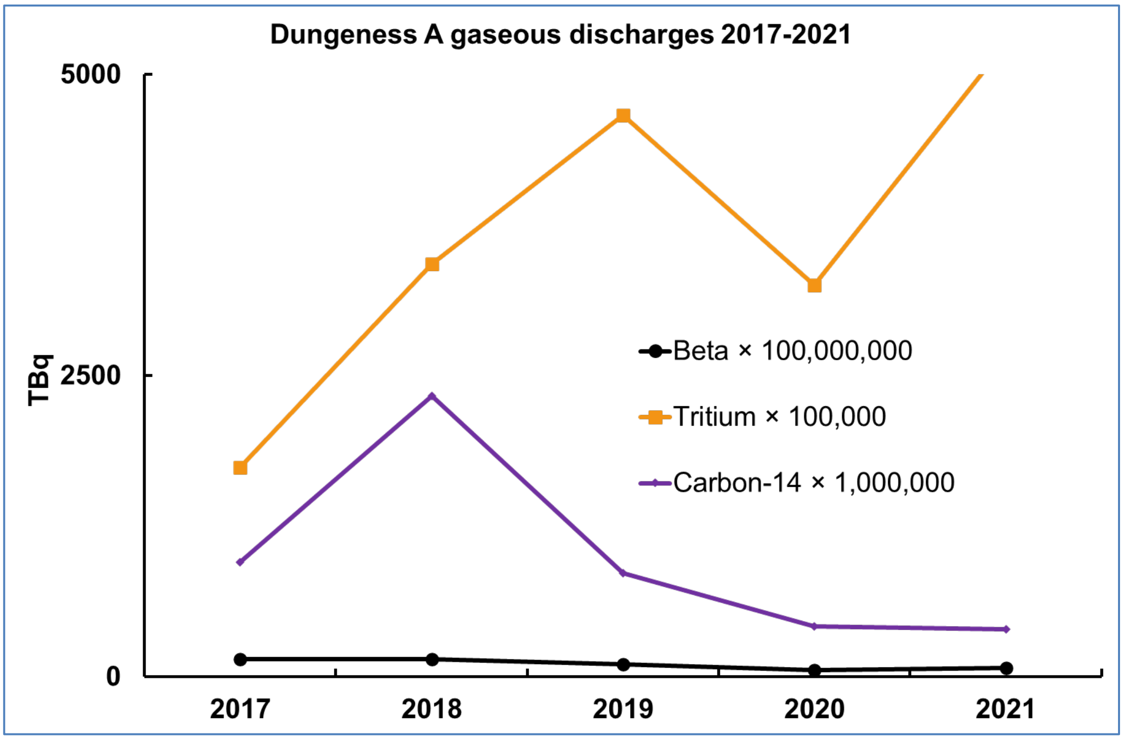


Figure 4.24 Gaseous discharges, Dungeness A (2017 to 2021)

Hinkley Point A: Overall, liquid discharges of tritium and caesium-137 have continued to be very low during the reporting period. The discharge of other radionuclides increased in 2017 but decreased the following year and remained low for the rest of the reporting period. This increase was related to decommissioning activities with the former fuel cooling ponds.

Gaseous discharges were generally similar from year to year and are significantly lower than the annual limits.

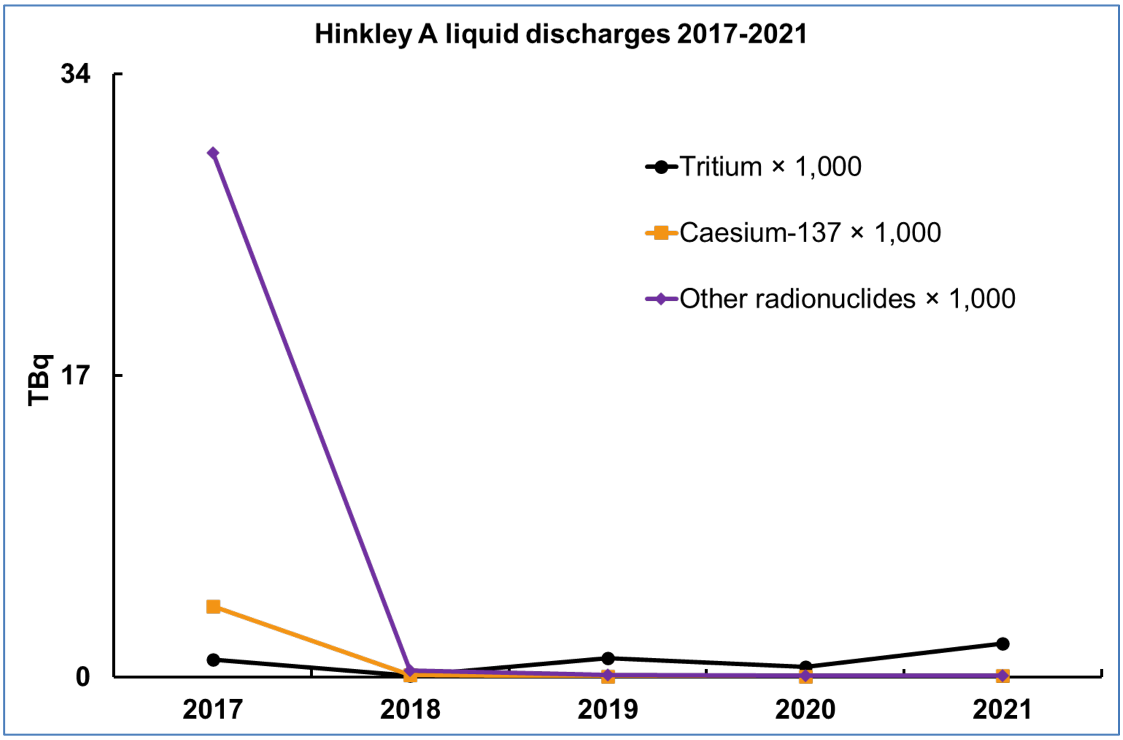


Figure 4.25 Liquid discharges, Hinkley Point A (2017 to 2021)

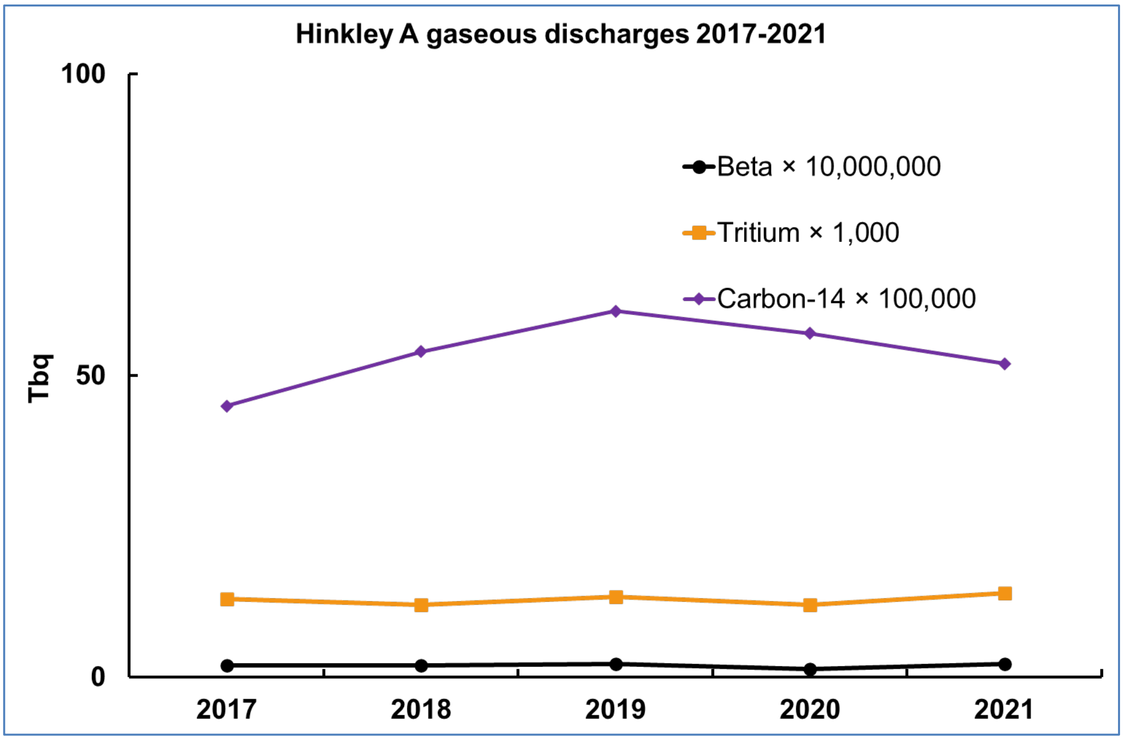


Figure 4.26 Gaseous discharges, Hinkley Point A (2017 to 2021)

Hunterston A: Liquid discharges generally decreased over the reporting period

Gaseous discharges were generally similar, except for other radionuclides than tritium and carbon-14 which decreasing over the reporting period.

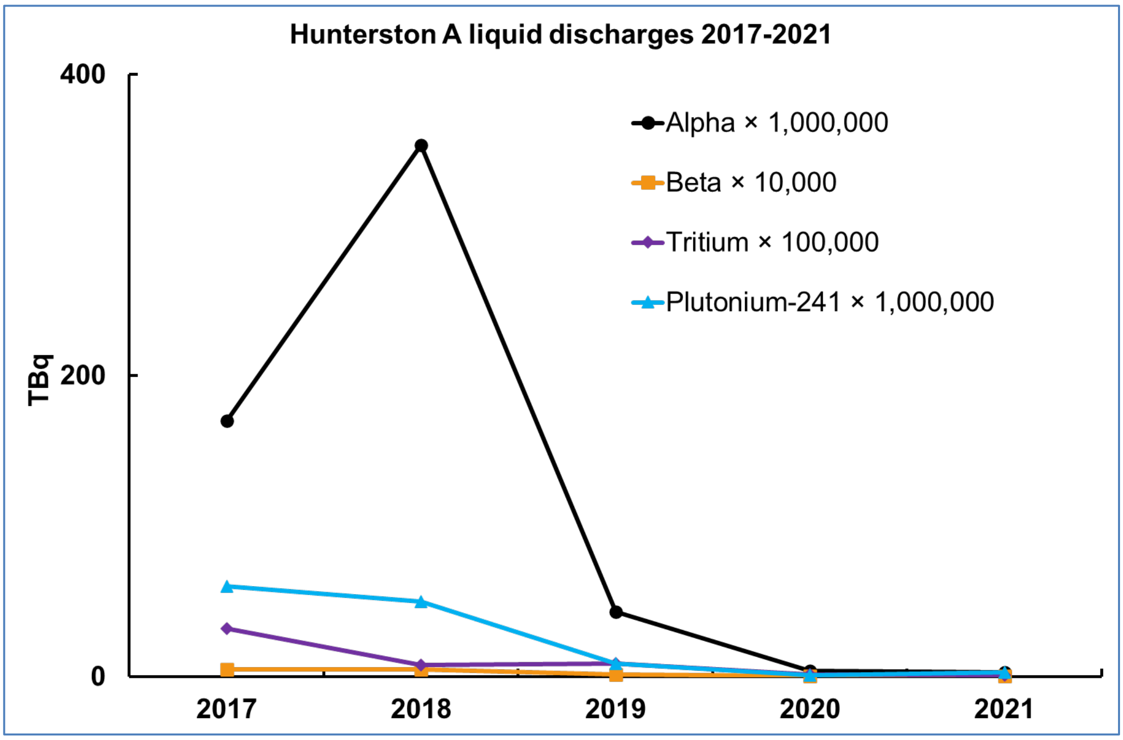


Figure 4.27 Liquid discharges, Hunterston A (2017 to 2021)

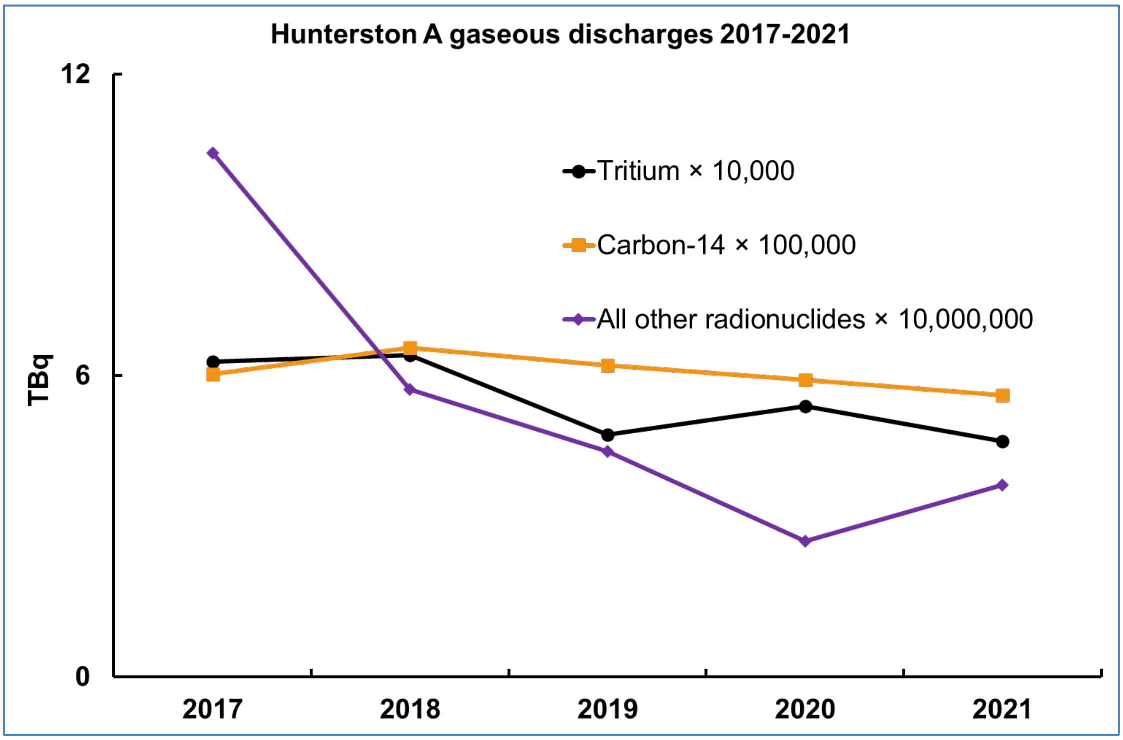


Figure 4.28 Gaseous discharges, Hunterston A (2017 to 2021)

Oldbury: Over the reporting period, liquid and gaseous discharges were similar from year to year and remained very low.

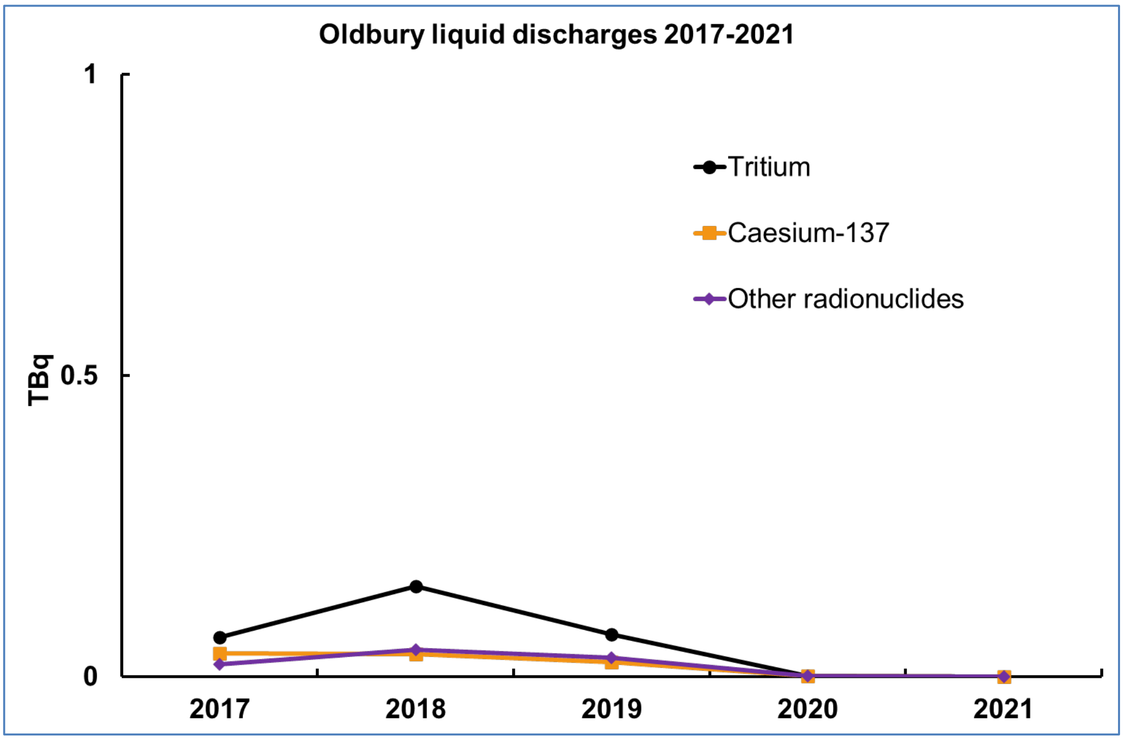


Figure 4.29 Liquid discharges, Oldbury (2017 to 2021)

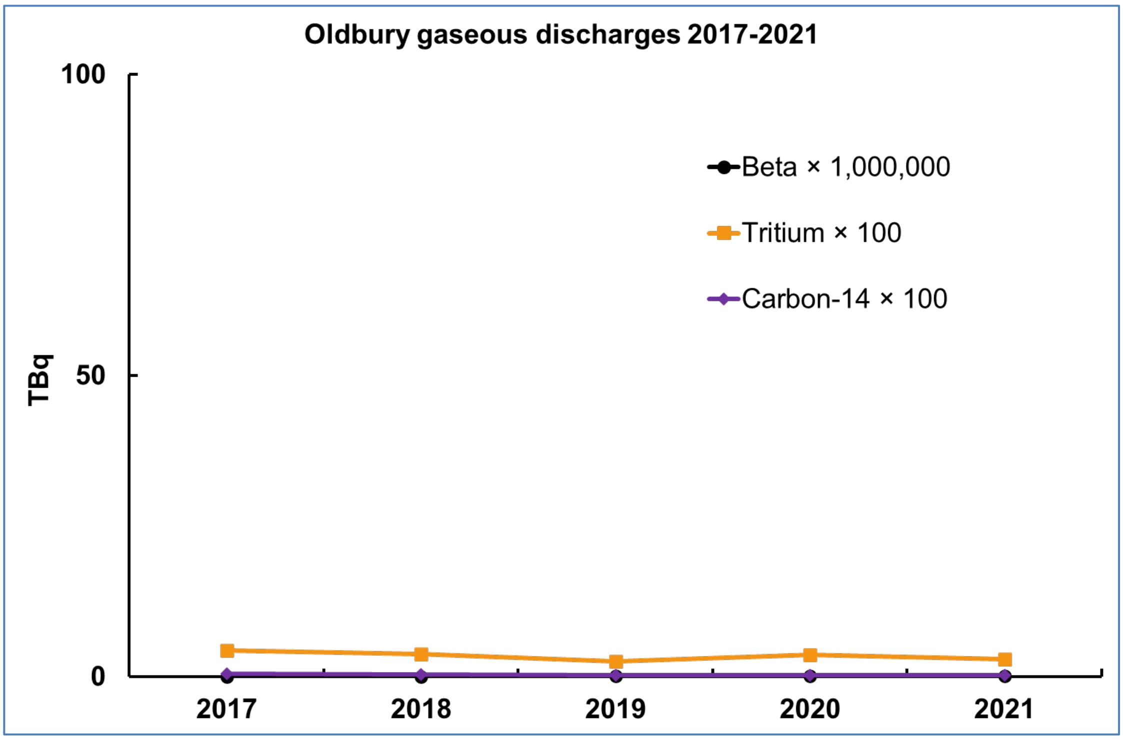


Figure 4.30 Gaseous discharges, Oldbury (2017 to 2021)

Sizewell A: Liquid discharges of other radionuclides than tritium and caesium-137 increased in 2017 and 2018 This fluctuation was due to decommissioning activities related to the lowering of Pond water pH in order to develop more efficient operation and management of the treatment plant. Discharges then decreased over the remaining part of the reporting period as the Pond was drained. This task was completed in 2019.

Gaseous discharges were similar over the reporting period and remained very low.

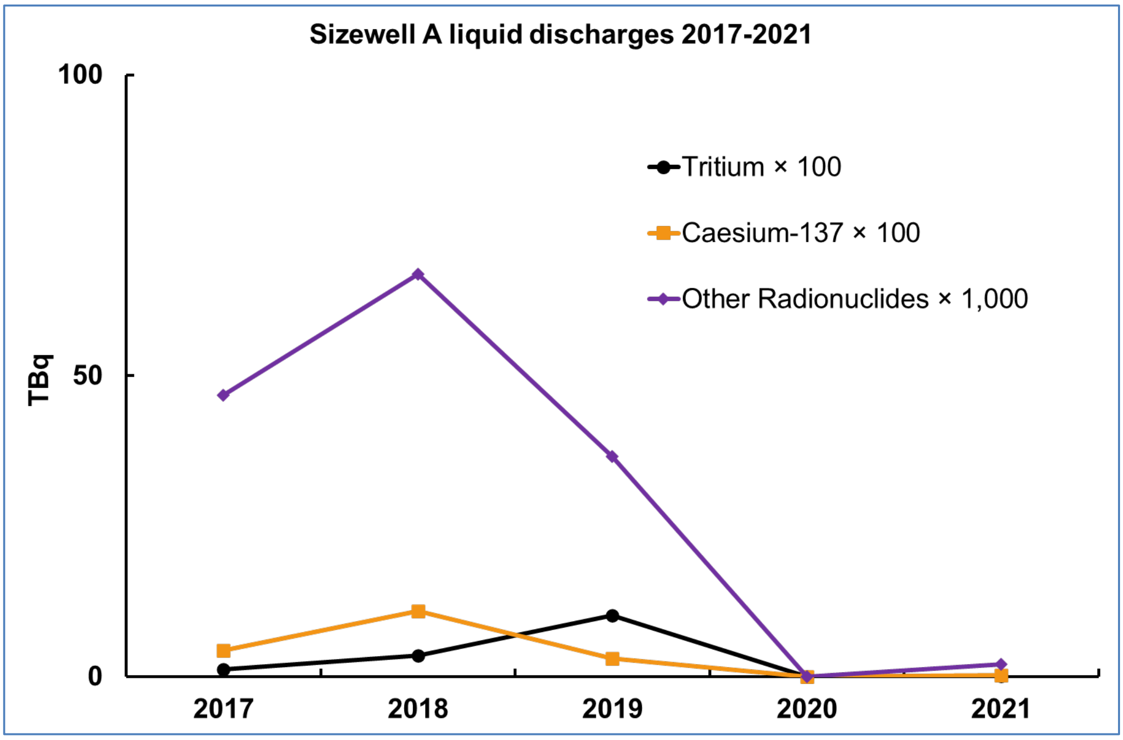


Figure 4.31 Liquid discharges, Sizewell A (2017 to 2021)

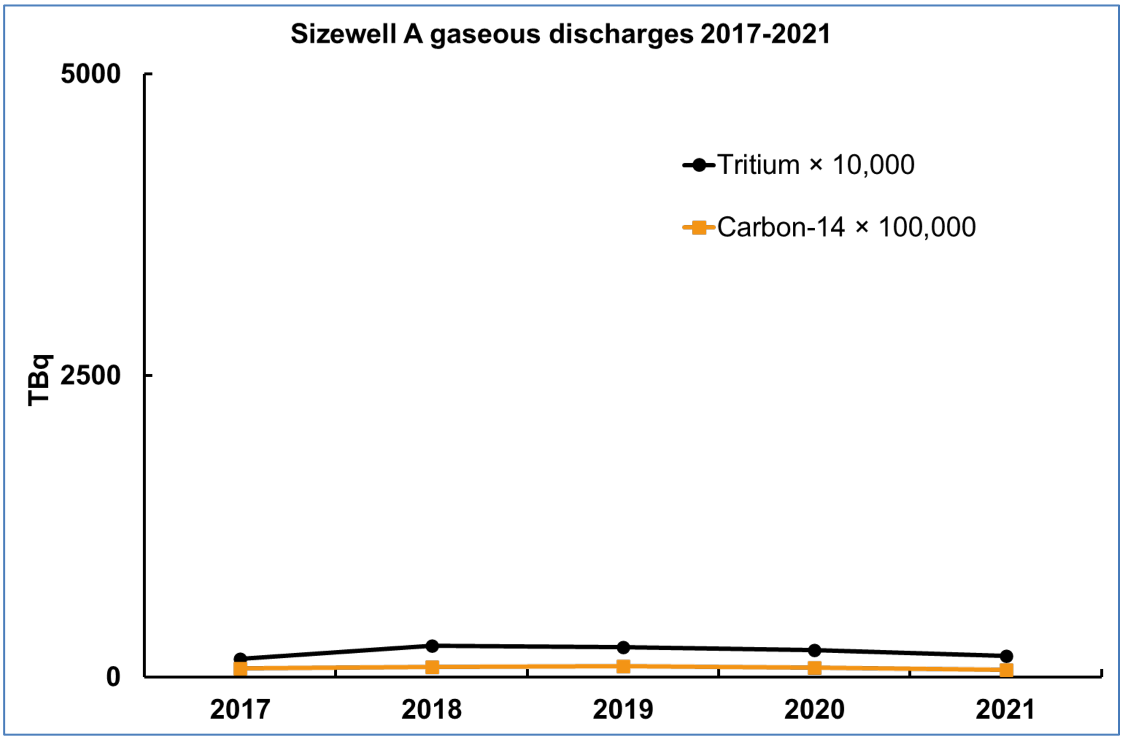


Figure 4.32 Gaseous discharges, Sizewell A (2017 to 2021)

Trawsfynydd: Liquid discharges are released to a freshwater lake and do not directly impact on OSPAR waters. However, data are presented for completeness. Liquid discharges have remained extremely low over the reported period. On-going decommissioning works on the site have had a minimal impact on liquid effluent discharges. Gaseous discharges generally decreased over the reporting period and remained very low.

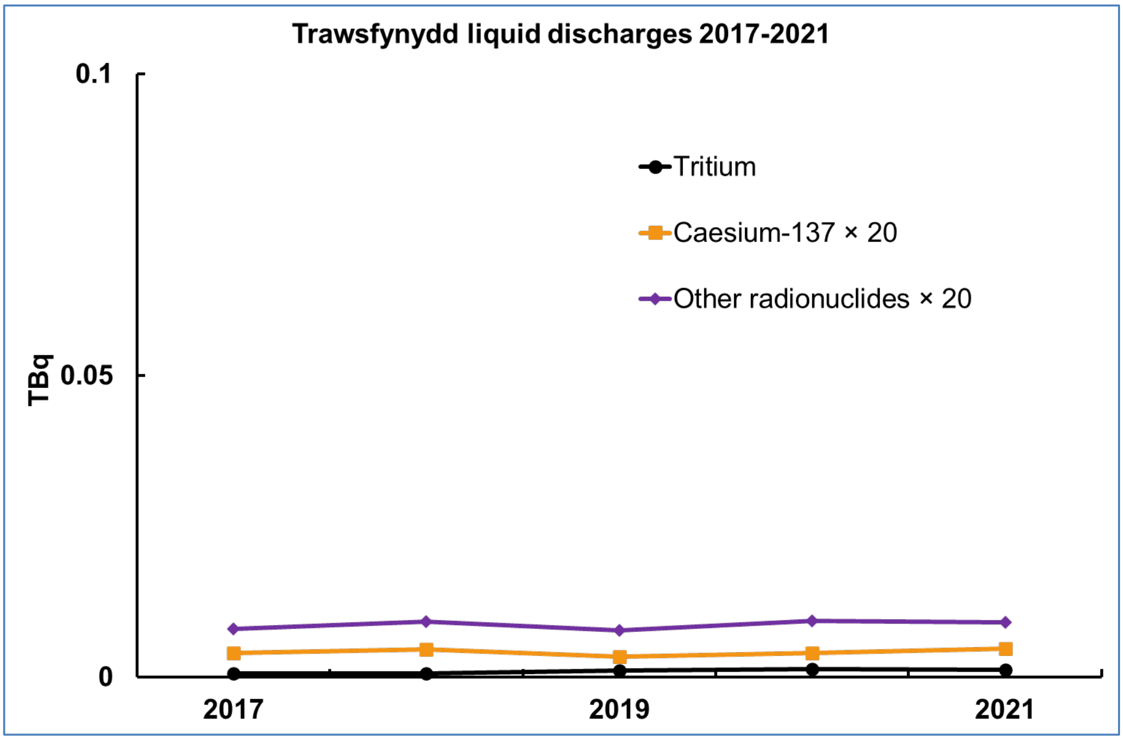


Figure 4.33 Liquid discharges, Trawsfynydd (2017 to 2021)

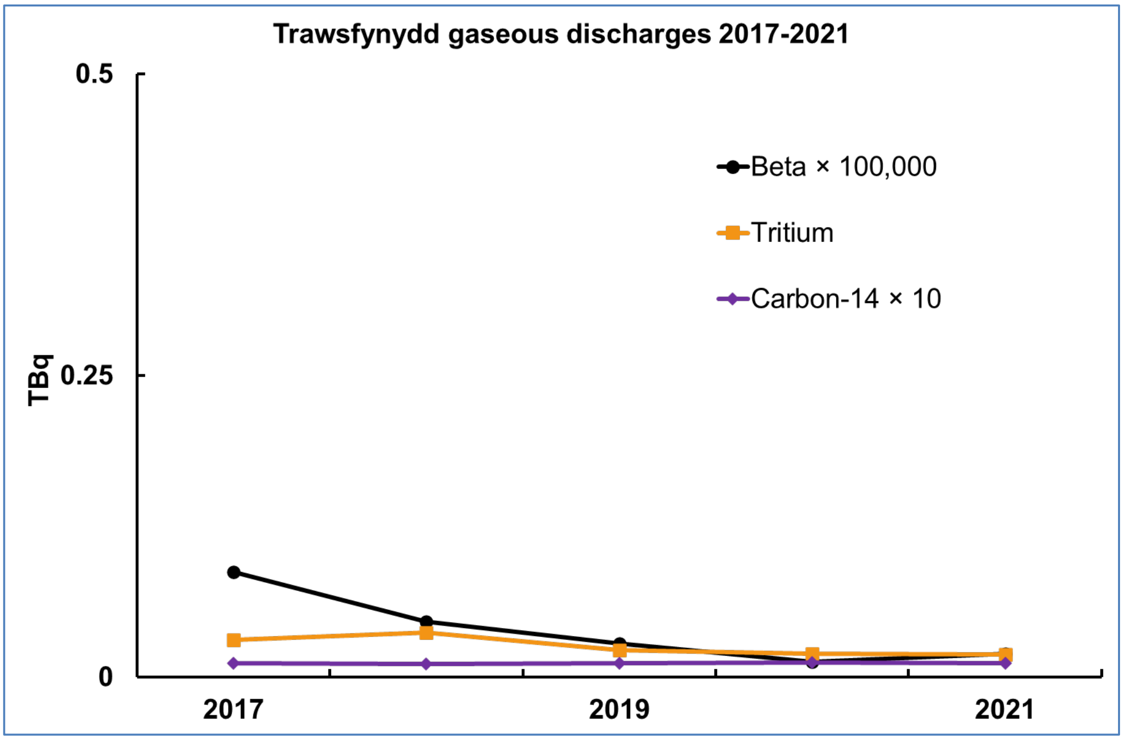


Figure 4.34 Gaseous discharges, Trawsfynydd (2017 to 2021)

Wylfa: Liquid and gaseous discharges were similar from year to year and remained low over the reporting period.

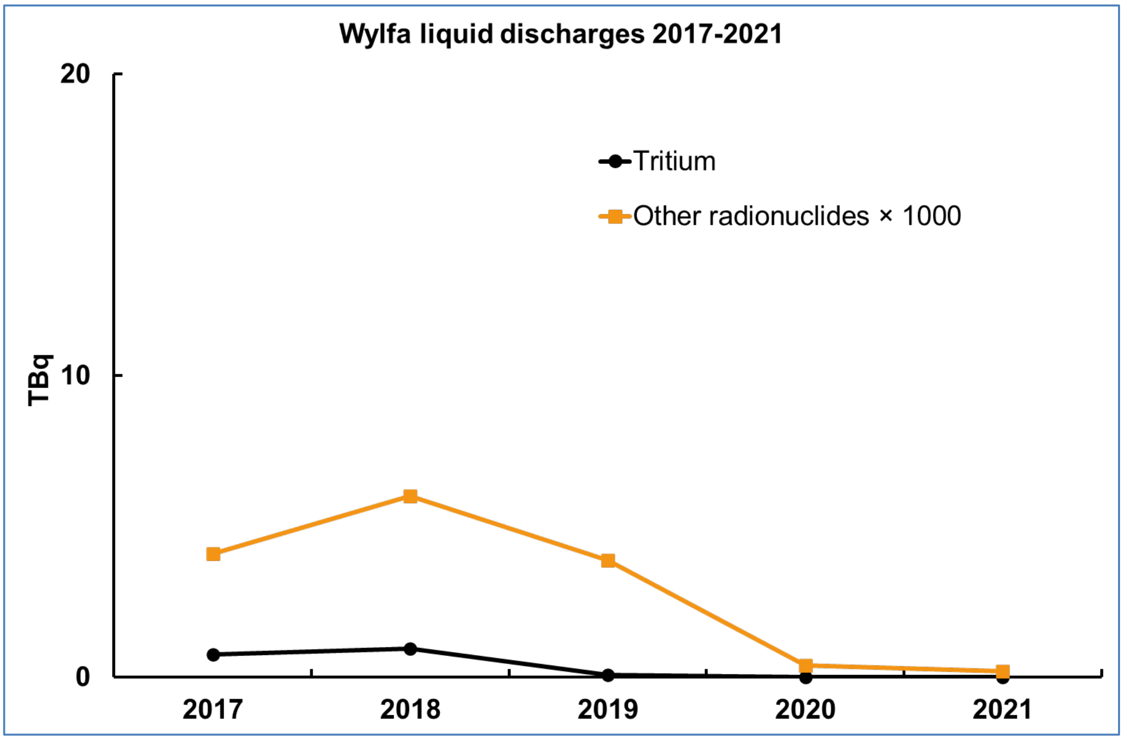


Figure 4.35 Liquid discharges, Wylfa (2017 to 2021)

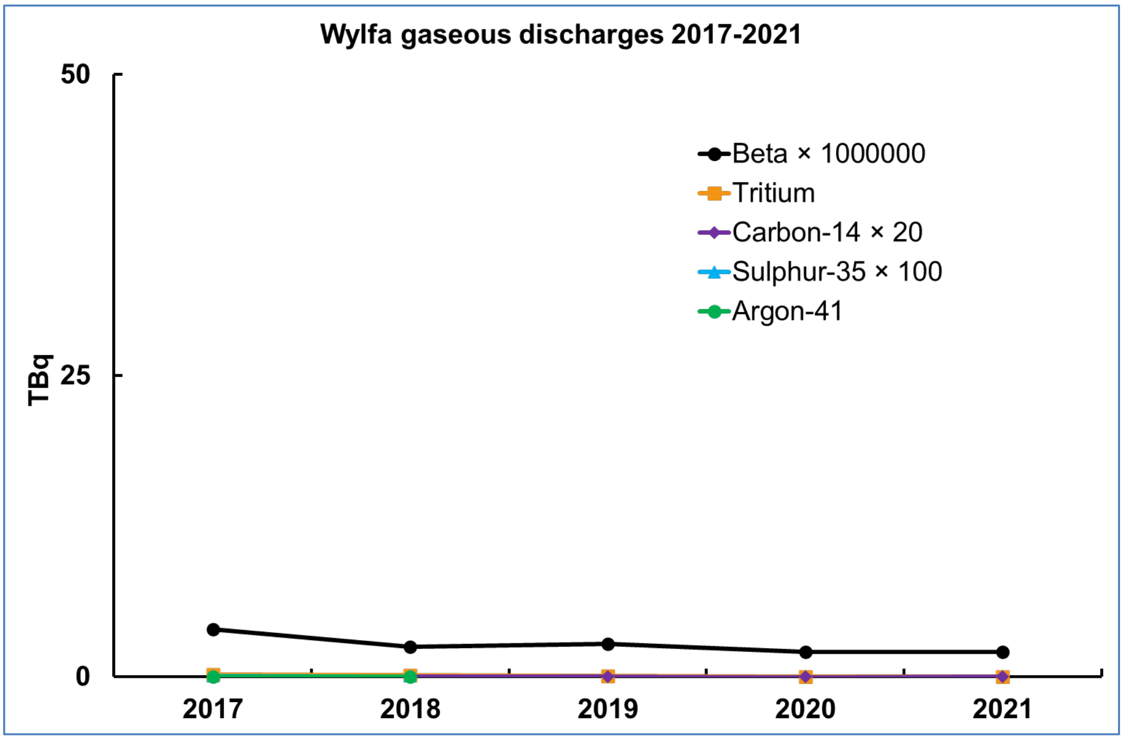


Figure 4.36 Gaseous discharges, Wylfa (2017 to 2021)

4.3.4 Radiological impact of gaseous and liquid discharges for Magnox

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004 to 2021. This has been achieved using the results of the environmental monitoring programmes, and the subsequent radiological assessments, that have been published in the annual report series 'Radioactivity in Food and the Environment' (RIFE). The information is provided in Part 2 of this report, as follows:

- time trends of 'total dose' (Part 2, Section 6.1)
- time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 6.2)
- time trends of exposure to the public, to the most exposed groups (Part 2, Section 9.1)
- time trends of radionuclide concentrations in food and the environment (Part 2, Section 9.3, 9.4)
- a summary of trend data for power generation sector (2004 to 2021) (Part 2, Section 9.5)

4.3.5 The application of BAT (decommissioning sites)

There are a number of management processes and controls that help achieve BAT. All Magnox sites have a plant labelling system which indicates environmentally sensitive plant/equipment. See Section 3.3.5 for more information. The abatement techniques commonly applied at decommissioning Magnox stations are summarised in Table 4.5.

Table 4.5 Decommissioning Magnox Stations: Abatement Techniques

Station	Liquid Abatement	Gaseous Abatement
Berkeley	No abatement where the bulk of effluent discharges are from hand washings and showers. Decontamination bath techniques utilising chemical cleaning. The waste effluent is separated using liquid settling techniques and filtration on extraction. All effluent is sampled prior to being consigned to the Liquid Effluent Compliance Plant. Controls are in place to ensure that no treated effluent is transferred to the plant that would be outside of the Liquid Effluent Compliance Plant Conditions for Acceptance.	High Efficiency Particulate Air filtration
Bradwell	None	High Efficiency Particulate Air filtration
Chapelcross	Delay tanks Settling tanks Ion exchange units Ion exchange units in the form of Zeolite skips are in use in the pond to manage soluble caesium-137.	High Efficiency Particulate Air filtration
Dungeness A	Delay tanks Fine filters Settling tanks Sand pressure filter	High Efficiency Particulate Air filtration

Station	Liquid Abatement	Gaseous Abatement
Hinkley Point A	Delay tanks Chemical precipitation Fine filter units Settling tanks FRAM Sludge and oil separators Ion exchange	High Efficiency Particulate Air filtration
Hunterston A	Delay tank Ion exchange Hydrocyclone Cartridge filtration	High Efficiency Particulate Air filtration
Oldbury	Delay tanks Sand filters Facet filters Filter catchpots	High Efficiency Particulate Air filtration
Sizewell A	Delay tanks Sand pressure filters Settling tank	High Efficiency Particulate Air filtration
Trawsfynydd	Modular Active Effluent Treatment system: Oil cartridge filters Coarse and fine polishing cartridge filters Hydrocyclone linked to a sludge settling tank	High Efficiency Particulate Air filters on contaminated ventilation systems

Station	Liquid Abatement	Gaseous Abatement
	Chemical dosing system Final effluent delay tanks	
Wylfa	Radial media filter (particulate removal system)	High Efficiency Particulate Air filters on contaminated ventilation systems. Main reactor pressure vessel ventilation is via supply of dry conditioned air (to minimise tritium discharges) discharged via High Efficiency Particulate Air filters.

The main function of the final delay tanks is to allow activity to be sampled and monitored to ensure compliance with discharge limits, prior to discharge into the sea.

The sand pressure filters reduce the amount of radioactive particulates discharged; their efficiency varies between individual radionuclides and depends upon particle size distribution in the waste stream.

Berkeley

At Berkeley, the current techniques being used for liquid discharge control have followed a detailed BAT assessment process. Prior to a project commencing decommissioning work, formal assessment is undertaken to ensure that the BAT is applied to minimise the production of secondary waste, including liquid effluent, at source. Radioactive effluent is treated for discharge using the Liquid Effluent Compliance Plant. The site bowser takes effluent from the different areas on site and transfers it to the Liquid Effluent Compliance Plant. All effluent is assessed to ensure that it is acceptable prior to transfer to the Liquid Effluent Compliance Plant. This plant stores effluent in the Ebb Tide Tank. After completion of full effluent discharge from the plant, the discharge line is flushed with town's mains water.

Bradwell

Prior to Bradwell entering its 'Care & Maintenance (C&M)' lifecycle phase in 2019, active effluent underwent a series of treatment options before discharge, including microfiltration, ultrafiltration, granular activated charcoal, and ion exchange. Active plant and systems were isolated and decommissioned when they had fulfilled their function and discharge outlets removed from the Permit once they became redundant to further support optimisation principles.

Upon C&M entry in 2019, the site reached a quiescent state with discharges reduced to fugitive emissions and water drainage. It was determined that no active abatement systems would be required for these discharges based on their very low impacts, the site does however still utilise mobile HEPA filtration systems to manage gaseous emissions during certain maintenance activities.

Chapelcross

At Chapelcross, radioactive liquid effluent is discharged to the Solway firth via the collection system and discharge tanks associated with the Ponds facility and the sea discharge pipeline. This arrangement uses the process of natural settlement to achieve abatement of discharges to the environment. Effluent is sampled and analysed to ensure it meets the requirements outline within the Permit before discharge. Samples are also obtained via a Proportional sampler to provide a representative sample of the discharge. Any new projects are subjected to BPM analyses to ensure the BPM is applied at source to ensure no unnecessary radioactive waste is generated.

The operational Pond radiochemistry is controlled and maintained by using zeolite skips.

A Modular Active Effluent Treatment Plant for Chapelcross is currently under construction at Chapelcross which will be used to treat site effluents and pond water at the time of final drain down (pond water will not be discharges until the Modular Active Effluent Treatment Plant Ion Exchange is available). BPM optioneering was undertaken, as per the company process, and determined that this option was the BPM for the site. This plant will provide abatement for soluble caesium and strontium and also provide the function of particulate and trace oil removal.

Dungeness A

Radioactive aqueous effluent at Dungeness A is discharged via the Active Effluent Water Treatment Plant (AEWTP). This plant consists of settlement tanks, sand filters and fine filters operating in series to abate the activity of any effluent discharged to the environment. Volumes of aqueous waste being discharged have significantly reduced recently following the successful draining of the redundant fuel cooling Ponds and the diversion of void water away from the active effluent system supported by BAT assessment.

Hinkley Point A

Hinkley Point A uses a range of processes (natural settlement, filtration, ion exchange resins, chemical flocculants) to achieve abatement of discharges to the environment. Deployment of these processes is determined by BAT requirements for the effluent. Treated effluent is routed to final monitoring delay tanks to allow sampling and analysis before being discharged.

Hunterston A

At Hunterston A, radioactive liquid effluent is discharged to sea via the Active Effluent Treatment Facility. Hunterston A has a dual system effluent treatment approach: effluent is initially retained in receiving tanks before being treated in either the Modular Active Treatment Plant (MAETP) or the Miscellaneous Cartridge Filtration Plant (MCFP) depending on the origins of the effluent. Both of these plants are part of the Active Effluent Treatment Facility.

Radioactive liquid effluent, originating from historical site fuel route facilities, containing both soluble and insoluble radioactivity is treated in the Modular Active Treatment Plant using ion exchange and particulate filtration. Low activity miscellaneous effluents arising from various sources on site with little or no soluble radioactivity which does not require ion exchange treatment are treated in the Miscellaneous Cartridge Filtration Plant using particulate filtration only. Following treatment in the MAETP or the MCFP, effluent is held in delay tanks for re-circulation and sampling prior to discharge to ensure that the discharge meets the requirements of the site's authorisation.

Trials are currently on-going for the installation of a new effluent treatment plant (NEffTP), similar to the current MCFP, in 2022/23.

Oldbury

At Oldbury, fuel is no longer stored on site and the fuel pond water has now been drained. All pond skips have been removed, characterised and size reduced, and all furniture has been deplanted from the ponds in preparation for processing and disposal. Two major projects are currently underway, one to physically empty the cation and anion tanks in the Pond Water Treatment Plant and one to complete sampling of sand medium in Sand Pressure Filters C and D within the Pond Filtration Plant to facilitate its removal and disposal. All other ILW tanks in the Pond Filtration Plant have been sampled already. Pro-active decommissioning clearance processes are used to minimise the generation of active waste.

There is a desire to divert some of the current influents to the Active Effluent Treatment Plant (AETP) (such as the hand washing and showers in the reactor block) to other routes once relevant permission has been obtained. This is part of the process of minimising the volume of material flowing into the AETP. The aim is that a smaller system can cope allowing the decommissioning of sections of the larger, existing AETP. Filter catchpots have also been introduced to the site drainage system prior to the AETP to segregate lower activity liquid sludge before it becomes cross contaminated with higher active liquors.

New passive ventilation ducts and sampling equipment were installed on the reactor vessels in 2017. The old Vessel ventilation systems and maintenance air driers were shut down at the same time; saving material, energy, and maintenance costs.

Projects are underway on site to consider the processing and packaging of ILW wastes at various potential locations, such as the loading of Ductile Cast Iron Containers with Sludge, Sand and Resin waste using a vacuum transfer system in the Fill House. To facilitate this, HEPA filtered MEUs are expected to be used to provide a cascade of air. Environmental support is being provided to the Projects to ensure BAT considerations are incorporated to decisions.

Sizewell A

At Sizewell A, aqueous discharges have significantly reduced with the draining of the redundant Fuel Ponds and isolation of the associated Ponds Water Treatment system. Aqueous discharges are further optimised using the process of natural settlement and filtration (using sand pressure filters). A review of the sites current and future aqueous treatment and discharge needs has highlighted the opportunity to adapt the current plant rather than installing a new mobile system which will ultimately reduce the amount of active plant requiring decommissioning and waste disposal prior to C&M entry. New HEPA systems have been installed on site to support Ponds decommissioning and waste processing with frequent checks of these systems, including stack sampling, to ensure that they remain in optimal condition.

Trawsfynydd

At Trawsfynydd Site, active effluent treatment facilities associated with the Ponds complex are no longer in use and are in the process of being decommissioned. The Site has a Modular Active Effluent Treatment Plant (MAETP), where incoming effluent is retained in one of two receipt tanks prior to undergoing treatment. For abatement of aqueous effluent, the MAETP employs an oil cartridge filter and two polishing filters (1μm and 10μm) and a hydrocyclone. The hydrocyclone is linked to a sludge settling tank, which enables the removal and consignment of sludge as radioactive waste. Once treated, the effluent is sampled and held in one of two final discharge tanks until analysis confirms that the effluent meets the requirement for discharge and that no further recirculation or processing is required. Ion exchange resins and flocculants were available when the system was originally commissioned, but given the low level of activity of effluent encountered during this stage of decommissioning these processes are not deemed as BAT due to the creation of additional waste streams.

Wylfa

At the Wylfa site, spent fuel was stored under dry conditions. The levels of active liquid effluents were therefore less than for other Magnox sites using cooling pond storage for spent fuel. At the Wylfa site (because spent fuel was dry stored) the Active Effluent treatment is much simpler (than for previously operating Magnox sites), therefore there were lower activity levels in aqueous effluents. Particulate material is removed through the use of radial media filters for liquid effluents and a particulate removal system. Effluents are then accumulated in delay tanks and discharged (providing analysis from pre-discharge sampling is compliant).

4.3.6 Comparison with performance of similar plants world-wide

There is limited scope for comparing performance with other plants world-wide due to the site-specific legacy issues. The focus on abatement options has been guided by having solutions that are appropriate and where possible using proven technology (from within and outside the nuclear industry) to balance the need to progress with decommissioning in a proportionate manner given the low radiological impact.

Magnox Limited management procedures are periodically reviewed and updated to reflect learning and good practice within the Magnox Fleet and practices from other organisations. There are numerous forums in which the company reviews performance. Internally, the company undertakes optioneering (for example, BAT/BPM assessments), strategy development, research, and development programmes. Externally, Magnox Limited supports and participates in EARWG (an industry forum which reviews BAT as it is applied to waste management). Subject

Matter Experts take part in British Standards Institute and International Standards Institute working groups in developing standards. Magnox is pro-actively engaged in various industry working groups such as the Ventilation Working Group sponsored by the Nuclear Safety Directors Forum. Magnox Limited participates in various NDA working groups (for example, Characterisation, NDA Technical Baseline and Underpinning Research and Development Requirements (TBuRD) Working Group). the Magnox TBuRD defines the scope of a number of development areas to seek the improvement of radioactive waste management.

5 The development and application of BAT

5.1 Introduction

The UK regulatory framework requires BAT (BPM in Scotland) to be used to minimise activity in radioactive discharges to air and to water from nuclear facilities. The UK regulators ensure that these requirements are met via conditions in the site permits/authorisations. Requirements are also met by programmes of inspection and audit of the operator's facilities. Assessments are undertaken by operators to inform the application of BAT or BPM to limit the activity of waste discharged, as described in the UK's country profile (LINK). Furthermore, the way in which discharge permits/authorisations are applied and reviewed, along with the supporting arrangements (for example, management arrangements and engineering controls) places a continuing requirement to demonstrate BAT. Thus, BAT, or BPM, as defined in the UK, together with the way in which these concepts are applied, delivers a level of discharge control that is at least consistent with BAT as defined by OSPAR.

A revised UK Radioactive Discharge Strategy was published in 2009 [12] and subsequently reviewed in 2018 [13]. This describes how the UK will implement the commitments in the OSPAR Radioactive Substances Strategy (RSS) on radioactive discharges to the marine environment of the North-East Atlantic. The UK Strategy has resulted in substantial reductions in radioactive discharges. The Environment Agency, NRW and SEPA have continued to take the strategy into account in their permitting/authorising decisions over the reporting period (as given in Table 5.1).

The permits/authorisations to dispose of radioactive waste continue to be periodically reviewed in a transparent, consultative, and integrated approach. The decision and explanatory documents associated with permits/authorisations are generally available on the environment agencies' websites and demonstrate the level of detail underlying the consideration of different abatement technologies and the corresponding discussions between the operator and regulator.

Table 5.1 New or varied permits/authorisations issued by UK regulators (2017 to 2021)

Year	Site	Text
2017	**Hartlepool**	Liquid Increase in the limit for sulphur-35.
	Springfields	Gaseous Introduction of a discharge limit for krypton-85
2018	**Aldermaston**	Gaseous Increase in the limit for volatile beta
	Capenhurst – UCP	Gaseous Introduction of discharge limits for uranium, other alpha emitting radionuclides taken together, technetium-99 and other radionuclides taken together
	Winfrith **(inner pipeline)**	Liquid Reduction in the limits for Alpha, Tritium, caesium-137 and "other radionuclides"
2019	**Bradwell**	Gaseous Decrease in the limits for Beta, tritium, and carbon-14
	Bradwell	Liquid Decrease in the limits for tritium, caesium-137 and "other radionuclides"
	Capenhurst – UUK	Gaseous Removal of the limits for alpha and beta (both incinerator)
	Wylfa	Gaseous Removal of sulphur-35 and argon-41 limits from the permit
	Cardiff	Gaseous The site operator surrendered its permit
2020	**Burghfield** **(Sewer)**	Liquid Began monitoring liquid alpha discharge
	Capenhurst – UNS	Gaseous Introduction of numerical limits for uranium, alpha-emitting radionuclides, and beta-emitting radionuclides.
	Sellafield	Gaseous The revised permit, issued in 2020, introduces a significant reduction in site discharge limits and a two tier (upper and lower) site discharge limit structure. The upper discharge limits will allow the site operator to undertake important decommissioning tasks. Where discharges have fallen below regulatory criteria for setting discharge limits, these have been removed from

		the permit. Plant discharge limits have been replaced by plant notification levels to allow the site operator to make the most effective use of the available discharge routes and treatment plants. A specific tritium limit for solid waste disposals at the on-site landfill site (Calder Landfill Extension Segregated Area). As a result, limits for iodine-131, radon-222 and plutonium-241 were removed from the permit. The limits for alpha, beta, tritium, carbon-14, krypton-85, strontium-90, ruthenium-106, iodine-129, caesium-137, plutonium alpha and americium-241 and curium-242 were retained (with lower limits) and the limit for antimony-125 was also retained.
	Sellafield	<u>Liquid</u> The revised permit, issued in 2020, introduces a significant reduction in site discharge limits and a two tier (upper and lower) site discharge limit structure. The upper discharge limits will allow the site operator to undertake important decommissioning tasks. Where discharges have fallen below regulatory criteria for setting discharge limits, these have been removed from the permit. Plant discharge limits have been replaced by plant notification levels to allow the site operator to make the most effective use of the available discharge routes and treatment plants. A specific tritium limit for solid waste disposals at the on-site landfill site (Calder Landfill Extension Segregated Area). As a result, the limits for zirconium-95 and niobium-95, caesium-134, verium-144, neptunium-237 and curium-243 and curium-244 were removed from the permit. The limits for alpha, beta, tritium, carbon-14, cobalt-60, strontium-90, technetium-99, ruthenium-106, iodine-129, caesium-137, plutonium alpha, plutonium-241 and americium-241 were retained (with lower limits). The limit for uranium alpha is now specified in Bq.
2021	**Berkeley**	<u>Gaseous</u> Permit varied to increase gaseous discharge limit for tritium
	Sizewell **(Station B)**	<u>Gaseous</u> Permit varied to increase gaseous discharge limit for carbon-14

5.2 Technologies in use or under development in the UK

5.2.1 Filtration

Techniques being used in UK nuclear installations employ the following main types of filter media, often in conjunction with decay storage and the application of suitable reagents and pH, to ensure precipitation of particular radionuclides.

- granular media such as sand or alumina of either fixed or varying grain size
- cloth or paper
- metal (or other rigid material) mesh
- carbon fibre, porous or sintered metal, and ceramic filters

The choice of filter media depends on the characteristics (generally, the particle size) of the material to be removed and the operational constraints; there is invariably a balance between filter rating (decontamination factor) and the required liquid throughput. Improved efficiencies are often achieved by placing filters of varying pore size in series. The principal area of development has been in regard to fine particulates (~ 0.001 to 0.1µm), filtration of which by fine pore media would normally require high pressure drops and low throughputs, and are therefore appropriate for removing low levels of activity from pre-treated liquid effluents.

Cross-flow filtration is receiving increasing attention, both for direct filtration of liquids and for the removal of solids formed by co-precipitation/flocculation treatments. The process stream is passed tangentially across the surface of the filter medium and a high cross-flow velocity is required if the formation of a filter cake is to be avoided. A clarified permeate passes through the filter and leaves a liquid with a greatly increased level of suspended solids/activity on the primary side of the filter – which can be removed as a separate mobile waste stream as required. An advantage of this technique is that it can operate on a ‘bleed-and-feed’ basis in a continuous loop; in this mode of operation, the primary side of the cross-flow filters works as a closed loop but is fed by new liquor at the same rate as the accumulated solid/active materials are bled off. It is possible to achieve a level of 10% solids in secondary waste bled from such a cross-flow loop and this is suitable for solidification in cement. The Enhanced Actinide Removal Plant (EARP) at Sellafield uses this process.

Two options are available for the removal of radionuclides in either the soluble or micro-colloidal forms in liquid effluent. The first is to Adjust the pH to facilitate a hydroxide precipitate and this is successful for some radionuclides. Other radionuclides (such as caesium-137) will not be removed by this process because a higher pH may be necessary to form a suitable precipitate. The second option is to seed the liquor with a fine powdered material which absorbs the radionuclide and is then removed by the filter. A number of seed materials have been identified and are mostly inorganic substances with ion exchange properties and include compounds such as hexacyanoferrates. These are able to absorb caesium radionuclides, even in the presence of a large excess of sodium ions, but are of little or no value for other radionuclides. For example, ion exchange resin has been used for this purpose in fuel ponds at a number of Magnox power stations.

The UK programme on ultrafiltration has sought to identify suitable seeds to provide not only high decontamination of radiologically important radioisotopes but also good overall beta-gamma decontamination. No single seed has been identified which can achieve this and development work has concentrated on the identification of cocktails of different seeds for this purpose. Co-precipitation and ultrafiltration form part of the EARP process at Sellafield.

5.2.2 Caustic scrubbers

Carbon-14 is released as carbon dioxide and carbon monoxide gases during fuel dissolution in the Magnox and THORP reprocessing plants at Sellafield. During the reprocessing of Magnox fuel, carbon-14 is released into the fuel dissolver off-gas ventilation system and is removed by sodium hydroxide (caustic) scrubbers.

The design of the dissolver and its nitric acid feed and off-gas treatment systems allows a significant fraction of the carbon-14 present initially in the fuel to be carried forward in nitric acid solution into the chemical separation process. Much of the carbon-14 gaseous releases are captured by caustic scrubbers, though some is discharged via high stacks.

In contrast to the Magnox Reprocessing Plant, THORP is designed to drive-off carbon-14 into the Dissolver Off-Gas treatment system and to minimise the amount of the radionuclide that is transferred into the uranium chemical separation process. In the Dissolver Off-Gas system, carbon-14 passes through an acid recombination column, an iodine desorber column and finally through a caustic scrubber, where it is removed from the gas stream. Carbon-14 is then removed from spent caustic scrubber liquor in a barium carbonate precipitate that is subsequently encapsulated in cement grout in the Waste Encapsulation Plant.

5.2.3 Ion exchange and adsorption

Ion exchange media used in the treatment and abatement of active liquids in nuclear installations in the UK are:

- organic resins – mostly crosslinked styrene-divinylbenzene copolymers or phenol formaldehydes which can carry various functional groups that provide the cation or anion exchange effect, and

- inorganic ion exchangers, such as hydrated metal oxides (for example, hydrous titanium oxide, hydrated iron oxide), insoluble salts of polyvalent metals (for example, titanium phosphate), insoluble salts of heteropolyacids (for example, ammonium molybdo-phosphate) and synthetic and natural zeolites (alumino-silicates)

The Site Ion Exchange Effluent Plant (SIXEP) at Sellafield is a notable example of the use of an array of pressure filters and ion exchange columns containing an alumino-silicate zeolite, clinoptilolite, to remove caesium and strontium isotopes.

A wide variety of organic resins have been developed which will cater for specific cations or anions, for example with a gel or macroreticular structure that have a high specific surface area and therefore give improved efficiencies. However, organic resins can give rise to disposal problems and the inorganic alternatives may then be more appropriate. Some of the inorganic media act as adsorbers rather than ion-exchangers and, to make them more efficient, are fabricated into beads or microporous gels with a high surface area.

5.2.4 Hydrocyclone centrifuge

Hydrocyclone centrifuges (for example, used in the Segregated Effluent Treatment Plant at Sellafield) remove solid radioactive materials by rapidly rotating the liquid effluent in a vortex, forcing particulate matter towards the wall of the centrifuge. The efficiency of this technique depends on particle size and particle density, and the overall effectiveness of the technique may be enhanced by treating effluents by a number of hydrocyclones in series.

5.2.5 Electrochemical and electrophysical processes

Most of these techniques use an applied electric field to separate radionuclides from the waste stream on the basis of their electrical properties. They have been developed only on a pilot scale and then only in regard to specific waste streams arising from certain nuclear operations. More development is required to enable introduction for large-scale treatment of liquors.

Electrochemical ion exchange has been tested with a number of simulated radioactive waste streams including those representative of Magnox and AGR ponds and PWR drains. The results have generally been very encouraging with high decontamination factors for a wide range of species being obtained. A number of issues require attention (for example, long-term stability of the electrodes, industrial manufacture of the electrodes, process scale up) but this approach has the potential to become an effective waste management technique, not only for radioactive species but also for heavy metal pollutants.

5.3 Conclusions

Progress in the application of BAT in the UK's nuclear facilities is clearly demonstrated in this report, specific examples (by nuclear sector) of processes and waste management activities occurred during the reporting period include:

5.3.1 Nuclear fuel production and reprocessing

- the development and implementation of Environment Cases, that include a demonstration of BAT and how it is implemented, for all operating plants and new project developments at the Sellafield site
- development and implementation of the Sellafield effluent management strategy discharge forecasting tool at Sellafield, which models the potentials impacts of different strategies on aqueous and gaseous discharges
- Reprocessing operations in THORP ended during this reporting period reducing the levels of some discharges associated with those operations
- Urenco ChemPlants Limited have constructed a new facility at Capenhurst, to allow safer long-term storage of depleted uranium, on a separate part of the site. This facility, the Tail Management Facility, will allow uranium to be stored in a more chemically stable oxide form for potential future reuse in the nuclear fuel cycle and will recover hydrofluoric acid for reuse in the chemical industry. The Capenhurst permit was varied in 2020 and introduced the discharge limits for the Tails Management Facility, which opened in 2019 and is currently undergoing commissioning.

5.3.2 Power Generation (operational)

- several AGR reactors exhibit carbon deposition on internal reactor surfaces, including the fuel. This inhibits efficient heat transfer and can result in the fuel over-heating and the leaking of fission products into the coolant, which can then be discharged. Two approaches have been adopted to minimise this risk. A revised fuel design (robust fuel) has been implemented to minimise the risk of fuel failure through over-heating and robust fuel is being introduced into reactors through their normal re-fueling programme
- in addition to the (bullet point) above, the injection of COS into the primary reactor coolant has been used to inhibit the deposition of carbon. COS injection increases discharges of sulphur-35, both in gaseous and aqueous forms, which is managed within permitted discharge limits
- at Sizewell B (the only PWR currently operating in the UK) reliable systems are also in place to manage discharges. The optimum coolant chemistry for each fuel cycle is reviewed and improvements are made accordingly. The presence of dissolved gases (oxygen and nitrogen) in the demineralised water is strictly controlled to reduce production of carbon-14 and nitrogen-16 within the system. Following review, secondary neutron sources were removed to

eliminate that source of tritium from discharges

5.3.3 Power Generation (decommissioning)

- at the Bradwell site, the new Aqueous Discharge Abatement Plant (ADAP) at Bradwell was actively commissioned in 2014 and has dealt with both general aqueous wastes and effluent from the FED dissolution plant. The performance of the plant has been monitored and has met the performance criteria specified in the BAT case for treatment of FED effluent
- Dungeness A completed the dissolution of Magnox FED in 2016. This is expected to lead to reduction in the volume of liquid discharges from the site over the next reporting period. In contrast, between 2017 and 2018 the fuel cooling ponds were drained has led to a short-term increase in activity discharged before an overall reduction is seen
- at Hinkley Point A, changes to abatement plant in the period have involved re-assessing the effluent fine filter requirements and limited usage of a hydrocyclone in pond draining operations and Kurion skid mounted resin abatement technology designed to reduce levels of caesium-137 and strontium-90
- at Oldbury, preparations for pond emptying and C&M are in progress. New passive ventilation ducts and sampling equipment is being installed on vessels (R1 and R2) in 2017. Vessel contaminated ventilation systems and maintenance air driers were shut-down in 2017, saving material, energy, and maintenance costs

5.3.4 Research and development

- at Dounreay, the Low-Level Radioactive Waste disposal facility adjacent to the site began accepting waste for disposal in April 2015
- at the Harwell site, Magnox Limited has installed a small and compact treatment plant that incorporates an evaporation stage (and cementation of concentrate). Key target nuclides are caesium-137 and strontium-90, but the process should be equally efficient for most radionuclides

5.3.5 Overall conclusion

The procedures and techniques applied in the UK nuclear industry are consistent with BAT. Measures are in place, as part of the permit/authorisation review process, to ensure BAT is considered and demonstrated. Where the regulators believe it is justified and proportionate they can, and do, impose improvement conditions. This includes the requirement to review and report, periodically, on international best practice on the abatement of discharges. The approaches identified in recent international reports are consistent with those currently adopted or under development in the UK.

The application of BAT has been effective in reducing discharges. There has been an overall reduction in discharges over the past 2 decades which followed the major reductions made in the 1970s and 1980s in the reprocessing sector, noting that discharges from this sector in the UK include arisings from legacy management activities including decommissioning.

The application of BAT in the UK brought about, for example, by stringent regulation, considerable investment in abatement plant, process optimisation and better application of the waste management hierarchy, including waste minimisation, has been effective in reducing discharges.

The UK will continue to apply BAT rigorously. Further substantial reductions in discharges may be increasingly difficult to achieve in some areas; in recent years we have seen fluctuations in discharges in line with operational throughputs and essential work to reduce hazards and decommission redundant facilities.

This page has been intentionally left blank

Summary of Radioactivity in Food and the Environment (2004–2021)

Department for Business, Energy & Industrial Strategy

Environment Agency

Food Standards Agency
food.gov.uk

Food Standards Scotland

Cyfoeth Naturiol Cymru
Natural Resources Wales

NIEA Northern Ireland Environment Agency
www.daera-ni.gov.uk

SEPA Scottish Environment Protection Agency
Buidheann Dìon Àrainneachd na h-Alba

Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004-2021)

Foreword

The environmental monitoring programmes in this report were organised by the environment agencies, Food Standards Agency (FSA) and Food Standards Scotland (FSS) and are independent of the industries discharging radioactive wastes. The programmes include monitoring on behalf of the Scottish Government, Channel Island States, the Department of Agriculture Environment and Rural Affairs (DAERA), the Department of Business, Energy and Industrial Strategy (BEIS), Department for Environment, Food and Rural Affairs (Defra), Natural Resources Wales (NRW) and the Welsh Government.

As partner agencies for environment and food protection, the joint findings are published in an annual report, 'Radioactivity in Food and the Environment' (RIFE) which brings together the results of the radiological monitoring and provides an overall detailed assessment of radioactivity for the UK. The report is a compilation of the evaluations made on the public's exposure to ionising radiation from authorised discharges, to show that exposure is within EU and UK limits.

Building on the information derived from the previous RIFE reports (RIFE 10 to 27), this review has been prepared to give an overview of recent trends in data from 2004 to 2021. The report primarily focuses on trends associated with:

- radiation exposure (doses) to people living around nuclear sites
- disposals of radioactive waste (discharges) to air and water
- radionuclide activity (concentrations) in samples collected around nuclear sites

This report shows that for all 39 nuclear licensed sites, the overall amount of radiation the public was exposed to was less than the UK limit of 1mSv per year, in each year over the review period. A key observation is that radionuclide concentrations were very low at many sites, indeed so low they could not be detected with the sensitive methods used. In many cases there is a correlation between lower environmental concentrations and reducing discharges to the environment, showing that the efforts of regulators and the industry to progressively reduce discharges is having a beneficial effect.

At several nuclear sites, trends in 'total doses' were dominated by direct radiation (radiation arising from processes or operations on the premises), with the largest 'total dose' over the period reported at Dungeness. However, this direct radiation reduced after 2006 when the first-generation Magnox reactors at Dungeness A ceased power generation. Radiation exposure around Sellafield and Whitehaven was the second largest ‘total dose’, with trends broadly reflecting a combination of changes in shellfish consumption rates, and the concentrations of naturally occurring radionuclides arising as a result of past discharges from the former phosphate works at Whitehaven, in these shellfish.

The cessation, decommissioning and defueling of the majority of first-generation nuclear power stations and reduction in reprocessing over the review period has clearly had a significant impact in reducing discharges and radiation doses to the public.

For nuclear power station sites with only Magnox reactors, the most significant trends were an overall decline in the gaseous and liquid discharges over the period 2004 to 2021. The most pronounced effects were at Chapelcross where discharges reduced significantly after the site stopped generating electricity. For the same reason, Sizewell A and Dungeness A both showed significant declines in discharges after 2006. For the sites with an advanced gas-cooled reactor (AGR) or pressurised water reactor (PWR), the overall trend was a decline in gaseous and liquid discharges over the period. Discharges from other sites were generally similar over the period, with fluctuations between years. Most of the apparent variations can be associated with changes in power output.

Discharges of artificial radionuclides over the last 2 decades have shown large and sustained reductions of the most important radionuclides. This is particularly true of the nuclear fuel reprocessing sector where investment, for example in new treatment plants, has had a significant effect. Concentrations of radionuclides in food and the environment have also declined over a similar timeframe. In addition, reductions in discharges and doses have occurred from older Magnox power stations where the reactors have been shut down and ended electricity production. Therefore, in comparison to earlier decades, some downward trends in environmental concentrations have become less significant. Where there have been radionuclide fluctuations in recent years, this has been mostly at low concentrations in the environment, due to normal year to year variation. In some cases, no clear trend is apparent and variation or ‘noise’ is a key feature of the monitoring data.

It is important to note that this is a summary of trends over the period 2004 to 2021 and is not a detailed technical report. The relevant annual RIFE report provides an in-depth background to the methodologies applied in the specific yearly assessments.

Introduction

This report provides a summary of the public's exposure (doses) to radiation, between 2004 and 2021, to people living around nuclear sites. It also gives more detail of time trends on discharges of radioactivity to the environment and concentrations of radionuclides in food and the environment over the same time period for each of the nuclear industry sectors (for example, nuclear fuel production and processing). The information in this report is taken from more detailed data published in the annual Radioactivity in Food and the Environment (RIFE) reports. The RIFE reports give analytical results from independent monitoring carried out by the Food Standards Agency (FSA), Environment Agency, Scottish Environment Protection Agency (SEPA), Food Standards Scotland (FSS), Natural Resources Wales (NRW) and the Northern Ireland Environment Agency (NIEA).

The data are presented to indicate the overall trends in doses (impacts), discharges and concentrations. These data allow a broad interpretation of the picture with time, to whether the trends are generally increasing, decreasing, largely staying the same or not showing a trend. In some trend plots, multipliers have been applied to allow the y-axis scales to be the same to permit simpler comparisons of trends, and small changes may be exaggerated in some cases.

This report provides information that can be considered in its own right and in relation to a strategic view of the UK approach to managing the impact of radioactive discharges over recent years. In particular, it allows the radioactivity concentrations and public radiation doses to be considered in relation to the 1998 Ministerial Oslo and Paris Convention (OSPAR) agreement and the UK's commitments under its national Radioactive Discharge Strategy. The OSPAR Radioactive Substances Strategy was agreed by Ministers in 1998. Its strategic objective is to prevent pollution of the OSPAR maritime area (marine environment of the North-East Atlantic) from ionising radiation through progressive and substantial reductions in radioactive discharges, emissions, and losses. This has the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. The aim of the strategy is that by the year 2020 any releases of radioactive substances are low enough so that any increase in the levels, above historic levels, in the marine environment from these discharges will be close to zero. The Fifth Periodic Evaluation [14], represents the final assessment against the 2020 RSS and will also form the basis for the next OSPAR Quality Status report, which is expected to be published in 2023. It demonstrated that Contracting Parties have successfully fulfilled the objectives of the OSPAR RSS for 2020 under the North-East Atlantic Environment Strategy (NEAES) 2010–2020 and have made significant progress towards fulfilling the ultimate aim of radionuclide concentrations in the environment near background values for naturally occurring radionuclides and close to zero for artificial radionuclides [14]. In October 2021, the Contracting Parties, which includes the UK, agreed the NEAES 2030 and signed the Cascais Declaration [15,16], setting OSPARs strategic direction up to 2030.

The UK Strategy for Radioactive Discharges presents Key Marine Environmental Indicators (KMEIs) at a number of locations around the coast of the UK. This helps evaluate progress against the OSPAR targets and are included in the OSPAR Periodic Report Series. The KMEIs include seaweed at all the locations. At some locations KMEIs include marine foods and seawater. All of the KMEI data are from monitoring carried out by the FSA, Environment Agency, SEPA, FSS, NRW and NIEA. Selected KMEI data have been presented in this report.

Further information describing the organisation of nuclear safety and radiation protection control, and the regulatory and legislative framework, in the UK is provided in the UK’s country profile (https://www.ospar.org/work-areas/rsc/bat-bep/implementation-reporting/united-kingdom).

6 Overview of ‘total dose’ and environmental indicators near the UK’s nuclear sites

Highlights

- all ‘total doses’ were less than the UK dose limit
- ‘total dose’ and their trends were dominated by direct radiation at many sites
- ‘total dose’ trend at Sellafield was influenced by changes in natural radioactivity from non-nuclear industry activity
- ‘total dose’ declined when electricity generation ended at several older Magnox power stations
- trends in Key Marine Environmental Indicators around the UK show decreasing concentrations over the period

This section considers the time trends of ‘total dose’[13] summed over all sources at each site in the UK. It also considers Key Marine Environmental Indicators (KMEIs) around the UK that have been used to evaluate the UK Strategy for Radioactive Discharges.

6.1 ‘Total dose’ assessment

Figure 6.1 (nuclear power stations) and Figure 6.2 (all other sites) provides time trends of ‘total dose’ from 2004 to 2021, due to the combined effects of authorised/permitted waste discharges and direct radiation, to those people

[17] ‘Total dose’ is an assessment that uses a defined method that takes account of all exposure pathways in combination, for example, radionuclides in food, the environment and direct radiation.

(representative person[14]), most exposed to radiation near all major nuclear licensed sites in the UK.

The 'total dose' from radiation at all sites were all less than the annual national (UK) limit for members of the public of 1mSv per year, in each year over the period. An additional comparison can be made with the exposure from natural radioactivity. The estimated dose for each person (per caput) in the UK population (in 2010) from natural radiation is approximately 2.3mSv per year [17].

Changes in direct radiation dominated the inter-annual variation at most of the power station sites, and small fluctuations in external dose rates had relatively large effects at some sites where high rates of intertidal occupancy were recorded.

Figure 6.1 shows the annual 'total dose' was highest at Dungeness in Kent, ranging between 0.012 and 0.63mSv, over the period. 'Total dose' at Dungeness were dominated by direct radiation, and following 2006, this dose has declined due to the end of power generation from the first-generation Magnox reactors.

The second highest annual 'total dose' was in the vicinity of Sellafield (Sellafield, Low-level Waste Repository (LLWR) (near Drigg) and Whitehaven) in Cumbria (Figure 6.2), ranging between 0.076 and 0.58mSv over the period. This trend broadly reflected a combination of changes in the amount of shellfish eaten and of naturally occurring radionuclides from the non-nuclear industry in these shellfish.

The larger step changes in 'total dose' in the vicinity of Sellafield (from 2004-2005, 2008 to 2009 and 2012 to 2013) were due to variations in naturally occurring radionuclides (mainly polonium-210). The changes in 'total dose' in the intervening years from 2005 to 2007 were mainly a result of changes in seafood consumption rates. The decrease in 2010 was due to both reductions in naturally occurring radionuclides concentrations (polonium-210) and consumption rates, whilst the variation in the radionuclide contributors in 2011 (from previous years) resulted from a change in the representative person (from a consumer of molluscan shellfish to locally harvested marine plants).

The largest proportion of the 'total dose' in the vicinity of Sellafield, up till 2008 and again from 2011 to 2012 and 2014 to 2021, was mostly due to enhanced naturally occurring radionuclides from the historical discharges at Whitehaven and a smaller contribution from the historical discharges from Sellafield.

In 2013, the highest 'total dose' (relating to the effects of Sellafield) was entirely due to external radiation from sediments. The change was due to both decreases in naturally occurring radionuclides concentrations (polonium-210) and a revision of

---

[14] The 'representative person' concept is considered equivalent to the previously used 'critical group' [24]

habits information, resulting in a change in the representative person. In 2014, the increase in ‘total dose’ was due to a change in the habits information from the most recent survey. In the following year (2015), the relative increase in dose were largely due to an increase in polonium-210 concentrations (from the non-nuclear industry) in locally caught lobsters and crabs. Thereafter, the relative changes in dose were due to variations in locally caught lobsters and crabs.

The third highest exposure was at Amersham in Buckinghamshire, where annual ‘total doses’ ranged from 0.083 and 0.24mSv over the period and were dominated by direct radiation. Exposures generally declined over time. The lower values over the period 2014 to 2020 were due to changes in working practices (for distribution activities, products spend less time in the dispatch yard) and the construction of a shield wall on the (western) side closest to the site boundary of a building that contains legacy radioactive wastes. The lowest value reported (0.083mSv in 2021) is due to the Amersham site no longer being used as a distribution hub for radiopharmaceutical products.

Other notable observations in ‘total dose’ included increased exposure at Capenhurst in Cheshire. Any changes in ‘total doses’ with time are attributable to changes in the estimates of direct radiation from the Capenhurst site. The small increases in ‘total dose’ at Bradwell (in 2015 and 2016), Harwell (in 2017 and 2018 and Winfrith (in 2015 and 2016) were also mostly due to higher estimates of direct radiation from the individual sites. The increases in 2016, 2018 and 2021 at Dounreay were due to the inclusion of caesium-137 concentrations found in venison (game), which had not been sampled in other years. At Springfields the ‘total dose’ decreased over time, although there were slight increases in 2008 (compared with 2007), 2018 and 2019. The increases reported in 2018 and 2019, were associated higher occupancy rates due to some workers undertaking a specific responsibility (with regard to the adjacent rail line). In the intervening years, the trend at this site was primarily due to variations in gamma dose rates over sediment, and improvements in the methods used for dose assessments for houseboat dwellers, resulting in an overall decline in dose over the period.

At Sizewell, the ‘total dose’ has reduced by a factor of 3 since Sizewell A ceased generation in 2006. The ‘total dose’ declined at the end of 2006, following the closure of the Magnox reactors at Sizewell A, thereafter any variations were due to the change in the contribution from direct radiation from the site. A habits survey was undertaken in 2012 at Barrow, allowing a full dose assessment to be introduced, making use of the marine data. Virtually all of this dose was due to the effects of Sellafield discharges.

‘Total doses’ at all the remaining locations in Figure 6.1 and Figure 6.2 were low. Any variations in ‘total doses’ with time at these sites were primarily due to changes in direct radiation or variations in gamma dose rates from environmental variability.

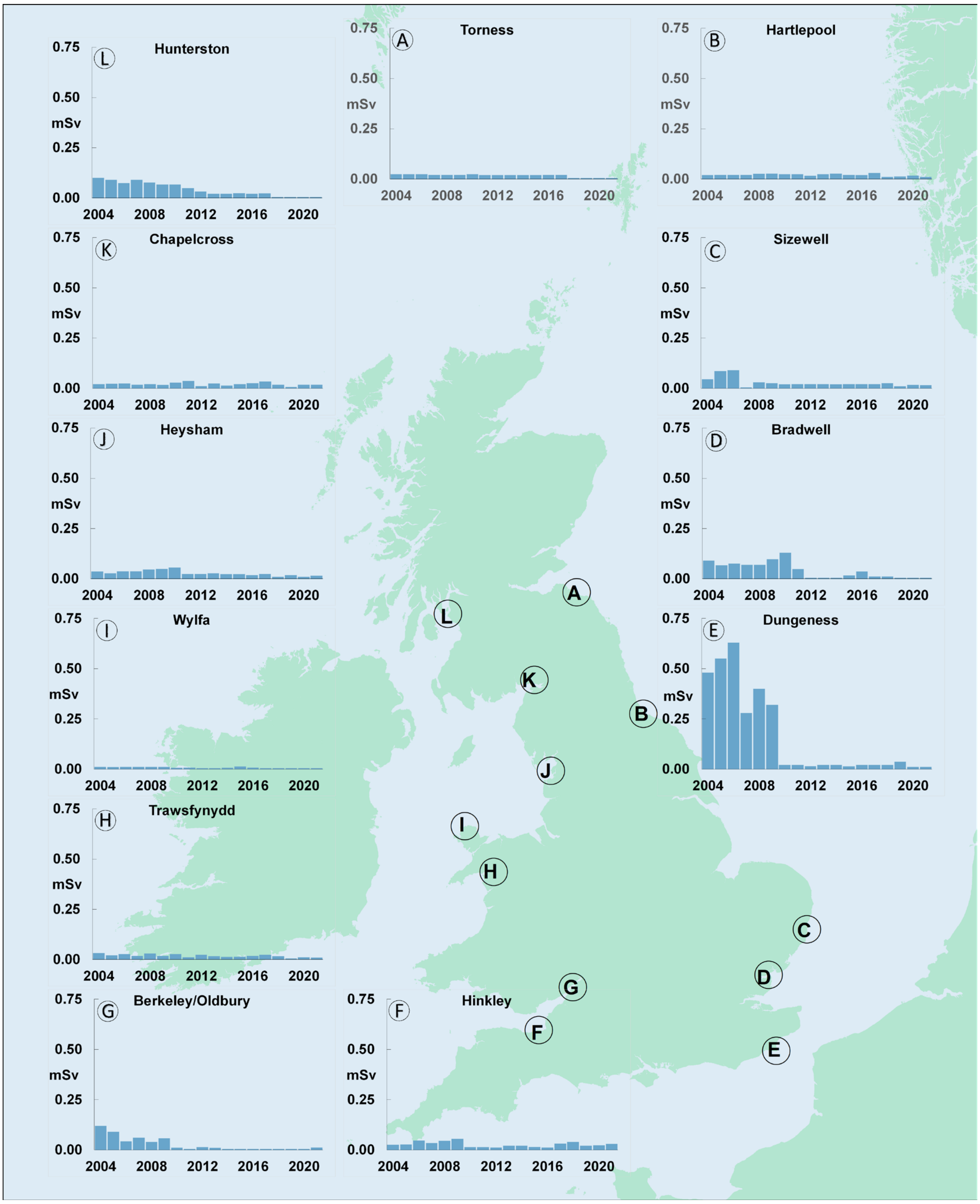


Figure 6.1 Total radiation exposures around the UK's nuclear power stations due to radioactive waste discharges and direct radiation (2004 to 2021).

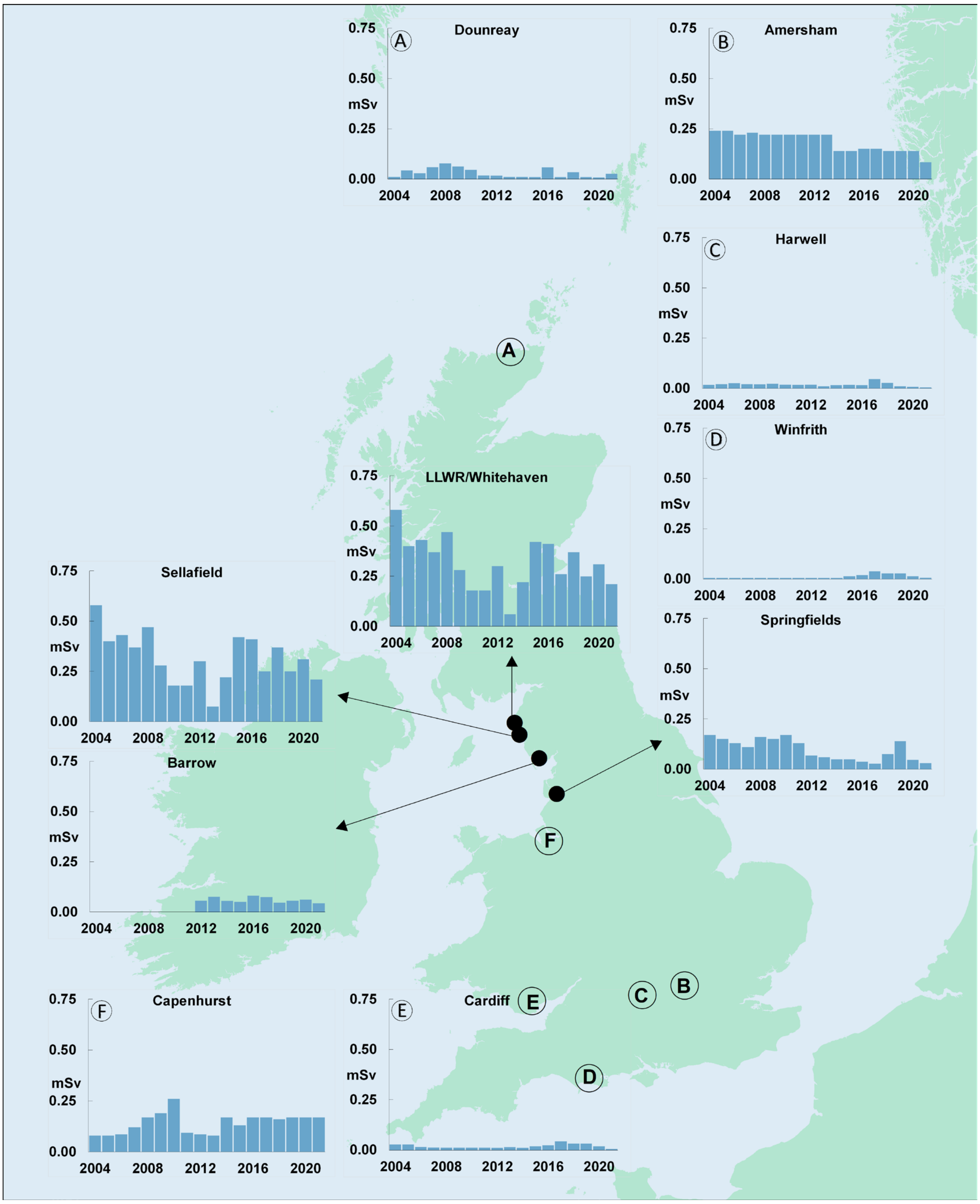


Figure 6.2 Total radiation exposures around the UK's nuclear sites (except power stations) due to radioactive waste discharges and direct radiation (2004 to 2021). (Exposures at Sellafield/Whitehaven receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

6.2 Environmental indicators close to and away from nuclear sites

Monitoring carried out on behalf of the Environment Agency, FSA, FSS, NIEA, NRW and SEPA includes data that are used as part of the KMEIs. These are used to show how the UK is meeting its OSPAR obligations. The KMEI include concentrations of radionuclides in fish and shellfish, seaweed, and seawater. Seaweed data are available for a wide range of locations around the UK (as indicators for Sellafield-derived technetium-99) and are shown in Figure 6.3. The data show that activity concentrations have declined around the Irish Sea (Chapelcross, Heysham, Northern Ireland, Sellafield and Wylfa). Further afield, the data also show a decrease for long distance transport of technetium-99 (Dounreay, Hartlepool and Torness) over the period 2004 to 2021.

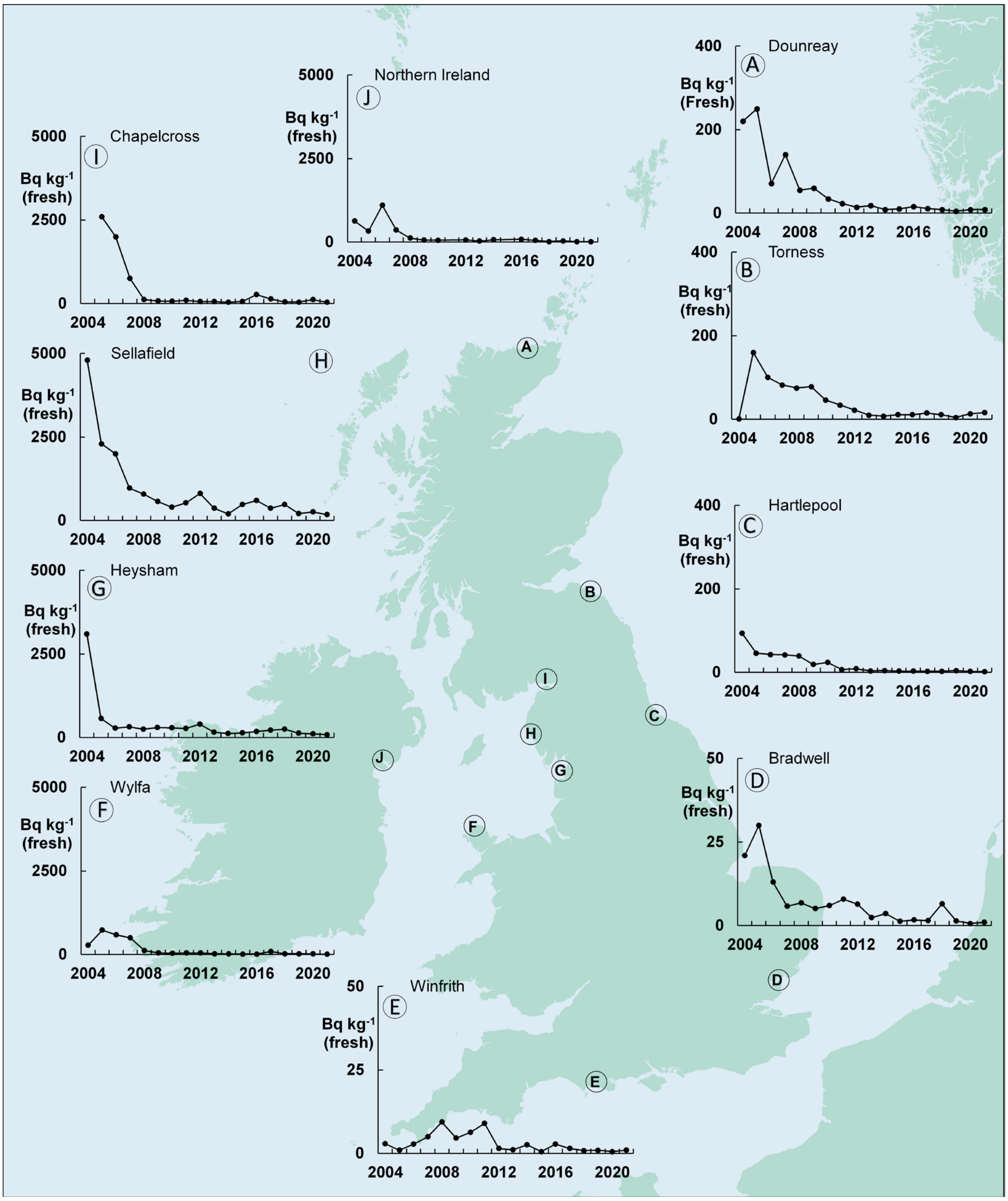


Figure 6.3 Technetium-99 concentrations in seaweed around the UK (2004 to 2021)

6.3 Doses to the public away from nuclear sites

The mean annual dose from consumers drinking water was assessed in the UK. Available data are presented in Table 6.1. This gives an indication of the range of doses to the public away from nuclear sites between 2005 and 2021.

Table 6.1 Ranges of estimated dose from radionuclides in drinking water between 2005 to 2021*

Country	Mean exposure, mSv/y		
	Artificial radionuclides	Naturally occurring radionuclides	All radionuclides
England	< 0.001	0.026 - 0.051	0.026 - 0.051
Wales	< 0.001	0.027 - 0.029	0.027 - 0.029
Northern Ireland	< 0.001- 0.001	0.010 - 0.062	0.010 - 0.063
Scotland	< 0.001	0.002 - 0.003#	0.002 - 0.003#
UK	< 0.001	0.014 - 0.054	0.013 - 0.054

* No data available in 2004
# Data only available in 2014 to 2021, inclusive (for K-40 only)

7 Nuclear fuel production and reprocessing

Highlights

- all doses were significantly less than the dose limit for members of the public of 1mSv per year
- highest annual dose (from artificial radionuclides) was 0.24mSv at Sellafield
- overall trend was a reduction in gaseous and liquid discharges, with all authorised discharges below authorised limits
- doses from historic non-nuclear industry activity (naturally occurring radionuclides) were significant near Sellafield

This section looks at the time trends between 2004 and 2021 from the UK's nuclear fuel production and reprocessing sites. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[15] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the

[15] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 7-11, is an exposure that uses a different assessment method to that of 'total dose' in Section 6.

environment. The public's exposure from naturally occurring radionuclides is also considered near Sellafield.

There are 3 sites in the UK involved with production and reprocessing of nuclear fuel. At Capenhurst, near Ellesmere Port (Cheshire), uranium enrichment is carried out together with the management of uranic materials and undertaking of decommissioning activities. At Springfields, near Preston (Lancashire), and Sellafield (Cumbria) the main commercial activities are the manufacture of fuel elements for nuclear reactors and fuel reprocessing from nuclear power stations, respectively.

7.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 7.1 provides time trends, between 2004 and 2021, of doses for those groups most exposed to radiation due to the effects of gaseous and liquid waste discharges from the UK's nuclear fuel production and reprocessing sites. At all locations, the doses from radioactive waste discharges were significantly below the UK limit for members of the public of 1mSv per year.

Figure 7.1 shows that the highest annual dose from artificial radionuclides (shown in blue) was 0.24mSv in 2007 near Sellafield. The Sellafield annual doses ranged from 0.058 to 0.24mSv. The maximum value is less than a quarter of the dose limit and the contribution to dose from artificial radionuclides has generally declined over the time period. The dose was determined for people who ate seafood, and was mostly due to the accumulation of radionuclides including caesium-137, plutonium isotopes and americium-241 in seafood and the environment. These doses were attributable to historic liquid discharges from Sellafield which were at their highest during the 1970s and 1980s. Between 2004 and 2007, habits surveys indicated an increase in the amount of fish and shellfish eaten, which led to a slight rise in doses during this time. In 2008 consumption went down again leading to a reduction in doses, together with a reduction in dose from artificial radionuclides. Since 2008, Sellafield annual doses have declined due to the reduced accumulation of artificial radionuclides in seafood. The small increase in 2013 was due to the revision of habits information.

Figure 7.1 also shows the trend of doses to people who ate seafood near Sellafield resulting from the historic discharges of naturally occurring radionuclides from the former phosphate works (non-nuclear industry) at Whitehaven (shown in green). The data show that the doses from naturally occurring radionuclides were significantly larger than for artificial radionuclides. The variations in dose for naturally occurring radionuclides were due to changes to both concentrations (polonium-210) in seafood and consumption rates (of fish and shellfish).

Exposure of communities associated with fisheries was also assessed in other parts of the Irish Sea. These were Whitehaven, Dumfries and Galloway, Morecambe Bay, Fleetwood (2004 to 2013), Northern Ireland, North Wales, and the Isle of Man (2004 to 2013). The assessments show that exposures in these areas were lower than to people local to Sellafield. This was due to the lower concentrations and dose rates further away from Sellafield. There were small changes in the reported doses in each area over the time period. These were caused by variations in gamma dose rates over sediment, new information on people's eating habits and fluctuations in radionuclide concentrations (mainly americium-241 in some shellfish). Doses to fisheries communities generally declined over the time period.

The annual doses received by people at Sellafield, who were exposed to gaseous discharges from the site, ranged between 0.010 and 0.036mSv over the time period. The dose was from inhaling gases, from radiation emitted from the gas and from eating food grown on land around the site. Before 2008, this trend was generally declining because of the permanent shut down of Calder Hall power station on the Sellafield site which ended gaseous discharges of argon-41 and sulphur-35. In 2008, the assessment method changed slightly to include cobalt-60 results (which were at the limits of analytical detection) which increased the dose over previous years.

The next group most affected by artificial radionuclide discharges was in the Ribble Estuary near the Springfields site. For those people living on houseboats in the Ribble Estuary, there was an apparent increase in annual dose, which ranged between 0.024 and 0.16mSv over the time period. However, the trend over time included improvements in the methods used for dose assessments. The increase in doses from 2006 was due to updated information and additional measurements concerning the exact location of houseboats. The further increase in 2008 was due to a combination of increased gamma dose rates and the time spent on the houseboats. Thereafter, the decline was due a change in the method for dose assessment, due to measurements on a houseboat being available from the habits survey in 2012.

At Capenhurst, children playing in and around Rivacre Brook received the highest annual dose. This ranged between 0.006 and 0.013mSv over the time period. The doses were estimated using gamma dose rates, assuming children spent time on the banks of the brook and swallowed some water and sediment. The changes in dose over time were due to variations in gamma dose rates over sediment.

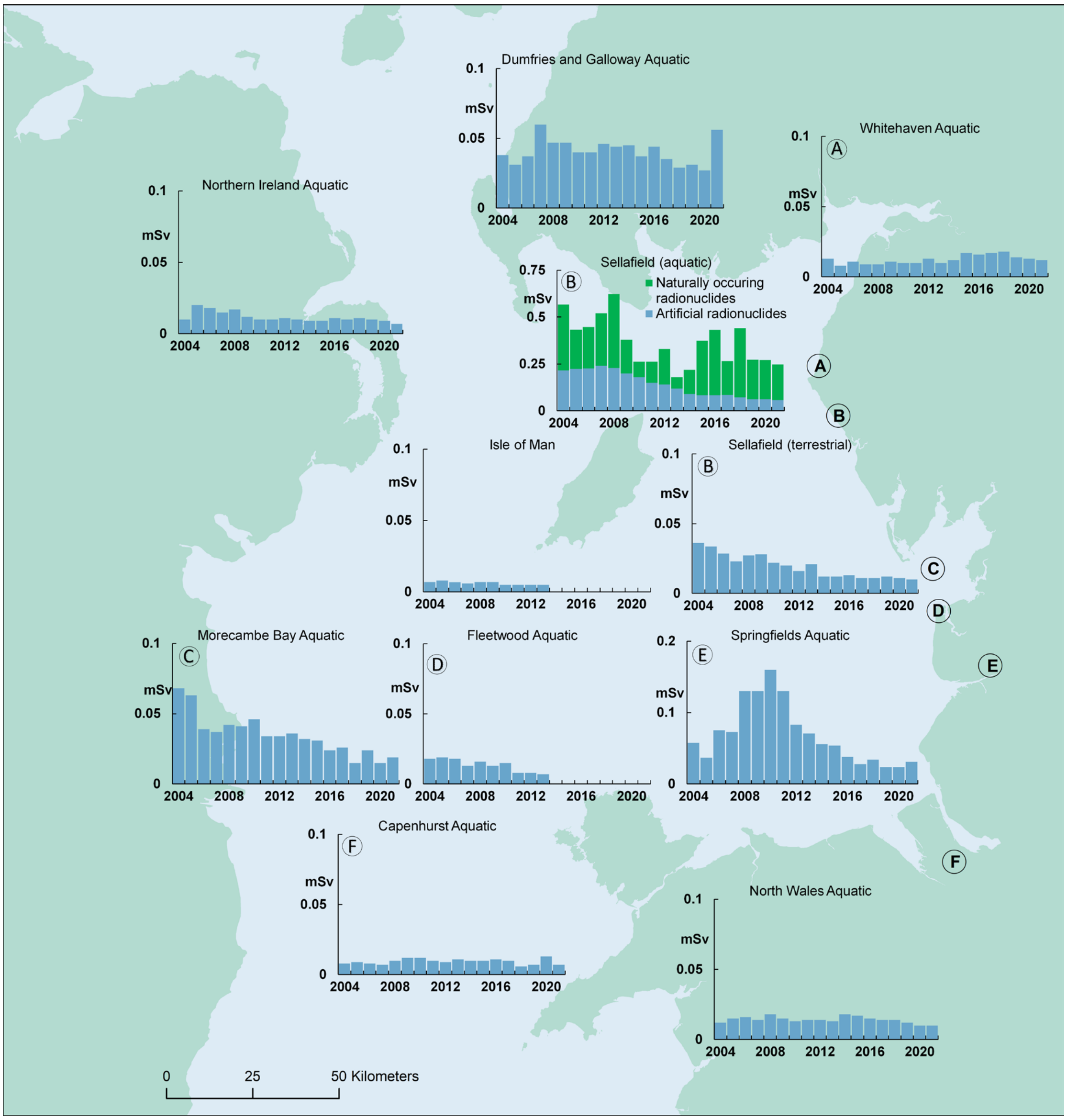


Figure 7.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Irish Sea (2004 to 2021) (includes exposures from naturally occurring radionuclides near Whitehaven)

7.2 Sellafield, Cumbria

7.2.1 Discharges of radioactive waste

Permitted discharges of gaseous and liquid waste are released into the atmosphere and into the Irish Sea, from a wide variety of facilities and sources.

Figure 7.2 and Figure 7.3 show the trends of liquid and gaseous discharges, respectively, over time (2004 to 2021) for a number of the permitted radionuclides.

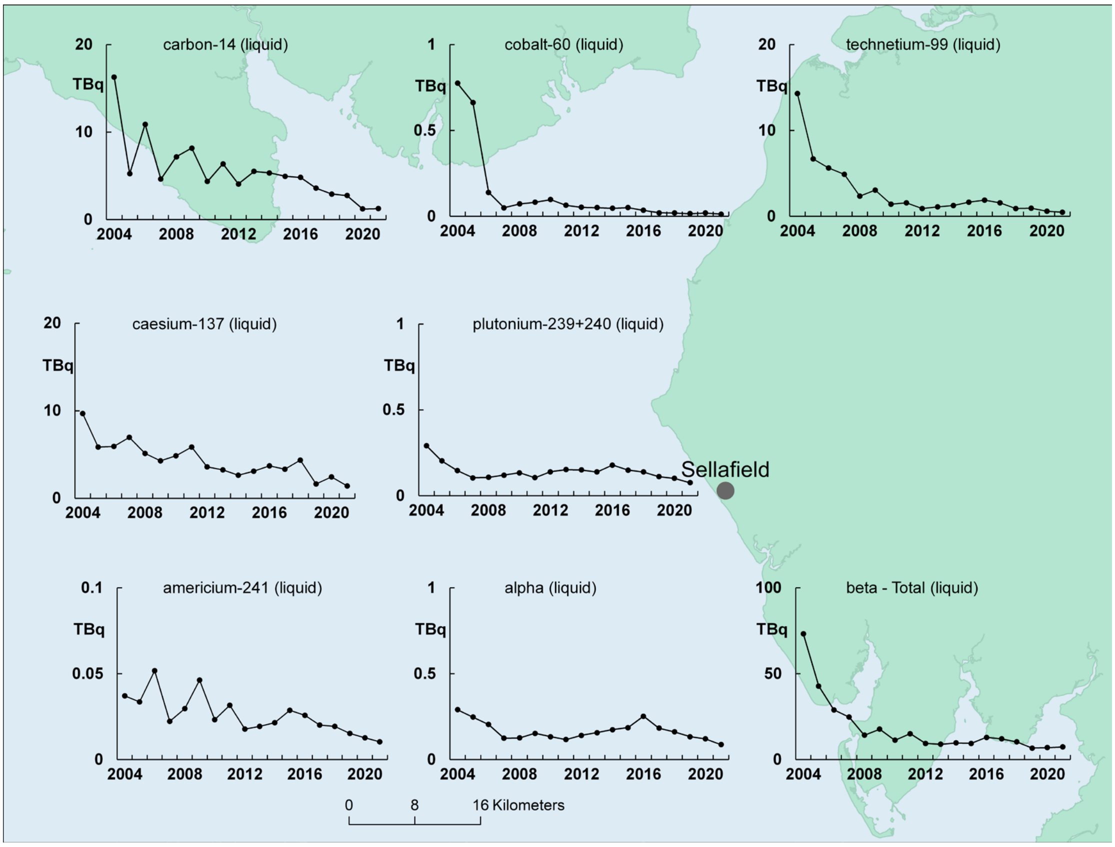


Figure 7.2 Permitted discharges of liquid wastes, Sellafield (2004 to 2021)

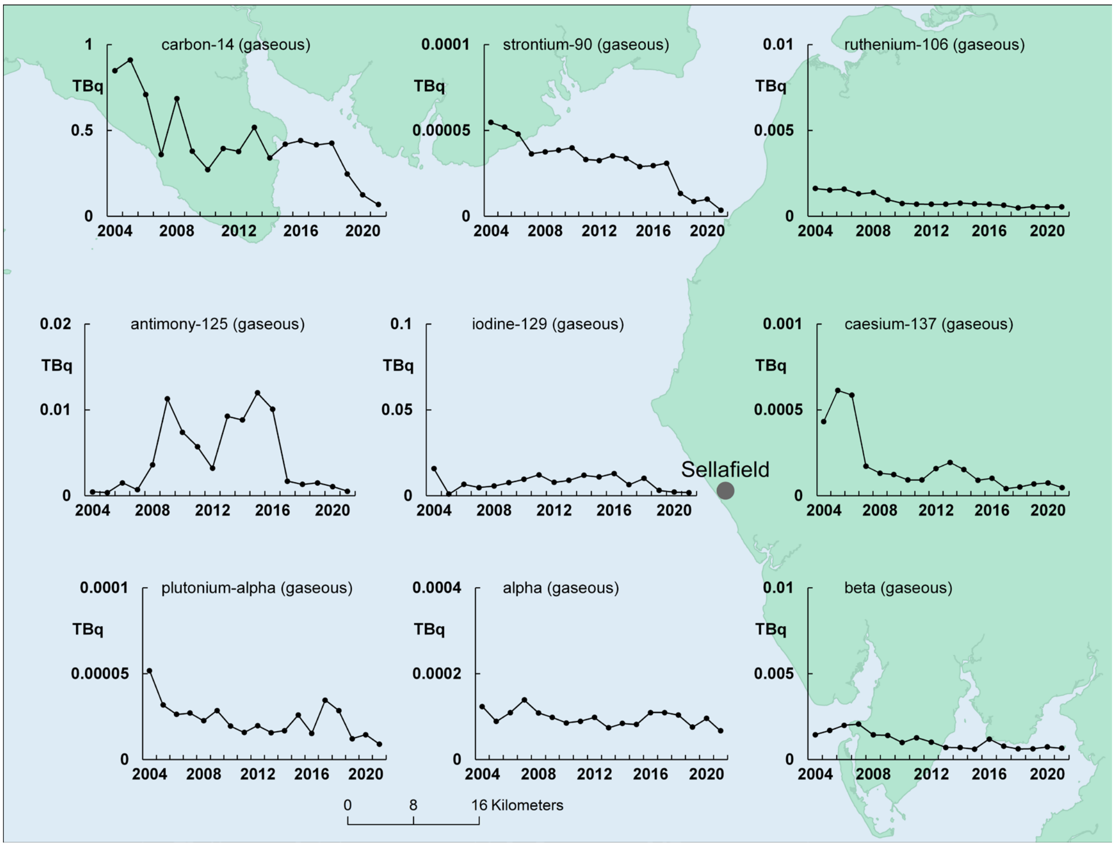


Figure 7.3 Permitted discharges of gaseous wastes, Sellafield (2004 to 2021)

Since 2004, the overall trend was a reduction of gaseous and liquid discharges with time. In 2010, a new permit, with a higher limit for gaseous antimony-125 was introduced to reflect increased discharges of this radionuclide as a result of reprocessing Magnox spent fuel. Between 2004 and 2021, all liquid discharges generally followed a pattern of overall reduction.

Following a major review of site operations, a revised permit, which came into effect in late 2020, was issued to Sellafield. This revised permit included:

- significant reduction in site discharge limits and introduction of a two-tier (upper and lower) site discharge limit structure
- removal of some site limits: where discharges have fallen below significant levels and do not meet the Environment Agency's criteria for setting discharge limits [18], as well as any limits related to the rate of fuel reprocessing (throughput) to reflect the end of reprocessing operations
- replacement of plant discharge limits with plant notification levels, so that Sellafield Limited can make most effective use of the available discharge routes and treatment plants
- a new specific tritium limit for solid waste disposals at the on-site landfill known as the Calder Landfill Extension Segregated Area (CLESA)

The upper discharge limits will allow Sellafield Limited to undertake important decommissioning tasks, for example, high hazard and risk reduction work in legacy facilities. However, Sellafield Limited are required to demonstrate to the Environment Agency that best available techniques (BAT) will be applied when seeking to move to the upper limit. The use of these upper discharge limits will only be permitted for a set task and period.

7.2.2 Concentrations of radionuclides in food and the environment

The food and environment monitoring programmes around Sellafield are the most extensive in the UK; this includes monitoring for the effects from Sellafield in other parts of the Irish Sea. The monitoring reflects the range and concentrations of radionuclides that have been discharged from Sellafield over a considerable number of years.

Figure 7.4 shows the trends of radionuclide concentrations in food (winkles, lobsters, plaice, and milk) and the environment (seawater and sediment) near Sellafield between 2004 and 2021. All radionuclide concentrations in the environment from gaseous discharges were very low. Over the time period, caesium-137 and strontium-90 concentrations in milk declined over time, whilst carbon-14 concentrations in milk were relatively constant.

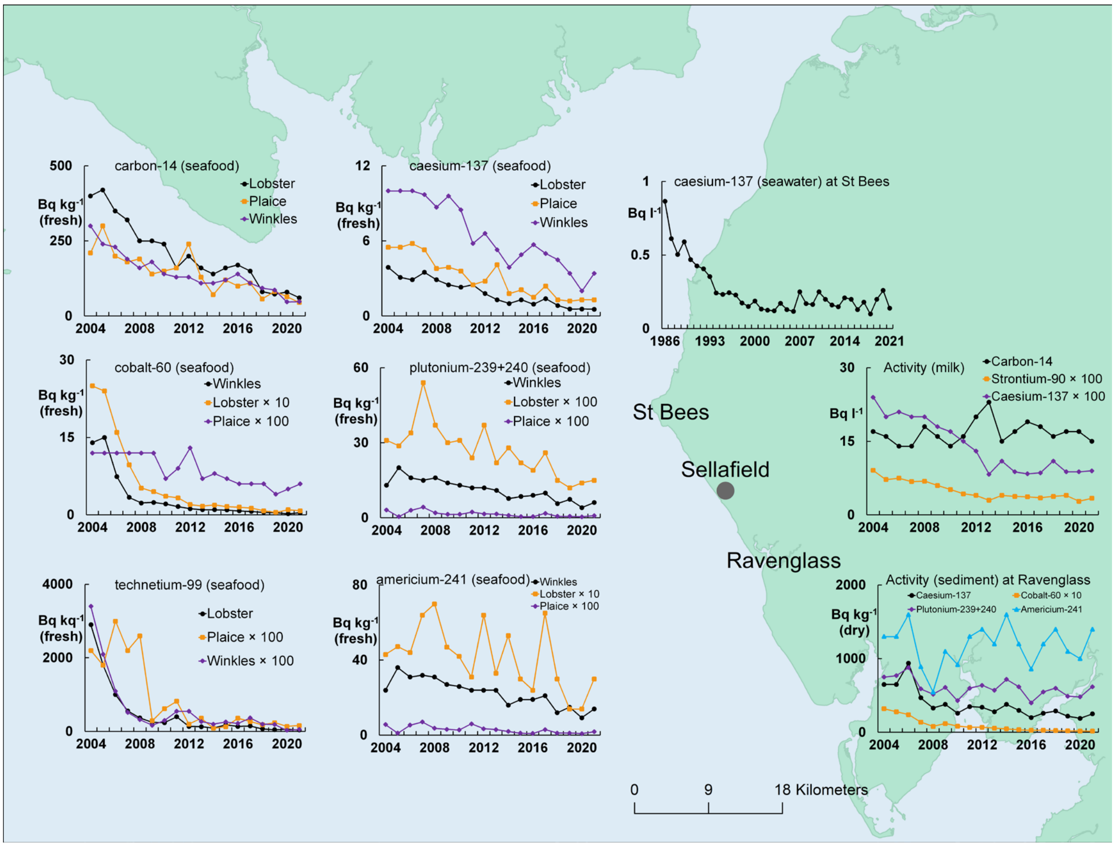


Figure 7.4 Monitoring of the environment from discharges of radioactive wastes, Sellafield (2004 to 2021)

Concentrations of radionuclides in seafood generally continued to reflect changes in liquid discharges over time. The majority of trends for carbon-14 and cobalt-60 concentrations showed large decreases directly associated with a fall in discharges since 2004, with smaller decreases in concentrations over the last decade. Overall, concentrations of technetium-99 in fish and shellfish have shown a continued reduction, from the relatively elevated levels shown at the beginning of the period, but were generally similar (with minor variations) over most recent years. Between 2004 and 2021, concentrations of caesium-137 in seafood generally declined at a constant rate, although this appears to be slowing in recent years, with some variations between years (due to natural variation in the environment). Caesium-137 concentrations in seafood may be affected by the release of this radionuclide from seabed and estuary sediment. For americium-241 and plutonium-239+240, the long-term trends of reductions in concentrations from earlier decades continued, but appear to be slowing. Over the last decade, despite generally decreasing discharges, concentrations of americium-241 and plutonium-239+240 in some shellfish have shown some variations from year to year. Over the last 10 years, concentrations of plutonium-239+240 and americium-241 in seafood were relatively constant, with a few slightly elevated concentrations in shellfish in the most recent years.

Figure 7.4 also shows the trends of caesium-137 in seawater (1986 to 2021) at St Bees and sediment activity concentrations from Ravenglass (2004 to 2021). For caesium-137 in seawater, the data show (as the rate of decrease is slower, relative to the reduction rate of discharges, over the longer period) that the current sources are liquid discharges from the site and the release of caesium from sediments (from earlier discharges in earlier decades) into the water column. In more recent years, the rate of decline of caesium-137 concentrations with time has been decreasing at St Bees. The concentrations of radionuclides in sediments from Ravenglass have remained relatively constant or decreased over the period, responding to decreases in discharges. Discharges of cobalt-60 have reduced over the last decade, as reflected in the sediment concentrations, with some evidence of a lag time between discharge and sediment concentration.

There is a suggestion of small progressive increases in caesium-137, plutonium-239+240 and americium-241 activities in sediments (peaking in 2006, 2014 and 2018). The likely explanation is that changes in these concentrations are due to remobilisation and subsequent accretion of fine-grained sediments containing higher activity concentrations. For americium-241, there is also an additional contribution due to radioactive in-growth from the parent plutonium-241 already present in the environment. The effect is less apparent in fish and shellfish.

7.3 Capenhurst - Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Uranium is the main radioactive constituent of gaseous discharges from Capenhurst, with small amounts of other radionuclides present in discharges by Capenhurst Nuclear Services Limited (previously Sellafield Limited) and Urenco ChemPlants. The UUK permit for the Capenhurst site allows liquid waste discharges to the Rivacre Brook for uranium and uranium daughters, technetium-99, and non-uranium alpha (mainly neptunium-237).

Figure 7.5 shows the trends of discharges over time (2004 to 2021) for a number of the permitted radionuclides.

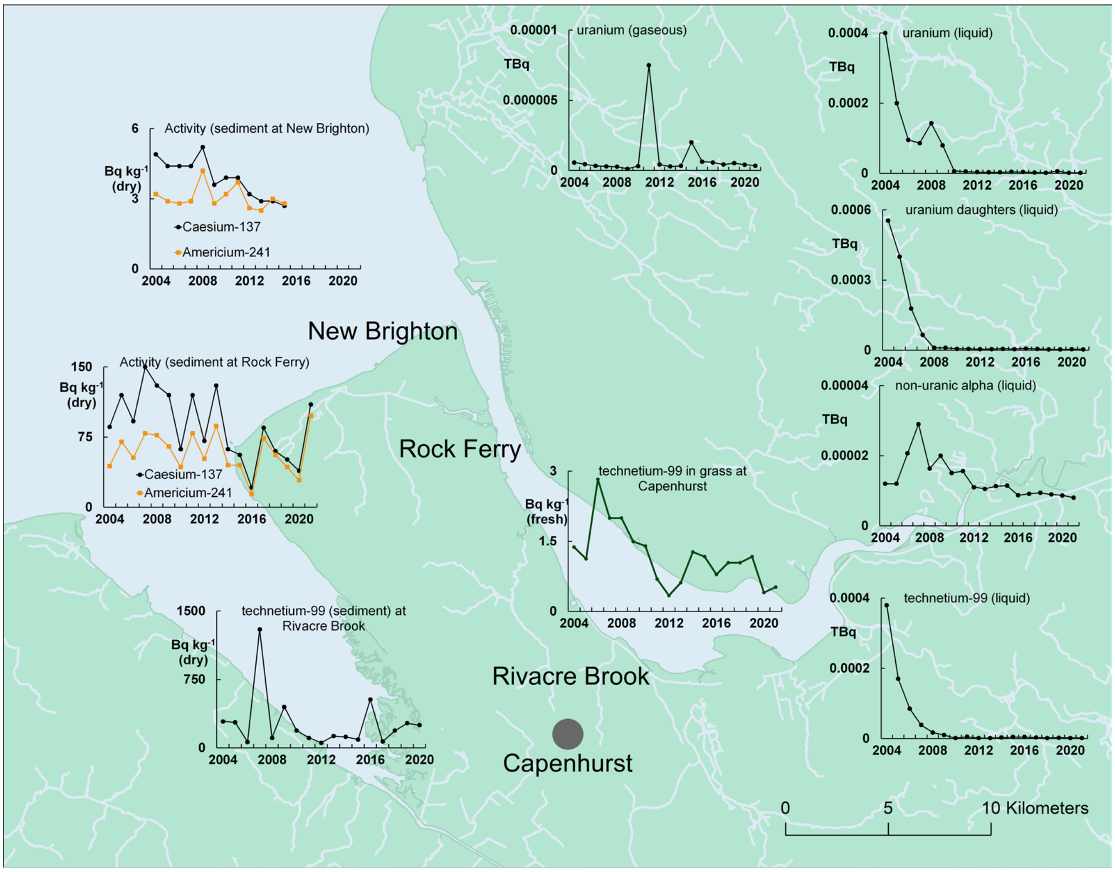


Figure 7.5 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2004 to 2021)

Since 2004, the overall trend was a reduction of gaseous and liquid discharges over time. Most of the reductions were attributed to progress in decommissioning some of the older plant and equipment. The decline in liquid technetium-99 discharges over time is reflected in the reduction of recycled uranium.

Figure 7.5 also provides selected monitoring trends to assess the impact on the surrounding environment. The concentrations of technetium-99 in grass were relatively low. The overall trend reflects the reductions in discharges of technetium-99 from recycled uranium. Concentrations of uranium radionuclides in the environment (and food) were very low. Concentrations of technetium-99 in sediment (Rivacre Brook) from liquid discharges were detectable close to the discharge point. The increase in 2007 was probably due to the discharge occurring at the same time as environmental sampling. Thereafter, sediment samples collected downstream from the Rivacre Brook contained very low but measurable concentrations of uranium (enhanced above natural levels) and technetium-99. Concentrations of caesium-137 and americium-241 in sediments at Rock Ferry and New Brighton on the Irish Sea coast were from past discharges from Sellafield carried into the area by tides and currents. The concentrations were generally similar over most of the time period and any fluctuations were most likely due to normal changes in the environment. The lowest activity concentrations were reported in 2016 at both locations.

7.4 Springfields -

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

The main radioactive constituent of gaseous discharges from Springfields is uranium with small amounts of other radionuclides from research and development facilities. Permitted discharges of liquid waste are made from the Springfields site to the Ribble Estuary by 2 pipelines. The largest discharge for a number of years was of short half-life beta emitting radionuclides (mainly thorium-234).

Figure 7.6 shows the trends of discharges over time (2004 to 2021) for a number of the permitted radionuclides.

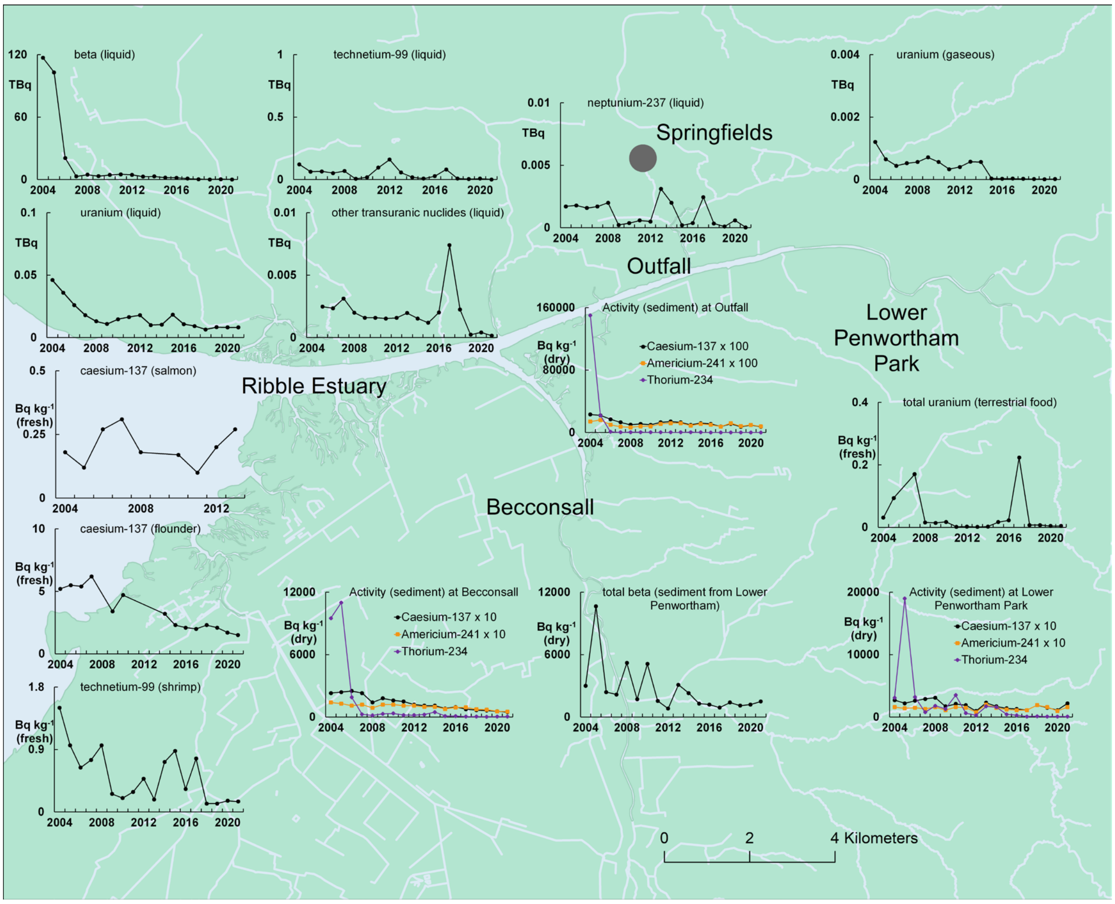


Figure 7.6 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields (2004 to 2021)

The most significant change in the discharge trends was the step reduction of short half-life beta emitting radionuclides in liquid discharges, mostly thorium-234. The reduction was because the Uranium Ore Concentrate purification process ended in 2006. Liquid discharges of uranium radionuclides decreased over time, whilst other discharges were relatively constant.

Figure 7.6 also shows the trends of radionuclide concentrations in food (cabbage, shrimps, flounders, and salmon) and the environment (sediment) near Springfields.

The concentrations of radionuclides from gaseous discharges were very low. Over the time period, concentrations of uranium were found in soil around the site, but the isotopic ratio showed they were naturally occurring. Total uranium in cabbage samples was also detected during the period (no data in 2006), but the apparent peaks in 2007 and 2017 were very low and significantly less, when compared to concentrations in slightly elevated soil samples.

Concentrations of technetium-99 and caesium-137 were present in flounder, shrimps, and salmon around Springfields. These were due to past liquid discharges from Sellafield, carried from the waters off West Cumbria into the Ribble Estuary by sea currents and adsorbed on fine-grained mud. The change in concentrations was due to natural changes in the environment, together with some evidence of declining concentrations over time (for example, caesium-137 in flounder).

The trends of concentrations in sediments over time from liquid discharges are shown in Figure 7.5 and were dominated by the reduction of thorium-234. Total beta activity in sediment generally declined over the whole period. Other activity concentrations (and including thorium-234) in sediments from liquid discharges were generally similar (with minor variations), or declining by small amounts, over the most recent years.

7.5 Summary

The information presented in Table 7.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 7.

Table 7.1 Summary of trend data for nuclear fuel production and reprocessing sector (2004 to 2021)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	10	1	0	Majority downward trend
Liquid discharges	17	0	0	Majority downward trend
Overall discharges	27	1	0	Majority downward trend
Environmental concentrations	10	0	0	Downward trend

Food concentrations	10	1	0	Majority downward trend
Food and the environment overall	20	1	0	Majority downward trend
Overall doses from gaseous and liquid discharges	7	3	1	Majority Downward trend
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

8 Research and development

Highlights

- all doses were less than the dose limit for members of the public of 1mSv per year
- highest annual dose (from artificial radionuclides) was 0.047mSv at Dounreay
- all discharges were well below the authorised/permitted limits
- overall, gaseous and liquid discharges were low
- concentrations in the marine and terrestrial environment and food continued to be very low

This section looks at the time trends between 2004 and 2021 from the UK's research establishments that hold nuclear site licences. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[16] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There are six sites associated with research reactors that are currently authorised/permitted to discharge radioactive waste in the UK. The main sites are Dounreay in Highland, Harwell in Oxfordshire, and Winfrith in Dorset. Other smaller research sites include Culham (Oxfordshire), the Imperial College Reactor Centre (Berkshire) (now closed and de-licensed) and Windscale (Cumbria) which is on the Sellafield site. These latter smaller sites make small discharges overall, and are not considered here.

[16] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 7-11, is an exposure that uses a different assessment method to that of *total dose* in Section 6.

8.1 Public’s exposure to radiation due to discharges of radioactive waste

Figure 8.1 shows the time trends of doses between 2004 and 2021, due to the effects of gaseous and liquid waste discharges at the main research sites. All doses were much less than the UK limit of 1mSv per year for members of the public.

Figure 8.1 shows that the highest annual dose was at Dounreay from consuming food produced on land around the site. This ranged between 0.007 and 0.047mSv over the time period. The sudden increase in dose in 2005 (and subsequent doses until 2008) was due to dose estimates being more conservative. Doses were more conservative because higher analytical limits of detection were used in the assessments. Between 2008 and 2012, reduced doses were mostly due to lower caesium-137 concentrations in game meat and the type of game sampled. A change in doses between 2013 and 2015 was mostly due to the contribution of goats’ milk not being included in the assessment (which has been assessed prior to 2013), as milk samples have not been available in most recent years. An increase in dose in 2016 was mostly due to the inclusion of the caesium-137 concentration in game, the activity most likely from historical releases. A decrease in dose from 2016 to 2021 was mostly due to lower caesium-137 concentrations in game than previous years.

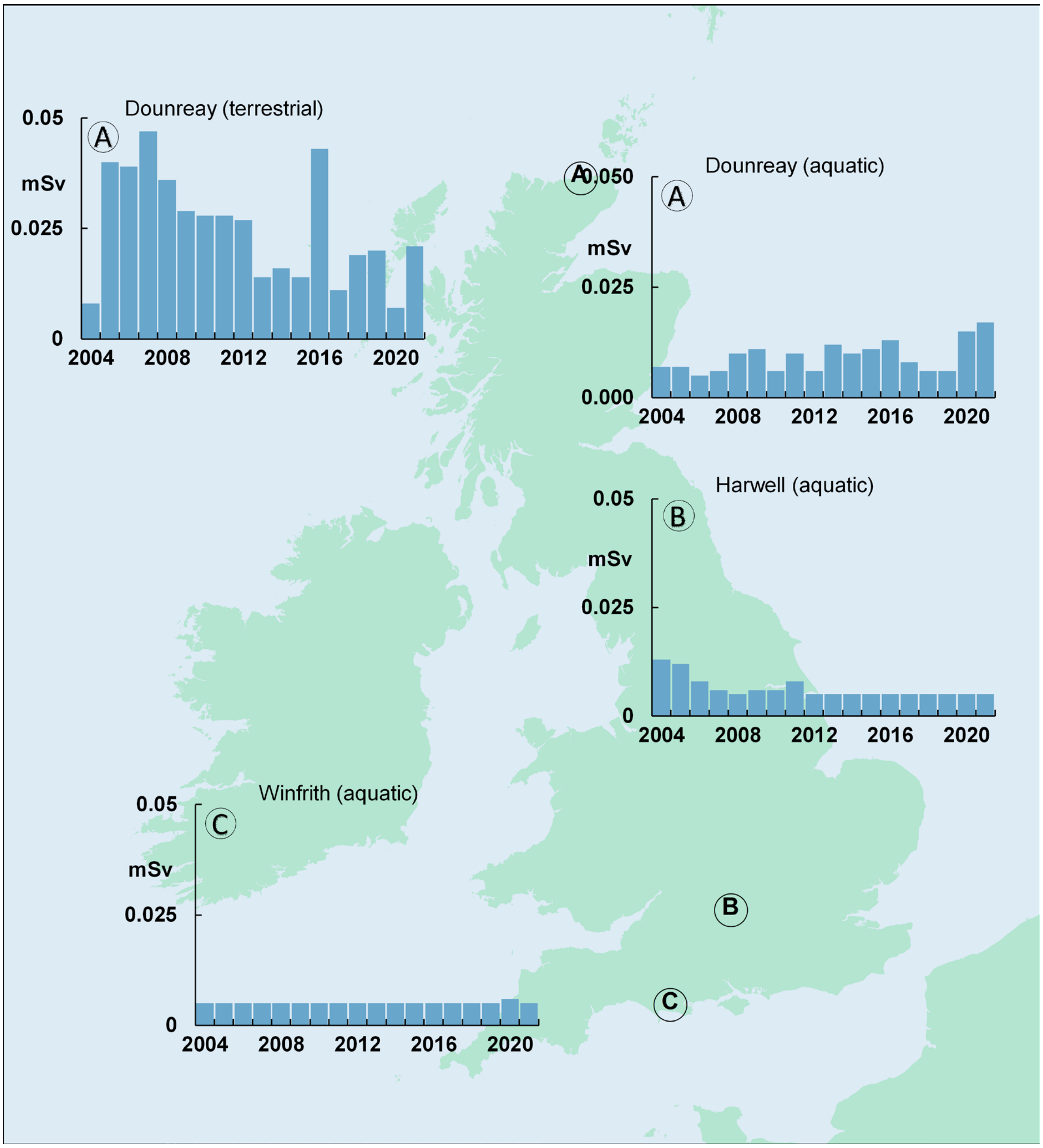


Figure 8.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Dounreay, Harwell and Winfrith (2004 to 2021) **(Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)**

The annual dose from seafood consumption and external exposure over local beaches at Dounreay ranged from less than 0.005 to 0.017mSv over the time period. Between 2004 and 2007, the variations in dose were mostly likely due to normal changes in the environment. Between 2008 and 2016, variations in dose were mostly due to changes in gamma dose rates over winkle beds and sand. Additionally, the apparent increase in dose in 2013 was due to increased occupancy rates from new habits information. The increase in dose between 2019 and 2021 is due to an increase in gamma dose rates.

At Harwell, the group of people most affected by radioactive waste discharges were anglers on the River Thames, with annual doses from less than 0.005 to 0.013mSv over the time period. The variations in aquatic dose with time were mainly due to changes in gamma dose rates (in 2006 and 2011) and revised occupancy rates on the riverbank (in 2007). There is an overall decline in aquatic doses over the time period.

At Winfrith (and all the other smaller sites), all assessed doses ranged from below 0.005mSv to 0.006mSv, which is less than 0.6% of the dose limit for members of the public.

8.2 Dounreay –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Radioactive waste discharges from the Dounreay site are made by Dounreay Site Restoration Limited (DSRL) under an Environmental Authorisations (Scotland) Regulations (EASR) radioactive substances authorisation granted by SEPA.

Figure 8.2 shows the trends of discharges over time (2004 to 2021) for a number of the authorised radionuclides. The overall trend was a reduction in both gaseous and liquid discharges (2004 to 2021).

Figure 8.2 also provides selected monitoring trends to assess the impact on the surrounding environment. The majority of measurements of radionuclide concentrations in food and the environment were at or below the analytical limits of detection, which made it difficult to produce valuable trend monitoring data that may correspond to discharge data. Nevertheless, concentrations of technetium-99 from Sellafield found in seaweed taken from Sandside Bay, Kinlochbervie and Burwick Pier showed an overall decline over the period. Variations in technetium-99 concentrations (mostly demonstrated in the earlier years) were most likely due to the complexity of how radionuclides move around in the Irish Sea, with technetium-99 being dispersed in varying amounts before arriving at distant locations. Concentrations of caesium-137 in sediments at Sandside Bay, Rennibister and Oigins Geo were likely to include a contribution from Sellafield discharges. The concentrations were generally unchanged over the time period with any fluctuations most likely due to normal variations in the environment.

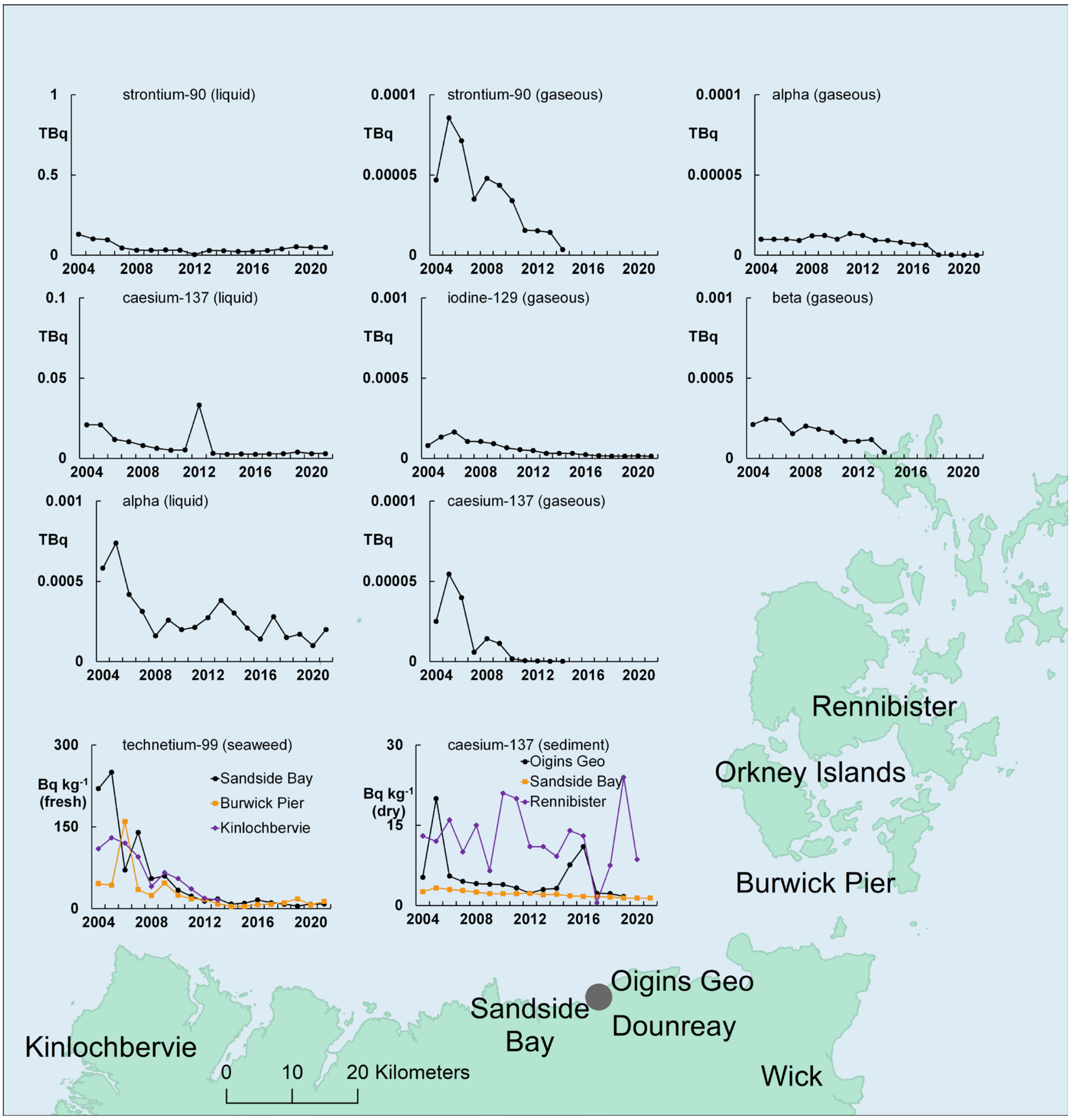


Figure 8.2 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Dounreay (2004 to 2021)

8.3 Harwell -

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous releases from Harwell are discharged into the atmosphere. Liquid releases are discharged to sewers serving the Didcot Sewage Treatment Works; treated effluent subsequently enters the River Thames at Long Wittenham. Discharges to the River Thames at Sutton Courtenay ceased in 2013, thereafter the decommissioning of the treated waste effluent discharge point was completed in 2014 by Research Sites Restoration Limited. During 2021, the final remediation work was completed for the decommissioned Liquid Effluent Treatment Plant (LETP). Discharges of surface water effluent from the Harwell site are made via the Lydebank Brook, north of the site, which is a permitted route.

Figure 8.3 shows trends of discharges over time (2004 to 2021) for a number of the permitted radionuclides.

The gaseous discharges were low and generally similar over the time period. There was an overall reduction in liquid discharges, particularly for cobalt-60. Liquid discharges of caesium-137 were the lowest release for many years.

Figure 8.3 also provides monitoring trends from 4 locations (Harwell outfall, Appleford, Day’s Lock and Lydebank Brook) to assess the impact on the surrounding environment. Concentrations of caesium-137 in sediments from the Appleford, and Lydebank Brook were generally declining due to reduced liquid caesium-137 discharges. As expected, the biggest difference in concentrations was observed near the Harwell discharge point (outfall), although discharges have declined since the peak value in 2013. Prior to 2013, discharges from Harwell to the Thames were not continuous but occurred in batches when tanks were emptied. The peaks in some years (and including the peak at Lydebank Brook in 2014) were probably due to the discharge occurring at the same time as environmental sampling.

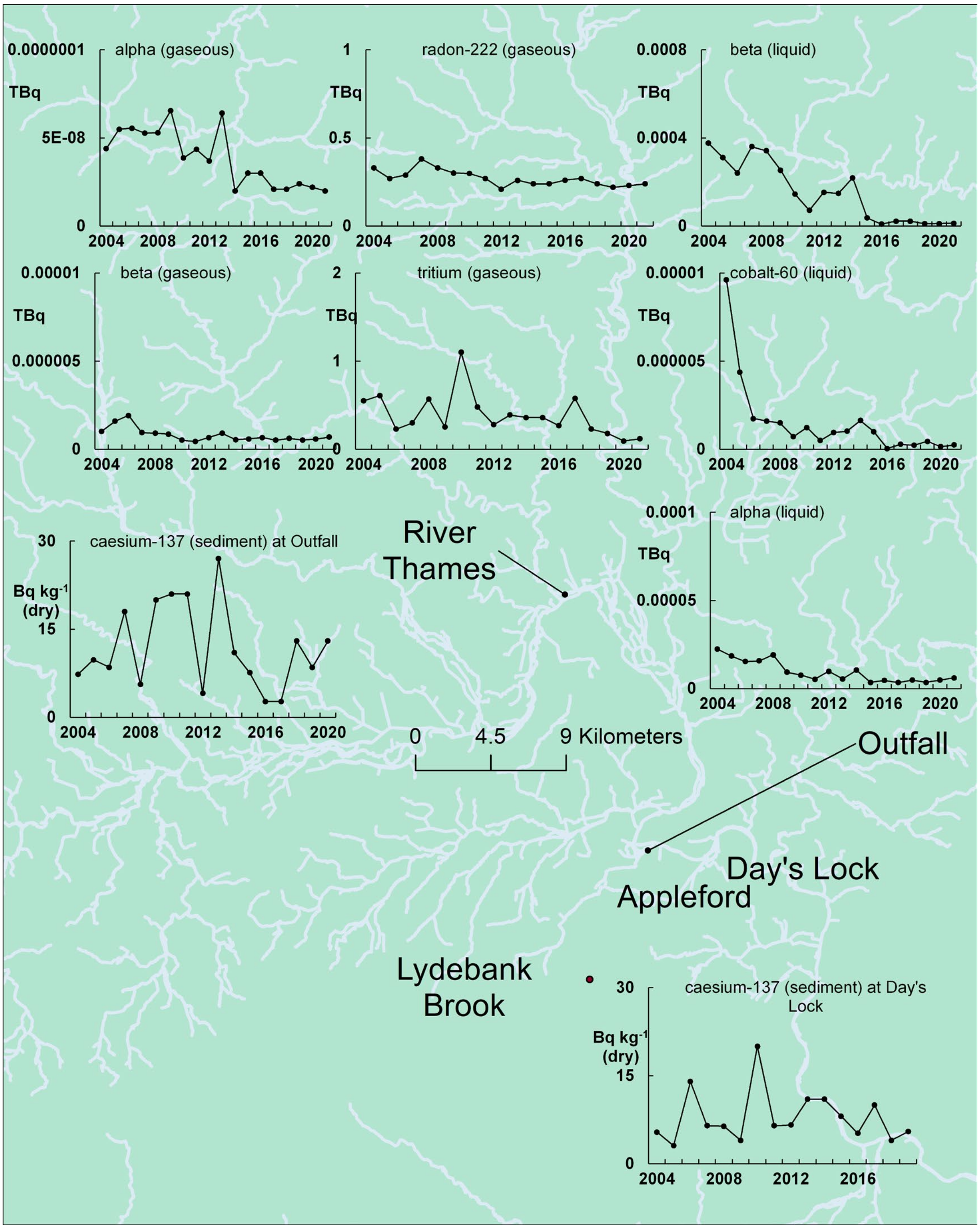


Figure 8.3 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Harwell (2004 to 2021)

8.4 Winfrith –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous emissions from Winfrith are discharged into the atmosphere, and liquids to deep water in Weymouth Bay.

Figure 8.4 shows the trends of discharges over time (2004 to 2021) for a number of the permitted radionuclides. Gaseous and liquid discharges generally remained at low rates over the period. Gaseous discharges of tritium peaked in 2006 and this coincided with a revised permit to increase tritium discharges from the site, for the processing of wastes. Gaseous tritium discharges increased again in 2012 due to operations of a tenant on the site (Tradebe Inutec, formerly Inutec). Gaseous discharges of carbon-14 declined since the peak value in 2007. Liquid tritium discharges have varied between years, with periodic peaks in releases, due to operations at Tradebe Inutec. Over the period, liquid discharges of alpha-emitting radionuclides have generally decreased (although discharges peaked in 2013) and were less than 1% of the annual limit in most recent years.

Figure 8.4 also provides radionuclide concentrations from 4 locations, to assess the impact on the surrounding environment. Tritium concentrations in a stream north of the site showed enhanced levels that slightly increased following the revision of the permit in 2006. These concentrations were still relatively low and were less than 10% of the World Health Organisation’s screening levels for drinking water. Since 2006, tritium concentrations have generally declined over time. Plutonium radionuclides concentrations in seafood from Lulworth Ledges, Lulworth Banks and Poole Bay were very low over the time period, albeit with some relatively small enhancement in activity concentrations in 2012 and 2019. Americium-241 concentrations in seafood from the same four locations were very low over the time period, however there were apparent enhancements in crabs at Lulworth Banks from 2012 to 2021, however this is due to a change from radiochemical analysis to gamma spectrometric analysis, the latter of which has higher limits of detection. Any changes in the concentrations of these radionuclides between years during the overall time period are most likely attributable to environmental variability.

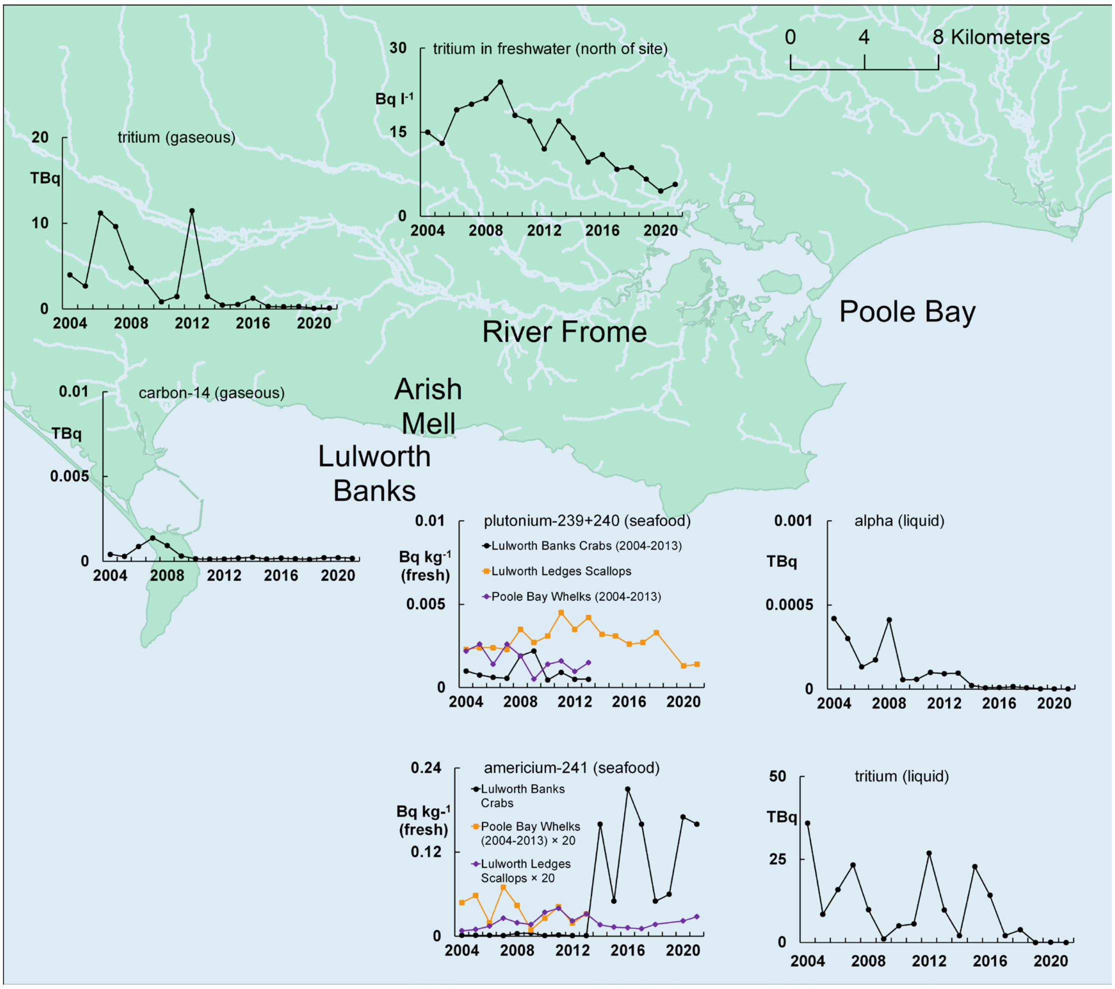


Figure 8.4 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Winfrith (2004 to 2021)

8.5 Summary

The information presented in Table 8.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 8.

Table 8.1 Summary of trend data for research sector (2004 to 2021)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	9	2	0	Majority downward trend
Liquid discharges	8	0	0	Majority downward trend
Overall discharges	17	3	0	Majority downward trend
Food and the environment overall	5	3	1#	Minority downward trend
Overall doses from gaseous and liquid discharges	2	2	0	Minority downward trend
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

The apparent increase is due to the change in analytical method

9 Nuclear power generation

Highlights

- all doses were less than the dose limit for members of the public of 1mSv per year
- highest annual dose (from artificial radionuclides) was 0.068mSv at Heysham
- most changes in dose between years resulted from natural changes in the environment
- overall decline in gaseous and liquid discharges, with all permitted/authorised discharges well below the limits
- some Magnox sites remained operational during the period, stopping electricity generation in; 2004 (Chapelcross), 2006 (Dungeness and Sizewell), 2012 (Oldbury), 2015 (Wylfa)
- concentrations on the land continued to be very low and concentrations in the sea were affected by natural changes in the environment and/or influenced by other source.

This section looks at the time trends between 2004 and 2021 from the UK's nuclear power stations. The time trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment.

The public's exposure[17] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There is a total of 19 nuclear power stations at 14 locations, 9 in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), 3 in Scotland (Chapelcross, Hunterston and Torness) and 2 in Wales (Trawsfynydd and Wylfa). Eleven of the 19 nuclear power stations are first generation Magnox power stations, 7 are more recent advanced gas-cooled reactor (AGR) power stations and 1 is a pressurised water reactor (PWR) power station. Five out of the original 11 first generation Magnox Power stations were operating in 2004. Over the period of this report, all the remaining first generation (Magnox) stations were defueled and are now being decommissioned. In the final year of this reporting period (2021), the first AGR nuclear power station, Dungeness B, ceased energy generation and began the decommissioning process.

9.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 9.1 shows the time trends of doses between 2004 and 2021 due to the effects of liquid waste discharges at the power stations.

The dose is made up from consuming seafood and external exposure over intertidal areas. External dose from intertidal areas can be important contributor to doses where people spend a lot of time on beach area. At all locations, around these sites, the doses were all less than the UK limit for members of the public of 1mSv per year.

Figure 9.1 shows the annual dose was highest to a group of local fishermen at Heysham. This ranged between 0.015 and 0.068mSv over the period, and with the highest value in 2004, and generally declined over the reported period. The doses were affected by past discharges from Sellafield, where radionuclides have travelled with currents around to the area. The decrease in dose after 2004 and 2011 was due to a reduction in the amount of shellfish eaten (containing americium-241 from past discharges from Sellafield) and a reduction in the occupancy rates, respectively. In 2018, the decrease in dose was mainly attributed to lower external radiation over beaches and tidal areas. Most of the dose to this group was affected by external radiation measured above beaches and tidal areas and variations in the trend reflected changes between years in measured gamma dose rates.

The next group of people most affected by radioactive waste discharges was at Hinkley Point. This was a group of local fishermen, with annual doses ranging

[17] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in the locations being assessed. This dose, referred to in Sections 7-11, is an exposure that uses a different assessment method to that of 'total dose' in Section 6.

between 0.014 and 0.046mSv over the period. The doses were from external radiation measured above beach sediment and a conservative estimate from tritium and carbon-14 in fish. Carbon-14 and tritium were likely due to discharges from the former GE Healthcare facility at Cardiff. The trend graph shows apparent increases in doses during the period (in 2006, 2009, 2013 and 2018). The increase was due to slightly enhanced external dose rates above sediments. Variations in these measurements have contributed to the trend in recent years. There was no site related reason to account for the trend in dose rates, and the changes between years was most likely due to variations in natural radiation.

People living near Berkeley and Oldbury, including seafood consumers and houseboat dwellers, received annual doses between 0.006 and 0.031mSv. This included external radiation, and a conservative estimate due to the tritium from Cardiff. The apparent increase in dose in 2008 was due to a higher gamma dose rate measured in a different type of sediment. Before 2008, the changes in dose were likely due to normal changes in the environment. Between 2009 and 2013, changes in doses in were due to variations in dose rates. The dose increased in 2014 due to a revision in the habits information and a new conservative assessment for houseboat dwellers. Thereafter, changes in dose were due to variation in dose rates.

Local fishermen and wildfowl consumers at Chapelcross received annual doses ranging from less than 0.005 to 0.027mSv over the period. The changes in doses were mostly attributed to variations in gamma dose rate measurements over sediments. The dose declined in 2010 due to a revision in the habits information. The discharges from Chapelcross contributed a very small fraction of the dose to the local population. Most of the dose was attributed to historic Sellafield discharges.

At Bradwell, the annual dose ranged from less than 0.005 to 0.017mSv. The highest dose was in 2007. In 2007, new habits information became available including about occupancy of boats at the main mooring locations. These data were included in the assessment of dose and lead to an increase in the dose calculated for the group. Before 2007, the changes were mainly due to normal changes in the environment. In 2008, a decrease was observed in dose rate above beaches, and this led to a decrease in doses to the group for the remainder of the period.

At Dungeness, the annual dose to a group of local bait diggers or a group of people living on houseboats ranged between 0.005 and 0.019mSv. The changes in dose were mainly due to the normal variations in concentrations and dose rates in the environment. Doses after 2019 are to the local bait diggers as no houseboat occupancy was recorded in the most recent habits survey [19].

At Hartlepool, between 2004 and 2007, the annual dose to a group of local fishermen was assessed to be less than 0.005mSv. The apparent increase in 2008 was due to the identification and assessment of a new pathway, for the external exposure of a group of sea coal collectors. Variations in dose (and group) between 2009 and 2013 were due to changes in dose rates. In 2014, the 2 groups were combined and assessed, due to a revision in the habits information. The relatively small changes in doses between 2015 and 2021 were mainly due to variations in dose rates.

At Hunterston, the annual dose ranged from less than 0.005 to 0.011mSv. This included a contribution from technetium-99 in shellfish, the activity having been discharged from Sellafield. Over the period, the overall trend was due to differences in measured gamma dose rates from normal changes in the environment.

At Sizewell, the assessed doses (between 2004 and 2011) for seafood consumers and houseboat dwellers were much less than 0.005mSv. In 2012 and 2013, the dose for houseboat dwellers increased due to higher dose rates. The reduction in dose in 2014 was a result of lower dose rates. Doses after 2015 are lower as the habits information was revised, which has resulted in lower houseboat occupancy rates [20].

At Trawsfynydd, the annual dose ranged between less than 0.005 and 0.026mSv over the period. The assessed dose was for a group of anglers using the lake for fishing. Part of their dose was from external exposure. It has proved difficult to obtain a reliable dose rate from artificial radionuclides by measurement, because of uncertainty in the dose rate from natural radionuclides. So, for this assessment, external dose was calculated from radionuclide concentrations (in particular caesium-137) using an external dose rate model. The higher dose figures observed in 2017 and 2018 were mostly due to higher caesium-137 concentrations recorded in lake sediments in comparison to previous years.

At Wylfa, the annual dose to a group of people who ate a large amount of fish and shellfish ranges from less than 0.005 to 0.010mSv. The reduction in dose in 2004 at Wylfa was due to new estimates of consumption and occupancy rates. Thereafter, changes in doses were mostly due to variations in dose rates.

All assessed doses were much less than 0.005mSv at Torness, over the period, with no significant variation in doses to seafood consumers.

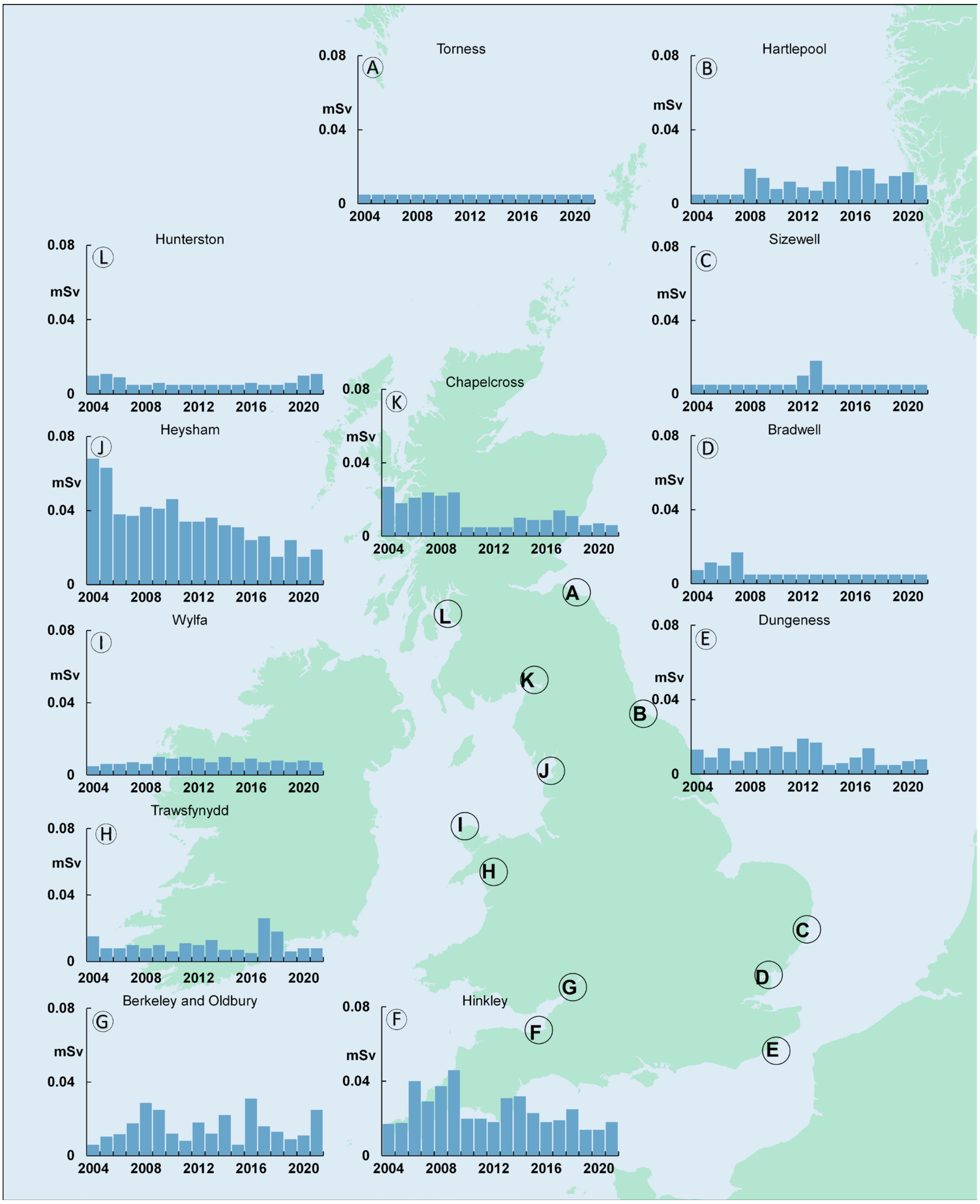


Figure 9.1 Individual radiation exposures around nuclear power stations from **aquatic pathways for artificial radionuclides (2004 to 2021) (Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)**

9.2 Discharges of radioactive waste from nuclear power stations

Permitted/authorised discharges of gaseous and liquid waste are made to the atmosphere and into the sea (except at Trawsfynydd where liquid discharges are released into Lake Trawsfynydd – see Section 9.4 for discharges). Figure 9.2 and Figure 9.3, respectively, show the trends of gaseous and liquid discharges over time (2004 to 2021) for a number of radionuclides.

For Magnox stations, radionuclide permits/authorisations include tritium and carbon-14 (gaseous), and tritium and caesium-137 (liquid). For operating Magnox stations discharges of argon-41 and sulphur-35 gases were made. For AGR and PWR stations, these include tritium, carbon-14, sulphur-35, and argon-41 (for gaseous discharges), and tritium, sulphur-35, cobalt-60 and caesium-137 (for liquid discharges).

For the locations with only Magnox reactors (excluding Trawsfynydd – see section 9.4), the most significant trends over the period were an overall decline in the gaseous discharges of tritium and carbon-14 and liquid discharges of tritium and caesium-137. There was a pronounced decrease in the discharge of gaseous and liquid tritium from Chapelcross. This is because Chapelcross stopped generating electricity in 2004. Sizewell A and Dungeness A both showed significant declines in gaseous discharges of argon-41 and sulphur-35 after 2006. This was the year that they were shut down permanently. Gaseous and liquid tritium discharges from Berkeley and Oldbury also declined with time. Gaseous and liquid discharges of tritium from Bradwell increased by a small amount in 2016 and 2017, due to decommissioning work.

For the locations with AGR or PWR reactors, the trend was an overall decline in gaseous and liquid discharges over the period 2004 to 2021, at Dungeness, Hartlepool (gaseous), Hinkley Point, Hunterston, and Sizewell. Discharges from other sites were generally similar over the period, with fluctuations between years. Most of the apparent variations can be associated with changes in power output (including shutdowns for maintenance operations). The most pronounced observation was the decreases of gaseous and liquid discharges in 2008 at Hartlepool. This is because both reactors at Hartlepool were shut down in 2008. In 2007, liquid tritium discharges declined due to the shutdown of Heysham 1 and liquid tritium discharges decreased in 2011 and between 2019 and 2021 from reduced power output at Dungeness B.

9.3 Concentrations of radionuclides in food and the environment

Monitoring of food and the environment is carried out around each of the power stations in the UK. The majority of measurements of radionuclide concentrations were at or below the analytical limits of detection. This meant that it was only possible to establish trends for a few radionuclides in environmental samples. Figure 9.4 shows monitoring trends of caesium-137 in sediments from marine locations to help assess the overall impact on the surrounding environment. Furthermore, it is difficult to differentiate the low concentrations of activity in marine material between site discharge and other factors such as liquid discharges of nearby sites, fallout from weapons testing and Chernobyl, and long-distance contributions (including past discharges) from nuclear reprocessing plants at Sellafield and Cap de la Hague (France).

Overall, the concentrations of caesium-137 in UK sediments were low over time at all locations. Data in Figure 9.4 show that, although there were minor changes between years for individual sites, the general trends were for activity concentrations to decrease or remain relatively constant over the period. The declining trend was most pronounced at Chapelcross and Heysham; the 2 power station sites (near the Irish Sea) most influenced by Sellafield. Further afield, the effects of Sellafield were less noticeable, partly due to the influence of releases from other sources and environmental variability. The apparent increase of caesium-137 at Dungeness in 2010 was due to the inclusion of a less than value (< 5.8Bq kg^{-1}).

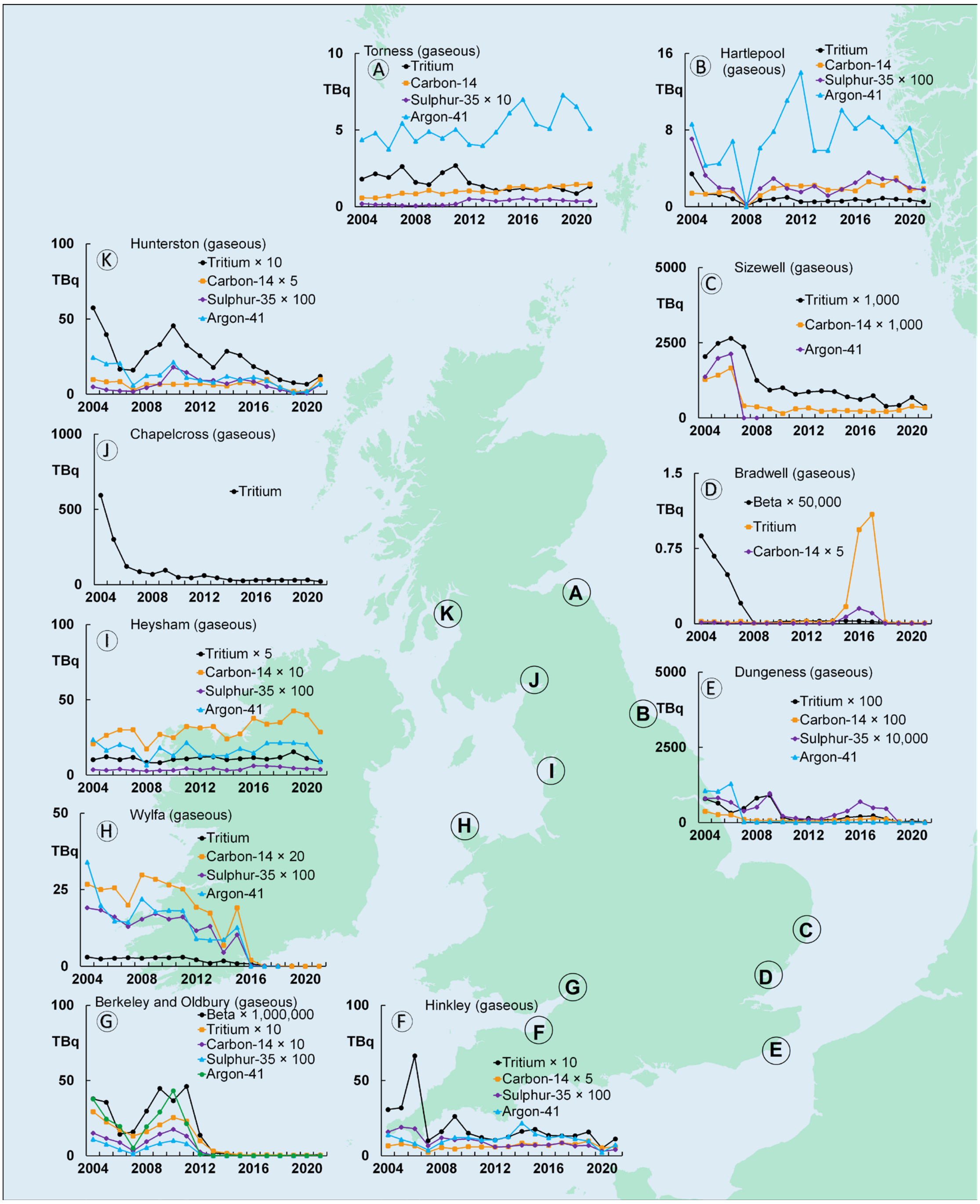


Figure 9.2 Permitted/authorised discharges of gaseous wastes from nuclear power stations (2004 to 2021)

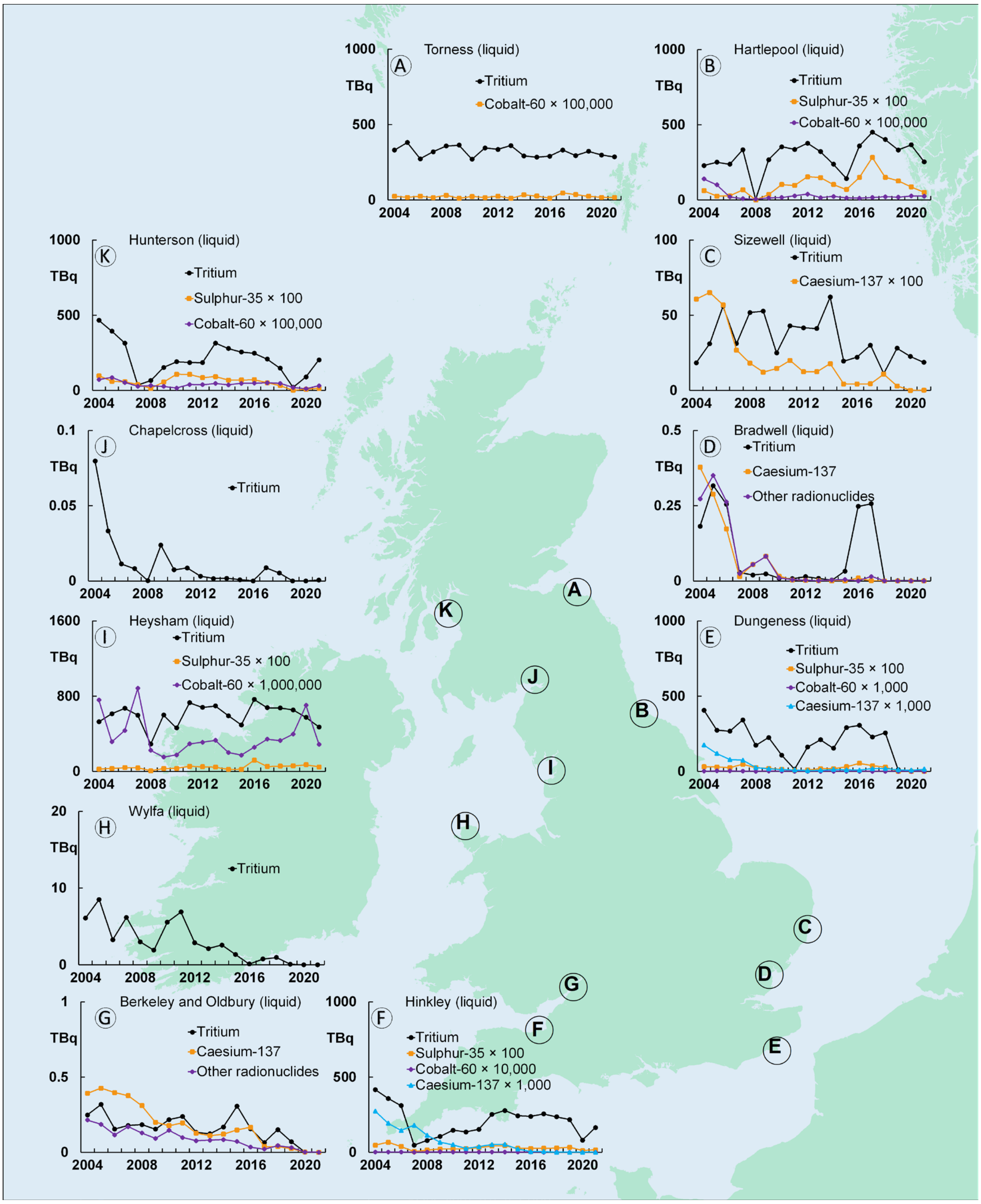


Figure 9.3 Permitted/authorised discharges of liquid wastes from nuclear power stations (2004 to 2021)

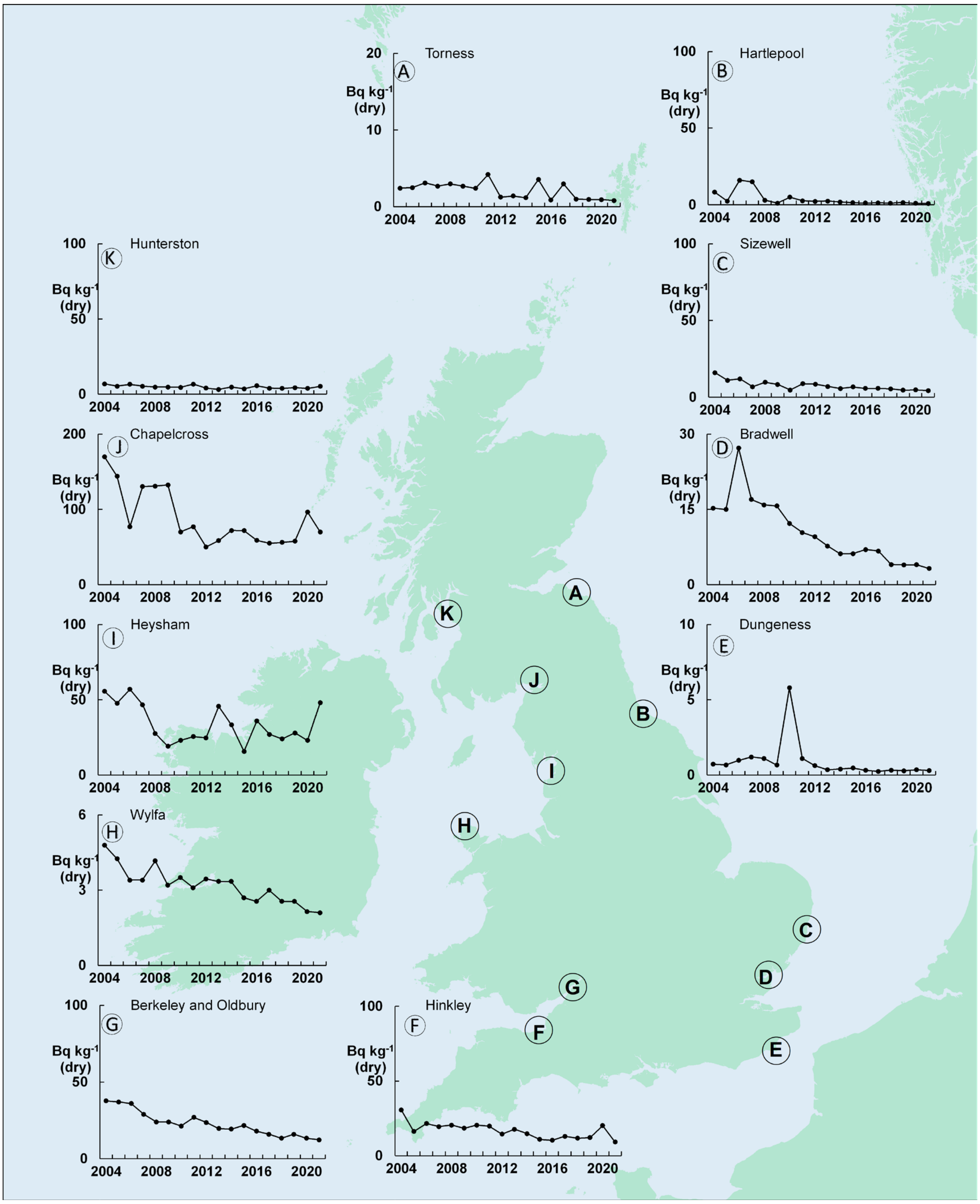


Figure 9.4 Caesium-137 concentrations in marine sediments near nuclear power stations (2004 to 2021)

9.4 Trawsfynydd - Discharges of radioactive waste and concentrations of radionuclides in the environment

Trawsfynydd power station is permitted to discharge low levels of liquid waste to Lake Trawsfynydd. All the other power stations make liquid discharges to the coastal environment. Figure 9.5 shows the trends of gaseous and liquid discharges over time (2004 to 2021) for a number of the permitted radionuclides. Gaseous tritium discharges from Trawsfynydd peaked in 2011 but generally declined over the whole period, with low releases in most recent years. From 2006, liquid tritium discharges were generally low, but peaked in 2014, before returning to previous levels.

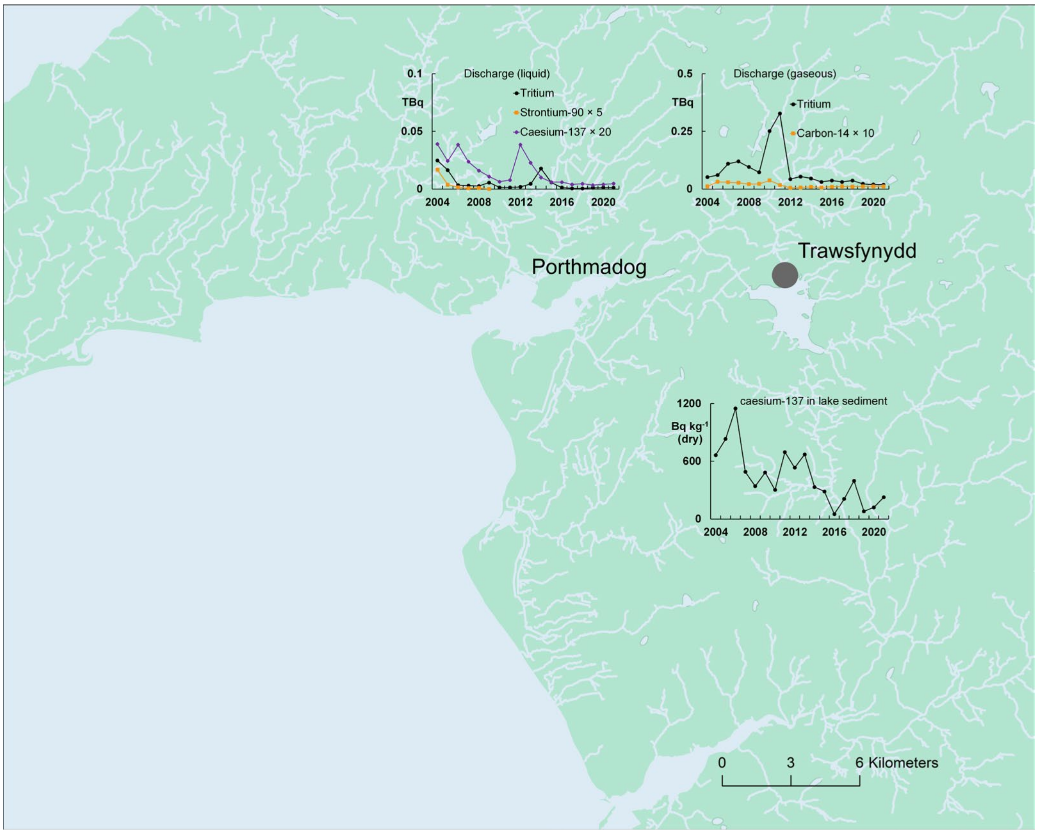


Figure 9.5 Permitted discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Trawsfynydd (2004 to 2021)

Figure 9.5 also shows trends of caesium-137 in lake sediments from Trawsfynydd to help assess the overall impact on the surrounding environment. In the lake itself, there remains clear evidence of the effects of caesium-137 discharges from the power station, particularly in sediment. A substantial decline in environmental radionuclide concentrations was observed in the late 1990s in line with reducing discharges. Over the period reported here, there was an overall decline in concentrations, although some variability is shown from year to year including movement of activity on sediments from beneath the sediment surface. Nevertheless, the lowest caesium-137 concentrations in sediments were observed in 2016 and 2019.

9.5 Summary

The information presented in Table 9.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 9.

Table 9.1 Summary of trend data for nuclear power sector (2004 to 2021)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	10	1	1	Majority downward trend
Liquid discharges	8	4	0	Majority downward trend
Overall discharges	18	7	1	Majority downward trend
Environment overall	11	1	0	Majority downward trend
Overall doses from gaseous and liquid discharges	9	3	0	Majority downward trend
All doses were below the dose limit				

***** Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only

10 Defence

Highlights

- all doses were significantly less than the dose limit for members of the public of 1mSv per year
- highest annual dose (from artificial radionuclides) was 0.026mSv at Rosyth
- all discharges were well below the authorised/permitted limits
- overall, gaseous and liquid discharges were low
- concentrations around the sites continued to be very low

This section looks at the time trends between 2004 and 2021 from the UK's defence establishments. The trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[18] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

There are 9 defence-related establishments that are currently authorised/permitted to discharge radioactive waste in the UK. The main sites are Aldermaston (and Burghfield) in Berkshire, Devonport in Devon, Faslane and Coulport in Argyll and Bute, and Rosyth in Fife. Other minor defence sites include Barrow (Cumbria), Derby

[18] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in areas in the locations being assessed. This dose, referred to in Sections 7-11, is an exposure that uses a different assessment method to that of *total dose* in Section 6.

(Derbyshire), Holy Loch (Argyll and Bute) and Vulcan (Highland). These latter smaller sites make small discharges overall and are not considered here.

10.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 10.1 shows the time trends of doses between 2004 and 2021, due to the effects of gaseous and liquid waste discharges. All doses were much less than the national UK limit for members of the public of 1mSv per year.

At Aldermaston and Devonport, the doses were all less than 0.005mSv over the entire period. The increase in dose at Faslane and Coulport in 2016 onwards was mostly due to the increased rate of consumption of fish and occupancy time over sand from the revised habits data. The increase in doses at Rosyth in 2015 was mostly due to a revision of habits information. The variations in dose between 2016 and 2021 are due to fluctuations in gamma dose rates.

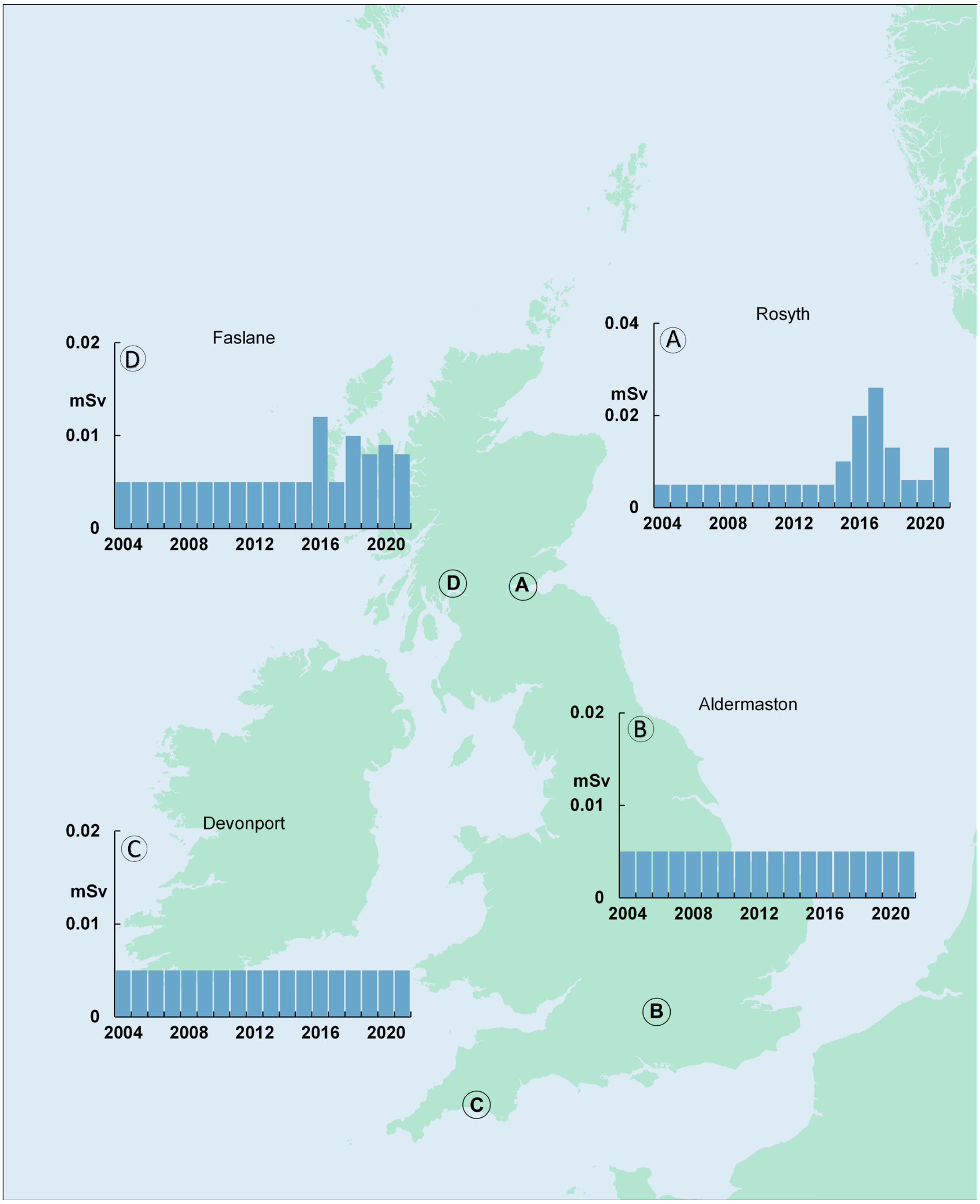


Figure 10.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Aldermaston, Devonport, Faslane and Coulport, and Rosyth (2004 to 2021) (Small doses less than 0.005mSv are recorded as being 0.005mSv)

10.2 Aldermaston, Devonport, Faslane and Coulport, and Rosyth – Discharges of radioactive waste

Gaseous and liquid discharges (mainly tritium, carbon-14, and cobalt-60) are released into the atmosphere and most to the sea. Figure 10.2 shows the trends of discharges over time (2004 to 2021) for a number of the authorised/permitted radionuclides.

Gaseous tritium discharges from Aldermaston significantly declined between 2004 and 2006 (thereafter, similar over time). Other gaseous radionuclides discharged from the site were very low and reasonably constant with time. Gaseous volatile beta discharges increased in 2015 (81% of the discharge limit) due to a change in operations on the site. There were no detected environmental effects (due to this increase). The Pangbourne pipeline (which previously discharged liquid waste to the River Thames at Pangbourne) closed in 2005. Consequently, liquid discharges of tritium, alpha emitting radionuclides and plutonium-241 decreased after that. At Devonport, liquid discharges generally decreased, whilst gaseous discharges were generally similar, during the period. Gaseous carbon-14 discharges were elevated in 2005-2006, 2009, 2012 and 2017 due to the periodic nature of routine submarine refit operations. Gaseous and liquid discharges at Faslane and Coulport, and Rosyth (liquid only) showed some minor changes and decreases over the period, and the discharges were very low.

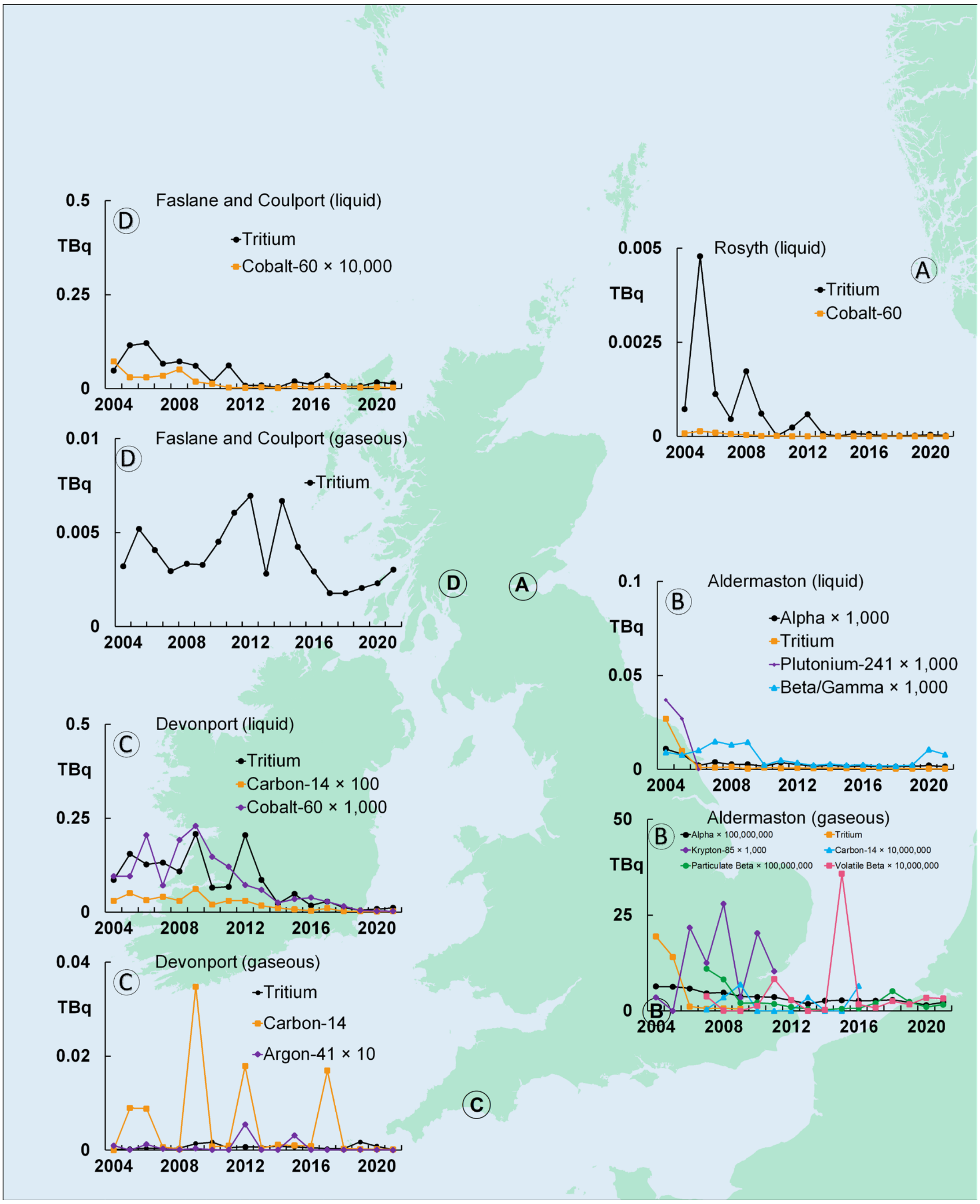


Figure 10.2 Permitted/authorised discharges of gaseous and liquid radioactive wastes, Aldermaston, Devonport, Faslane and Coulport, and Rosyth (2004 to 2021)

10.3 Defence establishments –

Concentrations of radionuclides in food and the environment

The Atomic Weapons Establishment at Aldermaston provides and maintains fundamental components of the UK's nuclear deterrent on behalf of the Ministry of Defence. Gaseous and liquid discharges are released into the atmosphere and to the sewage works at Silchester and to Aldermaston Stream. The concentrations of all artificially detected radionuclides in the Thames catchment area were very low (or below the limit of detection). The gross alpha (and gross beta) activity concentrations were below the World Health Organisation's screening levels for drinking water over the whole period. Figure 10.3 provides some monitoring trends to assess the impact on the surrounding environment. Concentrations of plutonium radionuclides and americium-241 (alpha emitting radionuclides) in freshwater crayfish from Ufton Bridge to Theale also showed low levels. Concentrations of alpha emitting radionuclides in sediments at Aldermaston, Mapledurham and Pangbourne were shown to decrease initially. This corresponded with a reduction in liquid alpha emitting radionuclides from 2004. Any fluctuations in recent years, for both food and sediment, were most likely due to normal variations in the environment.

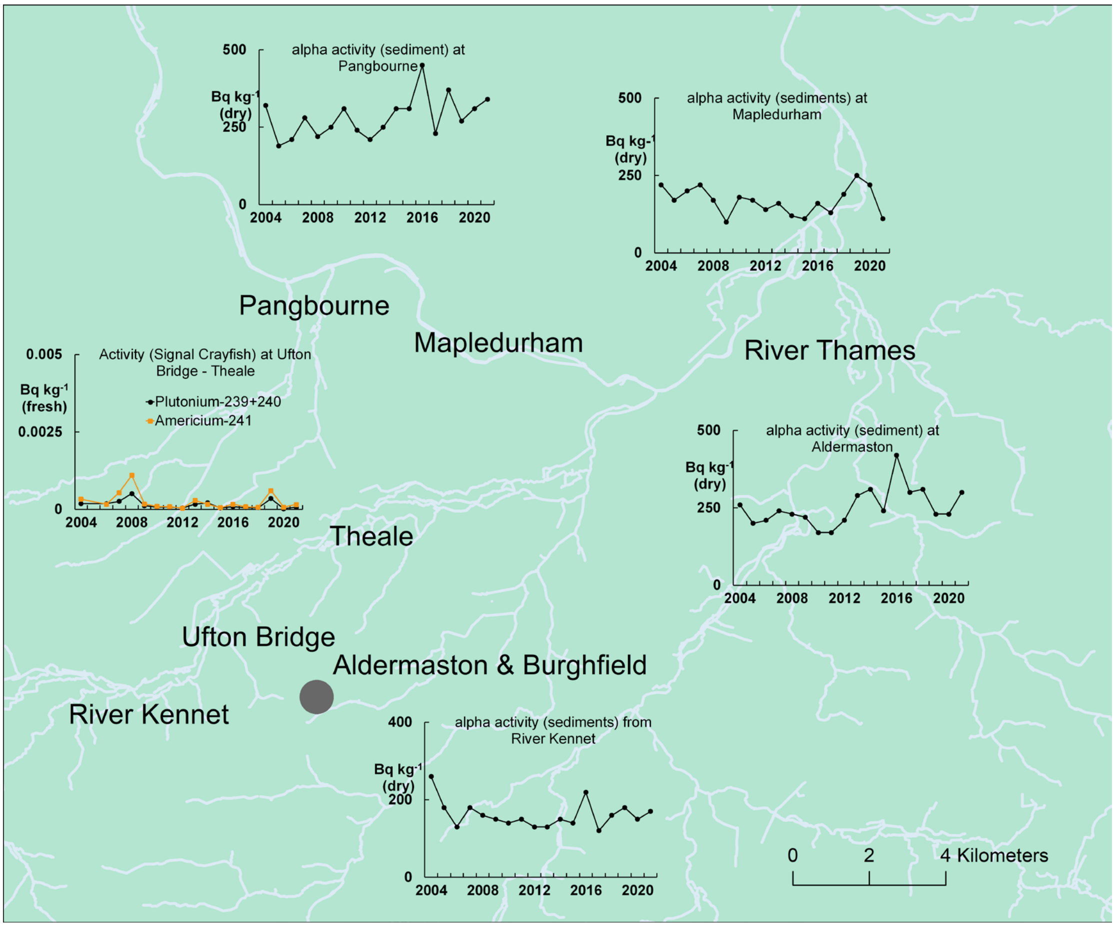


Figure 10.3 Monitoring of the environment from discharges of radioactive wastes, Aldermaston (2004 to 2021)

For other defence establishments, the majority of measurements of food and environmental samples were at or below the analytical limits of detection, which made it difficult to produce trend data from monitoring results.

10.4 Summary

The information presented in Table 10.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 10.

Table 10.1 Summary of trend data for defence sector (2004 to 2021)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	1	2	0	Minority downward trend
Liquid discharges	4	0	0	Downward trend
Overall discharges	5	2	0	Majority downward trend
Food and the environment overall	2	2	1	No overall direction
Overall doses from gaseous and liquid discharges	0	2	2#	No overall direction
All doses were below the dose limit				

***** Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.
# Increase mostly due to revised habits data

11 Radiochemical production

Highlights

- all doses were less than the dose limit for members of the public of 1mSv per year
- highest annual dose (from artificial radionuclides) was 0.029mSv at Cardiff
- highest group doses continually decreased with time
- all authorised discharges were well below the authorised limits
- concentrations on the land continued to be very low and concentrations in the sea declined following reduction in discharges

This section looks at the time trends between 2004 and 2021 from the UK's radiochemical production sites. The trends show the public's exposure, discharges of radioactive waste and concentrations of radionuclides in food and the environment. The public's exposure[19] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment. GE Healthcare is a health science company operating in world-wide commercial healthcare and life science markets, with radiochemical facilities at Amersham and formerly in Cardiff. GE Healthcare Limited (Cardiff) ceased manufacturing a range of radio-labelled products containing tritium in 2009 and products containing carbon-14 in 2010. Furthermore, in 2015, GE Healthcare Limited partially surrendered the environmental permit for the Cardiff site and around 90% of the footprint of the site was de-licensed, following decommissioning and clean-up of the wider Maynard Centre. The remaining 10% of the site was then re-licensed as a stand-alone nuclear site, known as the Cardiff Nuclear Licensed Site (CNLS) which continued to be operated by GE Healthcare Limited. The reduced licensed site at CNLS related to the storage and repackaging of legacy Intermediate Level Waste for off-site disposal and was located entirely within the confines of the previously licensed site (and its security boundary). In 2019, CNLS was fully delicensed and gaseous discharges from the site ceased from then.

11.1 Public's exposure to radiation due to discharges of radioactive waste

Figure 11.1 shows the trends of doses of the public's exposure to radiation (2004 to 2021) due to the effects of gaseous and liquid waste discharges. For locations near both sites, the doses were all much less than the UK limit for members of the public of 1mSv per year.

[19] The monitoring results are interpreted in terms of radiation exposures of the public, commonly termed 'doses'. These people are a group, who generally eat large quantities of locally grown food (high-rate consumers) or who spend long periods of time in areas in the locations being assessed. This dose, referred to in Sections 7-11, is an exposure that uses a different assessment method to that of 'total dose' in Section 6.

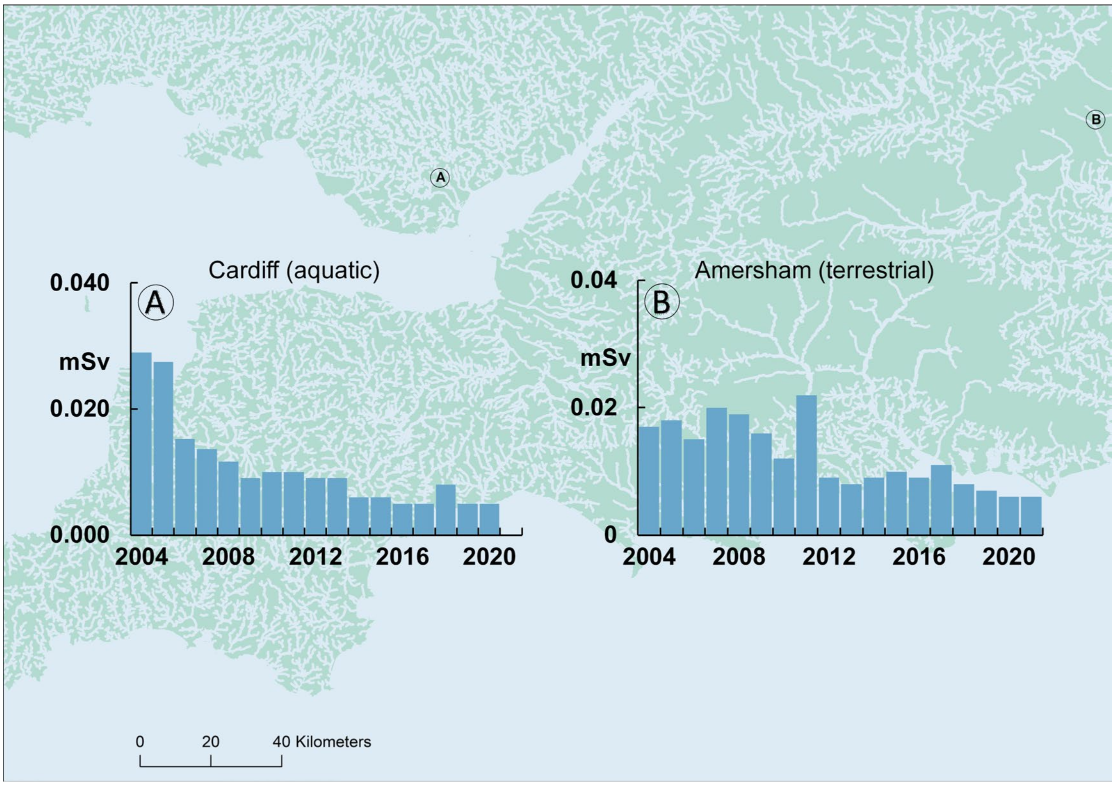


Figure 11.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Amersham, and Cardiff (2004 to 2021)

The annual dose was highest at Cardiff from consuming fish and shellfish (combined with external exposure) and ranged between less than 0.005 and 0.029mSv over the time period, with a clear and gradual decline with time. The reduction in the doses for the Cardiff site was largely due to the continuing reductions in concentrations of tritium (and carbon-14) in seafood, with the most significant reduction of tritium in seafood occurring in 2006.

At the Amersham site, the annual dose to people who ate locally grown food (combined with a contribution of discharged radionuclides in air) ranged between 0.006 and 0.022mSv over the time period. The changes in trends at this site were mostly due to variations in the estimated air exposure from inhaling gases and emitted radiation of the gaseous discharges, which overall lower atmospheric discharges of radon-222 between 2012 and 2021.

11.2 Amersham –

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous and liquid discharges from Amersham are released into the atmosphere and to sewers serving the Maple Lodge sewage works. Releases subsequently enter the Grand Union Canal and the River Colne. Figure 11.2 shows the trends of discharges over time (2004 to 2021) for a number of the permitted radionuclides.

The gaseous discharges were low over the period. Discharges of iodine-125 declined over the period, whilst radon-222 and alpha also generally declined (but with variations between years). Limits for sulphur-35 and iodine-125 were removed in 2012. There was an overall reduction in liquid discharges of tritium and iodine-125, and caesium-137 and alpha (from the peaks in earlier years).

Figure 11.2 also provides monitoring trends of sulphur-35 and caesium-137 in food, grass, and sediment from 3 locations, to assess the impact on the surrounding environment. Caesium-137 concentrations in sediment were low over the period and changes between years were attributed to natural variation. Caesium-137 concentrations upstream of the outfall generally declined over the period and the outfall concentrations were lower than further upstream. Caesium-137 activity includes that from fallout from weapons testing and Chernobyl. The trend for sulphur-35 concentrations in grass generally followed the pattern of gaseous discharges (between 2004 to 2012), although the activity concentrations were very low. In spinach, sulphur-35 concentrations were significantly less than in grass.

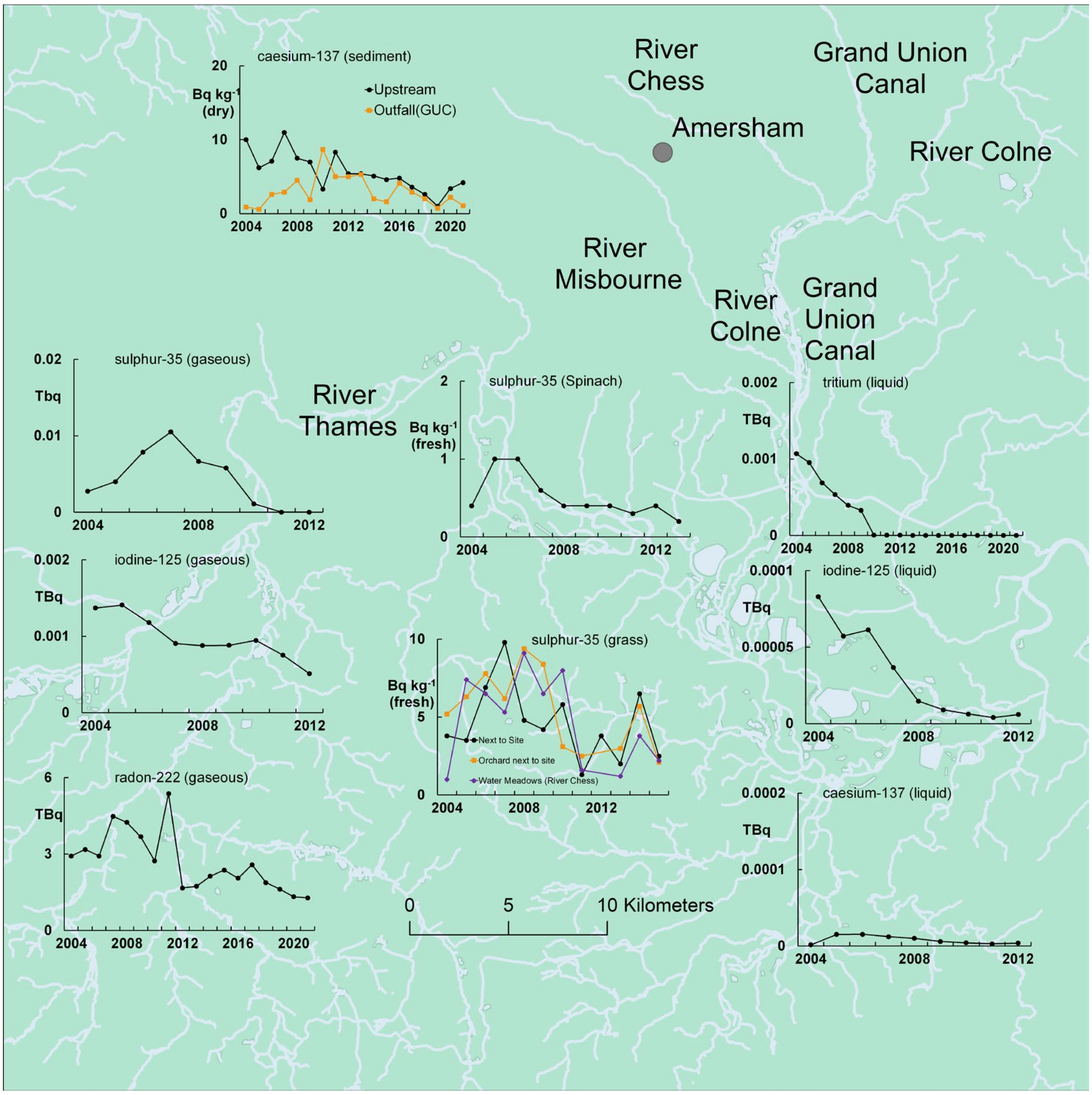


Figure 11.2 Authorised discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Amersham (2004 to 2021)

11.3 Cardiff -

Discharges of radioactive waste and concentrations of radionuclides in food and the environment

The gaseous discharges into the atmosphere from the Maynard Centre. Liquid waste to the Ystradyfodwg and Pontypridd (YP) public sewer ceased in 2015, because of the partial surrender of the permit. Figure 12.3 shows the trends of discharges over time (2004 to 2020) for a number of the permitted radionuclides. Gaseous and liquid discharges of all radionuclides declined over the period. The site operator surrendered it environmental permit in late 2019.

Figure 11.3 also provides monitoring trends of tritium, carbon-14 and caesium-137 in seafood and from 3 locations, to assess the impact on the surrounding environment. Overall, the trend was for concentrations of tritium in fish, molluscs, and sediments to significantly decline over the period, in line with reductions and cessation of liquid discharges. This also included the low tritium concentrations being detected in sediment from the Glamorganshire canal, which is not used as a source of water for public water supply.

Over the period, concentrations of carbon-14 and caesium-137 in seafood and sediments were low and relatively constant. Carbon-14 concentrations detected in sediment from the Glamorganshire canal declined after 2005. Changes between years were most likely due to normal changes in the environment, with caesium-137 coming from other nuclear establishments and fallout from weapons testing and Chernobyl.

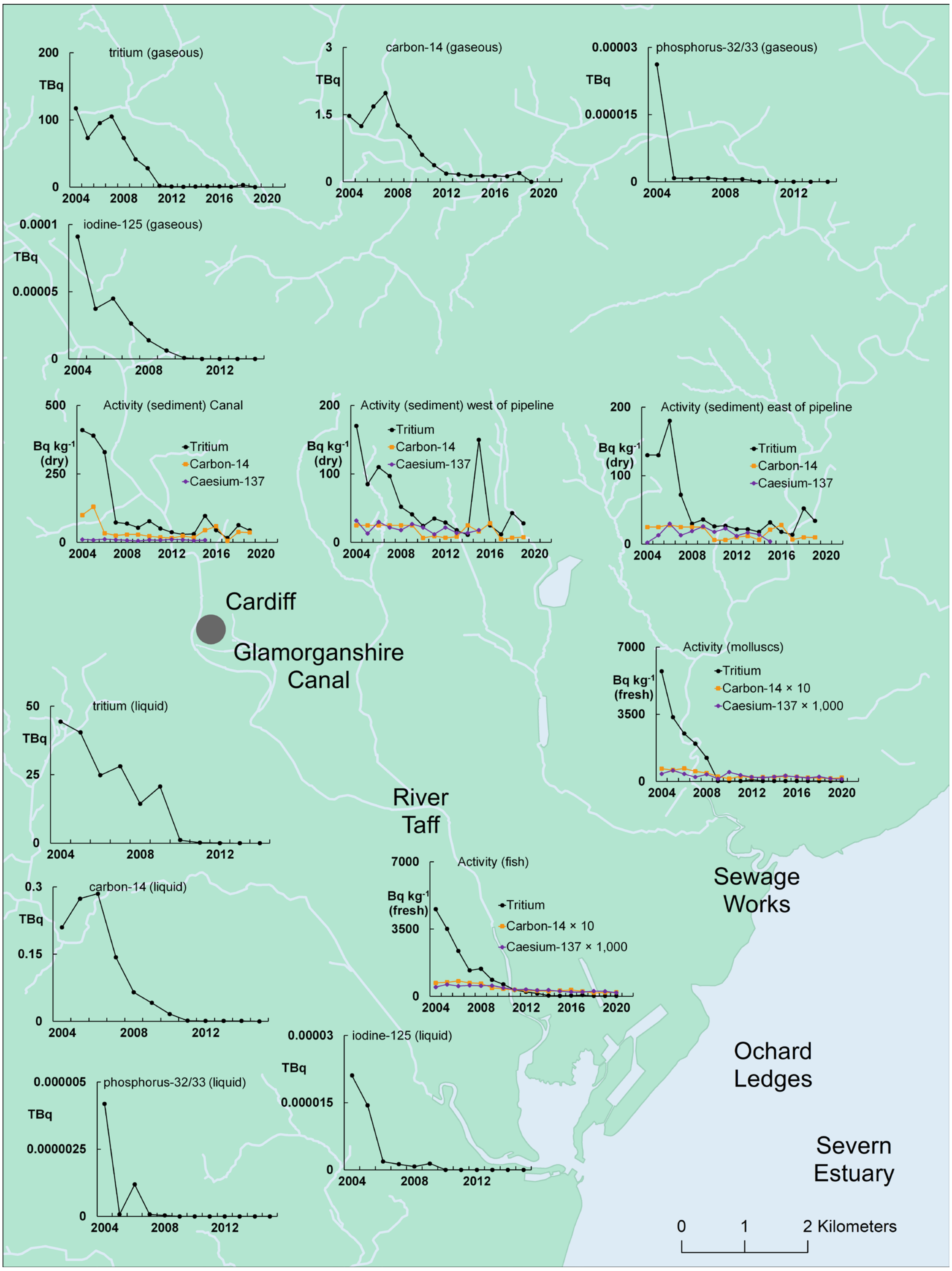


Figure 11.3 Discharges of gaseous and liquid radioactivity wastes and monitoring of the environment, Cardiff (2004 to 2021)

11.4 Summary

The information presented in Table 12.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 11.

Table 11.1 Summary of trend data for radiochemical production (2004 to 2021)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	7	0	0	Downward trend
Liquid discharges	7	0	0	Downward trend
Overall discharges	14	0	0	Downward trend
Food and the environment overall	6	2	0	Majority downward trend
Overall doses from gaseous and liquid discharges	2	0	0	Downward trend
All doses were below the dose limit				

* Taken from the number of trend graphs for this sector presented in this report. This is a visual evaluation only.

12 Summary and Conclusions

Information presented in Table 12.1 gives an overview of trends associated with discharges and environmental concentrations for each of the 5 nuclear sectors described in Sections 7-11.

Highlights

- discharge trends were downward in all 5 sectors
- trends of radionuclide concentrations in food and the environment were downward in 4 of the 5 sectors with no clear trends in the other sectors
- dose trends were downward in 4 of the 5 sectors
- doses at all sites were less than the dose limit, and in most cases, much less

It was previously noted, over the period 2004 to 2008, discharges and environmental concentrations of radionuclides both showed a distinct decline in 3 of the 5 sectors [21]. However, during 2004 to 2008, environmental concentrations responded relatively slowly to these reductions, in part due to the legacy of higher environmental concentrations of radionuclides from past higher discharges. Over the period 2004 to 2021 both discharges and environmental concentrations of radionuclides have fallen further.

Dose estimates are dependent on a number of inputs, including the method of assessment, concentrations of radionuclides in food and the environment, measurements of dose rates and data on human activities. All these are subject to variation and changes from year to year which can affect the dose assessment outcomes and produce step changes or false trends over time. Nevertheless, there is significant evidence to confirm that doses have declined overall, over the period 2004 to 2021.

Additional information on past discharges, radionuclide concentrations and doses for each year can be found in the RIFE reports.

Table 12.1 Overall summary for nuclear sectors (2004 to 2021)*

Sector		2004-2021 trend
All sectors	**Key Marine Environmental Indicators**	Majority downward trend
	Doses to consumers of drinking water	No overall direction
	Doses	Majority downward trend
Nuclear fuel processing	**Discharges**	Majority downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Majority downward trend
Research sites	**Discharges**	Majority downward trend
	Food and environmental concentrations	Minority downward trend
	Doses	Minority downward trend
Power production	**Discharges**	Majority downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Majority downward trend
Defence sites	**Discharges**	Downward trend
	Food and environmental concentrations	No overall direction

	Doses	No overall direction#
Radiochemical production	**Discharges**	Downward trend
	Food and environmental concentrations	Majority downward trend
	Doses	Downward trend

***** Taken from the trends presented in this report. This is a visual evaluation only.
# Changes occurred due to revised habits data

Appendix 1 Bibliography

[1] OSPAR. Part 1. UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2012-2016) Implementation of PARCOM Recommendation 91/4 on radioactive discharges. Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004-2016). London: 2018.

[2] Scotland & Northern Ireland Forum for Environmental Research. A Review of the Application of "Best Practicable Means" within a Regulatory Framework for Managing Radioactive Wastes. Edinburgh: 2005.

[3] Scottish Environment Protection Agency. Satisfying the optimisation requirement and the role of Best Practicable Means. RS-POL-001 Version 2.0. Stirling: 2019.

[4] OSPAR. UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2008-2011). Implementation of PARCOM Recommendation 91/4 on radioactive discharges. London: 2013.

[5] OSPAR. Implementation of PARCOM Recommendation 91/4 on liquid discharges. Report from the United Kingdom - Part 1. 2009.

[6] Punt A, George R. BAT Case: Radioactive Process Materials and Wastes, December 2011. Eden Report ref ENE/0034/AP. 2011.

[7] Dounreay Particles Advisory Group. 4th Report, November 2008. Stirling: 2008.

[8] Particles Retrieval Advisory Group (Dounreay). Annual Report to SEPA and DSRL, March 2011. Stirling: 2011.

[9] Particles Retrieval Advisory Group (Dounreay). Annual Report to SEPA and DSRL, March 2010. Stirling: 2010.

[10] Particles Retrieval Advisory Group (Dounreay). Annual report to SEPA and DSRL, SEPA, Stirling. March 2016. Stirling: 2016.

[11] UNSCEAR. Sources, Effects and Risks of Ionizing Radiation: Annex B Epidemiological Studies of Cancer Risk Due To Low-Dose-Rate Radiation From Environmental Sources. 2017.

[12] Department of Energy and Climate Change, Department of the Environment Northern Ireland, Scottish Executive, Welsh Assembly Government. Uk Strategy for Radioactive Discharges. London: 2009.

[13] Department for Business Energy and Industrial Strategy. UK strategy for radioactive discharges; 2018 Review of the 2009 Strategy. London: 2018.

[14] OSPAR. Towards the Radioactive Substances Strategy Objectives. Fifth Periodic Evaluation. London: 2022.

[15] OSPAR. Strategy of the OSPAR Commission for the Protection of the North-East Atlantic 2030. London: 2021.

[16] OSPAR. Cascais Declaration. Ministerial meeting of the OSPAR Commission October 2021. London: 2021.

[17] Oatway WB, Jones AL, Holmes S, Watson S, Cabianca T. Ionising radiation exposure of the UK population: 2010 Review. PHE-CRCE-026. Chilton: 2016.

[18] Environment Agency. Environmental Permitting Regulations (England and Wales) 2010: Criteria for setting limits on the discharge of radioactive waste from nuclear sites. Bristol: 2012.

[19] Greenhill B, Clyne F, Moore K, Mickleburgh F. Radiological Habits Survey: Dungeness, 2019. RL 01/20. Lowestoft: 2020.

[20] Garrod C, Clyne F, Papworth G. Radiological Habits Survey: Sizewell 2015. Lowestoft: 2016.

[21] Environment Agency, Food Standards Agency, Northern Ireland Environment Agency, Scottish Environment Protection Agency. Summary of Radioactivity in Food and the Environment 2004-2008. Bristol, London, Belfast, and Stirling: 2010.

[22] Scottish Government. The Environmental Authorisations (Scotland) Regulations 2018. Scottish Statutory Instruments. Edinburgh: 2018.

[23] United Kingdom - Parliament. Radioactive Substances Act, 1993. Her Majesty’s Stationery Office; 1993.

[24] Environment Agency, Food Standards Agency, Scotland FS, Natural Resources Wales, Agency NIE, Agency SEP. Radioactivity in Food and the Environment, 2015. Bristol, London, Aberdeen, Cardiff, Belfast, and Stirling: 2016.

Appendix 2 Acronyms

AETP	Active Effluent Treatment Plant
AGR	Advanced Gas-cooled Reactor

ALES	Active Liquid Effluent System
AWE	Atomic Weapons Establishment
BAT	Best Available Technology or Techniques
BDP	Babcock Dounreay Partnership
BEIS	Department of Business, Energy and Industrial Strategy
BPEO	Best Practicable Environmental Option
BPM	Best Practicable Means
C&M	Care and Maintenance
CNS	Capenhurst Nuclear Services Limited
COS	Carbonyl Sulphide
DAERA	Department of Agriculture Environment and Rural Affairs
Defra	Department for Environment, Food and Rural Affairs
DFR	Dounreay Fast Reactor
DPAG	Dounreay Particles Advisory Group
DSRL	Dounreay Site Restoration Limited
EARP	Enhanced Actinide Removal Plant
EARWG	Environment Agency Requirements Working Group
EASR18	Environmental Authorisations (Scotland) Regulations 2018
EC	European Commission
EDF	Electricité de France
EMITS	Environmental Maintenance, Inspection and Testing Schedule
EPR	Environmental Permitting Regulation
EPRI	Electric Power Research Institute

EU	European Union
FED	Fuel Element Debris
FSA	Food Standards Agency
FSS	Food Standards Scotland
GE	General Electric
HLW	High Level Waste (waste containing >4GBq α and/or 12GBq β/γ and with heat generating properties).
ILW	Intermediate Level Waste (as for HLW but not heat generating)
ISO	International Standards Organisation
IWS	Integrated Waste Strategy
KMEI	Key Marine Environmental Indicators
LETP	Liquid Effluent Treatment Plant
LLW	Low Level Waste (<4 GBq α and/or 12 GBq β/γ)
LLWR	Low-Level Waste Repository
LWR	Light Water Reactor
Magnox	Magnox Reprocessing Plant
NDA	Nuclear Decommissioning Authority
NIEA	Northern Ireland Environment Agency
NNL	National Nuclear Laboratory
NRW	Natural Resources Wales
ONR	Office for Nuclear Regulation
OSPAR	Oslo and Paris Convention
PFR	Prototype Fast Reactor

PARCOM	Paris Commission
PHE	Public Health England
POCO	Post-Operational Clean Out
PRAG (D)	Particles Retrieval Advisory Group (Dounreay)
PWR	Pressurised Water Reactor
RIFE	Radioactivity in Food and the Environment
RSA	Radioactive Substances Act
RSC	Radioactive Substances Committee
RSR	Radioactive Substances Regulation
RSS	Radioactive Substances Strategy
SEPA	Scottish Environment Protection Agency
SGHWR	Steam Generating Heavy Water Reactor
SIXEP	Site Ion Exchange Effluent Plant
THORP	Thermal Oxide Reprocessing Plant
THTR	Thorium High Temperature Reactor
UCP	Urenco ChemPlants Limited
UKAS	United Kingdom Accreditation Service
UNS	Urenco Nuclear Stewardship
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UOC	Uranium Ore Concentrate
UUK	Urenco UK
WMP	Waste Management Plan
YP	Ystradyfodwg and Pontypridd

The Aspect
12 Finsbury Park
London EC2A 1AS
United Kingdom

t: +44 (0)20 74305200
f: +44 (0)20 72423737
secretariat@ospar.org
www.ospar.org

OSPAR's vision is of a clean, healthy and biologically diverse North-East Atlantic used sustainably

ISBN: **978-1-909159-25-9 [to be updated]**

Publication Number: 592/2017 [to be updated]

OSPAR Secretariat
The Aspect
12 Finsbury Square
London
EC2A 1AS
United Kingdom

t: +44 (0)20 7430 5200
f: +44 (0)20 7242 3737
e: secretariat@ospar.org
www.ospar.org

Our vision is a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification

Publication Number: 966/2023