OSPAR COMMISSION

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)

United Kingdom

Radioactive Substances Series

2017

Summary of Radioactivity in Food and the Environment (2004–2016)

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

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 de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à 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.

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Summary

This report (Parts 1 and 2) has been prepared for the Radioactive Substances Committee of the OSPAR Commission as the UK statement on the implementation of PARCOM Recommendation 91/4 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 Radioactive Substances Act 1993 (as amended) (RSA 93) in Scotland, and the Environmental Permitting (England and Wales) Regulations 2016 (EPR16)[2].

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

[1] In PARCOM Recommendation 91/4, 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 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).

SEPA. The UK environment agencies consider that the terms BPM and BPEO taken 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 PARCOM Recommendation 91/4 and OSPAR is not appropriate to UK defence establishments. 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 (e.g. 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.

Récapitulatif

Le présent rapport (parties 1 et 2) a été préparé pour le Comité des substances radioactives de la Commission OSPAR à titre de déclaration du Royaume-Uni sur la mise en œuvre de la Recommandation PARCOM 91/4 sur les substances radioactives, portant sur l'application des meilleures technologies disponibles[3] (MTD) afin de minimiser et, le cas échéant, d'éliminer les rejets radioactifs des industries nucléaires (à l'exclusion des installations militaires et médicales) dans le milieu marin.

Politique et stratégie

Le Royaume-Uni a exposé sa stratégie initiale de mise en œuvre des accords conclus lors de la réunion ministérielle OSPAR de 1998, et lors des réunions suivantes de la Commission OSPAR sur les substances radioactives, dans sa Stratégie du Royaume-Uni pour les rejets radioactifs 2001-2020, publiée en 2002. Le gouvernement britannique et ses administrations décentralisées ont publié en 2009 la version mise à jour de la Stratégie pour les rejets radioactifs. Cette version révisée avait étendu sa portée afin d'inclure les rejets gazeux ainsi que liquides issus des déclassements comme des activités opérationnelles, et produits tant par les secteurs industriels non nucléaires que par le secteur nucléaire. Elle prend également en compte les incertitudes liées aux rejets des nouvelles centrales nucléaires, le prolongement éventuel de la vie utile de certains des réacteurs nucléaires actuels et les rejets issus des activités de déclassement. Les procédures d'octroi de permis et d'autorisation en vigueur au Royaume-Uni, et en particulier les conditions liées à l'examen périodique, garantissent que les MTD continueront d'être mises en œuvre conformément à la stratégie en matière de rejets et aux principes directeurs officiels connexes.

Règlement

L'évacuation des déchets radioactifs par les installations nucléaires britanniques est régie par la législation interne, et notamment le Radioactive Substances Act 1993 [loi anglaise de 1993 sur les substances radioactives] (telle que modifiée) (RSA 93) en Écosse, et les règlements sur les permis environnementaux (Angleterre et Pays de Galles) de 2016 (EPR16)[4].

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[3] Dans la recommandation PARCOM 91/4, le terme MTD porte sur les technologies. Cependant, le terme « techniques » est utilisé plus couramment par le Royaume-Uni 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.

[4] 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'évacuation des déchets radioactifs des sites nucléaires sont l'Agence de l'environnement en Angleterre, l'Agence écossaise 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 adoptés dans la Stratégie 2009 du Royaume-Uni sur les rejets radioactifs. En Écosse, les termes de meilleures techniques existantes (BPM) et meilleure option environnementale applicable (BPEO) sont toujours en usage à la SEPA. Les agences britanniques de protection de l'environnement considèrent que les termes BPM et BPEO pris ensemble équivalent à la condition requise d'utiliser les MTD et que les obligations sur les producteurs de déchets sont les mêmes. L'utilisation des MTD, BPM et BPEO au Royaume-Uni permet un niveau de contrôle des rejets qui est à tout le moins en cohérence avec celui des MTD, tel que défini par OSPAR.

Bilan des MTD

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

La production radiochimique est considérée comme un secteur non nucléaire et figure dans les rapports non nucléaires soumis à OSPAR. La mise en œuvre de la recommandation PARCOM 91/4 et d'OSPAR n'est pas appropriée aux établissements de défense du Royaume-Uni. Toutefois, les effets sur l'environnement de la production radiochimique et du secteur de la défense sont évalués et présentés dans la deuxième partie du présent 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 pas été couverts dans le présent rapport.

En plus de l'examen de l'application des MTD, fondé sur les pratiques actuelles, les technologies en cours de développement au Royaume-Uni et ailleurs ont été recensées, et des comparaisons avec les performances d'installations similaires dans le monde entier ont été faites le cas échéant.

Le gouvernement britannique et ses administrations décentralisées sont convaincus que les procédures et techniques en vigueur dans le secteur nucléaire britannique 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 britanniques sont clairement démontrés dans le présent rapport. Des exemples de processus et d'activités de gestion des déchets déployés au cours de la période de référence sont décrits et résumés pour chacun des secteurs nucléaires.

Conclusion

L'application des MTD au Royaume-Uni, entraînée notamment par une réglementation contraignante, des investissements considérables dans les installations de réduction de la pollution, l'optimisation des processus, et une meilleure application de la gestion hiérarchisée des déchets (dont la minimisation des déchets) a permis de réduire les rejets. Le Royaume-Uni continuera d'appliquer avec rigueur les MTD.

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 déclasser les installations redondantes.

Structure of the combined report

This combined report has been prepared for the Radioactive Substances Committee (RSC) of the OSPAR Commission as the UK statement on the implementation of PARCOM Recommendation 91/4 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, the implementation of BAT, site characteristics, together with 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 time 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 (2012-2016)

In Part 1, the implementation of BAT, detailing the organisation of nuclear safety and radiation protection within the national regulatory and legislative framework, is outlined for UK civil nuclear facilities. The 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 (2012- 2016).

Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004-2016)

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 (2004-2016).

PART 1. UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2012-2016)

1. Introduction

The 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 2004–03), 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 PARCOM Recommendation 91/4 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, 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 2013 (and predecessor reports) was also prepared on the basis of these Guidelines and covered the period 2008–2011. The present report provides an update on the implementation of BAT over the period 2012-2016 (Part 1), together with environmental activity concentration data and the public’s exposure (doses) to radiation for the period 2004-2016 (Part 2), in accordance with the Guidelines.

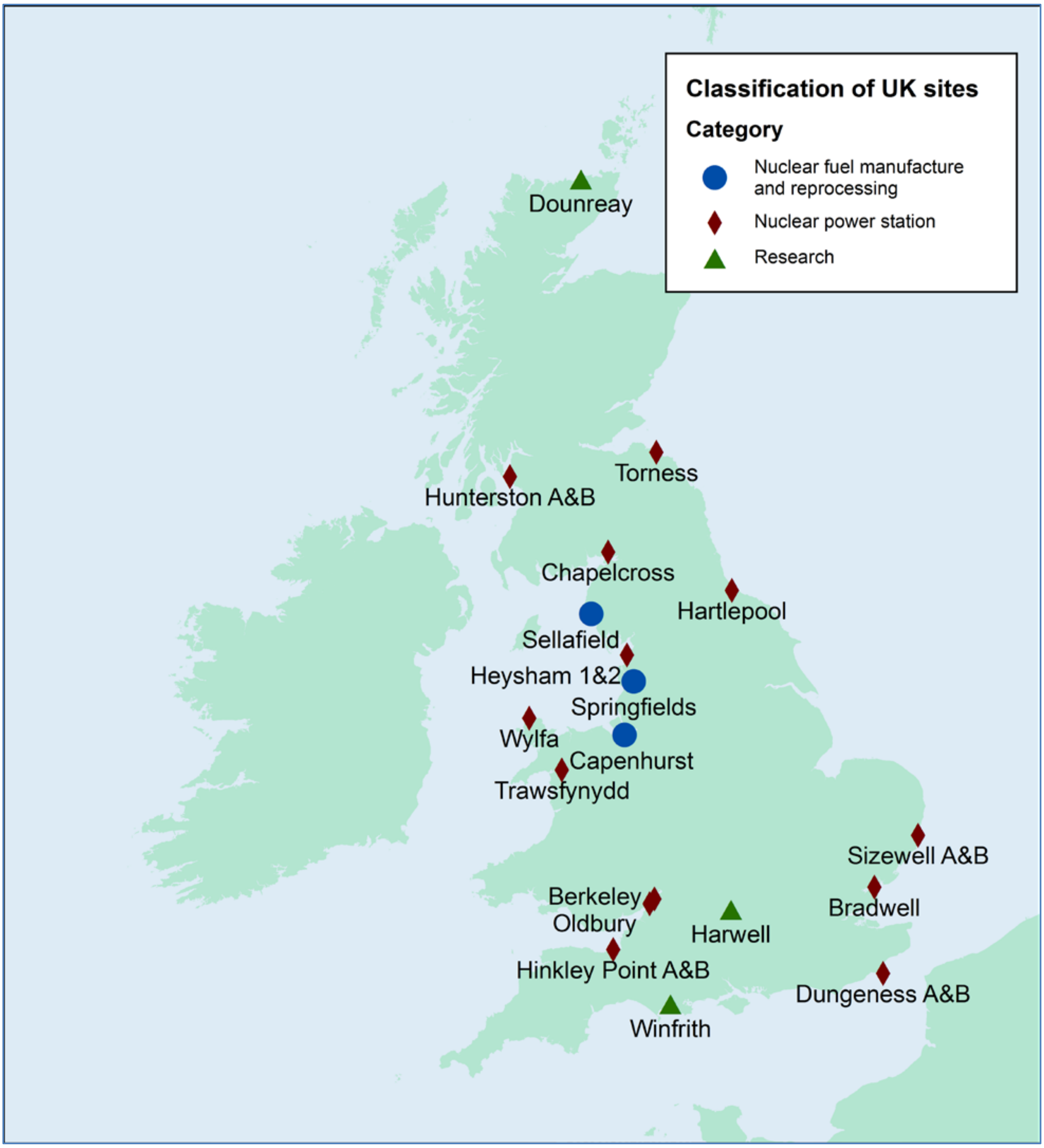

Figure 1.1 UK nuclear licensed sites
(excluding radiochemical production and defence)

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 PARCOM Recommendation 91/4 and OSPAR is not appropriate to UK defence establishments. 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 (e.g. 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, the implementation of BAT, detailing the organisation of nuclear safety and radiation protection within the national regulatory and legislative framework, is outlined for UK civil nuclear facilities. The 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 (2012-2016). It is noted that the term BAT relates to 'technology' in 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 6). Information on general nuclear licensed site characteristics is provided in Appendix 1.

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 (2004-2016). 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.
- 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 defuelling) 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 main process (e.g. 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 EPR16). The activities of all three entities are therefore included within Section 3 (Part 1) and 8 (Part 2) of the report.

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

2. General information

In accordance with the OSPAR guidelines (Ref number 2004-03), this section of the report provides a summary of the general information for the UK submission, related to:

- The implementation of BAT in legislation/regulation.
- The application and rationale of dose limits and constraints for licensed nuclear sites.
- Rationale for setting discharge limits.
- Environmental monitoring programmes.
- Environmental norms and standards (protection of the environment and wildlife).
- Competent authorities involved with the development and application of Government policy on radioactive waste (including discharges to the environment).
- Nature of inspection and surveillance programmes to support legislation and regulation.

2.1 Introduction

Permits/authorisations to dispose of radioactive wastes require the nuclear site operator to optimise radiation exposures to the public so they are kept as low as reasonably achievable (ALARA), social and economic factors being taken into account.

In England and Wales, the application of Best Available Techniques (BAT) is the means to demonstrate compliance with the optimisation requirement. The use of BAT was one of the principles adopted in the 2009 UK Strategy on radioactive discharges.

In Scotland and Northern Ireland, the term Best Practicable Means (BPM) and Best Practicable Environmental Option (BPEO) continues to be used by the Scottish Environment Protection Agency (SEPA) and NIEA. The Environment Agency and SEPA consider that the requirements to use BPM are equivalent to the requirements to use BAT and that the obligations on waste producers are the same.

Following publication of the revised UK Strategy for Radioactive Discharges in 2009 (DECC, Department of the Environment Northern Ireland, the Scottish Government and Welsh Assembly Government, 2009), the application of BAT (replacing BPM and BPEO) was reiterated as the basis for the regulation of radioactive discharges in England and Wales. The UK Government's Statutory Guidance requires the Environment Agency and Natural Resources Wales (NRW)[5] to ensure that nuclear site operators use BAT:

- To prevent the unnecessary creation of wastes or discharges.
- To minimise waste generation.

[5] NRW, formerly the National Resource Body for Wales, became operational from 1 April 2013.

- To minimise the radiological impact of discharges on people and the environment.

In 2010, the Environment Agency published a guidance document providing an overview of, and setting out, the principles and framework for undertaking studies on optimisation and the identification of BAT (Environment Agency, 2010). These principles are in addition to the established basis for radiation protection (justification, optimisation and the application of limits and conditions):

- Sustainable development, meeting the needs of the present without compromising the ability of future generations to meet their own needs and achieving the optimum balance in environmental, social and economic outcomes.
- The use of Best Available Techniques (BAT) in England and Wales to prevent and, where that is not practicable, minimise waste generation and discharges to the environment.
- The precautionary principle, that "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation".
- The polluter pays principle, by virtue of which the costs of pollution prevention, control and reduction measures are to be borne by the polluter.
- The preferred use of 'concentrate and contain' 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.

The document recognises that the concept of BAT is progressive and that developments in BAT will be adopted by operators where appropriate, taking into account economic considerations. The document also points out that the use of BAT will apply to all phases in the lifecycle of a facility, from the design stage to decommissioning and site restoration, and to the various activities which comprise its management, operation and maintenance.

SEPA has issued similar guidance on BPM and its role in ensuring that ionising radiation exposures to members of the public are ALARA (SEPA, 2012). A framework, created to comply with the requirement to keep public exposure ALARA, of three related BPM requirements is imposed on radioactive substances users by SEPA:

- Use BPM to minimise the activity and volume of radioactive waste generated.
- Use BPM to minimise the total activity of radioactive waste that is discharged to the environment.
- Use BPM to minimise the radiological effects of radioactive discharges on the environment and members of the public.

In its Statutory Guidance to the Environment Agency, the Department for Business, Energy and Industrial Strategy (BEIS)[6], formerly the Department for Energy and Climate Change (DECC), placed specific requirements related to the application of BAT to the building of new nuclear plants, as follows:

"*In relation to any designs for new nuclear power stations, the Environment Agency should ensure that BAT is applied so that the design is capable of meeting high environmental standards. This requirement should be applied at an early stage so that the most modern or best available technology can be incorporated into the design of the stations, where this would ensure improved standards. The application of BAT should ensure that radioactive wastes and discharges from any new nuclear power stations in England and Wales are minimised and do not exceed those of comparable stations across the world"* (DECC and Welsh Assembly Government, 2009).

In order to ensure that new nuclear power stations meet acceptable standards of safety, security and environmental protection, the Regulators established a tiered Generic Design Assessment (GDA) process to consider the acceptability of new nuclear power reactors prior to commencement of the licensing process. The GDA process includes an assessment of the application of BAT and the potential impact of liquid and gaseous discharges of radioactive wastes, (Environment Agency, 2007; 2016). More information on the GDA of new nuclear power stations is available on the Office of Nuclear Regulation (ONR) website: http://www.onr.org.uk/new-reactors/

2.2 The organisation of nuclear safety and radiation protection control in the UK

2.2.1 Responsibilities and authorities

In the UK, responsibilities are allocated in the following ways:

- Government maintains and develops policy and the regulatory framework.
- Regulators have the duty to ensure that the policy and regulatory framework is properly implemented.
- The producers and owners of radioactive waste are responsible for developing their own waste management strategies to implement policy and regulatory requirements.

Within the UK, the responsibility for radioactive waste policy has been devolved and (during 2012-2016) the relevant Government Departments were the Department of Business, Energy and Industrial Strategy (BEIS) in England, the Scottish Government, the Welsh Government and the Northern Ireland Department of the Environment[7]. The devolved administrations are responsible for the detailed

[6] BEIS was established, from a merger between the DECC and Department for Business, Innovation and Skills, on 14 July 2016 and took over the responsibility for the regulatory framework on radioactive substances from DECC.

[7] Responsibility for radioactive waste policy in Northern Ireland was transferred from the Northern Ireland Department of the Environment to the Department of Agriculture Environment and Rural Affairs (DAERA) in May 2016.

implementation and compliance with international conventions of which the UK, as a single unitary state, is ultimately responsible.

The relevant regulatory authorities ensure that Government policy is implemented. The authorities with responsibility for discharges to the environment in England, Northern Ireland, Scotland and Wales are: the Environment Agency, SEPA, NRW and NIEA, respectively.

ONR was created in 2011, as a separate regulatory body, to independently regulate nuclear safety and security at civil nuclear licensed sites in the UK, to regulate transport of radioactive material and to ensure that safeguards obligations are met for the UK. ONR has a duty to ensure that the nuclear industry controls its hazards effectively, has a culture of continuous improvement and maintains high standards. ONR is thus responsible for the licensing of nuclear sites, regulation of the management of radioactive material and radioactive waste stored on nuclear sites, and the regulation of transport of radioactive material by road, railway and inland waterways.

The current arrangements for managing civil sector nuclear clean-up are founded in the Energy Act 2004. The Nuclear Decommissioning Authority (NDA), a non-departmental public body (created through the Energy Act 2004), was established in 2005. NDA reports to BEIS and is also responsible to Scottish ministers. NDA manages the decommissioning and clean-up of the civil public sector nuclear sites, plus the associated liabilities and assets. The role of NDA is strategic, developing and implementing an overall strategy for cleaning up the civil public sector nuclear legacy safely, securely, and in ways that protect the environment. The Energy Act (2004) requires the NDA to review and publish its strategy every 5 years. The most recent strategy was published in 2016 (NDA, 2016a) and the plan for 2017/20 is available (NDA, 2017). The health and socio-economic impacts of the strategy have been considered (NDA, 2016b). In 2016, NDA published an up-to-date inventory and forecast of radioactive wastes in the UK (as of 1 April 2016) jointly with BEIS (NDA and BEIS, 2016).

The Food Standards Agency (FSA) has responsibility for food safety in England, Northern Ireland and Wales under the Food Standards Act 1999. Following the Food (Scotland) Act 2015, responsibility for food safety in Scotland was transferred to Food Standards Scotland (FSS). The Environment Agency, NRW, NIEA and SEPA are responsible for environmental protection in England, Wales, Northern Ireland and Scotland, respectively.

In the UK, other agencies and advisory bodies also provide relevant advice and guidance. Public Health England (PHE)[8], an executive agency of the Department of Health and formerly the Radiation Protection Division of the Health Protection Agency (HPA), has responsibility for providing information and advice on protection from radiation risks and for undertaking research to advance knowledge about protection from these risks. Other advisory bodies include the Committee on Medical Aspects of Radiation in the Environment (COMARE) and Committee on Radioactive Waste Management (CoRWM).

[8] From April 2013, the HPA become part of PHE.

2.2.2 Environmental monitoring programmes

All operators of nuclear licensed sites in the UK undertake environmental monitoring, both to comply with conditions in permits/authorisations and to provide the general public with information regarding the impact of the facility on the local environment. The operators' monitoring programmes include sampling of marine food chain and indicator species, local food produce, direct radiation from facilities, and external radiation from publicly accessible places (e.g. beaches). Operators are also required to take duplicate samples of discharges and to provide the duplicate sample to the regulators as required. These are analysed by the regulators' independent analysts in order to be assured that operators' measurements of discharges are accurate.

Independent environmental monitoring is undertaken by the relevant UK regulatory authorities. These monitoring programmes are organised by the environment agencies (Environment Agency, SEPA, NRW and NIEA), FSA and FSS, and are independent of the industries discharging radioactive wastes. During 2012-2016, the programmes included monitoring on behalf of the Scottish Government, Channel Island States, the Northern Ireland Department of the Environment, 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.

In England and Wales, the FSA conducts food monitoring, whilst the Environment Agency and NRW carry out environmental and dose rate monitoring. In Scotland, SEPA carries out food, environmental and dose rate monitoring, working closely with FSS on its programme, and in Northern Ireland this is carried out by the NIEA. Programmes of monitoring of drinking water, air and rain are carried out on behalf of BEIS, NIEA and the Scottish Government. SEPA (as part of the joint SEPA/FSS monitoring programme) and the FSA also carry out UK monitoring of milk and canteen meals that are collected remotely from nuclear licensed sites. Annual surveys of seas around the UK (including locations away from nuclear licensed sites) are carried out by the environment agencies on behalf of the Scottish Government and BEIS.

The Environment Agency has an agreement with NRW to undertake some specific activities on its behalf in Wales including some environmental monitoring (and aspects of radioactive substances regulation). In Scotland, as part of a co-ordinated programme SEPA undertakes environmental monitoring on behalf of FSS.

The monitoring programmes have several purposes. Ongoing monitoring helps to establish the long-term trends in concentrations of radioactivity over time in the vicinity of, and at distance from, nuclear licensed sites. The results are also used to confirm the safety of the food chain. Monitoring the environment provides indicators of radionuclide dispersion around each nuclear site. Environmental and food results are used to assess dose to the public to confirm that the controls and conditions placed in the authorisations/permits provide the necessary protection and to ensure compliance with statutory dose limits. Monitoring of food and the environment remote from nuclear licensed sites is also carried out, giving information on background concentrations of radionuclides; these data are reported to the European Commission (EC).

The Environment Agency and SEPA also undertake liquid effluent monitoring programmes to provide checks and an independent assessment on site operators' data. These checks encompass monitoring of liquid effluent samples and quality checking of solid waste disposals.

Since 1995, the results of the environmental monitoring programmes, and the subsequent radiological assessments, have been published in the annual report series 'Radioactivity in Food and the Environment' (RIFE). The most recent RIFE report (RIFE 22, 2016) represents collaboration by the Environment Agency, FSA, FSS, NIEA, NRW and SEPA across the UK. The publication of RIFE reports is independent of the nuclear industry. The RIFE report and the associated monitoring programmes conform to the requirements in Article 35 and 36 of the Euratom Treaty and Council Directive 96/29/Euratom laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation (EC, 2014). Specifically, it provides estimates of doses to members of the public from authorised practices and enables such results to be made available to stakeholders. In recent years, FSA, SEPA and EA have all completed reviews of their environmental radioactivity monitoring programmes. Further information of completed reviews is available in RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

2.2.3 National policies and strategies

The Marine Strategy Framework Directive (CEC, 2008) concerning the protection and conservation of the marine environment was transposed into UK law (United Kingdom - Parliament, 2010) and is supported by measures to improve management of the marine environment covering the UK, and latterly Scotland and Northern Ireland (United Kingdom - Parliament, 2009; Scotland - Parliament, 2010; Northern Ireland - Parliament, 2013). The Directive requires Member States to put in place the necessary management measures to achieve Good Environmental Status (GES) in waters under their jurisdiction by 2020. The UK submitted an initial assessment (part one of the Marine Strategy) to the Commission (HM Government, 2012), followed by publication of parts two and three in 2014 and 2015, respectively (Defra, Department of the Environment Northern Ireland, Scottish Government, Welsh Government, 2014; 2015). Further details on the Marine Strategy Framework Directive are provided on the GOV.UK website:

http://jncc.defra.gov.uk/page-5193

The UK Government has set out its view in the 2008 White Paper "Meeting the Energy Challenge" (Department for Business, Enterprise and Regulatory Reform, 2008) that new nuclear power stations should have a role to play in this country's future energy mix alongside other low-carbon sources; that it would be in the public interest to allow energy companies the option of investing in new nuclear power stations and that the Government should take active steps to facilitate this. As regulators of the nuclear industry, ONR, the Environment Agency and NRW, are working together to ensure that any new nuclear power stations built in the UK meet high standards of safety, security, environmental protection and waste management. More information concerning subsequent national policy statements, consultations and decisions, together with details of the approach for assessing the design of potential new nuclear power stations and approvals for their proposed developments, is available in RIFE reports (e.g. Environment Agency, FSA, NIEA, NRW and SEPA, 2014).

UK Government published the 2014 White Paper that sets out the policy framework for managing higher activity radioactive waste in the long-term through geological disposal (DECC, 2014). The White Paper sets out a policy framework for the future implementation of geological disposal and explains the “Initial Actions” that will happen before formal discussions begin between interested communities and the developer of a Geological Disposal Facility (GDF), Radioactive Waste Management Limited (a wholly owned subsidiary company of NDA). A public consultation has been undertaken on the National Geological Screening exercise to bring together information about UK geology that is relevant to the long-term safety of a GDF (Radioactive Waste Management, 2016). No specific sites have been selected or are currently under consideration (DECC, 2016a). A scoping report has considered the proposed content of an Appraisal of Sustainability for a GDF policy statement that is being prepared by BEIS (DECC, 2016b) and the NDA has developed Industry Guidance on the interim storage of packaged higher activity waste, effective from January 2017 (NDA, 2016c). Independent scrutiny of the Government’s long-term management, storage and disposal of radioactive waste is continuing by CoRWM who have published their proposed work programme for 2015-2016 (CoRWM, 2016).

Radioactive waste management is a devolved policy issue in the UK. Therefore, the Scottish Government, Welsh Government and Northern Ireland Executive each have responsibility for determining disposal policy in their respective areas. Further information of the policies of Devolved Administrations is available in RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

The UK Government and Devolved Administrations published the revised UK Strategy for Radioactive Discharges in 2009 (DECC, Department of the Environment Northern Ireland, Scottish Government and Welsh Assembly Government, 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 objectives of the 2009 Strategy are:

- To implement the UK’s obligations, rigorously and transparently, in respect of the OSPAR RSS intermediate objective for 2020.
- To provide a clear statement of Government policy and a strategic framework for discharge reductions, sector by sector, to inform decision making by industry and regulators.

The expected outcomes of the UK Strategy are:

- Progressive and substantial reductions in radioactive discharges, to the extent needed to achieve the sectoral outcomes, whilst taking uncertainties into account.
- Progressive reductions in concentrations of radionuclides in the marine environment resulting from radioactive discharges, such that by 2020 they add close to zero to historical levels.
- Progressive reductions in human exposures to ionising radiation resulting from radioactive discharges, from planned reductions in discharges.

To support implementation of UK Government policy on radioactive discharges, the Scottish Government has issued Statutory Guidance to SEPA (Scottish Government, 2008). Similarly, BEIS and the Welsh Government issued guidance to the Environment Agency (DECC and Welsh Assembly Government, 2009). The Environment Agency has developed Radioactive Substances Regulation (RSR) Environmental Principles (RSR Environmental Principles, or REPs) to form a consistent and standardised framework for the technical assessments that will be made when regulating radioactive substances (Environment Agency, 2010). Developed jointly with SEPA, the Environment Agency has also issued guidance for the assessment of assessment of Best Practicable Environmental Option studies at nuclear sites (Environment Agency and SEPA, 2004).

2.2.4 Quality assurance

UK operators of nuclear licensed sites in the UK, and laboratories undertaking independent environmental monitoring, utilise Quality Assurance (QA) and International Standards Organisation (ISO) accreditation to demonstrate quality management and sustainable development. Most notable standards include the ISO 9000 and ISO 14000 series, primarily concerned with quality management systems and environmental management (to minimise the harmful effects on the environment caused by human activities and to achieve continual improvement of environmental performance), respectively. These standards are globally recognised. Organisations that are not accredited use fully tested in-house management techniques, often based on ISO standards.

Quality assurance of discharge sample measurements and environmental analysis, and the assessment of the impact of discharges and exposure on members of the general public, is based on the work of operators, a national system of independent regulators (e.g. Environment Agency and SEPA), laboratories undertaking independent environmental monitoring, advisers (e.g. PHE) and other Government bodies. Each rely on accreditation to an appropriate ISO or other standard. Quality is therefore an in-depth feature of the system and arises from both the standard of individual laboratories and from cross-checking results and inter-comparison of assessment techniques.

Each nuclear licensed site laboratory is accredited by the United Kingdom Accreditation Service (UKAS) whereby the requirements of ISO/IEC 17025, the European standard for the operation of calibration and testing laboratories are fully met. Analyses are also undertaken in accordance with procedures set down in Implementation Documents. These documents are agreed with the regulators and are descriptions of the procedures the operator will use to comply with conditions in the EPR10 permit (EPR16, from 1 January 2017) or RSA 93 authorisation.

Laboratories undertaking independent environmental monitoring are also required to comply with technical and quality assurance specifications as defined by the relevant UK regulatory authorities. Each laboratory is accredited by the United Kingdom Accreditation Service (UKAS). Laboratories are also accredited for the appropriate ISO 9000 and ISO 14000 series of standards. Analytical quality control procedures (all covered under UKAS accreditation) include regular calibration of detectors using radiation standards (traceable to national standards), inter-comparison exercises with other laboratories (both national and international) and the use of standard operating procedures.

2.3 The regulatory and legislative framework for applying BAT in the UK

Management of radioactive waste in the UK is regulated through enforcement of a range of national and international legislation. EU Directives and international treaty obligations are implemented through their transposition into UK law.

During 2012-2016, the Environment Agency and NRW regulated radioactive waste disposal (and other aspects of the control of radioactive materials) under the Environmental Permitting (England and Wales) Regulations 2010 (EPR10), (United Kingdom - Parliament, 2010). On 1 January 2017, the new Environmental Permitting (England and Wales) Regulations 2016 came into force (United Kingdom - Parliament, 2016), revoking the previous Regulations. Whilst there are no major changes, the new regulations provide a consolidated system of environmental permitting in England and Wales and transpose provisions of fifteen EU Directives which impose obligations requiring delivery through permits or which are capable of being delivered through permits. SEPA and NIEA regulate radioactive waste disposal in Scotland and Northern Ireland, respectively under the amended Radioactive Substances Act 1993 (RSA 93), (United Kingdom - Parliament, 1993). The four Government agencies work together to ensure that a consistent approach is maintained across the UK. The Environment Agency and SEPA also have broader responsibilities under the Environment Act 1995 (United Kingdom - Parliament, 1995a) for environmental protection and determining general concentrations of pollution in the environment.

The environment agencies review each permit/authorisation for nuclear sites periodically to ensure that it is still suitable and to drive improvements in environmental performance. A major review of permits/authorisations is carried out as and when required. This process involves widespread consultation with relevant Government Departments, other stakeholders and the general public, post-consultation review and final decision and permit/authorisation revision. The review process takes account of all relevant activities conducted or foreseen including any modifications, processing (including legacy wastes) and decommissioning. A number of permits/authorisations have been reviewed and revised during or shortly after the reporting period. The regulatory authorities work in close contact with the ONR which regulates the safety of nuclear plants (including that for waste storage) and workers. Permits/authorisations are issued only after consultation.

Radioactive substance activities to be carried out are specified in the discharge permit/authorisation. The permit/authorisation requires operators to use BAT in respect of the disposal of radioactive waste to: minimise the activity of gaseous and aqueous radioactive waste disposed of by discharge to the environment; minimise the volume of radioactive waste disposed of by transfer to other premises; and dispose of radioactive waste at times, in a form, and in a manner so as to minimise the radiological effects on the environment and members of the public.

Except for national arrangements for incidents involving radioactivity (NAIR), radioactive waste disposals are only permitted/authorised by specified routes which do not exceed any specified limits on disposals. Disposals may occur by discharge to the environment. Discharge limits to the environment are established through an assessment process, initiated by either the operator or the relevant environment agency. Discharge limits on the disposal by discharges to the environment may be expressed as an annual or monthly discharge limit. The permit/authorisation may also include quarterly notification levels or weekly advisory levels. Where a quarterly notification level is exceeded, an investigation is triggered as to whether BAT or BPM have been applied in the control of the relevant discharge.

Other relevant legislation includes the Ionising Radiation Regulations 1999 (keeping exposure to ionising radiations as low as reasonably practicable), the Environmental Protection Act 1990 (basis for a regulatory regime for identifying and remediating contaminated land) and the Nuclear Installations Act 1965, (as amended) (regulation of nuclear safety including taking account of the international conventions on legal liability). Specific plants and operations may also be governed through the Pollution Prevention and Control Act 1999, the Control of Major Accident Hazards Regulations 2015 and the Water Industry Act 1991.

The UK continues to apply the principles of radiological protection, recommended by the International Commission on Radiological Protection (ICRP), to reduce levels of radioactive discharges and doses of ionising radiation to humans, and the protection of wildlife and the environment.

Current UK practice relevant to the public is based on the recommendations, as set out in ICRP Publication 60 (ICRP, 1991). The dose standards are embodied in national policy on radioactive waste (United Kingdom - Parliament, 1995b) and in guidance from IAEA in their Basic Safety Standards (BSS) for Radiation Protection (IAEA, 1996). Legislative dose standards are contained in the BSS Directive 96/29/Euratom (CEC, 1996) and subsequently incorporated into UK law in the Ionising Radiations Regulations 1999 (United Kingdom - Parliament, 1999).

In order to implement the BSS Directive, the standards in England and Wales concerning radiation doses to the public and their methods of estimation and regulation for all pathways are set down in EPR16. In Scotland, Ministers have provided SEPA with Directions (Scottish Executive, 2000). In Northern Ireland, regulations were made to implement the requirements of the BSS Directive in the Radioactive Substances (Basic Safety Standards) Regulations (Northern Ireland) 2003 (Northern Ireland Assembly, 2003).

The revised Basic Safety Standards Directive (BSSD) in 2013 consolidates and updates existing Euratom provisions for protection against the harmful effects of ionising radiation by replacing five existing Directives and a Commission Recommendation. The revised Directive takes account of developments in the recommendations and standards issued by the International Commission on Radiological Protection and the International Atomic Energy Agency. It covers standards for public exposure as well as those for occupational and medical exposures. Euratom member states are required to transpose the revised Directive into domestic law by 6 February 2018. Most of the requirements in the new directive for the public exposure resulting from radioactive waste disposal are already implemented in UK law. However, some changes to the Environmental Permitting Regulations 2016 covering England and Wales, and equivalent legislation in

Scotland and Northern Ireland, may be needed and BEIS will be consulting on these in the autumn of 2017.

The relevant dose limits (adopted in the UK since 1993), for permitted and authorised discharges, to members of the public are 1 mSv per year for (effective) dose. It may in some circumstances be necessary to make additional calculations of the equivalent dose to particular organs or tissues (for example skin or lens of the eye). The equivalent dose limits for skin and lens of the eye are 50 mSv per year (averaged over any area of 1 cm^2) and 15 mSv, respectively. Assessments consider those people in the population most exposed to radiation, due to radioactive discharges, because of their age, diet, location or habits. These results are for comparison with legal limits in EU and UK law. In the UK, two main types of retrospective doses are assessed. Both types of dose are assessed in this report (in Part 2). The first type of assessment is more complete in considering the combined effects of direct radiation exposure, gaseous and liquid radioactive discharges from nuclear licensed sites (*total dose*). The second type of assessment estimates dose from specific sources and associated exposure pathways. These dose assessments check on the adequacy of the *total dose* method and offer additional information for key exposure pathways. Further information describing the assessment of doses is available in RIFE reports (e.g. Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

In support of the assessment process, prospective assessments of doses to the public are made assuming discharges at the specified limits. Discharge limits are set so that doses to the public will be below the source and site dose constraints of 0.3 and 0.5 mSv per year, respectively if discharges occurred at the limits (Environment Agency, SEPA, NIEA, HPA and FSA, 2012).

In the UK, the current legislative measures that are most relevant to the protection of wildlife are the EU Birds Directive on the conservation of wild birds (CEC, 2009) and the EU Habits Directive on the conservation of natural habitats and wild flora and fauna (CEC, 1992). Both are implemented through the Habitats regulations in the UK. Under the Habitats Regulations, the Environment Agency, NRW and SEPA have obligations to review existing authorisations/permits to ensure that no authorised activity or permission results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000[9] habitat sites. Similarly, there is also an obligation for any new or varied authorisation/permit, whereby the applicant is required to make an assessment of the potential impact of the discharges on reference organisms that represent species which may be adversely affected.

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[9] Natura 2000 is made up of sites designated as Special Areas of Conservation and Special Protection Areas (SPAs).

3. Nuclear fuel production and reprocessing

3.1 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 and reprocessing, decommissioning and clean-up of redundant nuclear facilities, and materials and waste treatment and storage. In 2005, the NDA took on ownership of the Sellafield site and established a management model of ownership (Parent Body Organisation concept) by the private sector. On 1 April 2016, NDA became the owner of Sellafield Limited, the Site Licence Company responsible for managing and operating Sellafield on behalf of the NDA, replacing the previous management arrangements. The Sellafield site includes the Calder Hall nuclear power station, which is currently undergoing defuelling and decommissioning and the former Windscale site. All Sellafield operations are carried out under a single Nuclear Site License and EPR-RSR environmental permit. The National Nuclear Laboratory (NNL) also carry our activities contracted by Sellafield Limited at Sellafield (and by Springfields Fuels Limited at Springfields).

The Capenhurst site is owned partly by Urenco UK Limited (UUK) and partly by NDA. The major operators at the site are UUK, Capenhurst Nuclear Services Limited (CNS) and Urenco ChemPlants Limited (UCP). UUK operates three plants producing enriched uranium for nuclear power stations. CNS 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, planned to be commissioned in late 2017/early 2018). 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), under ISO 17025 and are also assessed and certified against the requirements of the Environment Agency’s Monitoring Certification Scheme (MCERTS).

3.2 Sellafield

The Sellafield site is the largest nuclear complex in the UK and, amongst other activities, undertakes the reprocessing of spent Magnox and oxide fuels[10] connected with the UK nuclear electricity generation programme and spent oxide fuel from other countries.

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

- Storage of irradiated Magnox, AGR and LWR fuels in water-filled ponds.
- Reprocessing of Magnox and oxide fuels.
- Storage of uranium and plutonium recovered through reprocessing.
- Processing and storage of HLW and ILW.
- Processing and disposal of 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).
- Defuelling of the Calder Hall reactors.
- Care and Maintenance of facilities that will be decommissioned in later years.

The reprocessing of spent fuel is still a major activity at Sellafield, although there has been an increased focus in recent years on the high hazard and risk reduction, involving the retrieval and conditioning of legacy waste and decommissioning of redundant facilities.

The Thermal Oxide Reprocessing Plant (THORP) and the Magnox Reprocessing Plant (Magnox) have continued to operate throughout the reporting period (see Figure 3.1). The outcome of the 2012 strategic review regarding the future of the THORP plant, affirmed that completing the reprocessing contracts at THORP remained a viable and cost-effective strategy[11], however it has since been decided that reprocessing operations in THORP will cease by 2019. At this point remaining AGR fuel, and new receipts, will remain in storage ponds for the duration of interim storage pending a decision on its the long-term disposition.

Although discharges will reduce the transfer of residual fuel through the head end and chemical separation processes, subsequent Post Operational Clean-Out operations will continue to generate some effluents. Therefore, it will remain appropriate to consider THORP discharges for some time to come.

It is anticipated that Magnox reprocessing contracts will be completed in 2020, at which time the Magnox reprocessing facility operations will cease and, similarly to

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[10] Sellafield Limited holds contracts for the reprocessing of all spent Magnox fuel arising from the UK nuclear electricity generating programme. It does not currently hold contracts to reprocess all AGR or PWR fuel.

[11] http://www.gov.uk/government/publications/oxide-fuels-preferred-option

THORP, will enter a period of a run-down of reprocessing operations prior to entering Post Operational Clean-Out.

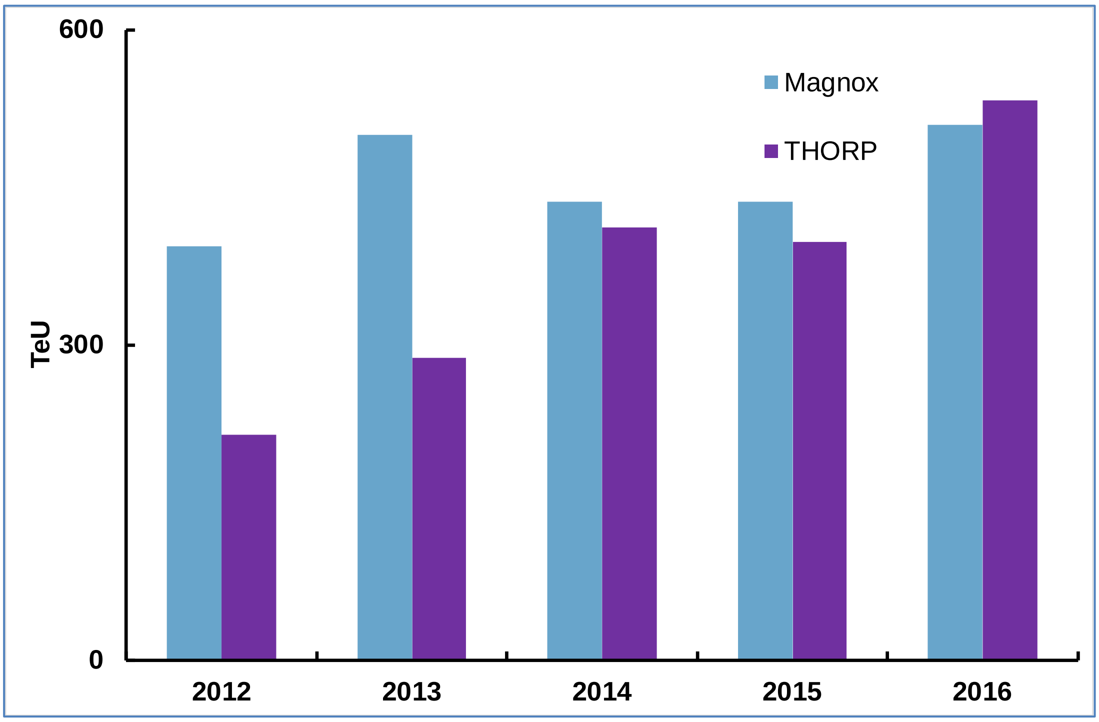


Figure 3.1 Sellafield Reprocessing Rates

Details of the timescales for the completion of Magnox reprocessing activities are set out in the ninth version of the Magnox Operating Programme (MOP9), available on the NDA website. The programme identified that the reprocessing of spent Magnox fuel was forecast to be complete by December 2020.

Progress has been made since 2012 on the clean-up of legacy facilities and decommissioning activities. This includes:

- 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 2012, the Local Effluent Treatment Plant has prevented the discharge to sea of over 9 TBq of beta activity.
- Solid waste removals from the Pile Fuel Storage Pond have continued. By the end of March 2016 over 200t of material had either been removed from the pond or consolidated in the pond ready for removal. A further 70t was processed during 2016/17, which together equates to about 70 per cent of the baseline radioactive inventory. In addition, all of the bulk legacy fuel has been removed from the Pile Fuel Storage Pond and is now stored in modern facilities.
- The Local Sludge Treatment Plant and Drum Filling Plant were actively commissioned in October 2016. Radioactive sludge is being pumped from the Pile Fuel Storage Pond to the Local Sludge Treatment Plant and on to the

Drum Filling Plant for export to the Waste Encapsulation Plant for processing and transfer to the Encapsulation Product Drum Stores. By the end of March 2017 approximately 13 m^3 of sludge had been pumped from the pond and a total of 40 drums had been processed.

- Ongoing management of floc, from the treatment of liquid effluent, which is stored in sludge storage tanks. This is being transferred from the original tanks to a higher integrity buffer tank before onward treatment via the Enhanced Actinide Removal Plant (EARP). Over the 2012-2016 period more than 430 m^3 of this floc has been treated in EARP.
- Successful retrieval of 51t of fuel from the First Generation Magnox Storage Pond to the Fuel Handling Plant with an additional 29 m^3 of historic sludge transferred to the Sludge Packaging Plant (SPP1) for storage prior to further management.
- Since 2010, Liquor Activity Reduction has resulted in the transfer and treatment of over 3500 m^3 of liquor and over 15,000 TBq from the Magnox Swarf Silo to the Site Ion Exchange Effluent Plant (SIXEP) for processing.
- Continuation of defuelling of the Calder Hall reactors. Two of the four reactors have been emptied, with defuelling underway from the third, and the fourth currently being prepared for defuelling.
- Optimisation of fuel storage and pond-water conditions in the Sellafield Fuel Handling Plant, the development of techniques to manage effluents from legacy waste and materials retrieval operations and the implementation of stringent feed controls for discharges to SIXEP, continues to lead to improved discharge management and capability. Work has also commenced to design the SIXEP Contingency Plant project. This new effluent treatment is planned to provide contingency and ultimately replacement capability for the SIXEP plant. The design should provide greater flexibility to support the minimisation of discharges associated with the decommissioning of legacy plants at Sellafield.

3.2.1 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. 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 EARP, depending upon their composition and activity.

Whilst new effluent streams will be generated as a result of legacy clean-up activities on site, some historic effluent streams are being managed such that they are no longer discharged from the site. For instance, some of the effluents from Magnox reprocessing operations were concentrated and collected in storage tanks on site and commonly referred to as Medium Active Concentrate. However, these arisings are now directed to the Highly Active Liquor route for vitrification and no longer contribute to liquid discharges.

Radioactive liquid effluents from the Sellafield site are discharged via pipelines which extend approximately two 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 THORP and Magnox reprocessing gaseous discharges.
- Carbon-14: The majority of these arisings at the Sellafield site are routed to final disposal as solid encapsulated waste after being driven off at the THORP dissolution stage. The main discharge routings from Sellafield are liquid effluents to sea resulting from the caustic scrubbing of gaseous streams associated with Magnox reprocessing and High Level Waste Plants.
- Cobalt-60: Over 99 per cent 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. Between 2012-2016, strontium-90 discharges to sea arose mainly from dilute aqueous liquors from both THORP and Magnox reprocessing operations concentrated by the salt evaporation process and subsequent treatment through the EARP process before discharge to sea.
- 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. The main liquid discharges are those routed to sea following treatment of Salt Evaporator Concentrates in the EARP process.
- 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 THORP and Magnox reprocessing gaseous discharges.
- Caesium-137: Discharges occur from various sources, such as from processing of historical wastes. Greater than 99 per cent 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 per cent routed via streams resulting in final discharges to sea. Effluents from fuel pond purges are treated primarily in 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 per cent 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 per cent is directed to site facilities and routed for treatment, and then storage in solid form prior to eventual disposal.

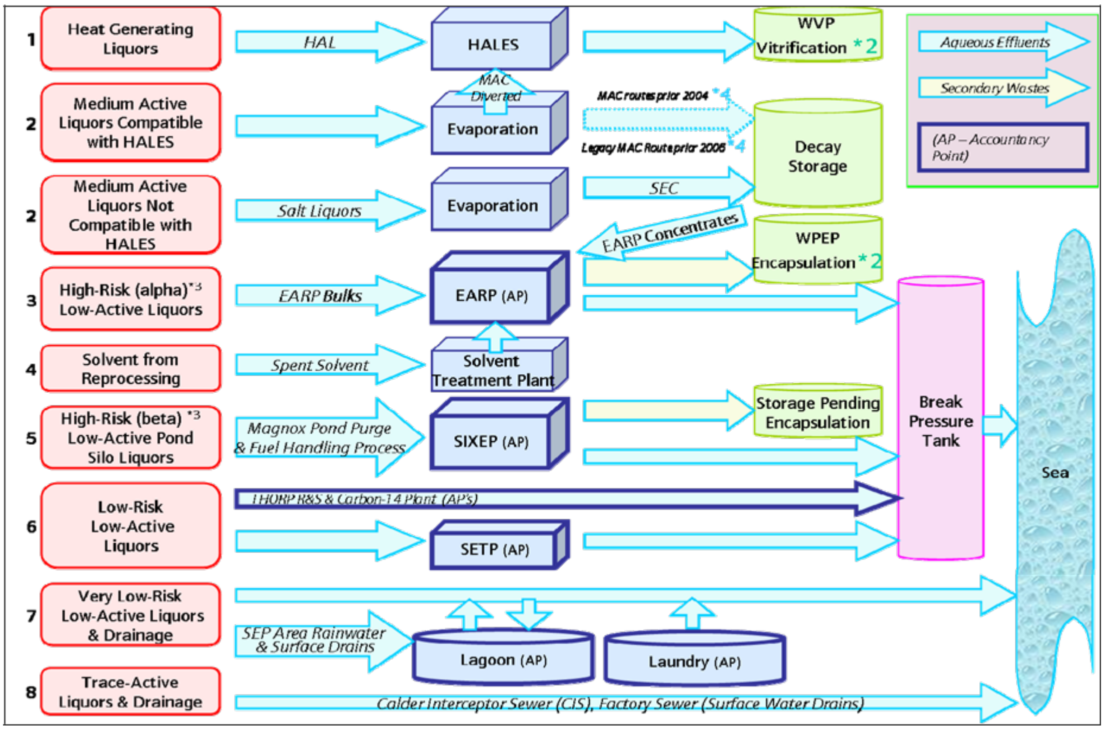
3.2.2 Liquid effluent treatment and abatement

Main (site-wide) treatment plants

The major liquid effluent treatment facilities operating on the site are summarised below:

- The High Active Liquor Evaporation and Storage plant evaporates highly active effluents prior to vitrification in the Waste Vitrification Plant.
- The Salt Evaporator is designed to condition and concentrate waste streams for interim decay storage prior to treatment in the EARP.
- SIXEP is designed to reduce discharges of effluents containing beta-emitting radionuclides through the use of ion-exchange and sand bed filtration.
- EARP has the primary purpose of reducing the levels of plutonium and other actinides in liquid discharges using ultra-filtration.
- Segregated Effluent Treatment Plant. This plant treats low-level effluent streams which are not directed to EARP. Treatment comprises of neutralisation of acidic effluent streams before mixing with alkaline effluent streams to ensure volatile species are discharged to the marine environment rather than air, thereby reducing dose, and removal of high specific gravity particulates using a hydrocyclone.
- Solvent Treatment Plant. This plant removes activity from the medium active solvent streams via a solvent wash process with the aqueous wash liquors directed to EARP for further treatment.
- Post reprocessing, Sellafield Limited aims to maximise the use of existing treatment facilities, such as diverting effluent streams from the Segregated Effluent Treatment Plant to EARP during Post Operational Clean-Out operations to enhance the level of abatement and deliver BAT prior to discharge to sea. In addition, a new effluent treatment plant (the SIXEP Contingency Plant) is currently being designed and is planned to replace SIXEP in the next decade.

These plants are well established and have been described in detail in previous reports. Figure 3.2 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 3.2 Liquid Effluent Management System

Table 3.1 History of Medium-Active Concentrate Processing at Sellafield and the Medium Active Concentrate diversion product (*4 in Figure 3.2)

1964 to 1981   *Medium Active Concentrate stored in tanks in MA Tank Farm to allow decay of short lived isotopes (e.g. ruthenium-106). After decay, the liquor was discharged direct to sea (within limits current at the time).*
1982 to 1994   *Medium Active Concentrate stored on Site until EARP available for treatment*
1994 to April 2003   *Medium Active Concentrate treated in EARP. Nearly all actinides removed and encapsulated in Waste Product Encapsulation Plant. All technetium-99 discharged to sea*
April 2003 to December 2005   *EARP process modified to abate up to 95 per cent technetium-99 using TPPBr. Treatment of the stored Medium Active Concentrate now completed.*
2005 Onwards   *New Medium Active Concentrate arisings diverted through Highly Active Liquor Evaporation and Storage plant to the* Waste Vitrification Plant. *Waste radionuclides incorporated into vitrified waste product (Medium Active Concentrate Diversion Product)*

Treatment plants specific to THORP

Waste arisings are minimised at source and waste streams are treated according to their activity levels. Medium-active salt streams are sent to the Salt Evaporator and then treated in the EARP concentrates process. Medium-active salt-free liquors are concentrated in a plant within THORP and transferred with high activity streams to the Waste Vitrification Plant for vitrification; with the result that the contribution of THORP to total site discharges is generally lower than for Magnox reprocessing. Flushings from washing fuel containers are sent to EARP for treatment, and the remaining low-level effluent streams are sent to the Segregated Effluent Treatment Plant.

A caustic scrubber is used to remove iodine and carbon-14 from the fuel dissolver off-gases; carbon-14 is precipitated out using barium carbonate, and the solid waste arisings are encapsulated in cement. The treated liquor is discharged directly to the sea following sampling and analysis, removing the need for acidification of the liquors and release to atmosphere of the radio-iodine (thus minimising the environmental impact). Spent fuel storage pond water is monitored and discharged to sea following filtration.

Future waste treatment and storage facilities

Self Shielded Box Interim Storage Facility

The priority of the First Generation Magnox Storage Pond programme is its safe remediation and hence reduction of the risk posed. This will be achieved through the removal of the pond inventory to more suitable and robust storage environments. Fuel, sludge and waste are already being retrieved from this legacy facility, however the Interim Storage Facility will provide additional interim storage capability for waste and nuclear material contained within thick walled ductile cast iron boxes, known as Self-Shielded Boxes. The removal of inventory and remediation of the First Generation Magnox Storage Pond and other similar ponds will reduce associated discharges to the marine environment.

Box Encapsulation Plant

When complete, this plant will deliver the capability to treat radioactive waste recovered from legacy ponds and silos, immobilise it and condition it for long-term storage.

SIXEP Contingency Plan

This project will involve the construction of an extension to the existing SIXEP facility. The SIXEP Contingency Plan replicates and replaces the liquid effluent abatement process within the existing SIXEP facility. Upon operation, it will provide a similar but more flexible capability.

SIXEP Waste Management

SIXEP Waste Management Study will identify and implement an optimised waste management route for the remaining SIXEP/SIXEP Contingency Plant lifetime arisings and provide the capability to empty stored spent sand/clinoptilolite/sludge waste before the end of operations.

3.2.3 Trends in liquid discharges over the 2012-2016 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 3.3). 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. In 2015, total beta discharges from the site were the lowest reported for many years (see also Figure 8.2).

The trends of radionuclides in liquid discharges, over a longer timescale, are also presented in Part 2, Section 8 (Figure 8.2). Between 2004 and 2011, all liquid discharges followed a pattern of overall reduction and low levels were maintained during this reporting period (2012-2016).

Liquid discharges from the site are also permitted via the Factory Sewer. This is a minor outlet and discharges via this route are several orders of magnitude lower than overall site discharges, with the resulting dose to the representative person being insignificant. The Calder Interceptor Sewer has recently been permitted as a relatively minor discharge route, but no radioactive discharges have been made yet.

Discharges of liquid radioactive effluents from the Sellafield site are closely related to the amount of fuel reprocessed, though there are also discharges associated with the clean-up of legacy wastes and decommissioning operations. There have been changes to the contributions to the recent annual discharges due to the improved management of legacy fuel pond stocks and associated pond water activities and discharges. This includes washing highly contaminated corroded fuel to remove the bulk of the activity source prior to returning to pond storage. This has led to a significant reduction of the average pond water activity.

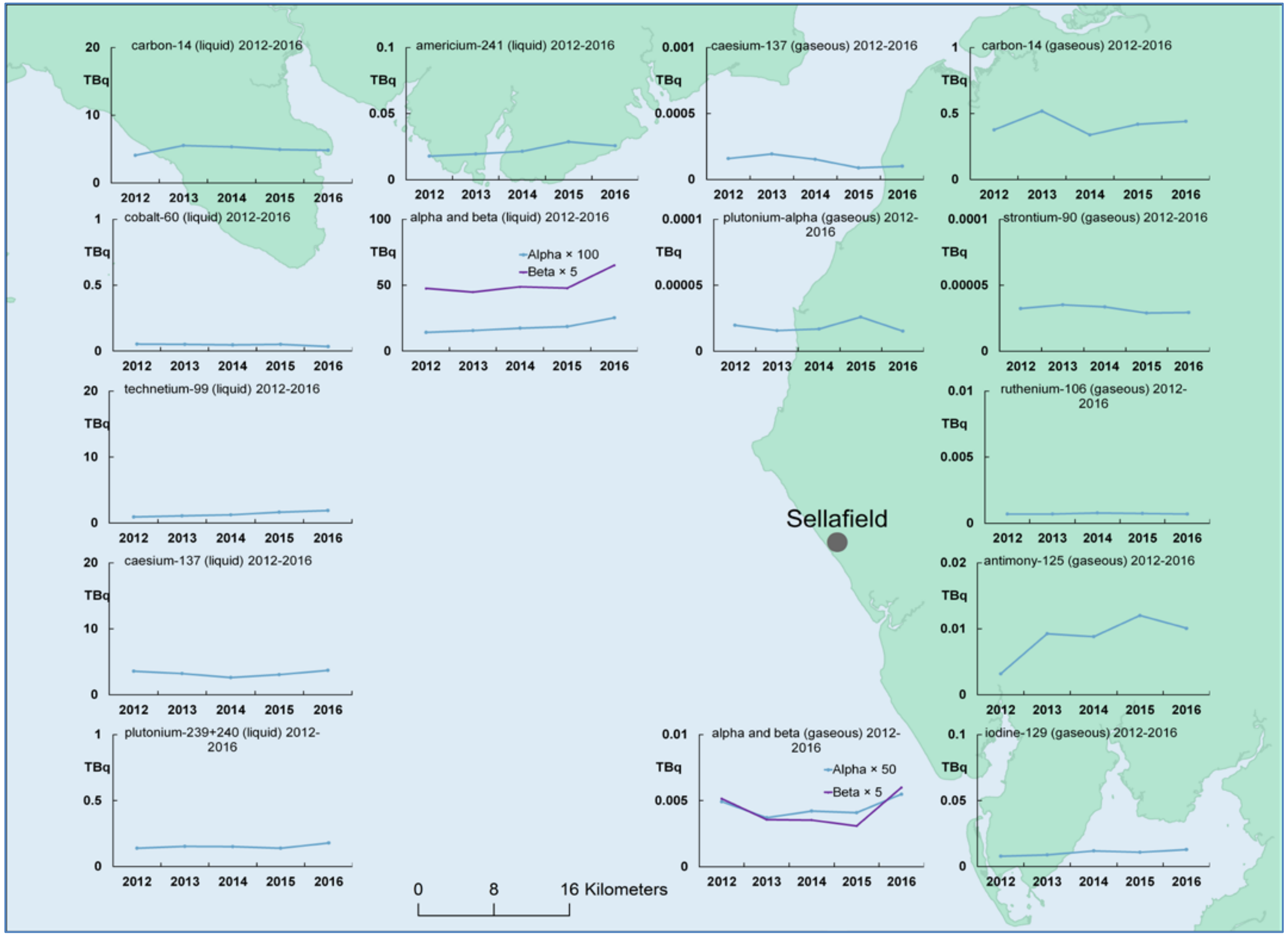


Figure 3.3 Gaseous and liquid discharges of key permitted radionuclides, Sellafield (2012-2016)

3.2.4 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, together with ventilation air from waste management processes and decommissioning projects.

The most recent development is the construction, commissioning and operation (from 2016) of the Separation Area Ventilation Plant which diverts gaseous discharges from Magnox Reprocessing and other facilities to a new discharge stack with additional High Efficiency Particulate Air filtration abatement plant. This has allowed the decommissioning and demolition of Pile 1 and a Redundant Reprocessing Plant to commence.

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 (2012-2016) are also given in Figure 3.3 and over a longer period (2004-2016) in Part 2, Section 8 (Figure 8.2). Over both periods, gaseous discharges of radionuclides either decreased or remained relatively stable (except for antimony-125).

Antimony-125 discharges generally increased over the reporting period, and over the longer period (2004-2016), as a consequence of an increase in the reprocessing of higher burn-up Magnox fuel from the Magnox reactors (Wylfa and Oldbury). The Environment Agency considered that continued reprocessing, rather than delaying or suspending reprocessing of this fuel, represented BAT. A new permit, with a higher limit for antimony-125, was effective from 1 April 2010 to reflect the trend of increasing releases of this radionuclide in 2009. The increase in the limit was accepted and permitted by the Environment Agency after a favourable Euratom Article 37 opinion was received from the European Commission.

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

3.2.5 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 2004-2016. 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 7.1).
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- 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 nuclear fuel production and reprocessing sector (2004-2016) (Part 2, Section 8.5).

3.2.6 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 (e.g. 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, e.g. 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 Post Operational Clean-Out, decommissioning and clean-up.

  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 Post Operational Clean-Out and decommissioning activities, these predications may change in future.

- Sellafield Limited also supports a range of research and development work, to facilitate improved management of effluents. This is detailed in Section 6.3.1, but can be summarised here as:
  - Research into the EARP chemical precipitation process to broaden its capability and allow transition from reprocessing to Post Operational Clean-Out, where feed volumes will be less predictable and more variable.
  - R&D into the characterisation of Magnox and uranium corrosion products and their roles in controlling the radionuclide challenge to SIXEP.
  - Work has been initiated to assess the use of settling aids to reduce the particulate and alpha activity challenge to SIXEP during retrieval operations.

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:

- Operation of the Local Effluent Treatment Plant in the Pile Fuel Storage Pond. The plant comprises of sand-bed filtration and ion exchange abatement, and provides both a significant reduction in discharge activity of pond water and final discharges.
- The Pile Fuel Storage Pond dewatering and decontamination project is preparing to lower pond water levels and decontaminate and coat the exposed surface of the pond walls. The aim of the dewatering and decontamination project is to take the pond to an interim state which leaves the structure empty of water and safe for a period of care and maintenance prior to final decommissioning and demolition.
- The Local Sludge Treatment Plant and Drum Filling Plant were actively commissioned in October 2016. Radioactive sludge is being pumped from Pile Fuel Storage Pond to Local Sludge Treatment Plant and on to the Drum Filling Plant for export to the Waste Encapsulation Plant for processing and transfer.
- Implementation of best practice projects to exclude solids from aqueous discharge streams. These projects have built on existing solids exclusion arrangements at site, and range from implementing simple filtration techniques at source plants to extensive trials to underpin, optimise and potentially improve final filtration systems on effluent discharges.
- Recycling of filtrates from the processing of Salt Evaporator Concentrate through the EARP 'bulks' route to reduce overall discharges of amercium-241 and ruthenium-106. This move has been facilitated by the use of new consolidated discharge limits for EARP in the environmental permit (formerly separate limits were in place for EARP 'bulks' and 'concentrates'). The limits are equal to or lower than the total of the previous individual limits, but the consolidated approach provides significantly increased operational flexibility to meet site hazard reduction obligations and the long-term effluent strategy, along with enhancing the ability to demonstrate application of BAT.
- De-canning and re-packaging of a significant quantity of the corroded fuel inventory in the Fuel Handling Plant pond. This has minimised loss of activity into the pond water which in turn contributes to lower activity in discharges from this source. Similarly, improvements to pond water cooling and pH control in the Fuel Handling Plant have led to further reductions in pond water activity.

- Tighter Conditions for Acceptance have been imposed on pH and competing ion values for feeds from donor plants to SIXEP thereby optimising plant abatement performance. Additionally, R&D 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:
  - Active column trials to assess the abatement performance of potential alternative ion exchange materials.
  - Assessment of the potential for deployment of a third ion exchange bed.
  - Plant trials of a pre-treated clinoptilolite ion exchange material.

3.2.7 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 La Hague in France and in the past broad comparisons have been made when undertaking major permit review. 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. More specifically, periodic reviews of developments in effluent management techniques are undertaken to support BAT assessments. The last major review was completed in 2015. The review is set in the context of a site effluent strategy which details how the nature and volume of effluents and the effluent treatment infra-structure will change as Sellafield transitions from reprocessing operations to decommissioning. The major planned effluent treatment developments are:

- The development of a replacement plant for SIXEP, which will employ similar technology but should provide greater flexibility and the ability to use alternative ion-exchange resins; and
- Diversion of effluent streams to the existing EARP provides additional discharge abatement as the site transitions to decommissioning.

Guided by the effluent strategy and the periodic reviews, but at a lower level, BAT to prevent and minimise effluent is assessed through the production, implementation and maintenance of nuclear facility environment cases. Environment cases are also used to assess BAT to prevent and minimise effluents when new facilities, included effluent treatment processes, are designed and built or when existing facilities/processes are significantly modified. This process provides the opportunity to replace and upgrade effluent management particularly as the site transitions to decommissioning.

A range of R&D is on-going to support the development of effluent techniques for decommissioning operations and this is supplemented with a portfolio of sponsored academic research, all of which is coordinated by the Sellafield Limited centre of expertise for effluent technology. Furthermore, an UK Aqueous Effluent Working Group (AEWG) has recently been established by the NDA, under the Nuclear Waste and Decommissioning Research Forum to share information and experience, leading to more effective programmes within individual organisations and to improved technical co-operation across the industry. This encompasses the following objectives:

1. Communicate and promote good practice relating to the design, operation and decommissioning of nuclear effluent treatment facilities.
2. Review and benchmark existing and developing practice.
3. Keep abreast of and communicate relevant national and international developments in liquid effluent treatment.

The AEWG includes representatives from the UK nuclear operators, NDA, regulators and a few international representatives.

3.3 Capenhurst

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

During the reporting period, the main process activities were:

- Uranium enrichment for fuel production.
- Uranic material storage facilities and activities associated with decommissioning.

3.3.1 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.

3.3.2 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 (Punt and George, 2011), 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 (e.g. 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.

3.3.3 Trends in discharges over the 2012-2016 period

Trends of liquid and gaseous discharges from Capenhurst during the reporting period (2012-2016) are given in Figures 3.4 and 3.5. Figure 8.4 (in Part 2, Section 8) also shows time trends of discharges over a longer period (2004-2016).

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.

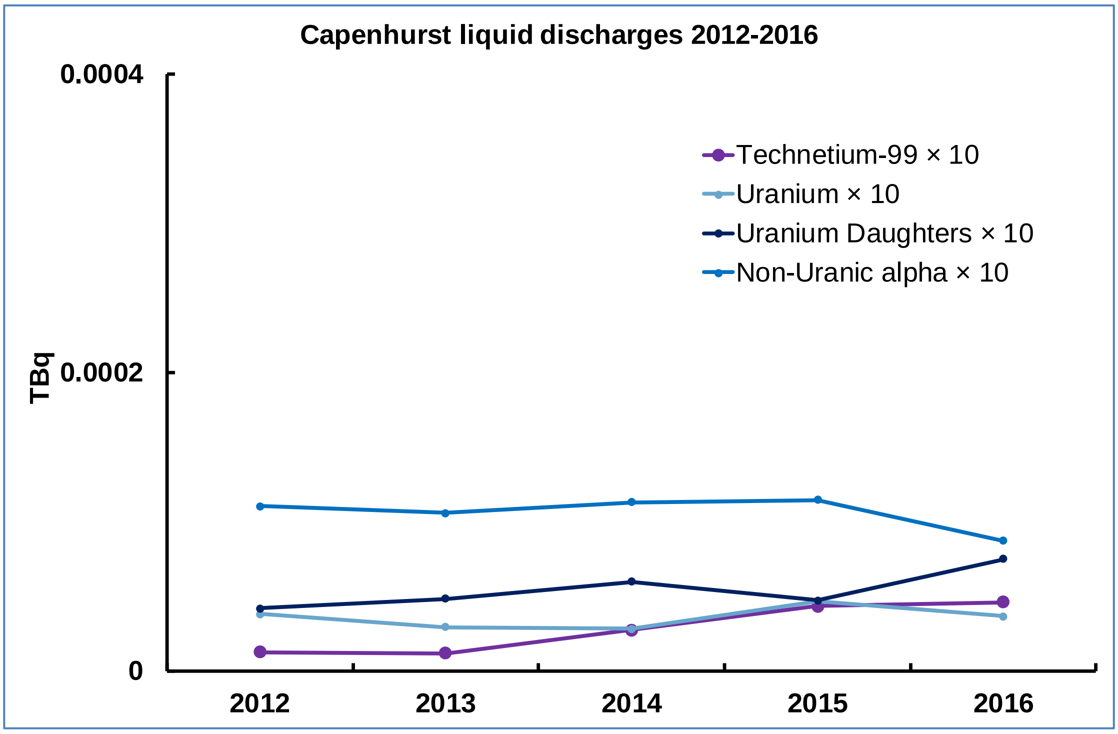

Figure 3.4 Liquid discharges, Capenhurst (2012-2016)

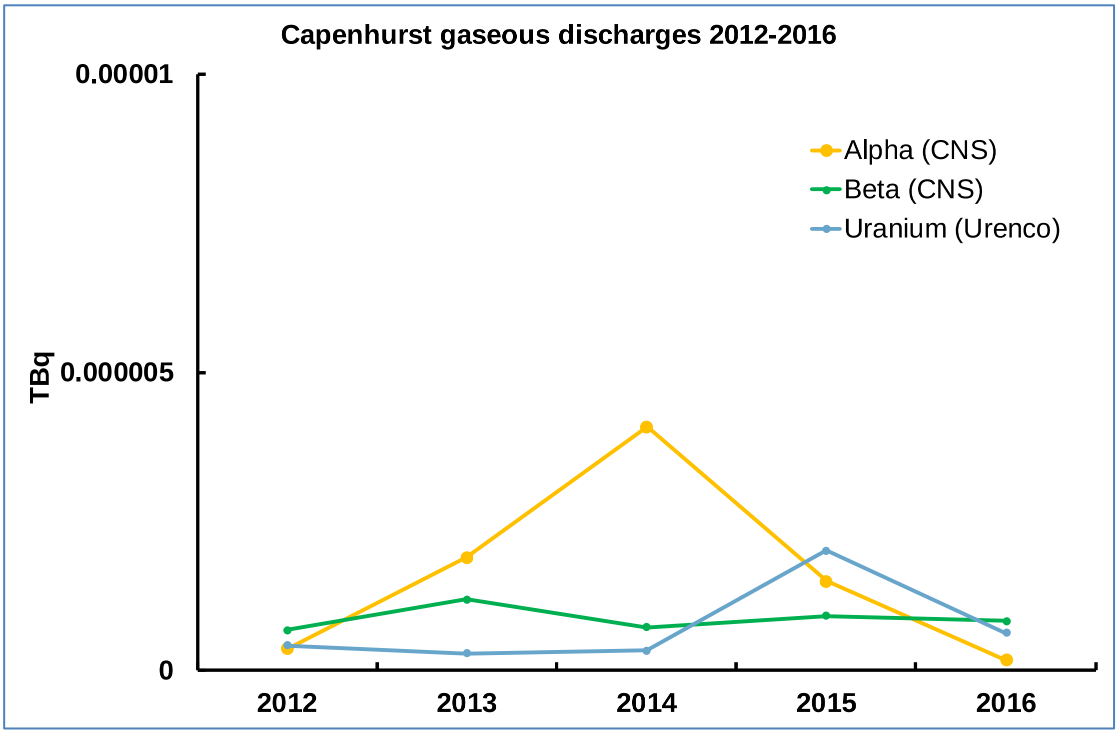

Figure 3.5 Gaseous discharges, Capenhurst (2012-2016)

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 2004-2016. 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;

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- A summary of trend data for nuclear fuel production and reprocessing sector (2004-2016) (Part 2, Section 8.5).

3.3.5 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 operations are anticipated to continue and will include new processes. A Urenco Limited subsidiary, Urenco ChemPlants Limited (UCP), is currently building a new facility (Tails Management Facility, planned to be commissioned in late 2017/early 2018) on a separate part of the site. This facility (and associated facilities) comprises cylinder washing, residue recovery, decontamination and maintenance plant that will de-convert uranium hexafluoride (Hex), or "Tails" to the more stable uranium oxide. This will allow the uranium to be stored in a more chemically stable oxide form for potential future re-use in the nuclear fuel cycle and will recover hydrofluoric acid for re-use in the chemical industry. The plant is permitted and, when commissioned, will discharge gaseous waste to the environment, aqueous waste to UUK's effluent disposal system and will dispose of solid waste by off-site transfer.

In compliance with the UUK environmental permit and nuclear industry guidance for BAT, a BAT assessment process is used 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.

In addition to new modules being constructed on the latest enrichment plant, UUK are also 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.
- Possible decommissioning of old centrifuge enrichment plants.

3.3.6 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.

3.4 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.
- Decommissioning and demolition of redundant plants and buildings.

3.4.1 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.

3.4.2 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.

3.4.3 Trends in discharges over the 2012-2016 period

Trends of liquid and gaseous discharges from Springfields during the reporting period (2012-2016) are given in Figures 3.6 and 3.7. Figure 8.5 (in Part 2, Section 8) also shows time trends of discharges over a longer period (2004-2016).

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.

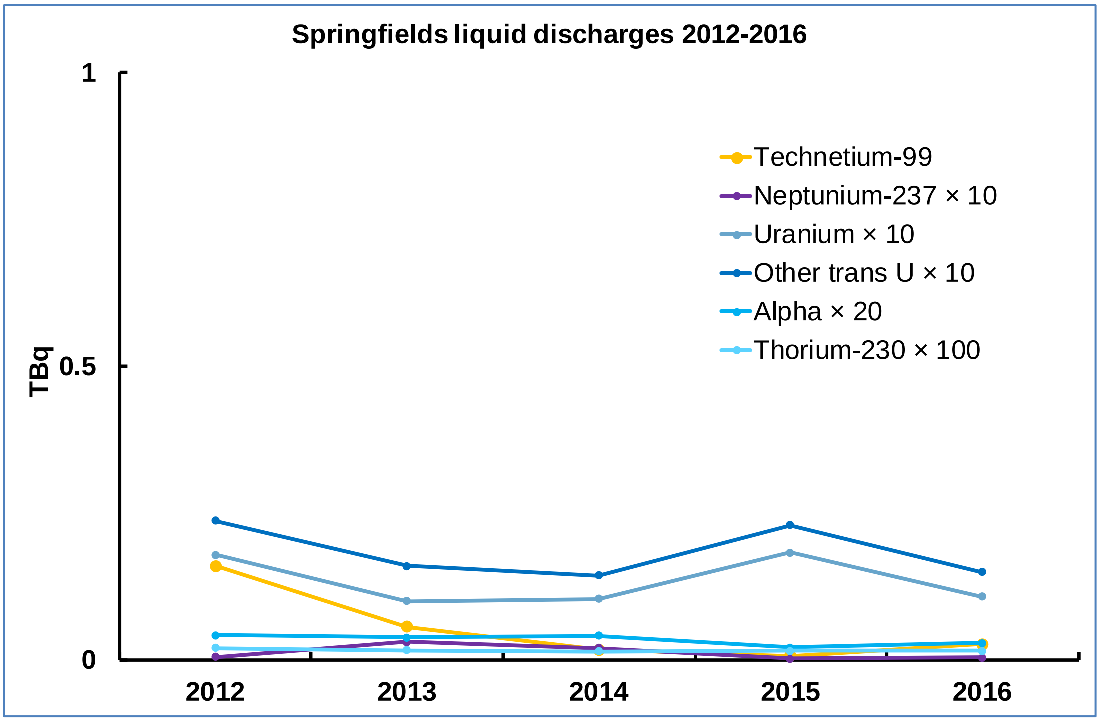

Figure 3.6 Liquid discharges, Springfields (2012-2016)

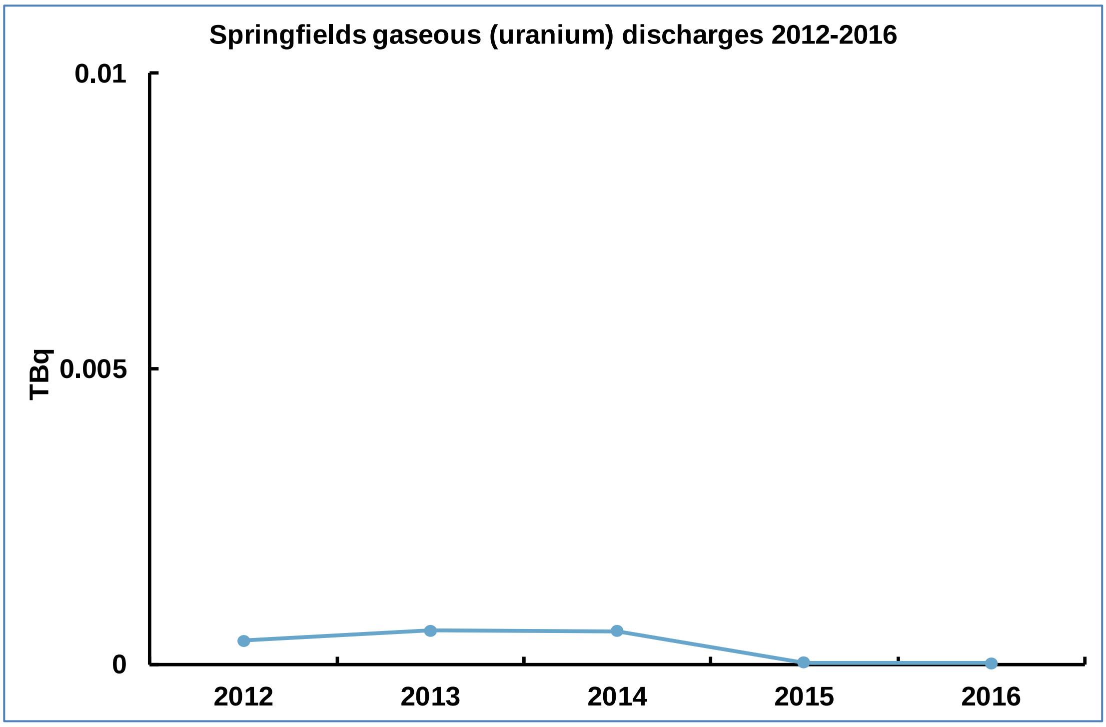

Figure 3.7 Gaseous discharges, Springfields (2012-2016)

3.4.4 Radiological impact of gaseous and liquid discharges

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- A summary of trend data for nuclear fuel production and reprocessing sector (2004-2016) (Part 2, Section 8.5).

3.4.5 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 two 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', i.e. 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.

3.4.6 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.

4. Research and development

4.1 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) and Windscale (Cumbria) which is on the Sellafield site. These latter smaller sites make very small discharges, 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. In 2015, Harwell and Winfrith sites, previously operated by Research Sites Restoration Limited merged to be part of Magnox Limited, controlled by the Cavendish Fluor Partnership (its designated PBO).

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 e.g. 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 e.g. 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 4.1.

Table 4.1 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.
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[#]. A project has commenced to transfer nuclear material from storage at Harwell to Sellafield. Phase 1 of the construction of the Harwell ILW Box Store is complete. Decommissioning of the above ground structures at the Local Effluent Treatment Plant continued; the project is anticipated to conclude in July 2017. The remaining structures were cleared and demolished, with the exception of the Higher Level Area facility. 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. The very earliest stages of B220 decommissioning will commence in late 2017/early 2018.
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.

4.2 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 three 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 to the environment. In April 2014, DSRL received a new multi-media Radioactive Substances Act (RSA) authorisation that consolidated several sub-limits into significantly lower discharge limits.

4.2.1 Sources of liquid effluent

The principal radionuclides discharged are: alpha, all other non-alpha, tritium, strontium-90, and 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.

Subsequent to the destruction of the bulk liquid coolant from the Dounreay Fast Reactor, that was completed in March 2012, work has been undertaken to deal with the residual amounts of the alkali metals.

4.2.2 Liquid effluent treatment and discharges

All major sources of liquid waste are filtered at source and, where caesium-137 levels are expected to be significant, are processed through ion exchange plants. Each of these systems is operated in accordance with BPM considerations. The treatment option for the high activity liquid wastes (raffinates) from past reprocessing is immobilisation in cement for subsequent disposal as solid intermediate level waste. The immobilisation of raffinates is now complete from the Dounreay Materials Test Reactor and Dounreay Fast Reactor (DFR).

Before completion of the DFR bulk alkali metals destruction operations, the aqueous solution associated with these operations was treated by filtration and passage through ion exchange material to remove the majority of the caesium-137.

During early operation of Dounreay, intermediate level waste was placed in a shaft that was originally built as a temporary access route for the removal of rock during the excavation for a 600 m long liquid waste discharge pipeline in the 1950s. The Government agreed with UKAEA (the former owner/operator of the site) that the waste should be retrieved, and conditioned for long-term storage and final disposal.

Groundwater leaking into the Dounreay shaft is pumped to the site’s liquid discharge system. Occasionally, higher levels of radioactivity have been found in the pumped effluent from the shaft. Therefore an ion exchange plant was installed in 2000, which is brought into operation in the event of high levels of activity being detected. In

2007/2008 the rock structure around the shaft was successfully sealed with grout (Shaft Isolation Project) with a corresponding decrease in groundwater ingress in to the Shaft. The attenuated groundwater is subsequently pumped to the Low Level Liquid Effluent Treatment Plant. The Shaft Isolation Project has resulted in a decrease in the volume of radioactive effluent discharged and a net decrease in the radioactivity discharged from the shaft. Reduced dilution of activity within the shaft has resulted in a progressive increase in the beta concentration level in shaft effluent since the completion of the Shaft Isolation Project, although these levels now appear to have stabilised.

The design and operation of Dounreay Low Level Liquid Effluent Treatment Plant allows for the settlement of entrained particulate, with the effluent being pumped through a 50 μm filter before discharge to sea. The use of ion exchange columns at DFR for the bulk alkali metals destruction operations achieved a caesium-137 decontamination factor in excess of one million. The clean out of the settlement tanks associated with the Dounreay Materials Test Reactor involved using pond clean-up units to filter out any sludge before the effluent was passed through ion exchange columns and a 1 μm filter prior to sentencing to the Low Level Liquid Effluent Treatment Plant via the Low Active Drain.

Prior to discharge of effluents to the site active drainage system and subsequently to the Low Level Liquid Effluent Treatment Plant, procedures are in place to sample, analyse and approve liquor movements where this is practicable. This analysis allows trend monitoring of cumulative discharges and comparison with internal limits and is part of the process of demonstration of the application of BPM in discharge management.

High Efficiency Particulate Air filters are used to minimise discharges to atmosphere with pre-filters being installed on building ventilation extract grills to reduce the amount of inactive dust entering active ventilation systems.

4.2.3 Trends in discharges over the 2012-2016 period

Trends of liquid and gaseous discharges from Dounreay during the reporting period (2012-2016) are given in Figures 4.1 and 4.2. Figure 9.2 (in Part 2, Section 9) also shows time trends of discharges over a longer period (2004-2016).

In April 2014, a new authorisation was issued, which contained amended radionuclide groupings. All beta and gamma emitting radionuclides (other than those individually specified) taken together in the previous liquid authorisation were replaced by 'all other non-alpha' emitting radionuclides (not specifically listed, taken together). Therefore, a direct comparison of discharges during 2012-2016 is difficult. However, liquid discharges have remained low, and where comparisons can be made, radionuclides were generally similar (e.g. tritium) or declined (e.g. caesium-137) over the period. Variations in discharges between years were related to specific decommissioning activities. Strontium-90 discharges were lower in 2012 than in preceding years (see Figure 9.2, in Part 2, Section 9).

Gaseous discharges (where comparisons can be made) generally declined over the reporting period, with the exception of krypton-85. The large increase in krypton-85 discharges in 2013 and 2014 was based on pessimistic calculated releases from the processing of two fuel cans. In 2016, gaseous krypton-85 discharges were less than 1 per cent of the annual discharge.

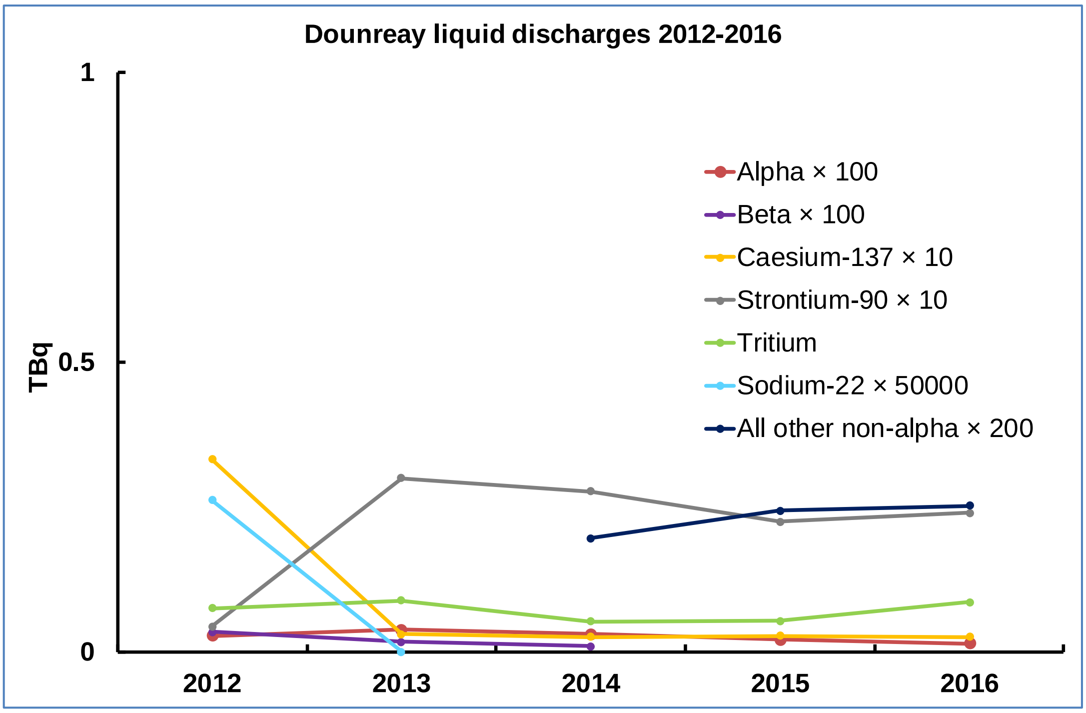

Figure 4.1 Liquid discharges, Dounreay (2012-2016)

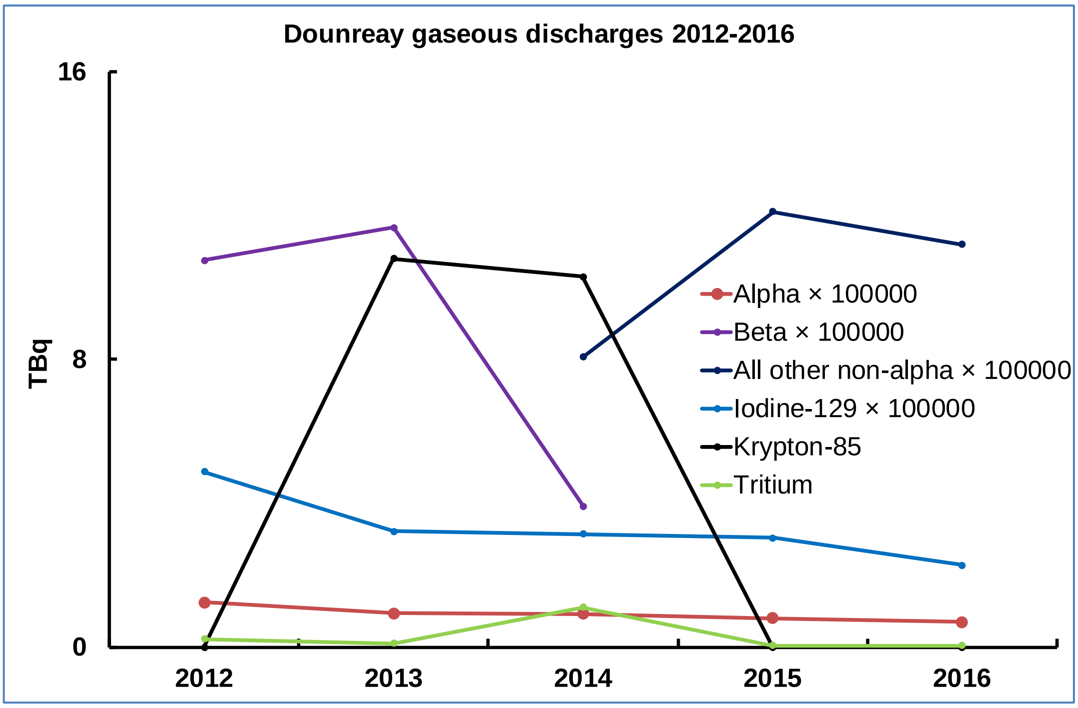

Figure 4.2 Gaseous discharges, Dounreay (2012-2016)

4.2.4 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 2004-2016. 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;

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- Time trends of radionuclide concentrations in food and the environment (Part 2, Section 9.2).
- A summary of trend data for research and development sector (2004-2016) (Part 2, Section 9.5).

4.2.5 Particles on the Dounreay foreshore

The previously conducted offshore survey work provided data on repopulation rates of particles (with high activity concentrations) 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 (DPAG, 2008). Since the work of DPAG was concluded, the Particles Retrieval Advisory Group (Dounreay) (PRAG (D)) has published reports in March 2010 and March 2011 (PRAG (D), 2010; 2011). 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 (PRAG (D), 2016). 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 public beach (Sandside Bay) will take a number of years to assess and recommends that in the interim the monitoring of local beaches be continued.

The management of particles also recognises that the risk from the particles is reducing with time, due to radioactive decay, corrosion and their ongoing dispersion in the marine environment. The future management strategy for the particles therefore also needs to consider when the active management of particles (through monitoring and recovery) might cease and how this decision will be made. These aspects need to be considered in the context of the site's planned decommissioning programme and timescales, in particular the scheduled date for the Interim End State (i.e. completion of decommissioning). The optimised management strategy needs to be co-ordinated with the rest of the site's decommissioning programme.

4.2.6 The application of BAT

As new decommissioning and waste treatment projects are planned, minimisation of potential discharges at source is used where practicable, to reduce radionuclides in the final discharges.

Tritium recovery was not considered to be BPM in the alkali metals destruction as the high salt content in the effluent and the presence of gamma emitting radionuclides made these liquid effluents unsuitable for treatment with currently available techniques.

A BPEO study was undertaken and published in 2003, to underpin the Dounreay Site Restoration Plan, in which it was concluded that evaporation of effluent and solidification of the residue would be neither practical nor cost effective (estimated to cost £400 million for very little benefit). An updated BPEO was submitted to SEPA in June 2009. The updated BPEO concluded that the current waste management strategies for the gaseous waste and all Remote Handled Intermediate Level Waste streams did not require further consideration along with most of the Contact Handled Intermediate Level Waste (CHILW) streams. It was also concluded that the majority of the LLW, HVLA, Clean[12] and Exempt waste streams did not require review. The following waste streams were identified as requiring further assessment:

- Solid CHILW Graphite - Thorium High Temperature Reactor (THTR) Graphite and Activated Graphite.
- LLW Sludge - Low Specific Activity Scale, Granular, and Putrescible.
- Clean and Exempt Hazardous Sludge – Putrescible.

DSRL undertook a review of the BPEO in June 2013 concluding that its waste minimisation techniques continued to represent both best practice in waste minimisation and the BPEO.

Two bespoke Medium Volume Combination Tankers were purchased in 2010 and 2011 for the purpose of cleaning gullies in the Fuel Cycle Area and General Site Areas (GSA), to reduce the ingress of standing water into the Low Active Drain ducts and the Low Level Waste Pits. These continue to be used. The tankers also carried out cleaning operations in the northern part of the site adjacent to the coast. Trace radioactive effluent from this process was discharged to the Low Level Liquid Effluent Treatment Plant. There is now a regular cleaning schedule for the Fuel Cycle Area and GSAs to prevent radioactive contamination of these drains.

Further improvements were made in the diversion of off-site water that had previously run onto the Dounreay Site. This has had the effect of reducing the hydraulic loading on the Non-Active Drains and ingress to the Low Level Waste Pits, which in turn discharge to Low Level Liquid Effluent Treatment Plant.

Radioactive contamination in the Non-Active Drains of one of the former Fuel Cycle Area facilities was isolated, sealed and bypassed in 2011.

DSRL is currently undertaking an enhanced monitoring programme within the NADs and surface waters entering the Dounreay Site from upstream, to determine both the process contribution (as a result of DSRL historic and current operations) and the

[12] Clean and Exempt (waste streams) and HVLA refer to non-radioactive wastes and High Volume Low Activity (waste), respectively.

local background in the surface waters in the vicinity of Dounreay. The monitoring programme includes a routine radioactive and non-radioactive analysis.

4.2.7 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 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 (e.g. in the form of Hazard and Operability Studies).

4.3 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 five 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.

4.3.1 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.

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.

4.3.2 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 three 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 ~ 60 m^3 of effluent per year. At the Liquid Effluent Treatment Plant, a large tank (Tank 9) of around 1,000 m^3 has recently been commissioned, this has only been used once to date to make a discharge of mainly rainwater.

4.3.3 Trends in discharges over the 2012-2016 period

Trends of liquid and gaseous discharges from Harwell during the reporting period (2012-2016) are given in Figures 4.3 and 4.4. Figure 9.3 (in Part 2, Section 9) also shows time trends of discharges over a longer period (2004-2016).

Discharges arise mainly from active showers (i.e. 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.

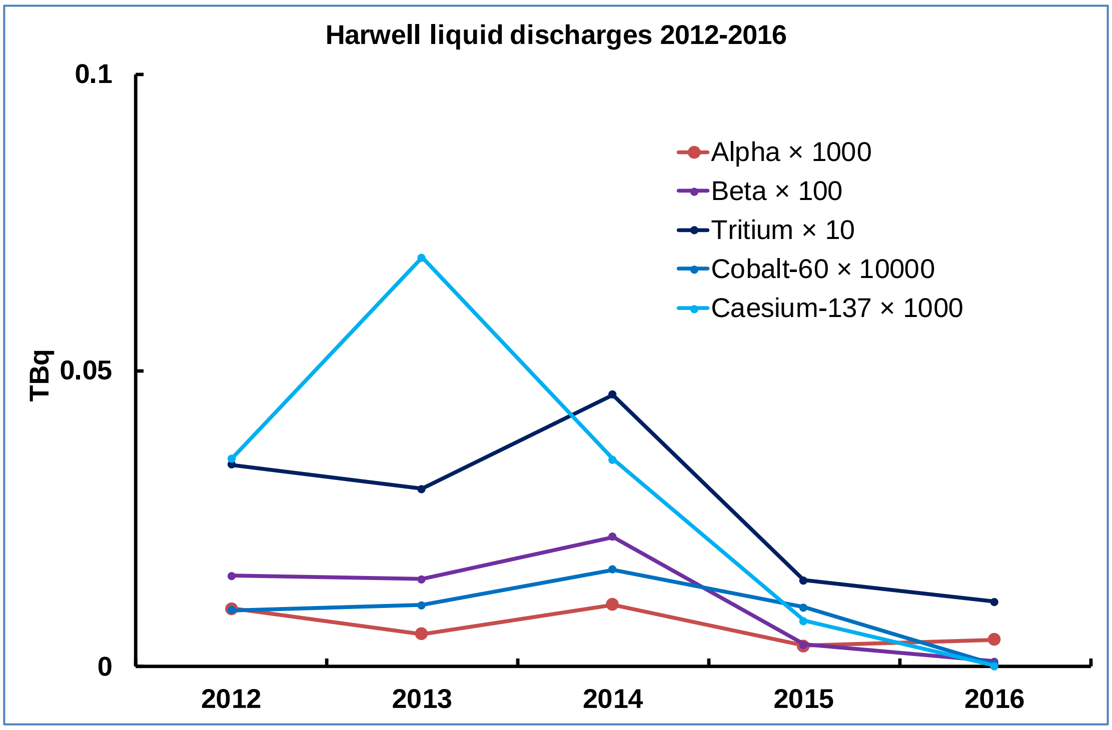

Figure 4.3 Liquid discharges, Harwell (2012-2016)

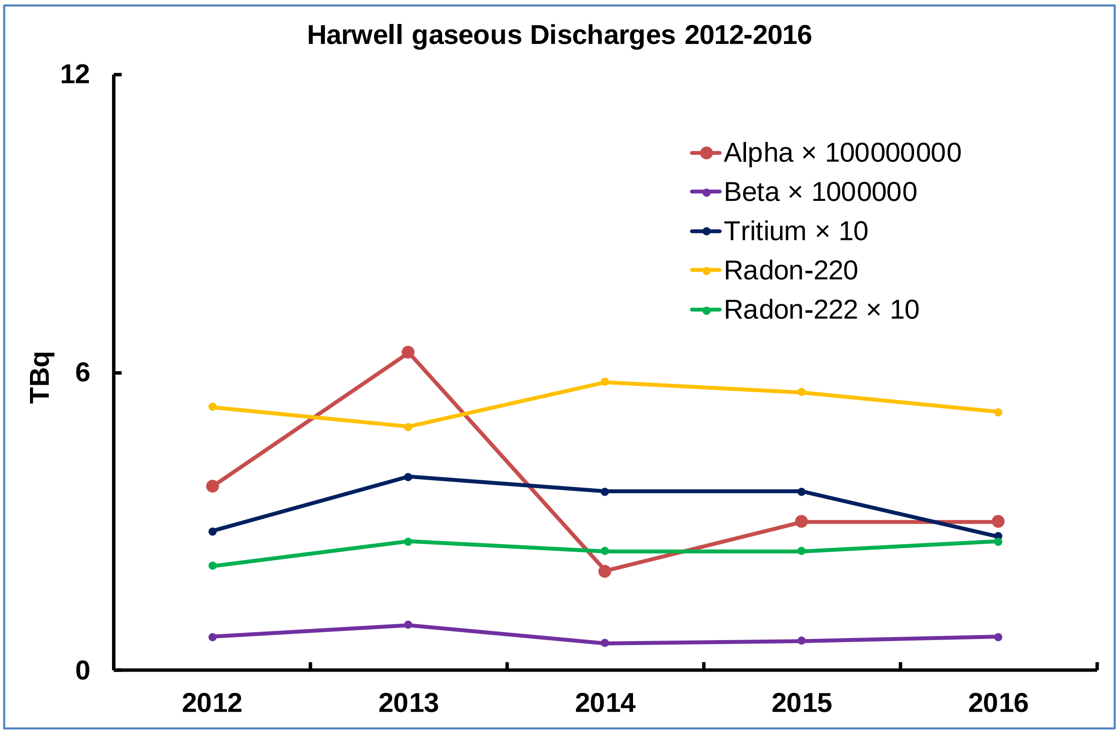

Figure 4.4 Gaseous discharges, Harwell (2012-2016)

4.3.4 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 2004-2016. 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;

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- Time trends of radionuclide concentrations in food and the environment (Part 2, Section 9.3).
- A summary of trend data for research and development (2004-2016) (Part 2, Section 9.5).

4.3.5 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 indicates environmental sensitive plant/equipment. The labelled plant is managed through the Radiological Environmental Maintenance Schedule. The routines ensure an appropriate frequency of testing, calibration and maintenance.

Work planning and approval ensures that due consideration is given to environmental impacts through the Decommissioning Modification Proposal process. In addition, “Suitably Qualified and Experienced Persons” are in key roles supervising and controlling operations. Asset Management and Plant Health 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.

4.3.6 Comparison with performance of similar plants world-wide

There are difficulties in comparing the performance of the treatment plants 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 expected performance of the proposed 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 (e.g. the AWE evaporator) and some industrial evaporators from the non-nuclear sector.

4.4 Winfrith

The Winfrith site was established in 1957 as an experimental reactor research and development site. There have been nine research and development reactors, including the Steam Generating Heavy Water Reactor (SGHWR). The last operational reactor at Winfrith closed in 1995. Seven of the reactors have been decommissioned and dismantled.

The current focus of work on the site is the decommissioning of remaining reactors and supporting waste management operations. Since 2015, the Winfrith site has been operated by Magnox Limited on behalf of the NDA.

4.4.1 Sources of liquid effluent

Current operations at Winfrith are concerned primarily with decommissioning activities. Discharges from this site therefore depend on the decommissioning programme. Tenants on the Magnox Limited Winfrith site transfer liquid waste to the Magnox active liquid effluent system. The principal radionuclide discharged is tritium; a significant component of which arises from the waste processing work of a tenant (Tradebe Inutec Limited, formerly Inutec). All liquid discharges are made via pipelines to the English Channel.

4.4.2 Liquid effluent treatment and discharges

In accordance with Magnox Limited procedures, the volume and radioactive content of waste arisings are minimised at source and by the application of BAT. Liquid wastes at Winfrith are not treated, with the exception of pH adjustment, 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.

4.4.3 Trends in discharge over the 2012-2016 period

Trends of liquid and gaseous discharges from Winfrith during the reporting period (2012-2016) are given in Figures 4.5 and 4.6. Figure 9.4 (in Part 2, Section 9) also shows time trends of discharges over a longer period (2004-2016).

Liquid discharges were generally similar over the reporting period. The principal radionuclide was tritium. A significant component of the tritium liquid wastes originated from a tenant on site (Tradebe Inutec). This tenant processes a wide range in wastes (with different radionuclide fingerprints). Consequently, activity concentrations from the site are variable, difficult to predict and not representative of Magnox's activities. The majority of liquid arisings from Magnox's activities are from groundwater and change facilities within active areas. Following the start of primary containment dismantling operations at SGHWR, a number of circuits have been flushed with water to transfer tritium into the liquid phase. This results in a contribution to the total tritium activity discharged, but is relatively insignificant given the small volumes discharged. It is expected that in the coming period discharges to sea from Winfrith will cease to allow decommissioning of the Active Liquid Effluent System and the Sea Pipeline. A route for future discharges is currently being identified.

Gaseous discharges were generally similar over the reporting period, with the exception of tritium. Variations in particulate discharges can be attributed to phases of decommissioning operations (cutting operations etc). The small increase in recent years is attributed to decommissioning of the primary containment at SGHWR, which is contaminated with heavy water. In 2016, the gaseous tritium discharge was 5.4 per cent of the annual limit. The increases were expected and considerable work has gone into optimising the management of tritium from the facility via practical techniques and management system controls. Tritium discharges are expected to increase as decommissioning of the two remaining reactors (SGHWR and Dragon) continues, though not to an extent where limits are likely to be challenged.

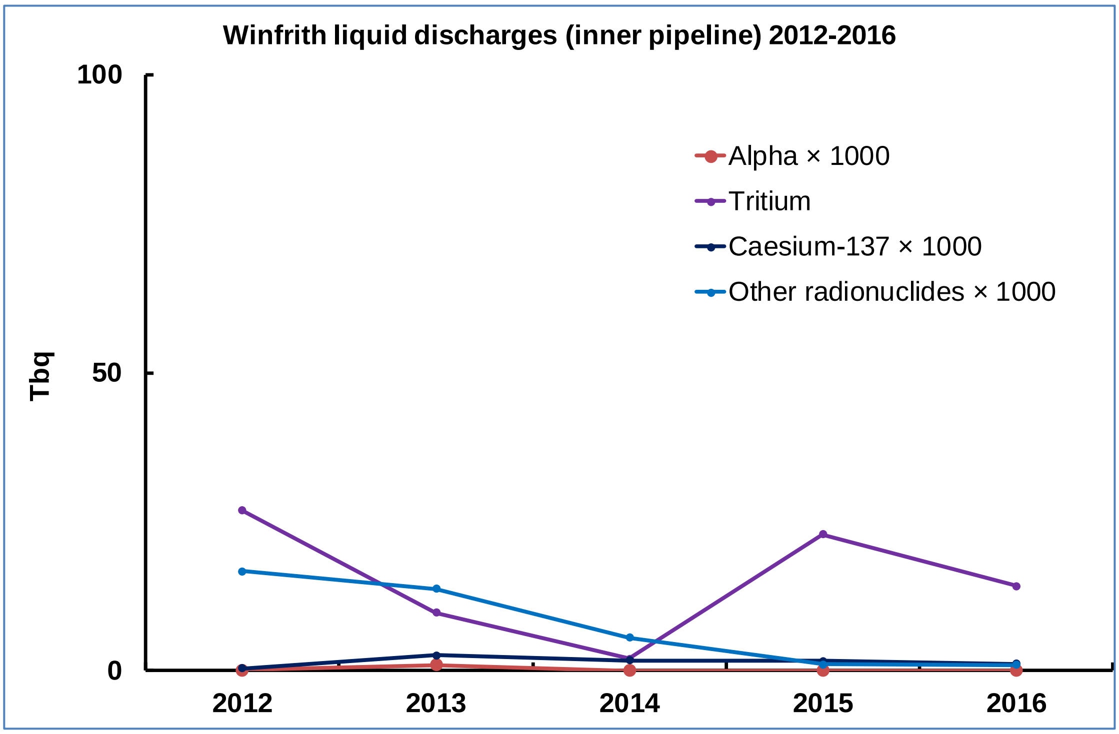

Figure 4.5 Liquid discharges, Winfrith (2012-2016)

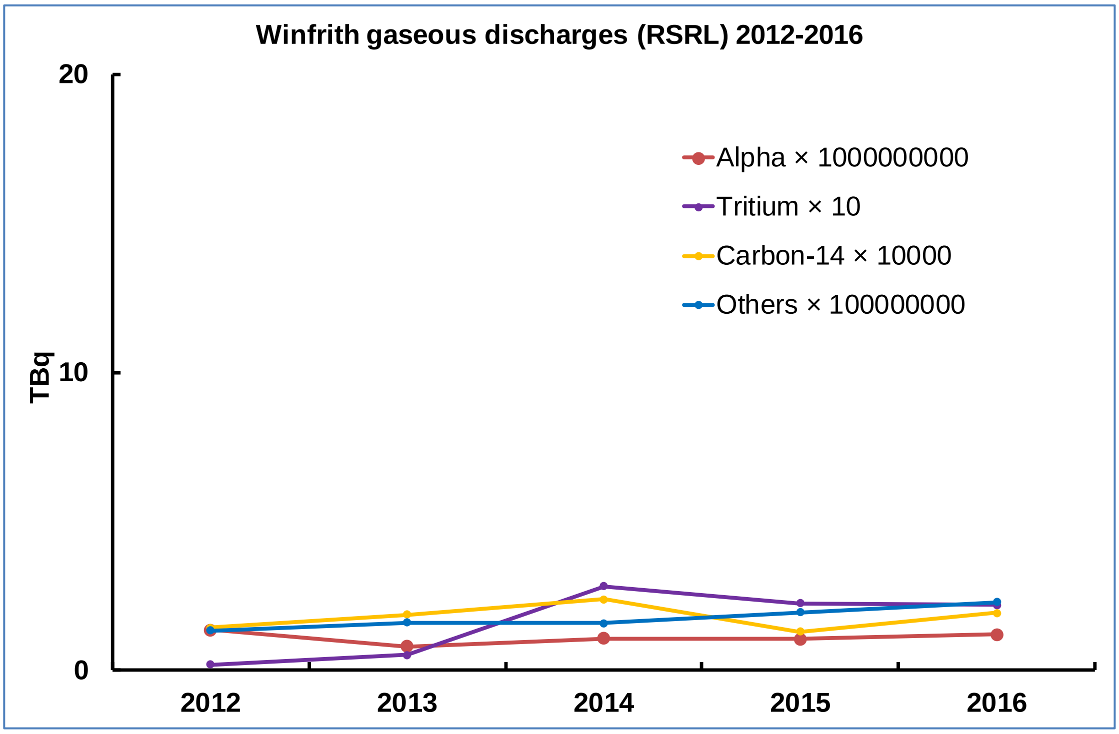

Figure 4.6 Gaseous discharges, Winfrith (2012-2016)

4.4.4 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 2004-2016. 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;

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- A summary of trend data for research and development sector (2004-2016) (Part 2, Section 9.5).

4.4.5 The application of BAT

BAT at Winfrith is achieved through similar processes and controls at other Magnox sites, as given in Section 4.3 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.

During the reporting period, a clarifier was installed at the Active Liquid Effluent System (ALES). The clarifier contains lamella inclined plates which allow the removal of entrained solids from the aqueous phase by sedimentation. The system also has a multi-layer pressure filter installed in series to further remove finer solids before the effluent is discharged. This system became operational in July 2011.

The principal radionuclides discharged are tritium and carbon-14. As noted earlier, the discharges recorded and reported by Magnox Winfrith (particularly tritium) contain a significant active component received from a tenant (Tradebe Inutec Limited) who discharge to the Magnox Active Liquid Effluent System (under a transfer permit granted by the Environment Agency). At present, there is no realistic treatment to reduce the discharges of tritium (which has low radiological impact). Furthermore, given that the discharge strategy for the site is to significantly change over the coming period with the closure of Active Liquid Effluent System, then resource is being invested in determining an appropriate future discharge route.

4.4.6 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 world-wide. 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 which the company reviews performance. Internally, the company applies optioneering (e.g. 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 (e.g. 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.

5. Nuclear power generation

5.1 Introduction

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

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

The 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 seven AGR power stations and one 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 2012- 2016.

No Magnox Power stations were operating in 2016. Over the 5 year-period of this report (2012-2016), only two of the Magnox design gas-cooled reactors had been operational (Oldbury and Wylfa). Oldbury Power Station ceased to be an electricity generator in February 2012, with the closure of Reactor 1 (Reactor 2 was previously shut-down in 2011). Wylfa Power Station ceased to be an electricity generator in December 2015, with the closure of Reactor 1 (Reactor 2 at the Wylfa site shut-down in April 2012).

Section 5 has been divided according to the operational status of the power stations during the reporting period (2012- 2016). Information is provided under the appropriate headings for two categories of site:

- Operational sites – those that were operational throughout the reporting period.
- Decommissioning sites – those that permanently ceased operation and began defuelling or decommissioning before 2016.

The nuclear licensed sites included under each category are set out in Table 5.1.

Table 5.1 Operational status of UK power stations in 2016

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.
[#]Wylfa power station was operational until 30th December 2015 and therefore will be reported under the operational sites.

5.2 Operational power stations

For the operational sites, the information is reported in two sub-sections:

- AGR and PWR.
- Magnox.

The reason for this distinction is related to the management arrangements; the current fleet of AGRs and the PWR are owned and operated by EDF Energy Nuclear Generation Limited and the Magnox stations are owned by the NDA and operated by Magnox Limited. In each case, a generic approach to the management of the sites is adopted, such that it is appropriate to consider them under these sub-sections.

There were seven AGRs, one PWR and two Magnox power stations in operation during the reporting period. However, Oldbury station ceased generating electricity in February 2012 and is therefore reported under Section 5.3.

5.2.1 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 waste water 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 ten 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.

5.2.2 Source of liquid effluents for Magnox (Wylfa)

During the reporting period (2012-2016), Wylfa power station was operational until 30th December 2015 and therefore will be reported under the operational sites. Wylfa has a dry spent fuel store which effectively eliminates the source of radioactivity that had been experienced by other Magnox sites (using cooling pond storage for spent fuel).

The main source of liquid tritium discharges is tritium build-up in desiccant used to capture water vapour (produced from processes to minimise oxidation of the graphite moderator). The desiccant is recycled by driving off absorbed water, along with the tritium and other radionuclides associated with it. Additionally, liquid effluents arise from laundry operations.

Oldbury ceased operations in February 2012 and will be reported under decommissioning sites (Section 5.3).

5.2.3 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 reasonable 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 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. However, boron is a hazardous substance and its introduction into the water environment is limited.

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 (300 m^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 two low level waste spent resin storage tanks and three 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.

5.2.4 Management of liquid effluents for Magnox

At the Wylfa site, spent fuel is stored under dry conditions. The levels of active liquid effluents are therefore less than for other Magnox sites using cooling pond storage for spent fuel.

5.2.5 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.

5.2.6 Liquid effluent treatment and abatement from Magnox

At the Wylfa site (because spent fuel is dry stored) the Active Effluent treatment is much simpler (than for previously operating Magnox sites), therefore there are lower activity levels in aqueous effluents. Particulate material is removed through the use of radial media filters for liquid effluents and particulate removal system. Effluents are then accumulated in delay tanks and discharged (providing analysis from pre-discharge sampling is compliant). Reactor gas drier liquor is collected and stored for 6 months prior to disposal to allow for sulphur-35 decay.

5.2.7 Trends in discharges over the 2012-2016 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, Figures 5.1-5.18 illustrate the variations in discharges over the reporting period (2012-2016) for each site. Figure 10.3 (in Part 2, Section 10) also shows time trends of discharges over a longer period (2004-2016).

Dungeness 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 ranged from 25 to 47 per cent of the annual discharge limit between 2012 and 2016. Similarly, gaseous discharges were generally similar and were all low

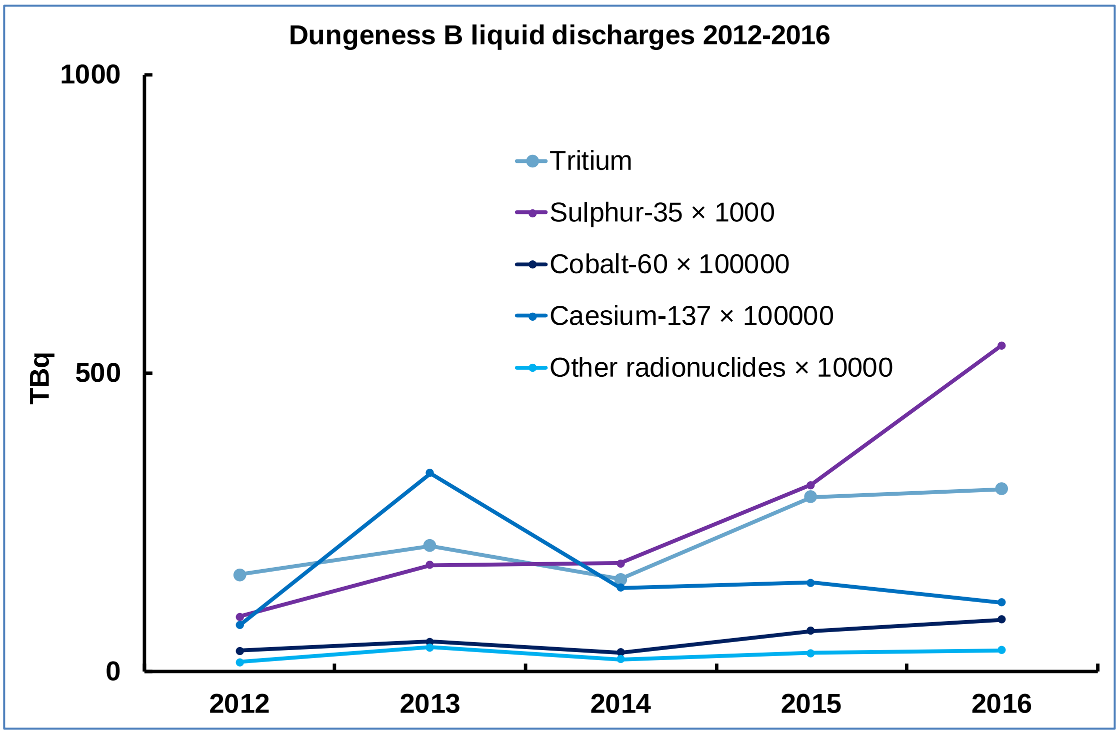

Figure 5.1 Liquid discharges, Dungeness B (2012-2016)

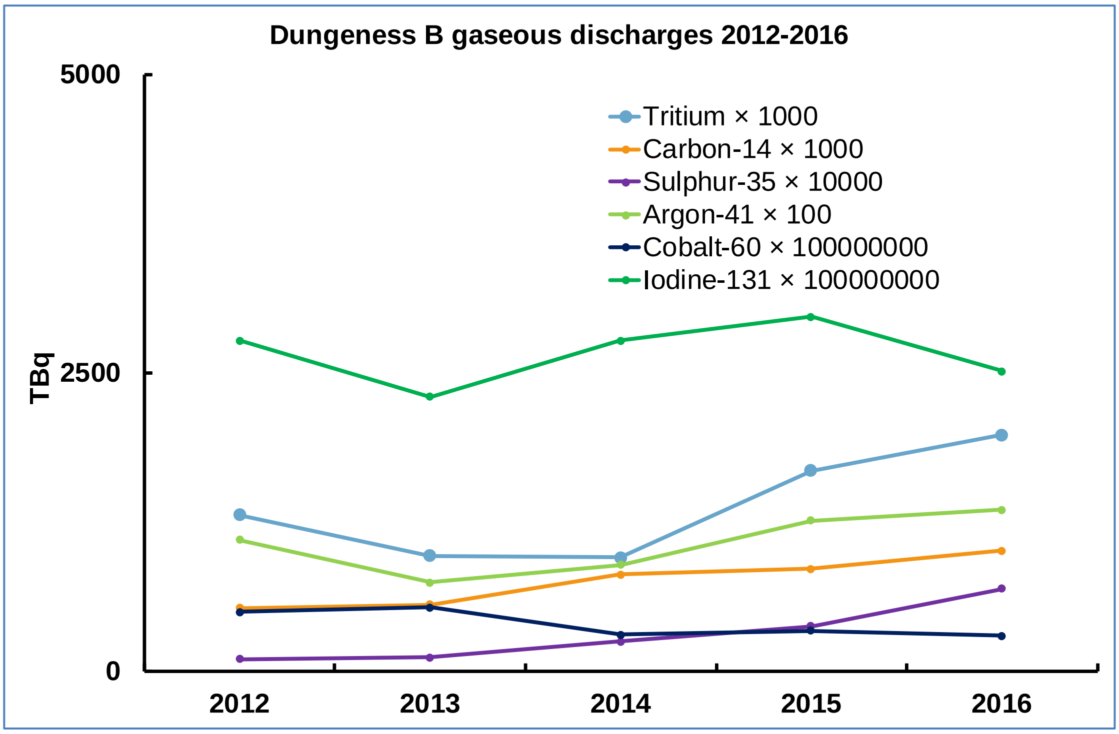

Figure 5.2 Gaseous discharges, Dungeness B (2012-2016)

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. Towards the end of the period, sulphur-35 discharges show an increasing trend due in part to the use of increasing levels of carbonyl sulphide (COS) in the reactor circuit to manage carbon deposition. Levels in discharges remain well below the corresponding permitted discharge limits.

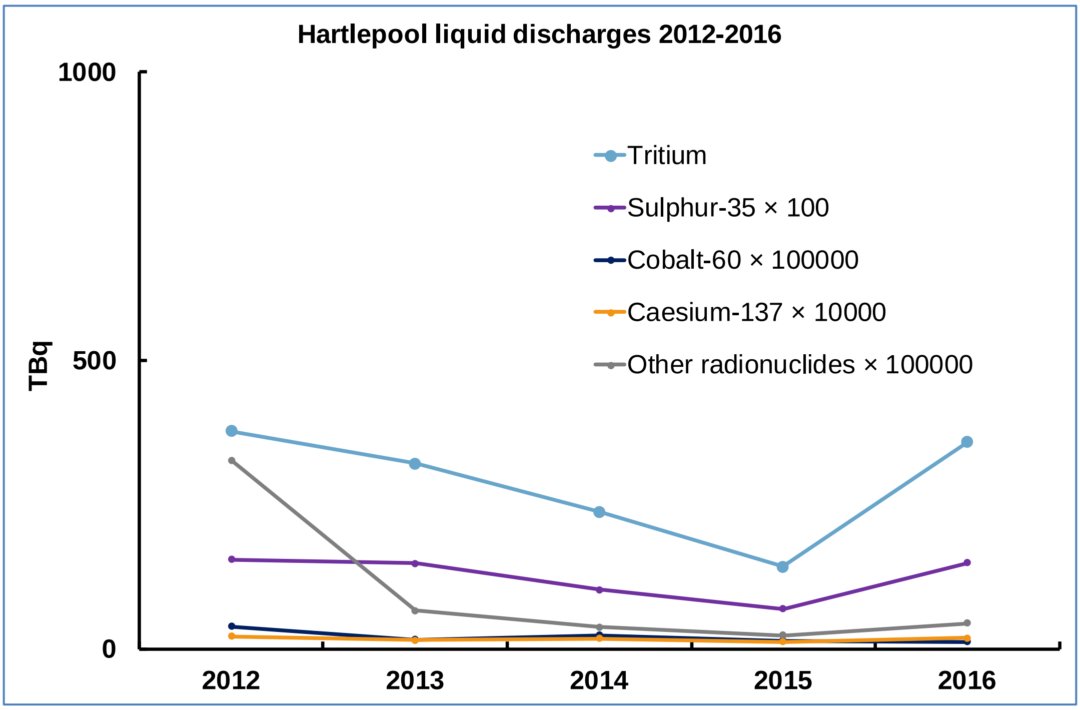

Figure 5.3 Liquid discharges, Hartlepool (2012-2016)

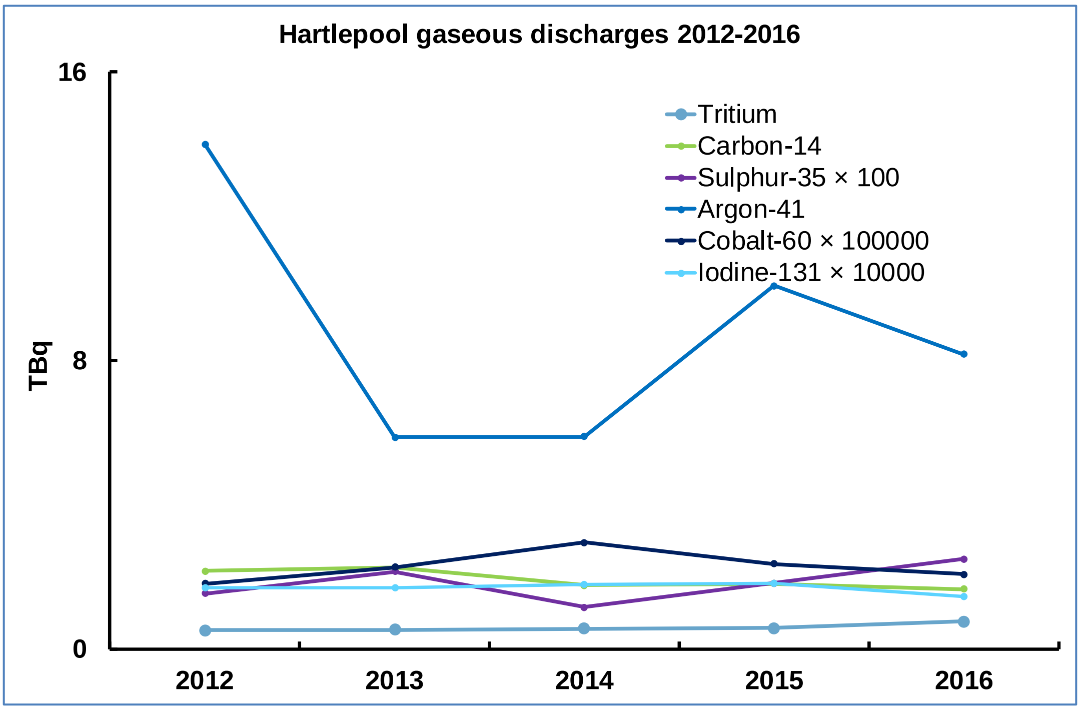

Figure 5.4 Gaseous discharges, Hartlepool (2012-2016)

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

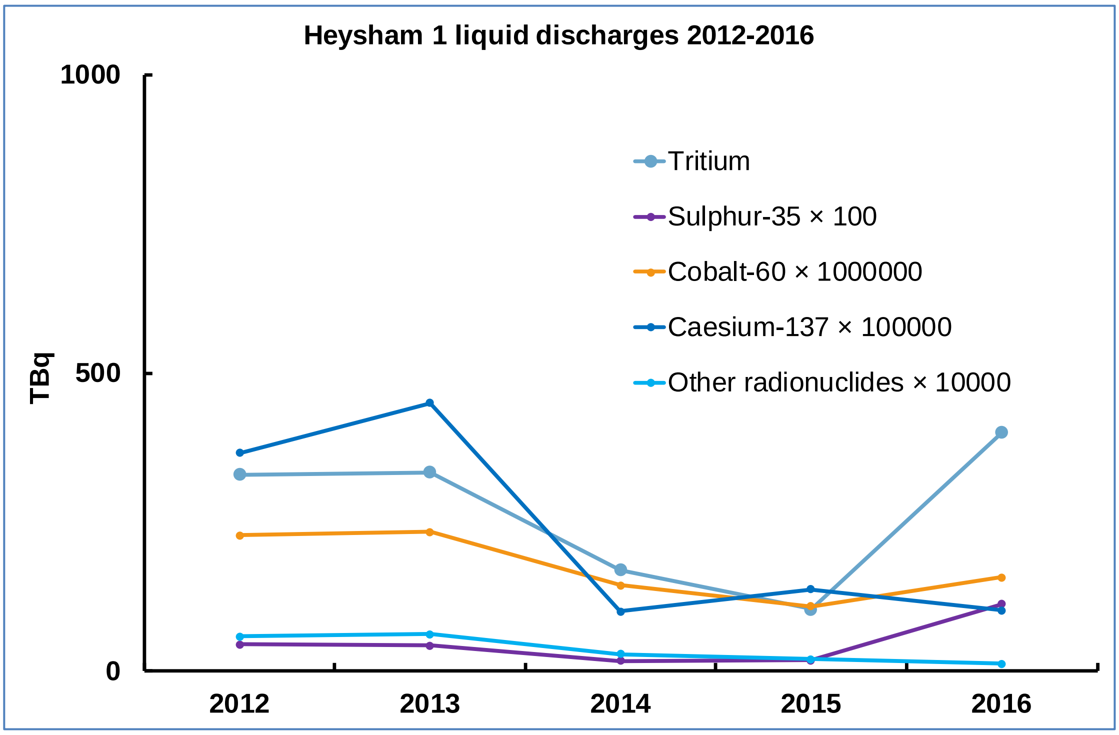

Figure 5.5 Liquid discharges, Heysham 1 (2012-2016)

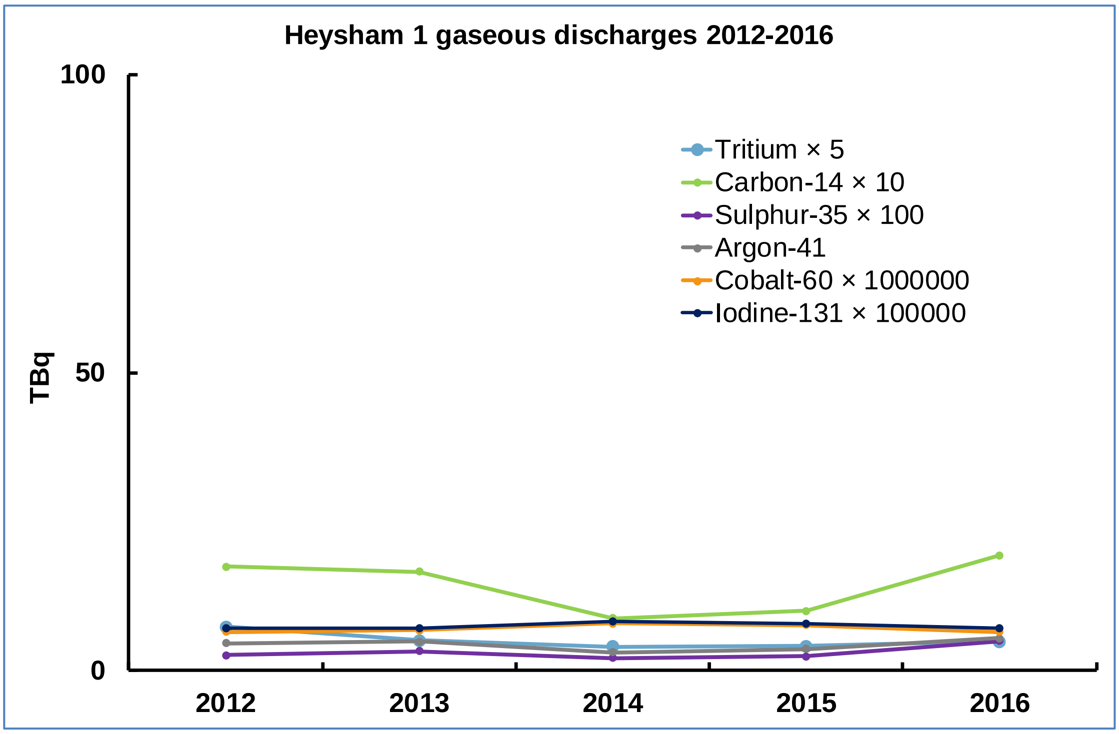

Figure 5.6 Gaseous discharges, Heysham 1 (2012-2016)

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

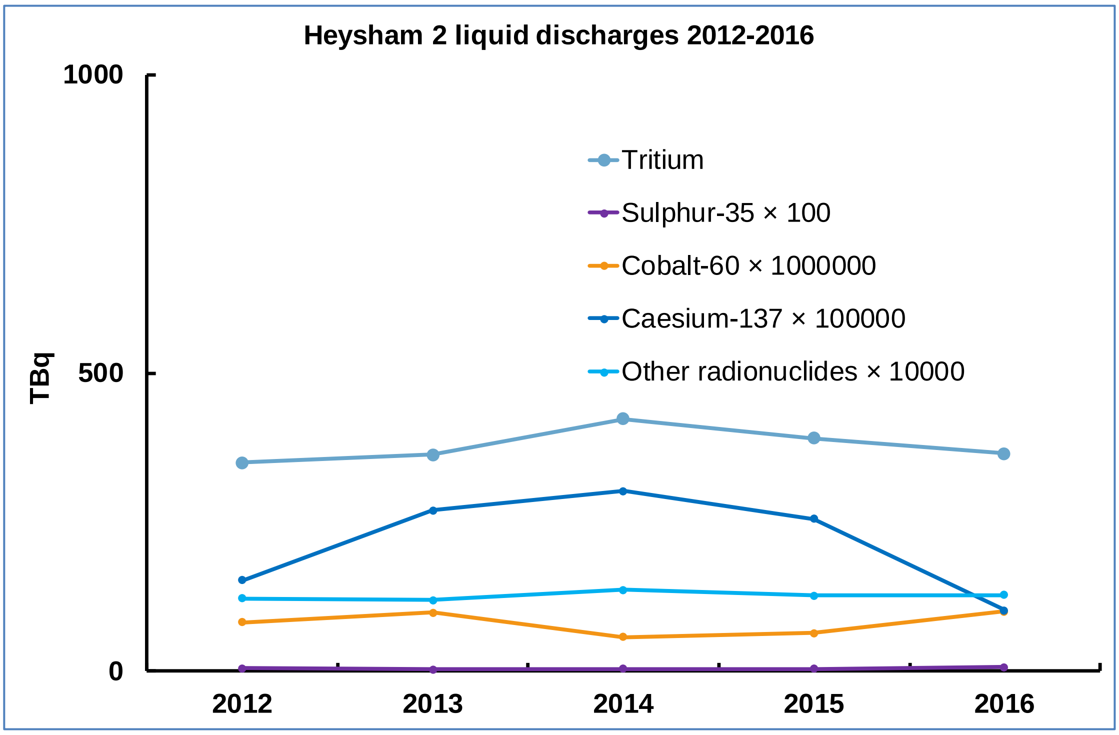

Figure 5.7 Liquid discharges, Heysham 2 (2012-2016)

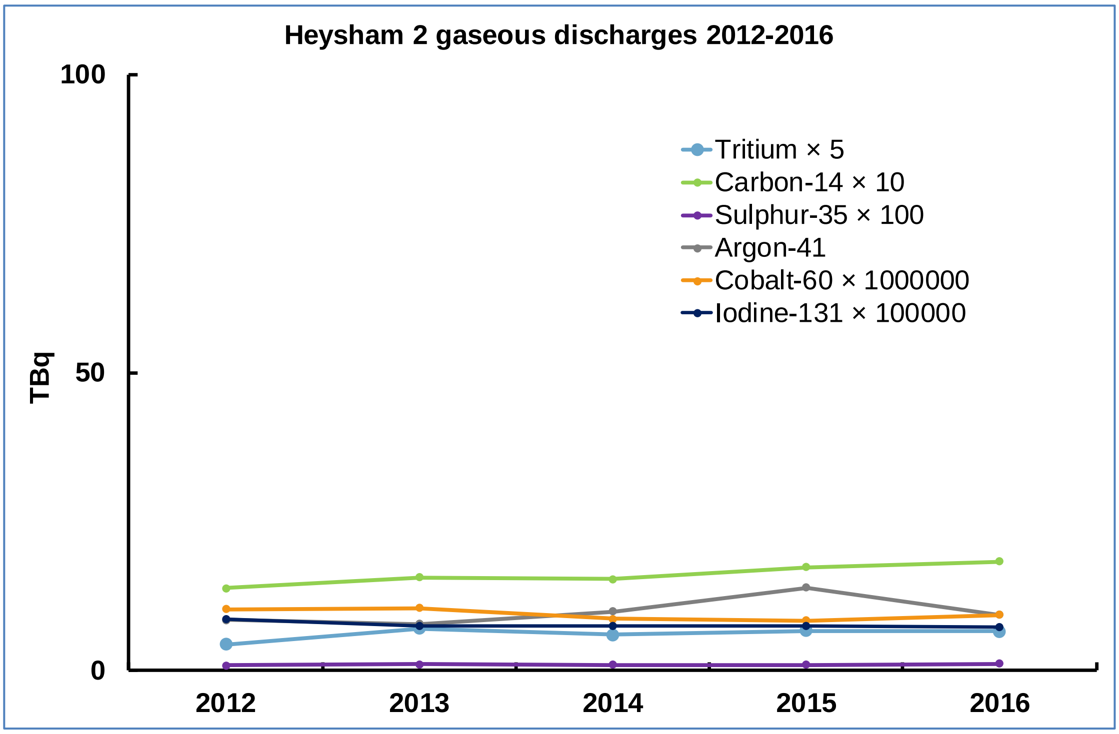

Figure 5.8 Gaseous discharges, Heysham 2 (2012-2016)

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

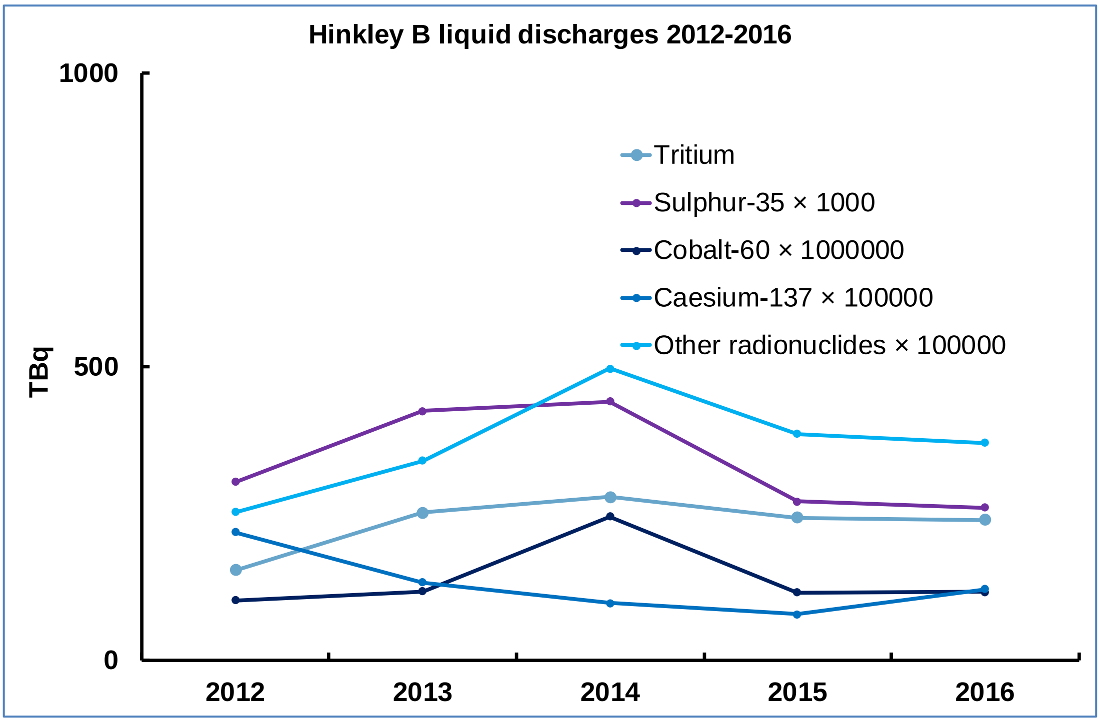

Figure 5.9 Liquid discharges, Hinkley Point B (2012-2016)

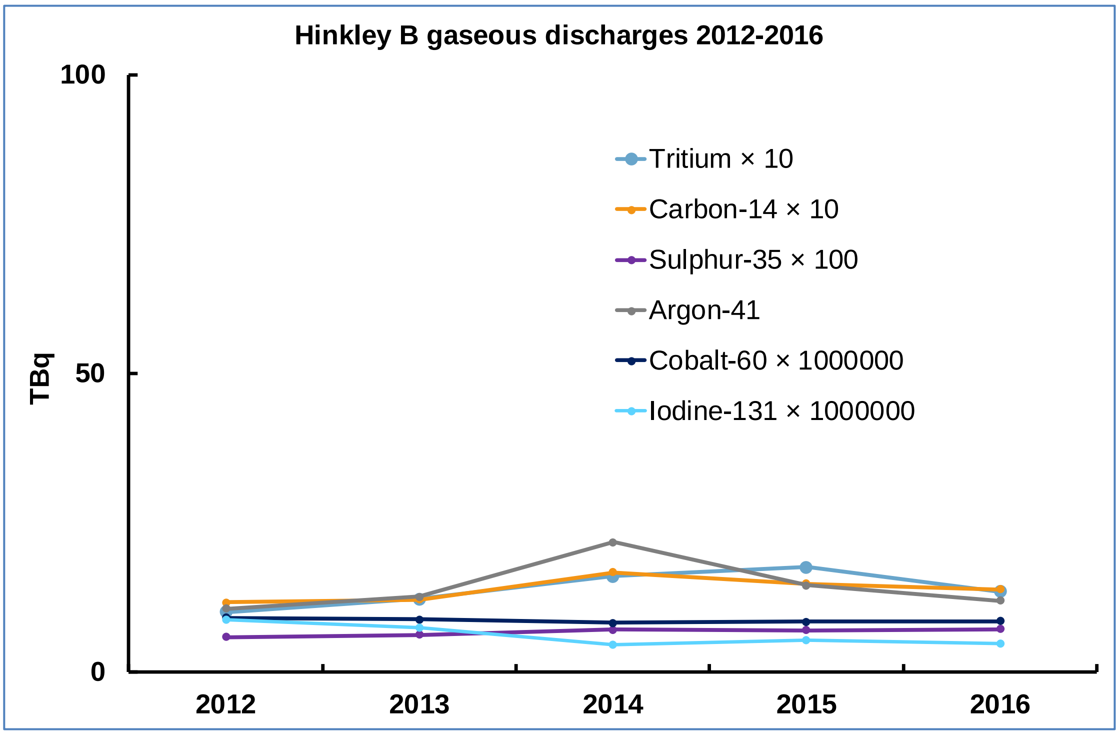

Figure 5.10 Gaseous discharges, Hinkley Point B (2012-2016)

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.

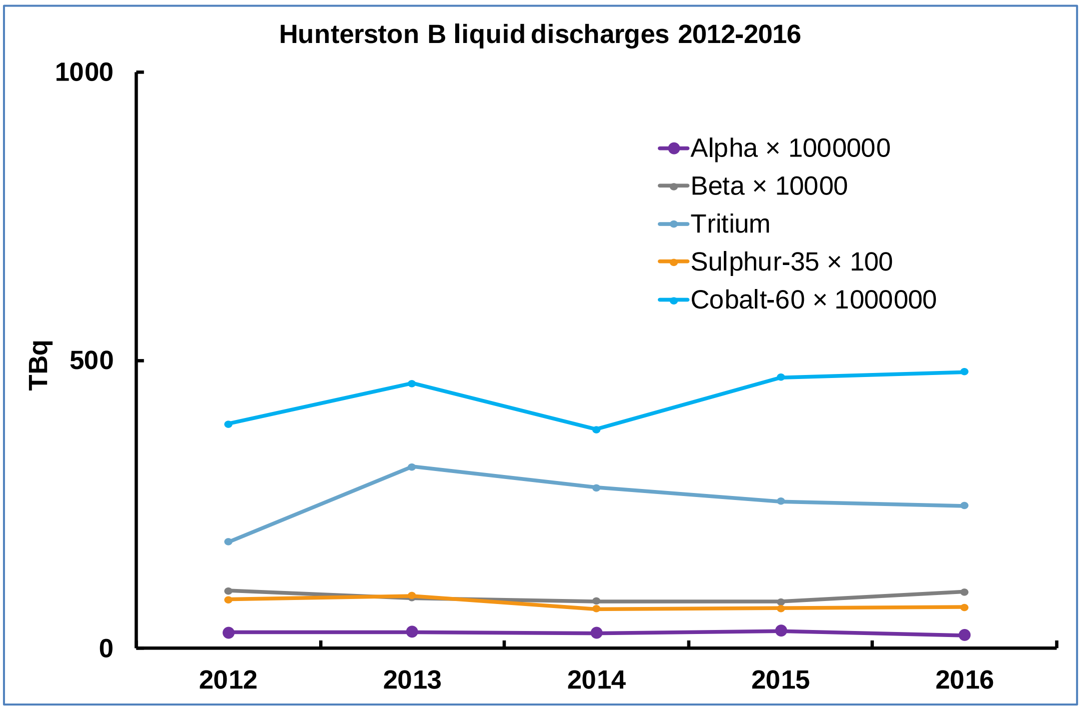

Figure 5.11 Liquid discharges, Hunterston B (2012-2016)

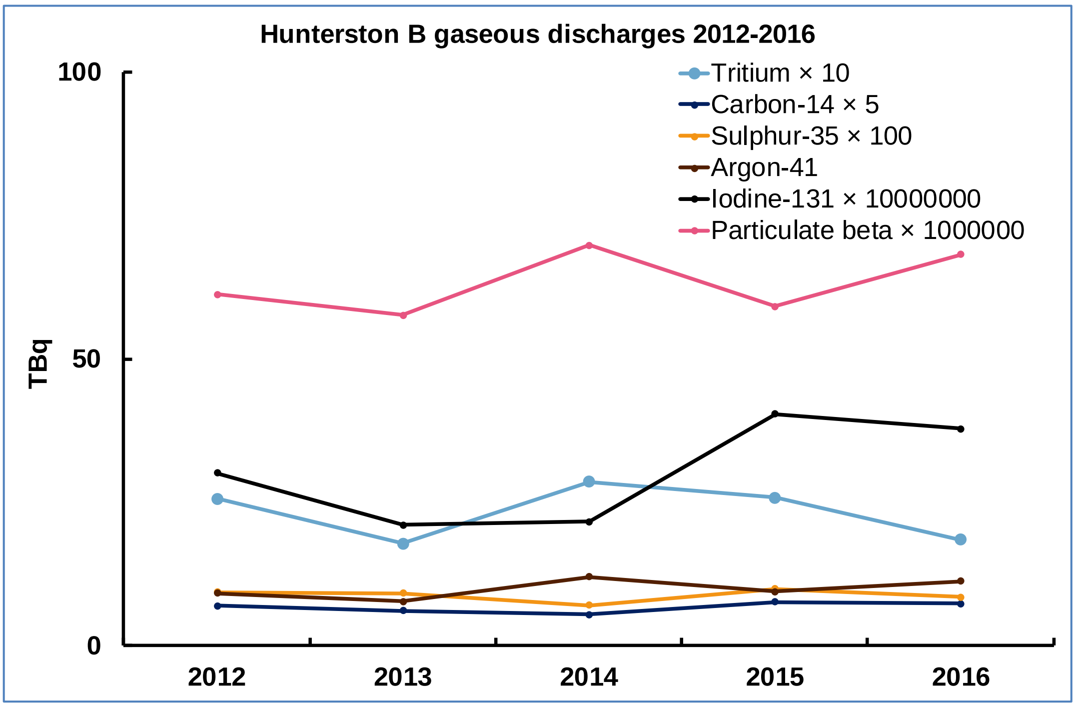

Figure 5.12 Gaseous discharges, Hunterston B (2012-2016)

Torness: Liquid discharges were generally similar over the reporting period, with some minor variation from year to year. Similarly, gaseous discharges have been generally similar and were all low. Gaseous argon-41 discharges ranged from 9.3 to 5.4 per cent of the annual discharge limit between 2012 and 2016.

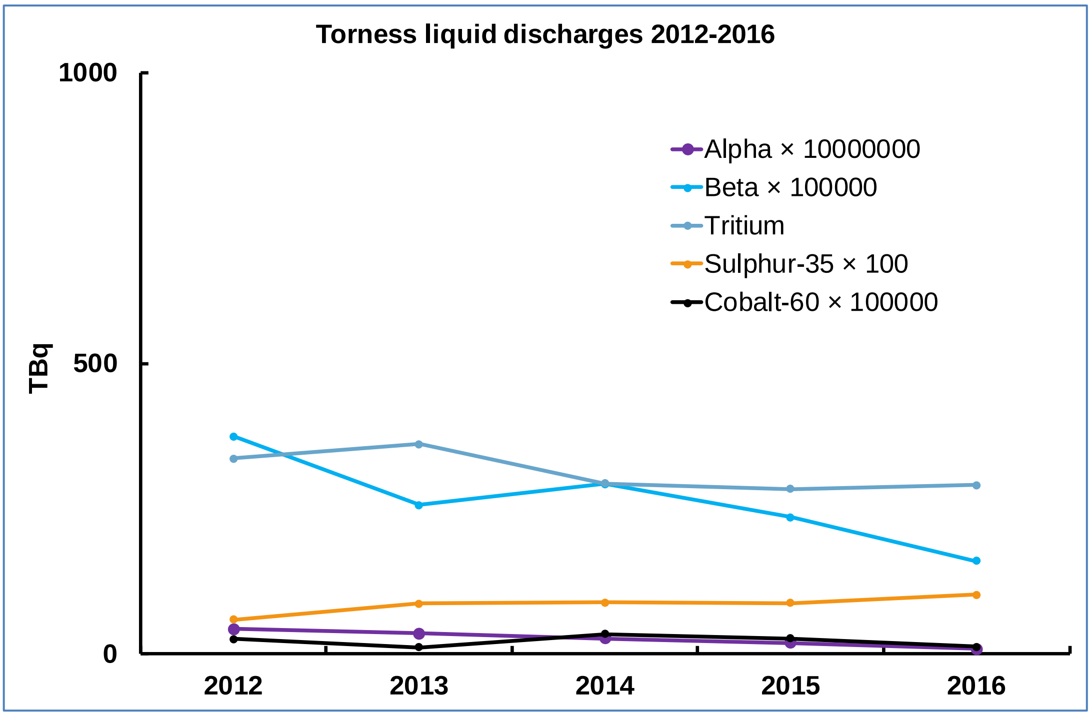

Figure 5.13 Liquid discharges, Torness (2012-2016)

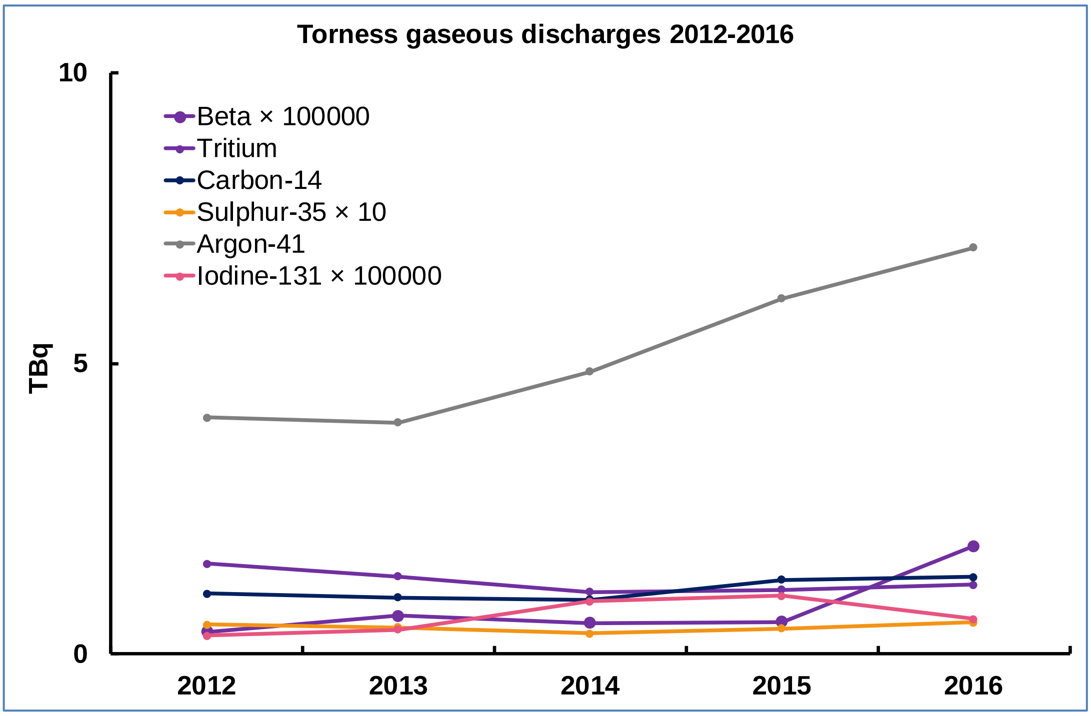

Figure 5.14 Gaseous discharges, Torness (2012-2016)

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 ranged from 24 to 78 per cent of the annual discharge limit between 2012 and 2016. Similarly, gaseous discharges were generally similar and were all low.

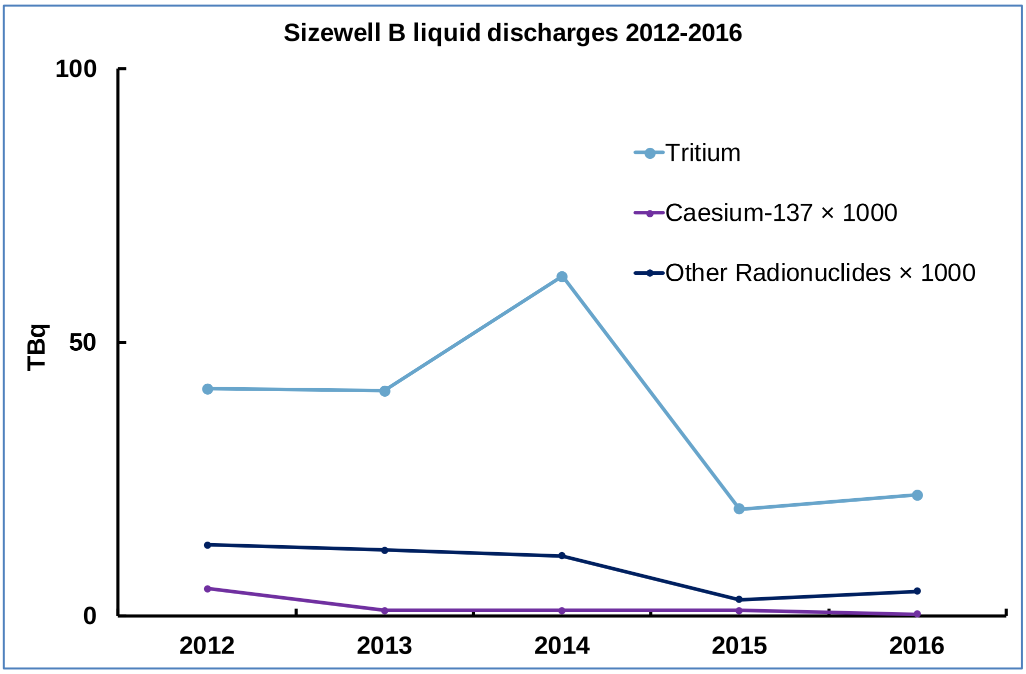

Figure 5.15 Liquid discharges, Sizewell B (2012-2016)

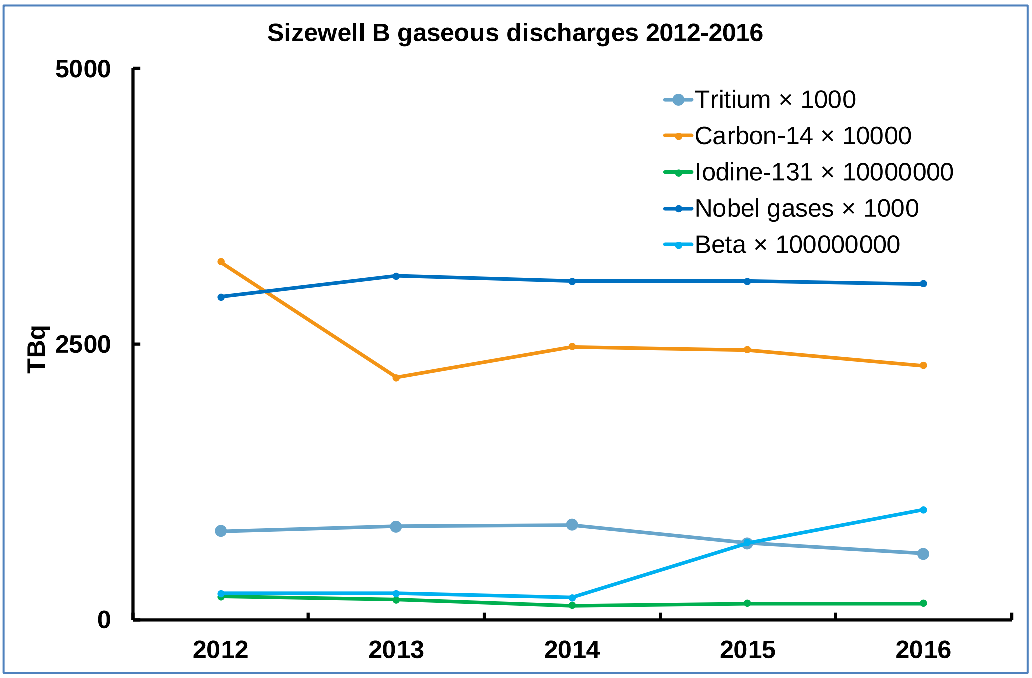

Figure 5.16 Gaseous discharges, Sizewell B (2012-2016)

Wylfa: Liquid discharges of tritium have varied from year to year (by very small amounts) depending on the number of disposals of gas drier liquors. No disposals of the gas drier liquors occurred in 2016 due to on-going maintenance of the plant. Discharges of 'other radionuclides' were generally similar each year over the reporting period. Gaseous discharges of permitted radionuclides have declined over the reporting period due to the permanent closure of Reactor 2 in 2012 and Reactor 1 in 2015.

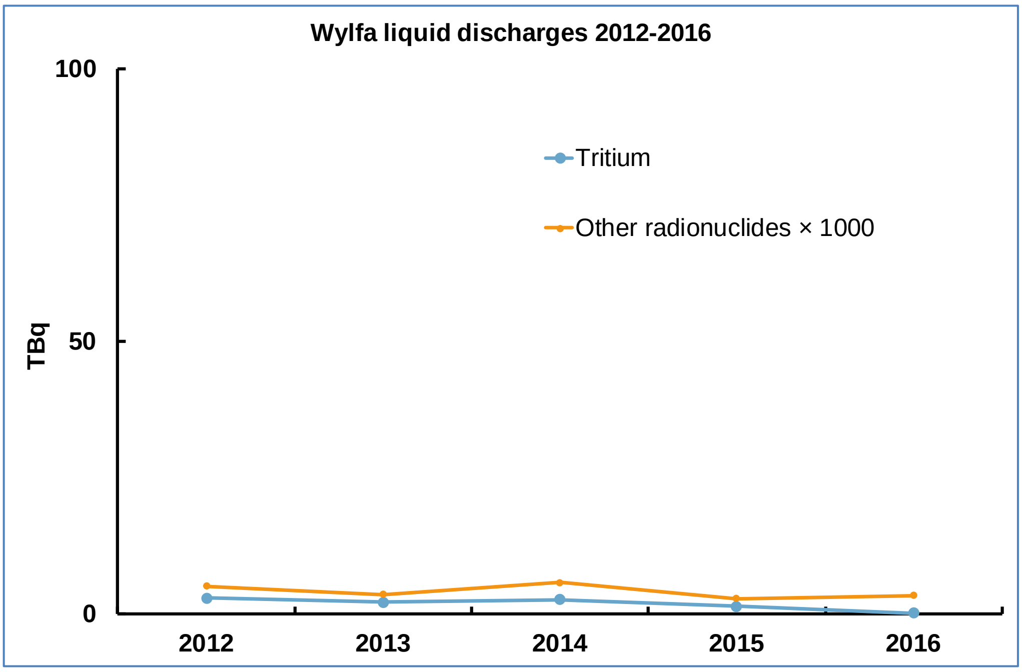

Figure 5.17 Liquid discharges, Wylfa (2012-2016)

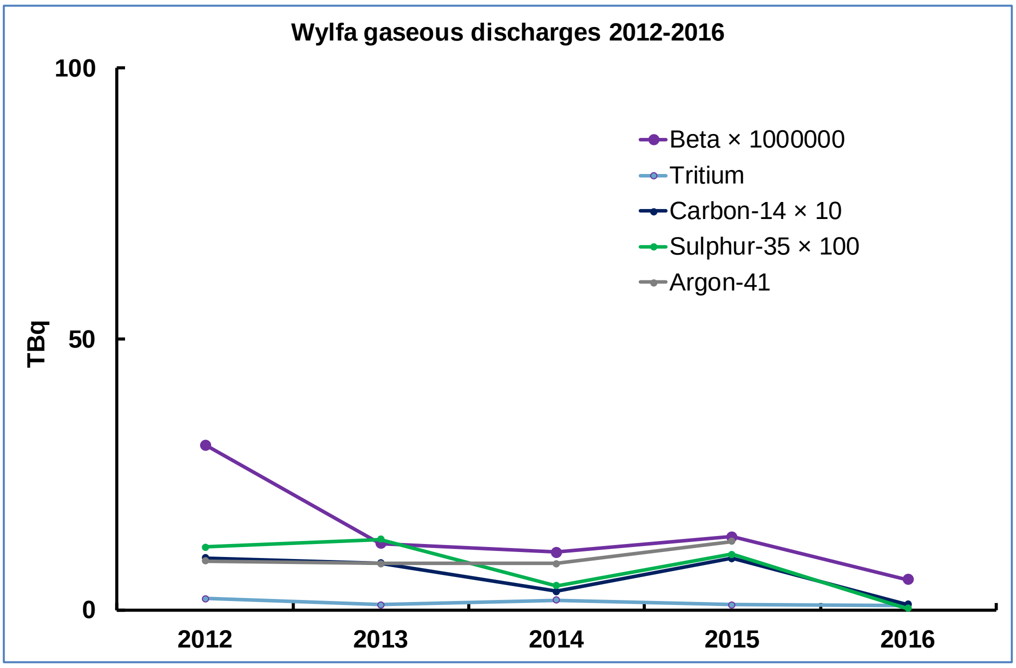

Figure 5.18 Gaseous discharges, Wylfa (2012-2016)

5.2.8 Radiological impact of gaseous and liquid discharges for Magnox, AGRs and PWR

In this report, the radiological impact of gaseous and liquid discharges has been considered and assessed over the period 2004-2016. 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 7.1).
- Time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 7.2).
- Time trends of exposure to the public, to the most exposed groups (Part 2, Section 10.1).
- Time trends of radionuclide concentrations in food and the environment (Part 2, Section 10.3).
- A summary of trend data for power generation sector (2004-2016) (Part 2, Section 10.5).

5.2.9 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.

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 5.2.

Table 5.2 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 absorption 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:

- Dry-bottle storage for 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. This is especially relevant for failed fuel, where the BAT assessment suggests retention of the fuel in the buffer store for several months or years to allow for decay.
- 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.
- 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 practicable, although measures to further reduce discharges are continuously reviewed and remain under consideration.

The Alternative Failed Fuel Project has trialled the use of unbottled, targeted and selective processing of failed fuel stringers through the ponds at AGR sites. Generally, this has successfully reduced the amount of failed fuel across the fleet without a noticeable increase in radioactivity discharged to the environment.

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. 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. Robust fuel is being introduced into reactors through their normal refuelling programme; it may take up to 14 years for reactor inventories to be completely replaced. Although the introduction of robust fuel may result in a small increase in discharges, it is unlikely that such increase will be detectable over the usual variability and will be less than that released by over-heated fuel.

Both approaches have undergone assessments to demonstrate that the consequent discharges are consistent with BAT.

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 recently been improved to reduce the amount of ILW generated.

Sizewell B was constructed with two 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 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.

As described earlier, secondary neutron sources used to provide essential 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 has been decided to remove them completely to eliminate that source of tritium from discharges.

5.2.10 The application of BAT for Magnox

A number of management processes and controls are utilised to help achieve BAT. Further information for Magnox sites (in general) is provided in Section 4.3.5).

The abatement technologies used at Wylfa power stations are given in Table 5.3. The efficiencies of each abatement technique depend on the specific use and characteristics of the waste streams at the stations and therefore any figures given are only approximate. For example, the radial media filter used at Wylfa, with a 10 µm filter is 97.7 per cent efficient. This filter is also 90 per cent efficient at removing particles of 5 µm.

At Wylfa, the liquid effluent from the gas dryer system was continuously collected until reactor shutdown. The container was filled and stored for six months prior to discharge to allow the radioactive decay of sulphur-35. Focusing on water usage has also led to improvements in leak management, which has reduced volumes entering the active aqueous effluent streams

Table 5.3 Operational Magnox Station Abatement Techniques (Wylfa)

Liquid Abatement	Gaseous Abatement
Delay tanks Radial media filter (particulate removal system)	Charcoal iodine absorbers (emergency only) and sintered metal filters on blowdown stack and High Efficiency Particulate Air filters on contaminated ventilation systems. Main reactor pressure vessel ventilation is discharged via High Efficiency Particulate Air filters rather than sintered metal filters since respective reactor shutdowns. Improved control of post-outage reactor gas pressure cycling and changes to condensate polishing plant resin and system to reduce boiler leaks. (Though outages ceased in 2015 after the permanent shutdown of Reactor 1).

Magnox Limited is committed to maintaining BAT in order to minimise discharges and emissions from its sites.

5.2.11 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 5.4 shows the estimated normalized discharges from global PWRs for 2010, taken from the most recent UNSCEAR report (UNSCEAR, 2017), compared with the normalised discharges from the Sizewell B power station, averaged between 2010-2016.

Table 5.4: Estimated normalized discharges from Global PWRs (in 2010) and Sizewell B (2010-2016)

	Normalized discharges (TBq/GWh)						
	Gaseous					Liquid	
	Nobel gases	Tritium	^{131}I	^{14}C	Particulates	Tritium	Other
Global PWRs (2010)*	6.62×10^{-4}	1.71×10^{-4}	9.13×10^{-9}	9.47×10^{-6}	4.11×10^{-9}	2.05×10^{-3}	4.33×10^{-7}
Sizewell B (2010-2016)**	3.71×10^{-4}	9.43×10^{-5}	2.49×10^{-9}	2.91×10^{-5}	6.18×10^{-10}	4.40×10^{-3}	1.55×10^{-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 two normalised discharges shows many of the Sizewell B values are below the average 2010 global normalised PWR values. Values for some Sizewell B discharges (gaseous carbon-14 and liquid discharges are higher, but are generally comparable to the average global values.

5.3 Decommissioning power stations[13]

All Magnox power stations, apart from Wylfa, are defuelled and are at different stages of decommissioning. Defuelling and decommissioning strategies for Magnox stations and other UK civil nuclear facilities are the responsibility of the NDA. The Magnox defuelling programme, relevant for the reporting period, is described in the Magnox Operating Programme (MOP9 issued in July 2012)[14].

Current reactor decommissioning plans are based on the following phases:

- Defuelling: Provided that reprocessing capacity is available at Sellafield, sites will be defuelled as soon as practicable after cessation of electricity generation. Where reprocessing capacity is constrained, then fuel will remain in reactors until reprocessing capacity is available. This will minimise the time that fuel is stored wet, in order to reduce consequent discharges from the fuel cooling ponds.
- Care and Maintenance (C&M) preparations: The majority of facilities and buildings except the reactor buildings will be decontaminated and demolished.

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

[14] This document is available on the NDA website at https://www.gov.uk/government/publications/magnox-operating-programme-mop-9 Magnox Operating Programme (MOP) 9 - GOV.UK The key change introduced by MOP 9 is the use of a performance range approach rather than a single delivery schedule to take account of uncertainties associated with Magnox reprocessing.

The reactor buildings will be put into "Safestore[15]", i.e. 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 (e.g. 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 the Defuelling and decommissioning processes. This will be due to the associated processing of radioactive waste.

The current status of the defuelling and decommissioning power stations discussed in this section is summarised in Table 5.6.

Table 5.6 Status of Decommissioning Sites

Site	Defuelling status	Defuelling/ decommissioning status
Berkeley	Defuelled	Berkeley reactors 1 and 2 have now achieved Safestore status. The remaining 3 of the original 8 boilers (312 te each) were sent to Sweden for recycling. The Caesium Removal Plant was put into a quiescent state. ILW store is operational and ILW retrieval and packaging is underway. The remaining buildings on site await remediation / demolition.
Bradwell	Defuelled	LLW and ILW retrieval treatment and processing has progressed, including dissolution of Fuel Element Debris (FED), which is now complete. Various dismantling and decommissioning projects including demolition of buildings and structures have progressed. Where possible, use of rubble as infill material in voids was optimised. Ponds have been drained, decontaminated and sealed. The ILW store is operational.

[15] 'Safestore' is a component of the preferred strategy for the decommissioning of UK Magnox and AGR. It refers to the period following defuelling 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.

Chapelcross	Defuelled	All reactors were defuelled by early 2013, removing 99 per cent of the radiological hazard from the site. Activities since the completion of defuelling have been focussed around the dismantling of the reactor circuit, preparations for retrieval, packaging and conditioning of radioactive wastes and gaining planning permission for the construction of an interim storage facility for ILW.
Dungeness A	Defuelled	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	Defuelled	The site was defuelled 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 two fuel cooling ponds was completed in 2016. Works are on-going for the retrieval, processing and storage of ILW.
Hunterston A	Defuelled	Hunterston A is undergoing decommissioning, having been defuelled prior to 2005. Activities are on-going for the retrieval, processing and storage of ILW wastes. The Fuel cooling pond is partially decontaminated and drained with draining of the pond expected to be complete during 2018. The ILW store is operational.
Oldbury	Defuelled	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	Defuelled	Defuelling was completed in 2014. Post Operational Clean-Out activities have been underway.
Trawsfynydd	Defuelled	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 FED 3 m^3 boxes; 23 x 3 m^3 sludge drums and approximately 1500 m^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.

[#]No underpinned disposal route or agreed transfer established.

5.3.1 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 sources for defuelling and decommissioning sites are:

- Spent fuel ponds management (where irradiated fuel is stored under water before being despatched for reprocessing).
- Reactor defuelling and decommissioning operations.
- Laundry operations.
- ILW and LLW waste management.

During defuelling, 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 defuelling and decommissioning activities were considered as part of a BAT (or BPM) study and minimised accordingly.

5.3.2 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) 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[16] 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

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

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 (e.g. 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 10 µm), often used in conjunction with coarse filters (15 µm), 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 is normally installed, 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 (e.g. 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 sites (e.g. Hunterston A) to abate radioactive liquid arisings during 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 (e.g. 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.

5.3.3 Trends in discharges over the 2012-2016 period

The variation in discharges is primarily associated with the phasing, nature and scale of operations and decommissioning projects. In this Section, Figures 5.19-5.36 illustrate the variations in discharges over the reporting period (2012-2016) for each site. Figures 10.3 and 10.5 (in Part 2, Section 10) also show time trends of discharges over a longer period (2004-2016).

Berkeley: For liquid discharges, the site’s active effluent tritium arisings increased in 2012 due to the removal of supernate from the Caesium Removal Plant. The slight increase in tritium, caesium-137, and other radionuclides in 2014 was attributed to a range of decommissioning work (including the Caesium Removal Plant sludge and resin drying). There has not been a significant increase in the effluent arisings since 2014 despite the conditioning of ILW waste, and discharges remain very low.

Gaseous discharges of tritium and carbon-14 (from the Safestores 1 & 2) appear to have increased over the reporting period (since October 2010), but are still low. The apparent increase is attributed to the method of reporting, that is now made on estimated discharges. The use of Mobile Extraction Units (for other plant areas) has been increased when the plant ventilation system cannot be used during decommissioning. With the ability to filtrate particulate discharges at less than 99.99 per cent efficiency, this is unlikely to significantly increase with operations at Berkeley.

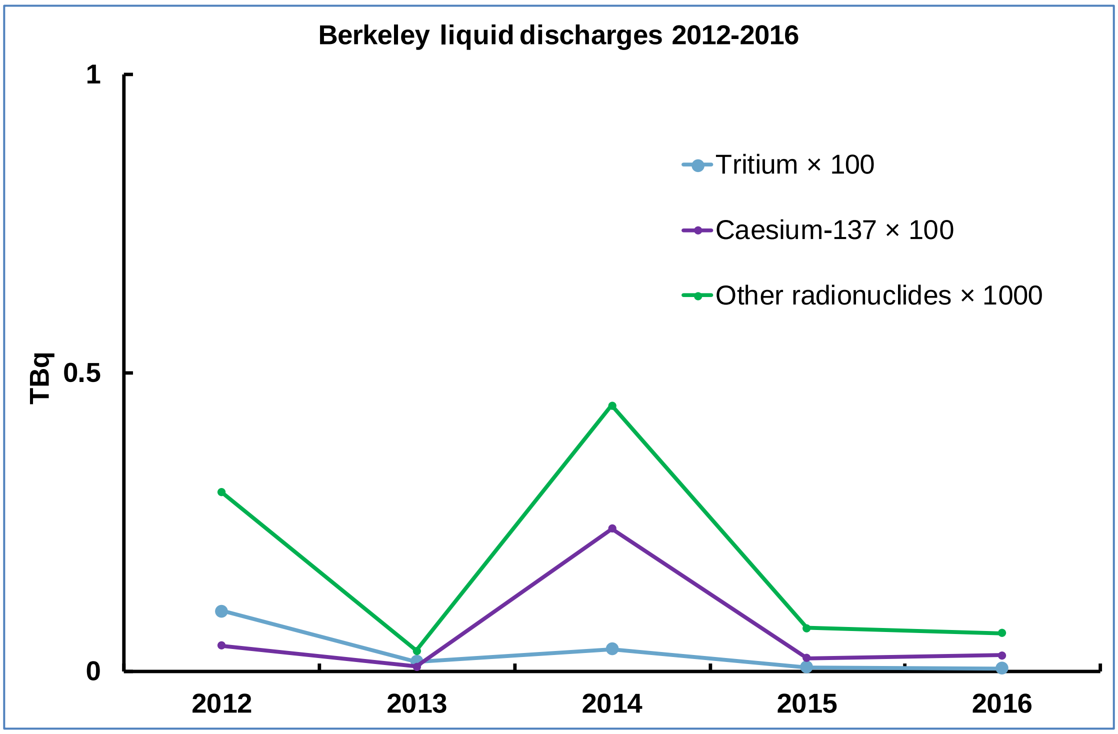

Figure 5.19 Liquid discharges, Berkeley (2012-2016)

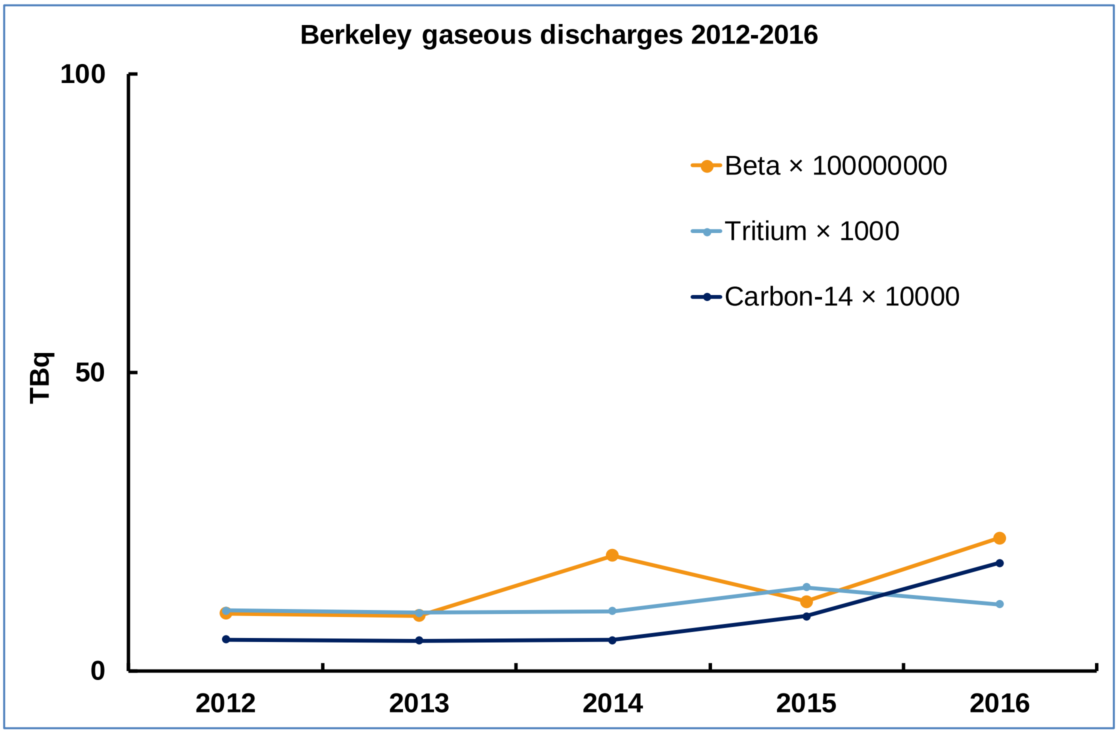

Figure 5.20 Gaseous discharges, Berkeley (2012-2016)

***Bradwell**:* During the reporting period, work has increased to prepare the site for the C&M phase of its lifecycle. It is intended to leave all systems and ILW in a passively safe state to minimise the need for personnel to attend site for maintenance and monitoring activities. As part of this work retrieval and treatment of ILW has been undertaken. These passively safe packages will be stored on site until a central repository is available.

The BAT case for treatment of ILW Fuel Element Debris (FED) was to dissolve the metal in nitric acid (to remove most of the heavy metals and radioactivity) prior to treatment of the resultant aqueous effluent and then discharging the treated effluent via the permitted discharge route. Levels of radioactivity were minimised through the use of abatement techniques such as precipitation, filtration and ion exchange treatment. Therefore, the increase in liquid discharges over time was expected, as the ILW was processed in the most recent years of the reporting period.

In addition to the liquid discharges, the FED dissolution process also resulted in increased gaseous tritium and carbon-14 releases. FED dissolution was completed in June 2017. Other ILW has been treated and conditioned into packages using vacuum drying systems which has also resulted in increased gaseous tritium discharges.

Discharges are expected to drop in 2017 as decommissioning projects are completed, and then remain at minimal levels through the C&M period.

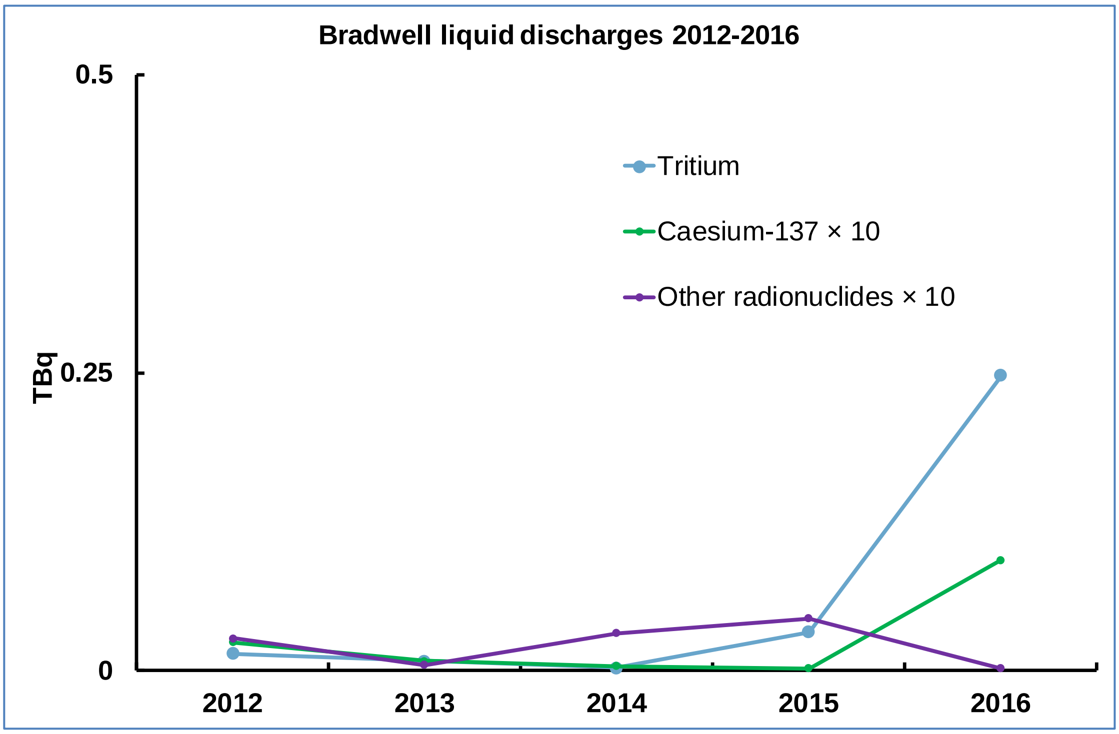

Figure 5.21 Liquid discharges, Bradwell (2012-2016)

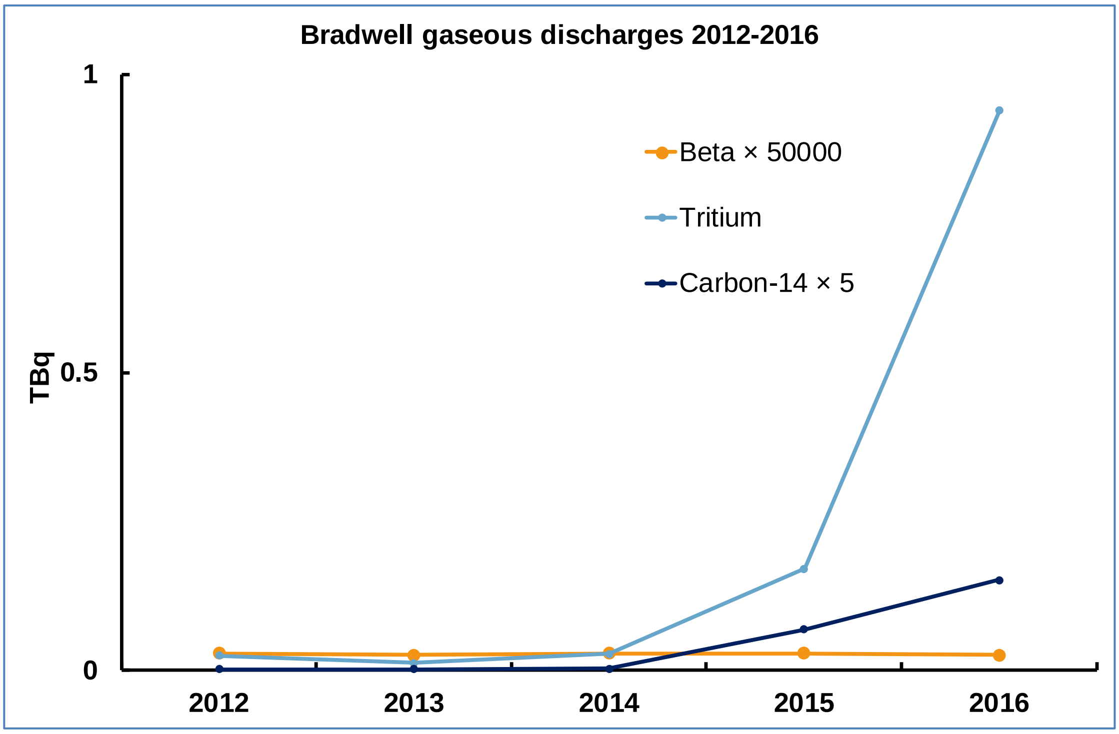

Figure 5.22 Gaseous discharges, Bradwell (2012-2016)

Chapelcross*:* Following the completion of defuelling, liquid discharges, over the reporting period, have decreased in both total activity in the discharges and also in the frequency. 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 2016.

Gaseous discharges of tritium have showed a decline in releases over the reporting period. Carbon-14 discharges (included in “all other nuclides”) from the reactor vessels have increased, by small amounts, due to a change from a dry air environment to natural ventilation.

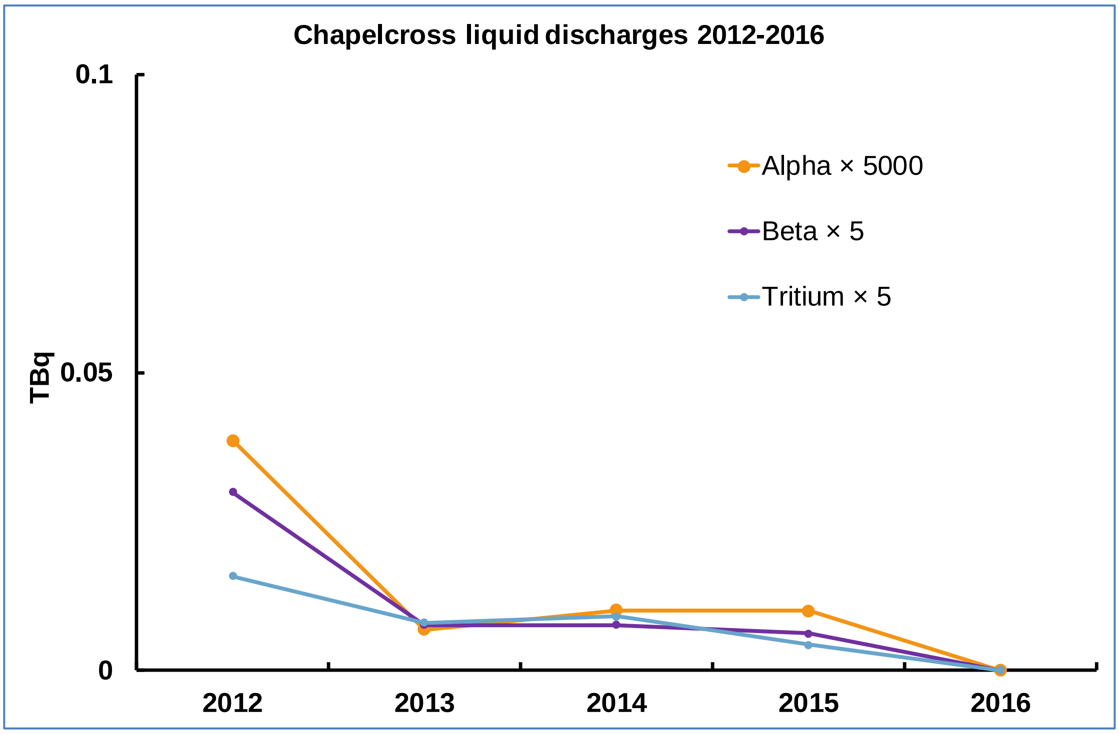

Figure 5.23 Liquid discharges, Chapelcross (2012-2016)

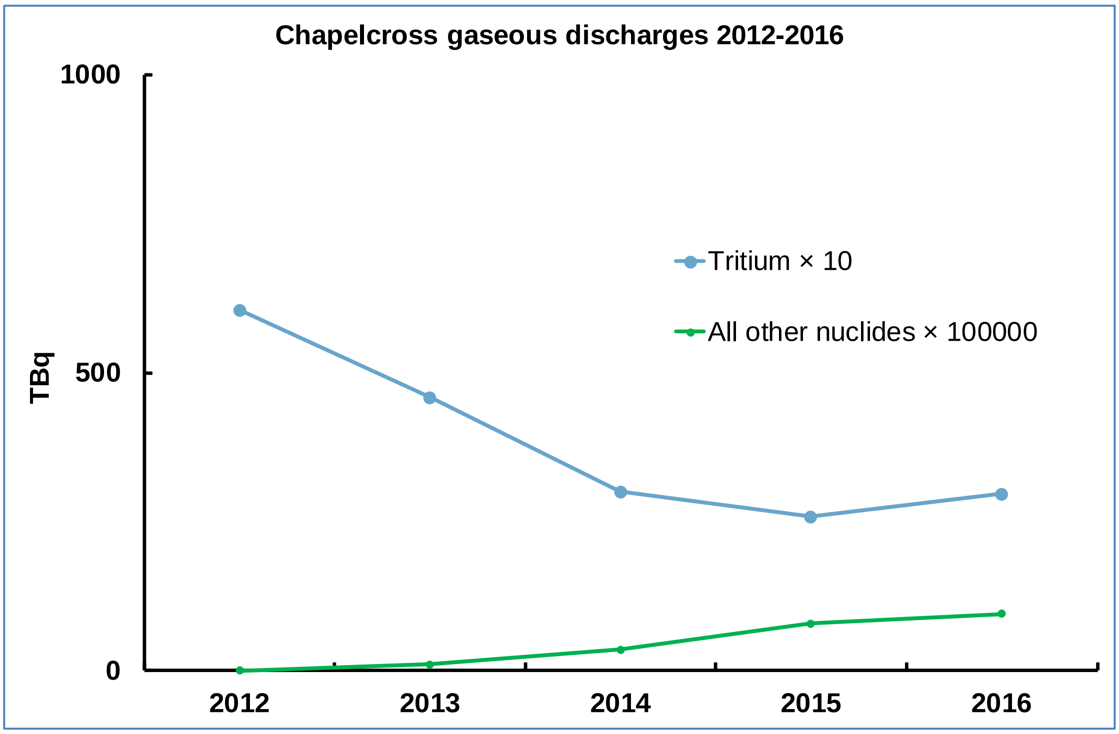

Figure 5.24 Gaseous discharges, Chapelcross (2012-2016)

***Dungeness A**:* Since defuelling activities were completed in 2012, liquid tritium discharges have decreased and caesium-137 and other radionuclides were generally similar over the reporting period. However, a small increase in caesium-137 discharges occurred in 2014 and 2015 due to the processing of FED from the Bradwell site. This was processed through the site's Magnox Dissolution Plant and operations have now been completed.

Gaseous discharges have generally declined overall by the end of the reporting period, the largest reduction being tritium.

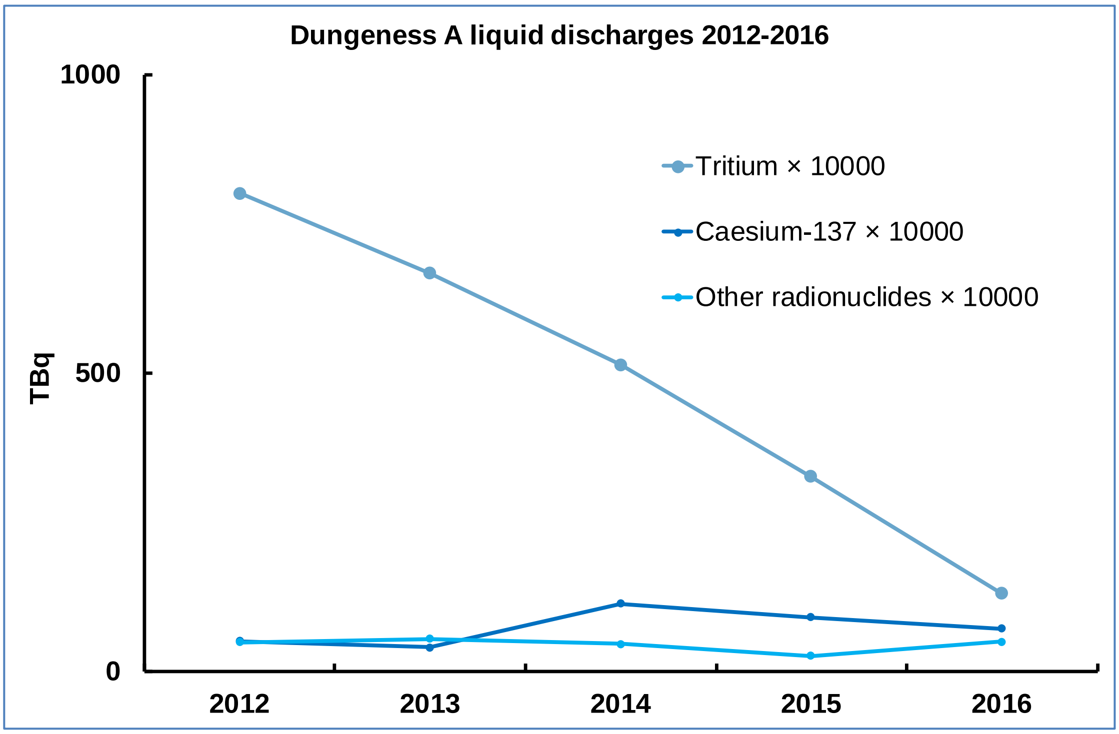

Figure 5.25 Liquid discharges, Dungeness A (2012-2016)

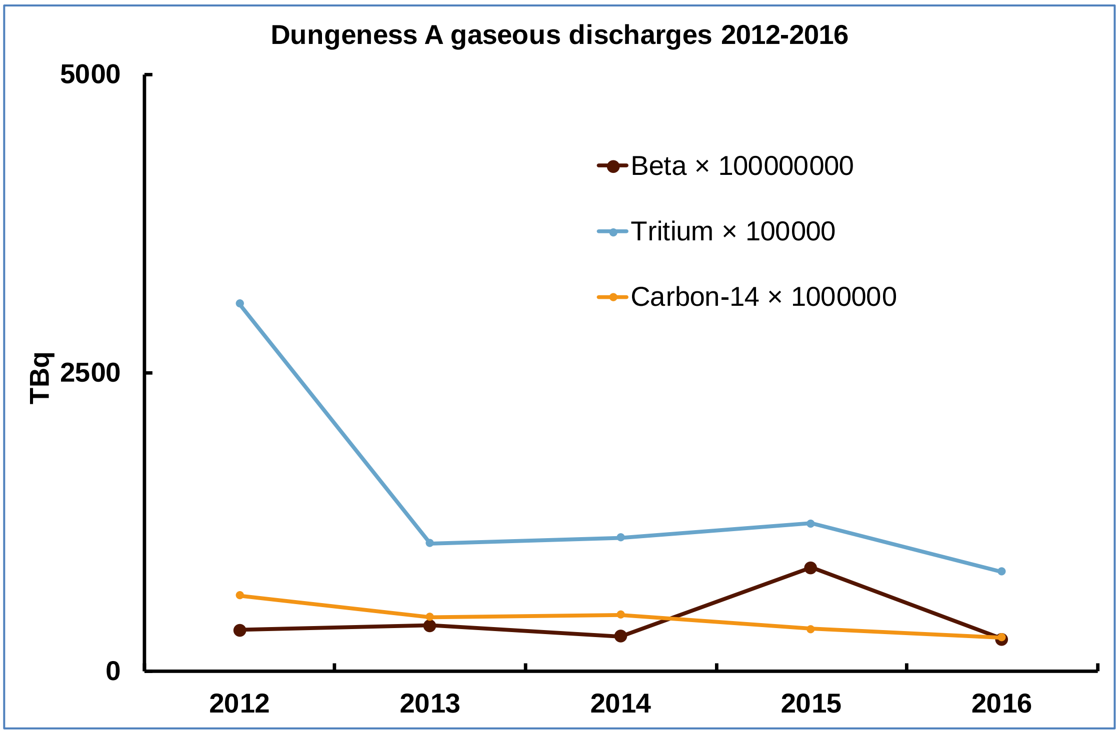

Figure 5.26 Gaseous discharges, Dungeness A (2012-2016)

Hinkley Point A: In 2013, Hinkley Point A commenced the draining and cleaning of the fuel pond of Reactor 1, this led to increased discharges from the site. Overall, liquid discharges of tritium and caesium-137 have continued to decrease during the reporting period and the lowest releases were in 2016. This is a consequence of the completion of removal of fuel fragments and waste items from the fuel cooling ponds. The discharge of other radionuclides has fluctuated over the period depending on activities related to decommissioning of the former fuel cooling ponds.

Gaseous discharges of tritium and carbon-14 have also declined during the reporting period and the lowest releases were in 2016. Discharges of beta particulate activity were generally similar from year to year and are significantly lower than the annual limits.

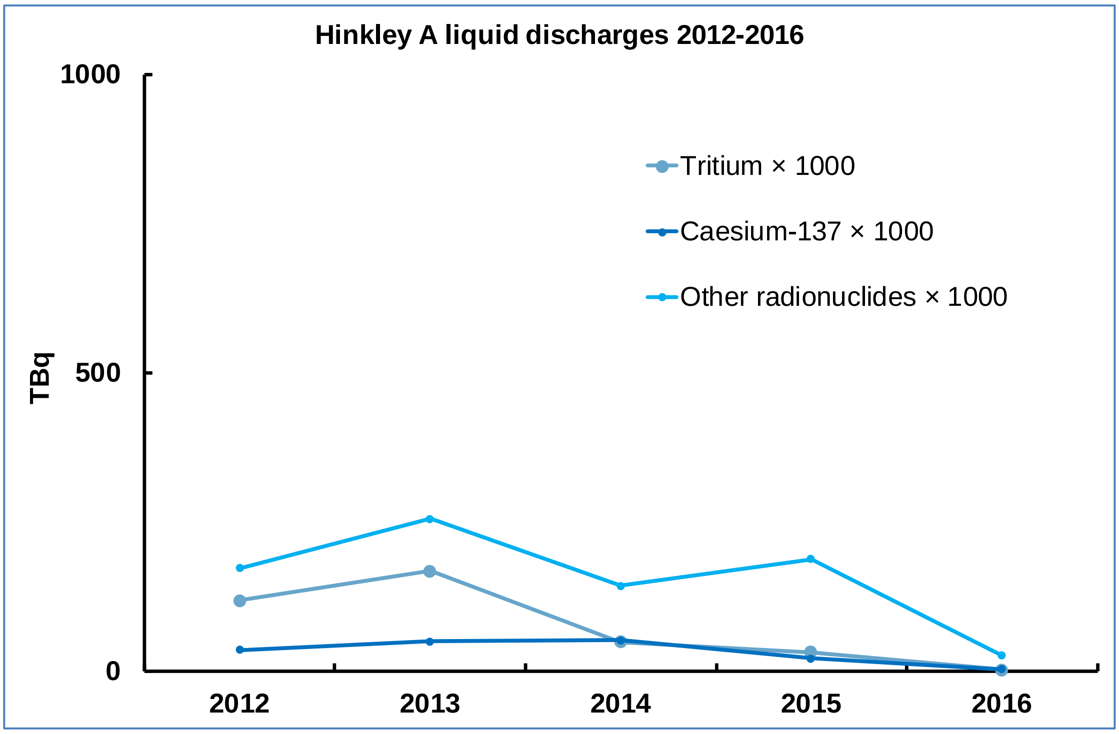

Figure 5.27 Liquid discharges, Hinkley Point A (2012-2016)

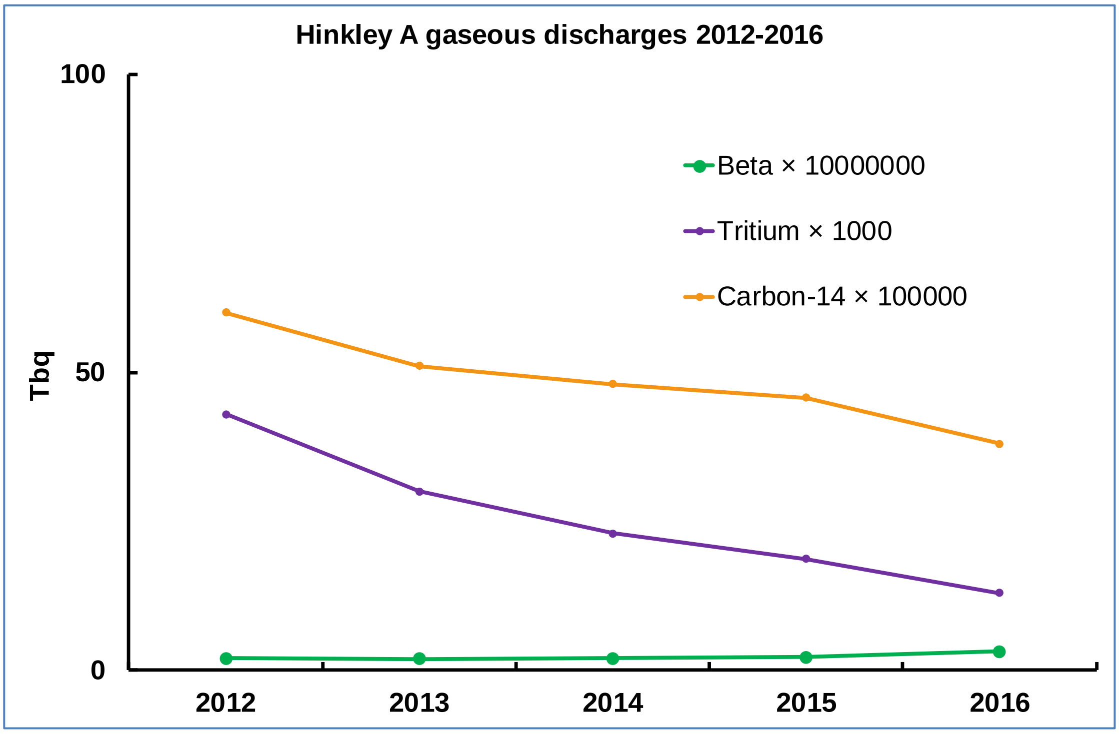

Figure 5.28 Gaseous discharges, Hinkley Point A (2012-2016)

Hunterston A: Liquid discharges generally increased (excluding tritium), by small amounts, over the reporting period, due to the continuation of draining of the Cartridge Cooling Ponds. With the introduction of the new site multimedia authorisation in July 2014, total beta activity was replaced by reporting of caesium-137 and “Non-Alpha” activity separately. Non-Alpha activity is predominantly made up of Sr-90, and Pu-241 activity, both of which are found in higher concentrations in ponds sludge and encountered towards the end of dewatering.

Gaseous discharges were generally similar over the reporting period, as decommissioning continued, with the stabilisation of the reactor atmosphere.

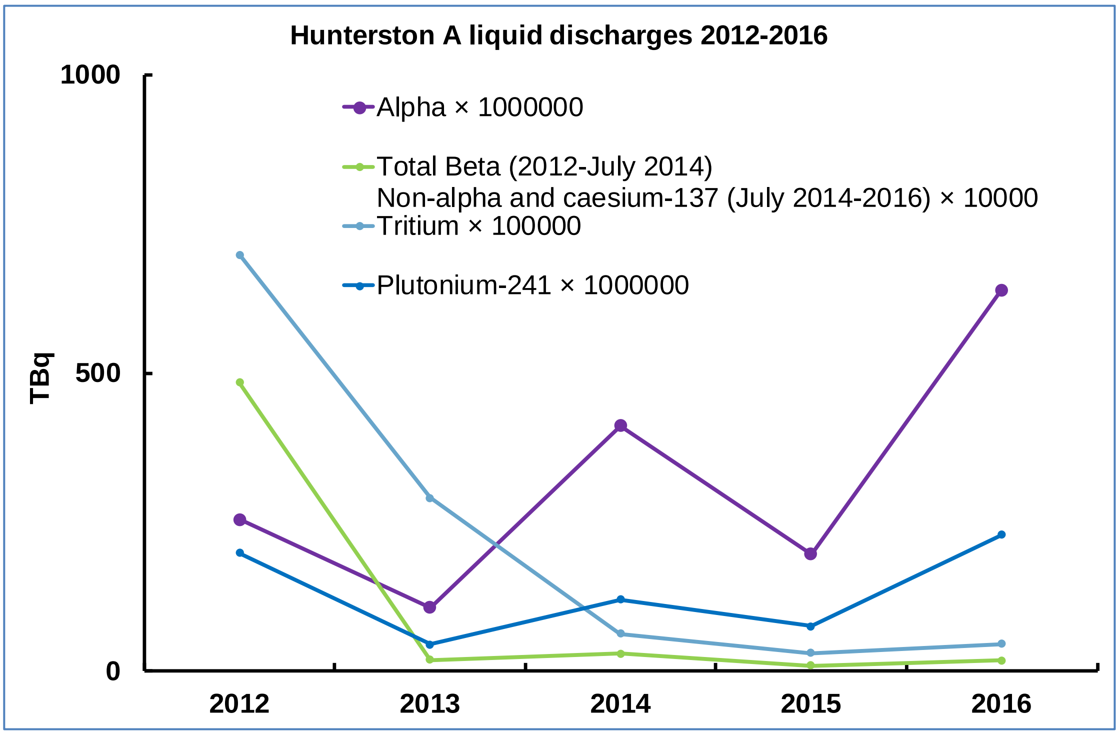

Figure 5.29 Liquid discharges, Hunterston A (2012-2016)

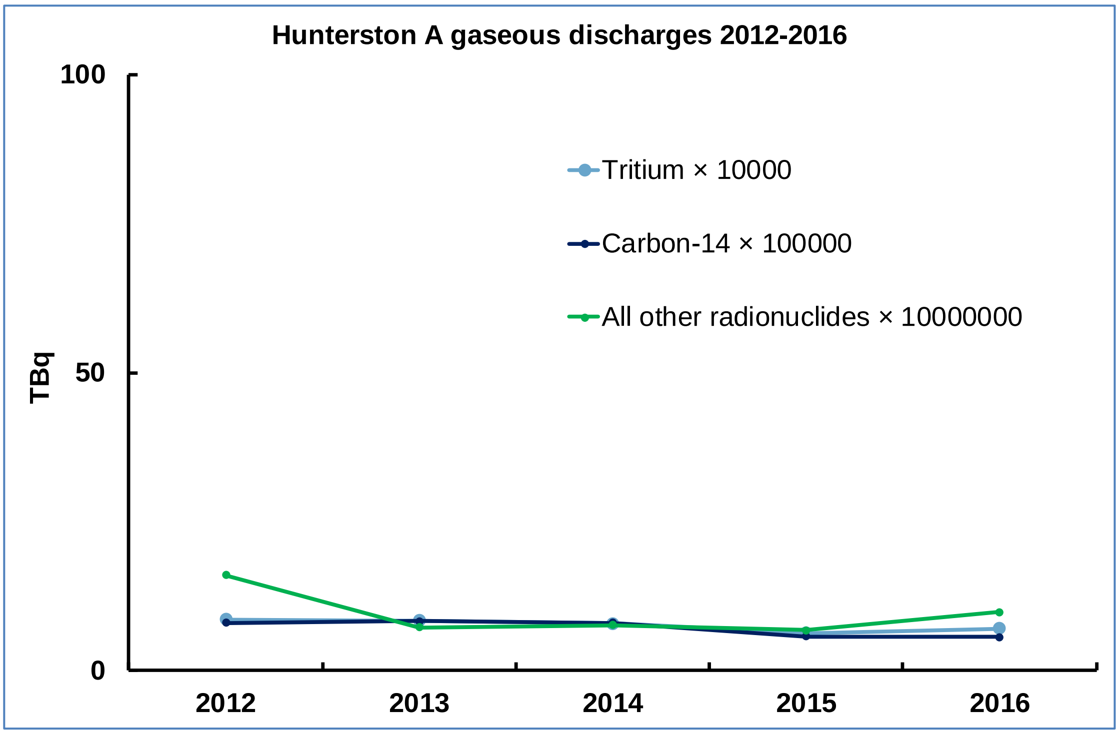

Figure 5.30 Gaseous discharges, Hunterston A (2012-2016)

Oldbury**:** The major source of liquid alpha and beta discharges was from the storage of spent fuel elements being stored in the cooling ponds, prior to being sent to Sellafield for interim storage and reprocessing. Considerable efforts were made to minimise the release of activity from the spent fuel into the pond water by controlling the pond storage conditions. Oldbury achieved fuel-free status early in 2016.

At the Oldbury site, corrosion of the Magnox fuel cladding was minimised through careful pond management, the main features being:

- Maintaining pond water alkalinity at pH >11.5, to encourage formation of a stable protective film on the Magnox surface.
- Maintaining very low anion concentrations using ion exchange plant.
- Removal, through high-rate pond water filtration, of particulate (which, if allowed to accumulate on the Magnox fuel cladding surface, could accelerate corrosion).
- Maintaining pond temperature (i.e. removal of decay heat from spent fuel, by use of pond water cooling plant) thus minimising the temperature-dependent rate of Magnox corrosion.
- Carrying out an intensive monitoring and cleaning programme on Fuel Flasks before they were placed into the pond and filled with spent fuel to prevent any cross-contamination.
- Use of fuel storage skips that do not show significant paint damage (reducing the possibility of galvanic corrosion of the Magnox cladding), and removal of lugs and spacers from fuel pins (desplittering) immediately before being

despatched for reprocessing to minimise the possibility of fission products leakage from mechanically damaged fuel in the ponds.

Owing to the storage of spent reactor fuel in the cooling ponds over the reporting period, permitted liquid discharges of tritium and caesium-137 have generally increased, by small amounts, over the reporting period. Ventilation air from the ponds facility at Oldbury is directed via the adjacent Pond Ventilation Plant, which provides High Efficiency Particulate Air filtration of the supply extract air. Gaseous discharges have continued to decrease during the reporting period and the lowest releases were in 2016.

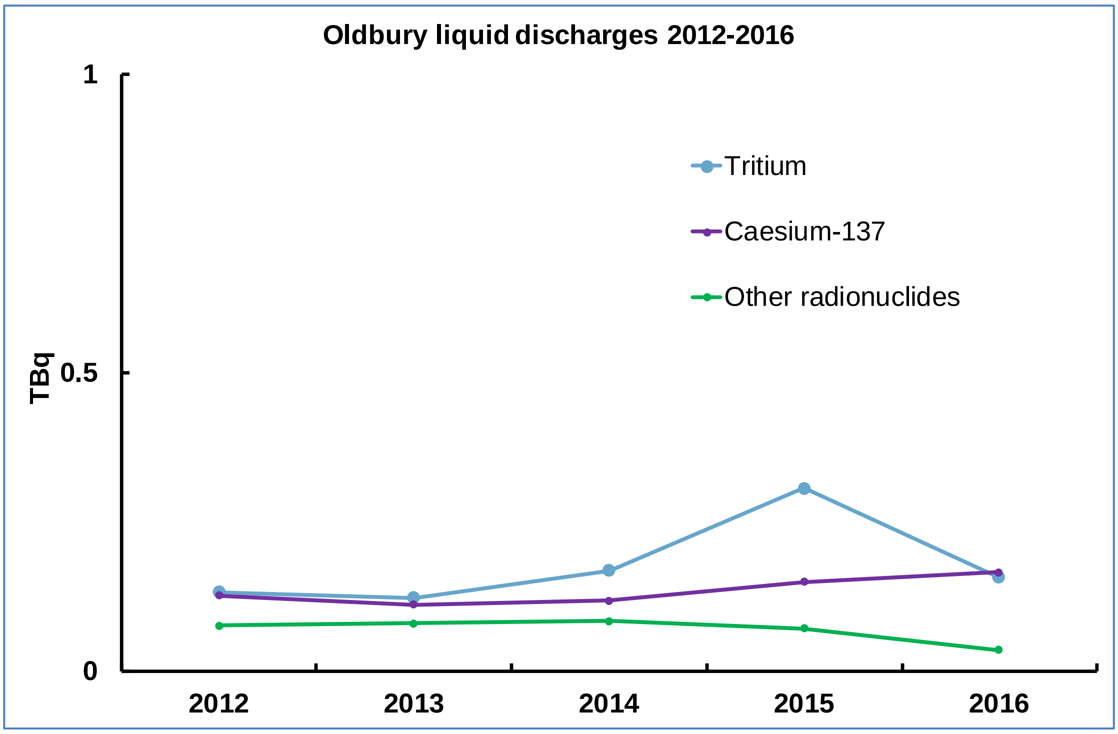

Figure 5.31 Liquid discharges, Oldbury (2012-2016)

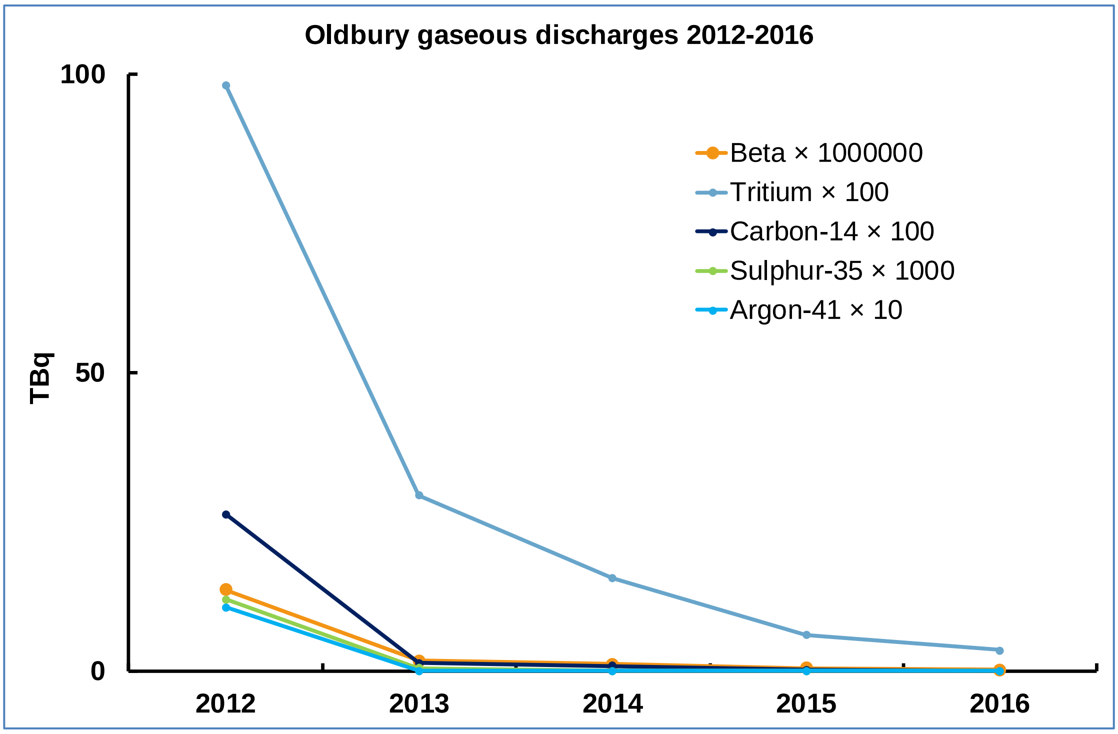

Figure 5.32 Gaseous discharges, Oldbury (2012-2016)

Sizewell A: Liquid discharges of tritium and caesium-137 have generally declined over the reporting period, due to a reduction in the discharge frequency, resulting from the optimisation of effluent treatment plant operations. A small increase in caesium-137 occurred in 2014 due to fuel free verification works. Discharges of other radionuclides were generally similar from year to year, with a small decrease in 2015 and a small increase in 2016 (associated with the lowering of ponds water pH to develop more efficient operation and management of the treatment plant following the end of defuelling).

Gaseous discharges of tritium and caesium-137 have reduced significantly over the reporting period from the effective management of the reactor dry air system, leading up to the end of fuel storage at the site. The dry air system was no longer required and was withdrawn from use resulting in a small increase in tritium discharges in 2016, from the natural exchange of gaseous species (as the reactors equilibrate with atmospheric conditions). The beta particulate discharge monitoring ceased in 2012 as the site demonstrated that discharges had essentially ceased. Therefore, data are not available for this reporting period.

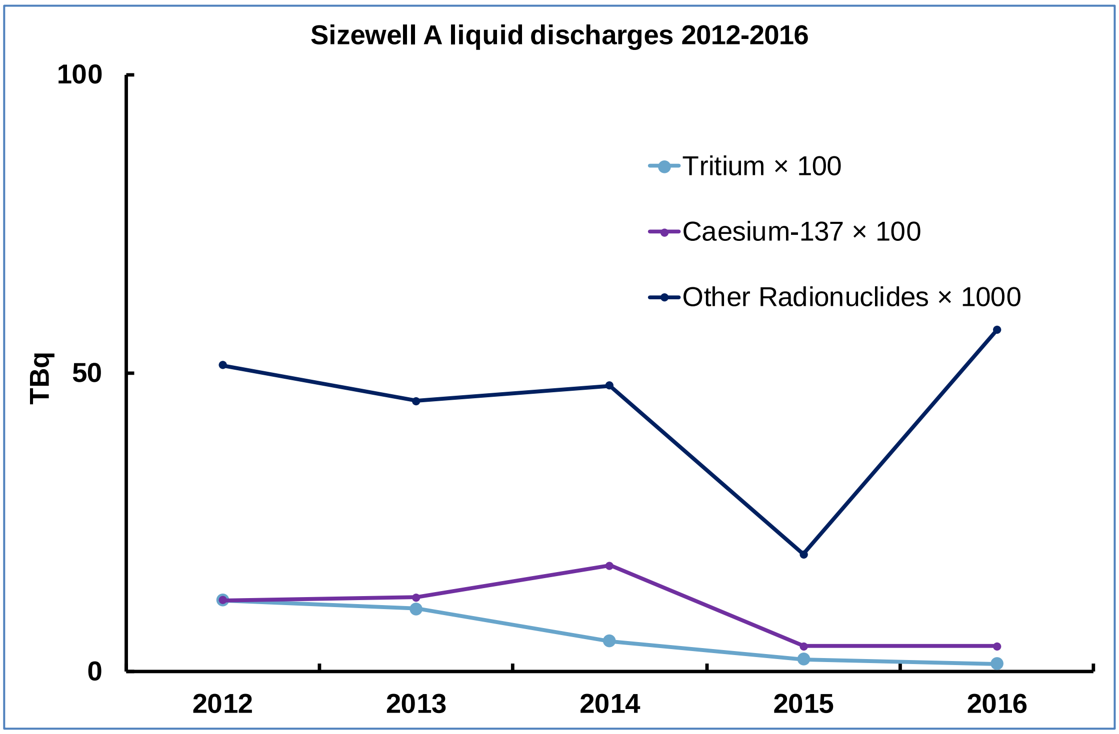

Figure 5.33 Liquid discharges, Sizewell A (2012-2016)

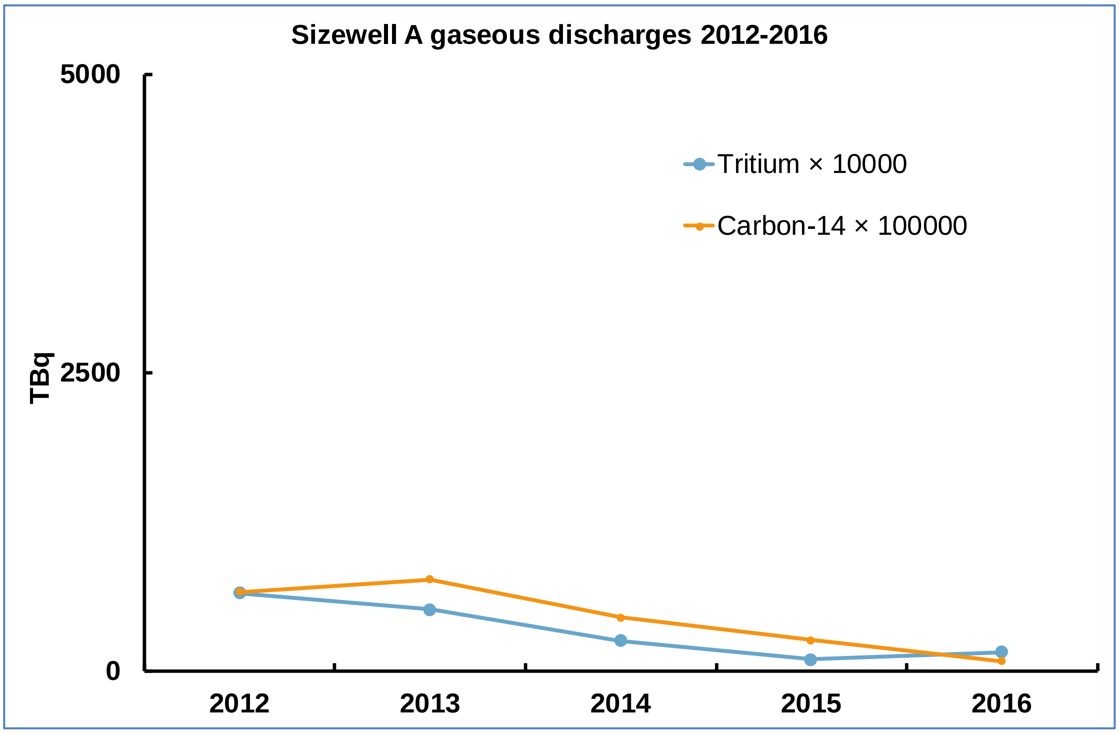

Figure 5.34 Gaseous discharges, Sizewell A (2012-2016)

***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 generally declined (caesium-137) or were generally similar over the reporting period. On-going decommissioning works on the site have had a minimal impact on liquid effluent discharges. Gaseous discharges were generally constant over the reporting period.

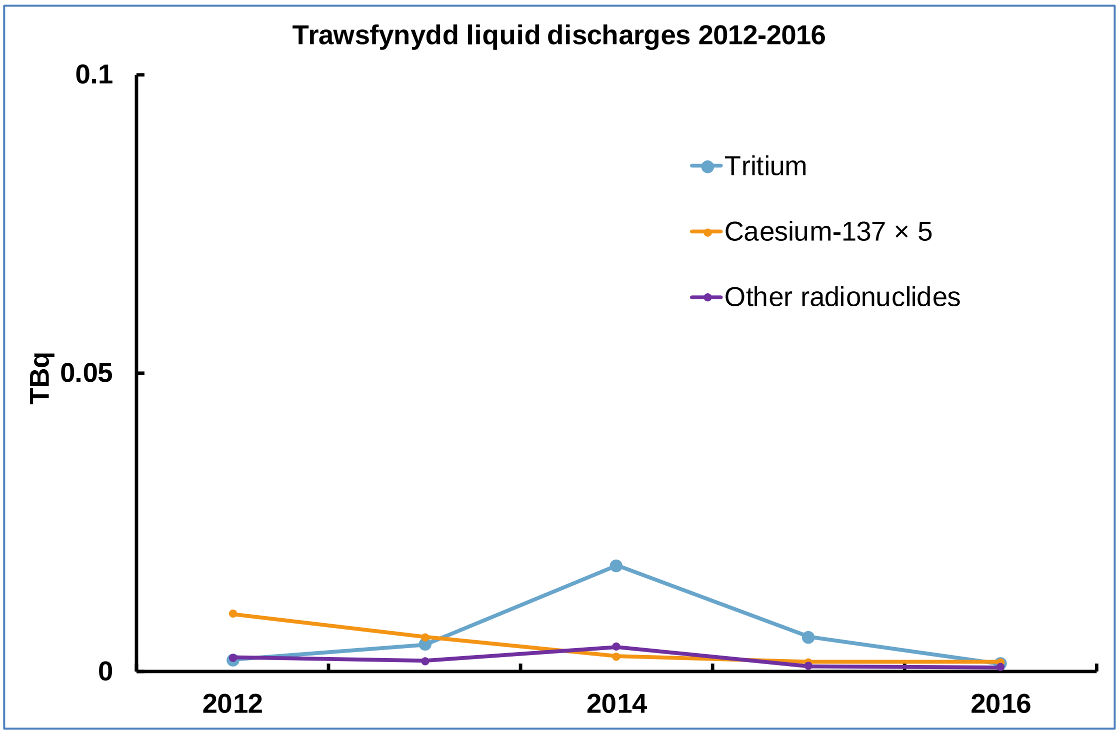

Figure 5.35 Liquid discharges, Trawsfynydd (2012-2016)

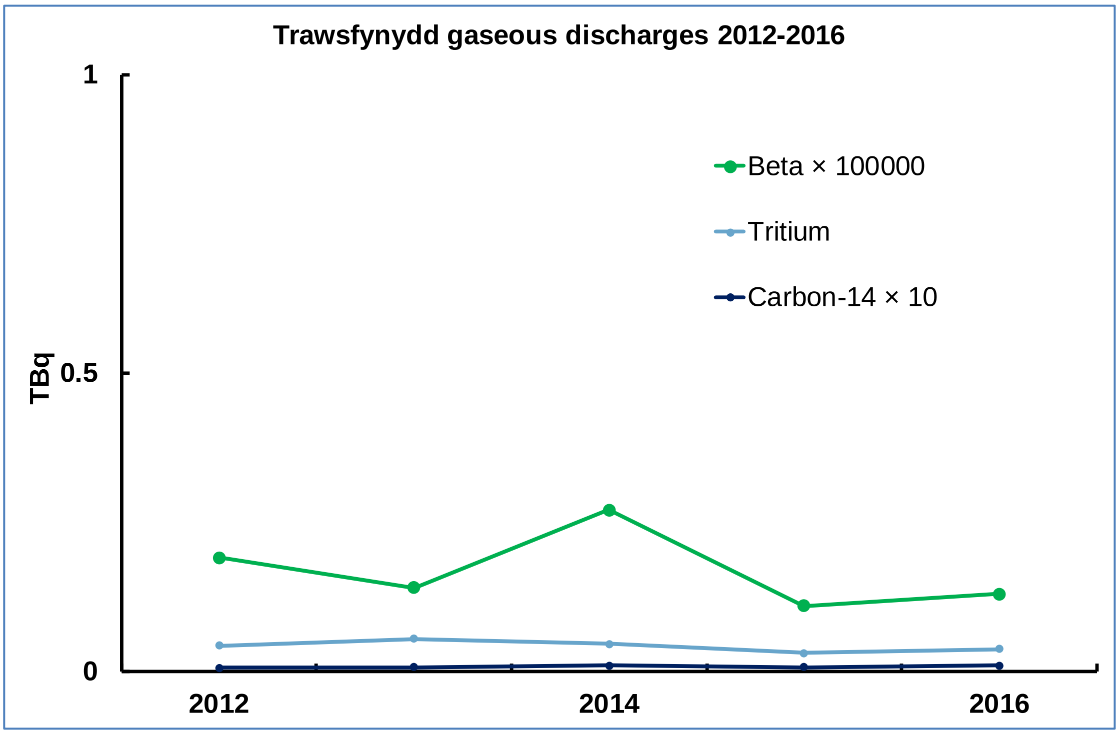

Figure 5.36 Gaseous discharges, Trawsfynydd (2012-2016)

5.3.4 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 2004-2016. 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 7.1).
- Time trends of Key Marine Environmental Indicators (KMEIs) (Part 2, Section 7.2).
- Time trends of exposure to the public, to the most exposed groups (Part 2, Section 10.1).
- Time trends of radionuclide concentrations in food and the environment (Part 2, Section 10.3, 10.4).
- A summary of trend data for power generation sector (2004-2016) (Part 2, Section 10.5).

5.3.5 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 4.3.5 for more information. The abatement techniques commonly applied at decommissioning Magnox stations are summarised in Table 5.7.

Table 5.7 Defuelling and Decommissioning Magnox Stations: Abatement Techniques

Station	Liquid Abatement	Gaseous Abatement
Berkeley	No abatement as effluent discharges are mainly from hand washings and showers. 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	Microfiltration, ultrafiltration, granular activated charcoal and non-regenerable ion exchange resin for general aqueous effluent. Precipitation, flocculation, microfiltration, granular activated charcoal and non-regenerable ion specific exchange resin for FED effluent.	High Efficiency Particulate Air filtration
Chapelcross	Delay tanks Settling tanks Ion exchange units *The site is managing gaseous discharges at source, e.g. using cold cutting techniques, crimp and cut, wrapping and sealing to minimise gaseous releases of tritium during decommissioning. Ion exchange units in the form of Zeolite skips are in use in the pond to manage soluble caesium-137. The site also uses dry techniques or seeks to recycle and reuse water to minimise the quantity of liquid to waste disposed of.*	High Efficiency Particulate Air filtration
Dungeness A	Delay tanks Fine filters Ion exchange Settling tanks Sand pressure filter Water chemistry management	High Efficiency Particulate Air filtration
Hinkley Point A	Delay tanks Chemical precipitation Sand pressure filters, cross-flow filtration using fine filter units Kurion resin Ion exchange resin to reduce caesium and strontium radionuclides	High Efficiency Particulate Air filtration

Hunterston A	Delay Tank Ultrafiltration Sand pressure filters Ion-exchange Hydrocyclone	High Efficiency Particulate Air filtration
Oldbury	Delay tanks Sand filters Facet filters Ion exchange resin caesium removal units Ponds chemistry management	High Efficiency Particulate Air filtration
Sizewell A	Delay tanks Ion exchange Sand pressure filters Settling tank Ponds chemistry management	High Efficiency Particulate Air filtration
Trawsfynydd	Delay tanks Sand pressure filters Ion exchange units Mobile Active Effluent Treatment Process Hydro-cyclone, followed by a fine filter (5 µm)	High Efficiency Particulate Air filters on contaminated ventilation systems

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

The new Aqueous Discharge Abatement Plant 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. For general aqueous effluent, every batch undergoes treatment via microfiltration, ultrafiltration and granular activated charcoal. It is assessed to determine if it is BAT to treat the effluent via non regenerable ion exchange resins. Following the completion of FED dissolution and a reduction in production of other aqueous waste, a new BAT assessment is being undertaken to determine the optimum route for near term aqueous waste arising at the Bradwell site, through to the early stages of the C&M phase of the site's lifecycle.

Chapelcross

At Chapelcross, pond chemistry control, the use of zeolite skips and settling or filtration are in place to reduce the activity burden in the pond water. Dry decontamination techniques are used to minimise liquid waste arisings. A Modular Active Effluent Treatment Plant for Chapelcross is currently under development and this will be equipped with particulate removal, trace oil removal and abatement for soluble caesium and strontium radioisotopes. The Modular Active Effluent Treatment Plant will be used to treat site effluents and pond water at the time of final drain down (pond water will not be discharged until the Modular Active Effluent Treatment Plant is available), the modules deployed to treat each effluent stream will be subject to BPM assessment.

The processes of natural settlement and filtration are the main means applied to achieve abatement of discharges to the environment. Treated effluent is routed into Final Delay Tanks (FDTs) and Collection Monitoring Tanks (CMTs), to allow sampling and analysis. Active effluent is filtered through sand pressure filters with a filtration capability of 10-20 µm and through fine filters with a filtration capacity of a nominal 5 µm and 10 µm absolute rating. The results are inspected by appointed "Suitably Qualified and Experienced Persons" who will recommend whether further treatment is appropriate before discharge to sea.

Hinkley Point A

Hinkley Point A uses the process of natural settlement and filtration (using sand pressure filters) to achieve abatement of discharges to the environment. Treated effluent is routed in final monitoring delay tanks to allow sampling and analysis before being discharged. 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. This site has also utilised chemical flocculants to protect existing abatement plant and minimise secondary waste generation, where necessary.

Hunterston A

At Hunterston A, radioactive liquid effluent is discharged to sea via the Active Effluent Treatment Facility. The effluent initially undergoes treatment through ion exchange and ultrafiltration in the Modular Active Effluent Treatment Plant. The effluent is retained in receiving tanks before undergoing treatment through ion exchange and filtration in the Modular Active Effluent Treatment Plant. The effluent is then held in delay tanks for re-circulation and sampling to ensure the effluent meets the requirements of the discharge authorisation. A new Active Effluent Treatment Facility was commissioned in 2009 that uses submersible caesium removal units and filtration to reduce caesium activity in the Cartridge Cooling Pond water. The decision to use the Modular Active Effluent Treatment Plant was the result of an extensive BPEO process.

Oldbury

At Oldbury, fuel is no longer stored in the fuel ponds. Pond water is filtered and managed to keep the pond water conditions within standard parameters. All LLW skips have been removed and other items such as LLW IONSIV filters, cartridges and pond furniture are being removed from the ponds in preparation for processing and disposal. Preparations for pond emptying and C&M are in progress. New passive ventilation ducts and sampling equipment is being installed on vessels in 2017. Vessel contaminated ventilation systems and maintenance air driers were shut-down in 2017, saving material, energy and maintenance costs. Pro-active decommissioning clearance processes are used to minimise the generation of LLW. Filter catchpots have been introduced to the site drainage system prior to the Active Effluent Treatment Plant to segregate lower activity liquid sludge before it becomes cross contaminated with higher active liquors.

Sizewell A

At Sizewell A, a review of ponds water chemistry parameters and treatment operations, following the site becoming free of fuel, has identified further opportunities to optimise the management of the ponds water treatment plant. This included gradually lowering the pH of the ponds water to increase plant operating times, reducing ponds dosing (to minimise chemical usage) and optimising water circulation to lessen the burden on key systems. These management changes have had no adverse effects on radioactive discharges, although there was a slight increase in the level of other radionuclides during 2016. The end of defuelling operations has also led to the withdrawal of the dry air system that used to supply conditioned air to the reactors. This has resulted in a reduction in energy resource without detriment to gaseous discharges and will ensure that the reactors can be passively managed in terms of their radioactive emissions throughout C&M.

Trawsfynydd

At Trawsfynydd, Mobile Active Effluent Treatment, including Hydro-cyclone followed by fine filters (5 µm) sand pressure filters, delay tanks and ion exchange units are being used for aqueous discharges.

5.3.6 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 (e.g. 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 (e.g. 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.

6. The development and application of BAT

6.1 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 Section 2. Furthermore, the way in which discharge permits/authorisations are applied and reviewed, along with the supporting arrangements (e.g. 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. 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 6.1).

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 6.1 New or varied permits/authorisations issued by UK regulators (2012-2016)

Year	Site	Main changes
2012	**Capenhurst**	Gaseous Reduction in the limits for uranium, other alpha, technetium-99 and "others".
	Sellafield	Gaseous Reduction in the limits for ruthenium-106 and iodine-131. Inclusion of radon-222 in the permit.
	Sellafield	Liquid Reduction in the limits for strontium-90, ruthenium-106, neptunium-237 and curium-243+244.
	Dounreay	Gaseous Reduction in the limits for krypton-85 at the Fuel Cycle Area and prototype fast reactor.
	Bradwell	Gaseous

		The limits for tritium and carbon-14 were increased for FED work.
2013	**Chapelcross**	<u>Gaseous</u> Removal of sulphur-35 and argon-41 from the authorisation, lowering of the tritium limit and a new category “all other radionuclides” instituted.
	Chapelcross	<u>Liquid</u> Retention of the alpha and tritium, albeit at lower limits. The beta category was replaced by non-alpha.
	Amersham	<u>Gaseous</u> Removal of suphur-35, iodine-125 and noble gases from the permit, all other limits unchanged.
	Amersham	<u>Liquid</u> Removal of iodine-125 and caesium-137 limits from the permit.
2014	**Dounreay**	<u>Gaseous</u> The authorisation issued in 2014 covers disposals of gaseous, liquid and solid radioactive waste combined into one authorisation (i.e. the most recently issued authorisation covers all 3 media, when previously there were individual authorisations for each media). The previous gaseous authorisation included limits for the facility groups (e.g. Fuel Cycle Area, Fast Reactor etc.), however the new authorisation does not include limits for the facility groups. Instead the new authorisation includes site wide limits and subsidiary limits based on stack height groupings. The change in reporting of radionuclides from April 2014 is due to the issuing of the new authorisation. As a result, several nuclides are no longer reported after end April 2014. The nuclides no longer reported are: beta, strontium-90, ruthenium-106, iodine-131, caesium-134, caesium-137, cerium-144, plutonium-241, curium-242 and curium-244. Alpha, tritium, krypton-85 and iodine-129 are retained (with lower limits) and a new category ‘all other non-alpha’ introduced.
	Dounreay	<u>Liquid</u> The previous authorisation contained separate limits for the PFR liquid metal disposal plant and the other site facilities. The new authorisation does not contain separate limits for the different facilities, and instead contains site wide limits for the disposal of liquid waste. Sodium-22 and beta were removed from the authorisation, although both are included under the category of ‘all other non-alpha’.
	Hunterston A	<u>Gaseous</u> A new authorisation was enacted partway through the year (end June). The limits for tritium and carbon-14 were reduced. The beta category was replaced by all other radionuclides.
	Hunterston A	<u>Liquid</u>

		A new authorisation was enacted partway through the year (end June). The limits for tritium, alpha and plutonium-241 were reduced. The beta category was replaced by all other non-alpha and a limit for caesium-137 was introduced.
	Oldbury	Gaseous Sulphur-35 and argon-41 were removed from the permit.
2015	**Cardiff**	Gaseous The limit for carbon-14 has been reduced. The limits for soluble and insoluble tritium were replaced by a lower limit for tritium. The remaining nuclides (phosphorus-32/33, iodine-125 and other radionuclides were removed from the permit).
	Cardiff	Liquid Liquid permit revoked during 2015.
	Sellafield	Liquid The factory sewer permit was incorporated into the main site permit. Restructuring of the liquid discharge limits introduced annual site limits (incorporating sea pipelines; factory sewer and Calder Interceptor Sewer) that were 10 per cent lower than the previous sea pipeline limits for total alpha, beta and tritium. The remaining limits were unchanged.

6.2 Technologies in use or under development in the UK

6.2.1 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 per cent 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 and similar materials have been installed at a number of AGR sites.

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.

6.2.2 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.

6.2.3 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 (e.g. hydrous titanium oxide, hydrated iron oxide), insoluble salts of polyvalent metals (e.g. titanium phosphate), insoluble salts of heteropolyacids (e.g. 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.

6.2.4 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.

6.2.5 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 (e.g. 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.

6.3 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:

6.3.1 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.
- Operation of the Liquid Effluent Treatment Plant in the Sellafield Pile Fuel Storage Pond. The plant comprises sand-bed filtration and ion exchange abatement, and provides significant reduction in pond water activity and final discharges from this pond, and also important abatement capability to support future fuels and retrievals work.
- Continued retrieval of legacy fuels and materials from the Sellafield Pile Fuel Storage Pond, the retrieval of radioactive liquors from the Magnox Swarf Storage Silos, and the retrieval of sludge from the floc tanks: all represent significant advances in the decommissioning and clean-up of these legacy facilities.
- Implementation of additional arrangements at Sellafield site to exclude solids ranging from implementing simple filtration techniques at source plants to extensive trials to underpin, optimise and potentially improve final filtration systems on effluent discharges.
- Recycling of filtrates from the processing of Salt Evaporator Concentrate through the Sellafield EARP 'bulks' route to reduce overall discharges of americium-241 and ruthenium-106.
- De-canning and re-packaging of a significant quantity of the corroded fuel inventory in the Sellafield Fuel Handling Plant pond, and improvement in pond water cooling and pH control in the Fuel Handling Plant, leading to low and stable pond water activity levels, and correspondingly reduced discharges to the SIXEP plant.
- Imposition of tighter controls on donor plant feeds to SIXEP, and on-going R&D, to optimise SIXEP plant abatement performance.
- Sellafield Limited has commissioned a significant body of research in the fundamental understanding of the EARP chemical precipitation process through the NNL and through academia to enable the process envelope to be broadened to cope with the imminent transition from reprocessing to Post Operational Clean-Out, where feed volumes will be less predictable and more variable. It has also established an inactive process rig to enable both

abatement of new feeds and encapsulation of the resultant floc to be assessed.

- Sellafield Limited has commissioned significant R&D into the characterisation of Magnox and uranium corrosion products and their roles in controlling the radionuclide challenge to SIXEP. This work has underpinned the optimisation of process conditions in the high hazard plants as retrievals operations come on stream and ramp up. In conjunction with extensive plant sampling, it has provided (and continues to provide) valuable insights into the effluent generated during sludge retrieval from the First Generation Magnox Storage Pond and into the risks inherent in retrieving waste from the Magnox Swarf Storage Silos. Work has been initiated to assess the use of settling aids to reduce the particulate and alpha activity challenge to SIXEP during retrieval operations.
- At the Sellafield site, a review of the application of effluent abatement technology was conducted by the NNL and reviewed by representatives of the UK nuclear industry (operators and regulators) and overseas organizations (IAEA and CEA) under the auspices of the Nuclear Waste and Decommissioning Research Forum (NWDRF). This review concluded that the technology employed continued to represent BAT.
- Urenco ChemPlants Limited are currently constructing 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. It is anticipated that this facility will become commissioned in late 2017/early 2018.

6.3.2 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-fuelling 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. This has resulted in increased discharges of sulphur-35, both in gaseous and aqueous form, albeit to levels well within existing permitting 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.

6.3.3 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 are expected to be drained which may lead 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 & R2) in 2017. Vessel contaminated ventilation systems and maintenance air driers were shut-down in 2017, saving material, energy and maintenance costs.

6.3.4 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.

6.3.5 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 two 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.

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Summary of Radioactivity in Food and the Environment (2004–2016)

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

Part 2. Summary of Radioactivity in Food and the Environment in the UK (2004-2016)

Preface

The environmental monitoring programmes in this report were organised by the environment agencies, FSA and 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 10-22), this review has been prepared to give an overview of recent trends in data from 2004-2016. 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 and European limit of 1 mSv 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 defuelling 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 2004-2016. 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 AGR or PWR reactors, 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 man-made radionuclides over the last two 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 time-frame. 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 2004-2016 and is not a detailed technical report. Anyone wanting to understand the in-depth background to the methodologies applied in the specific yearly assessments should consult the relevant annual RIFE report.

INTRODUCTION

This report provides a summary of the public's exposure (doses) to radiation, between 2004 and 2016, 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 (e.g. 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.

The 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 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. This strategy will be implemented so 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 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 Part 1, Section 2 (UK Report on application of Best Available Techniques (BAT) in civil nuclear facilities (2012-2016)) of this combined report.

7. Overview of *total dose* and environmental indicators near the UK's nuclear sites

> **Key points**
>
> - All *total doses* were less than the UK and European 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*[17] 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.

7.1 *Total dose* assessment

Figure 7.1 provides time trends of *total doses* from 2004-2016, due to the combined effects of authorised/permitted waste discharges and direct radiation, to those people (representative person[18]), most exposed to radiation near all major nuclear licensed sites in the UK.

The *total doses* from radiation at all sites were all less than the annual national (UK) and the European limit for members of the public of 1 mSv 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 2.3 mSv per year (Oatway *et al*., 2016).

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 7.1 shows the annual *total dose* was highest at Dungeness in Kent, ranging between 0.014 and 0.63 mSv, over the period. *Total doses* 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.

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

[18] The 'representative person' concept is considered equivalent to the previously used 'critical group' (Environment Agency, FSA, FSS, NIEA, NRW and SEPA, 2016).

The second highest annual *total dose* was in the vicinity of Sellafield (Sellafield, LLWR (near Drigg) and Whitehaven) in Cumbria, ranging between 0.076 and 0.58 mSv 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, 2008-2009 and 2012-2013) were due to variations in naturally occurring radionuclides (mainly polonium-210). The changes in *total dose* in the intervening years from 2005-2007 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 2011-2012 and 2014-2016, 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 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.

The third highest exposure was at Amersham in Buckinghamshire, where annual *total doses* ranged from 0.14 and 0.24 mSv over the period. This trend remained broadly similar with time and was dominated by direct radiation. The lower value in 2014 (and subsequently thereafter) was 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 of a building that contains legacy radioactive wastes.

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 and Winfrith (both in 2015 and 2016) were also mostly due to higher estimates of direct radiation from the individual sites. At Springfields the *total dose* decreased over time, although there was an increase in 2008 (compared with 2007). Thereafter, 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 three 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

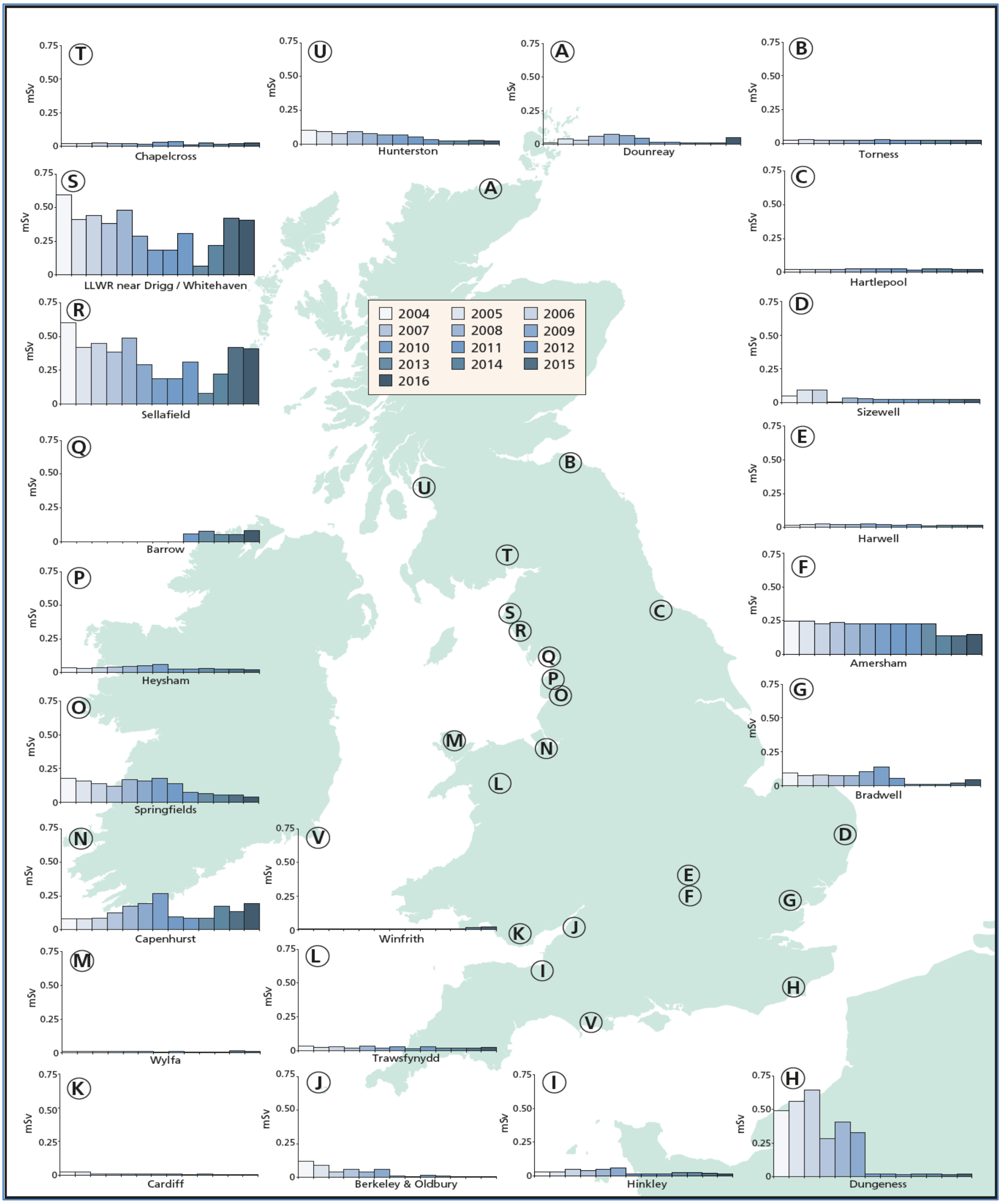

Figure 7.1 Total radiation exposures around the UK's nuclear sites due to radioactive waste discharges and direct radiation (2004-2016). (Exposures at Sellafield/Whitehaven receive a significant contribution to the dose from technologically enhanced naturally occurring radionuclides from previous non-nuclear industrial operations)

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 7.1 were low. Any variations in *total dose*s with time at these sites were primarily due to changes in direct radiation or variations in gamma dose rates from environmental variability.

7.2 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 7.2. 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.

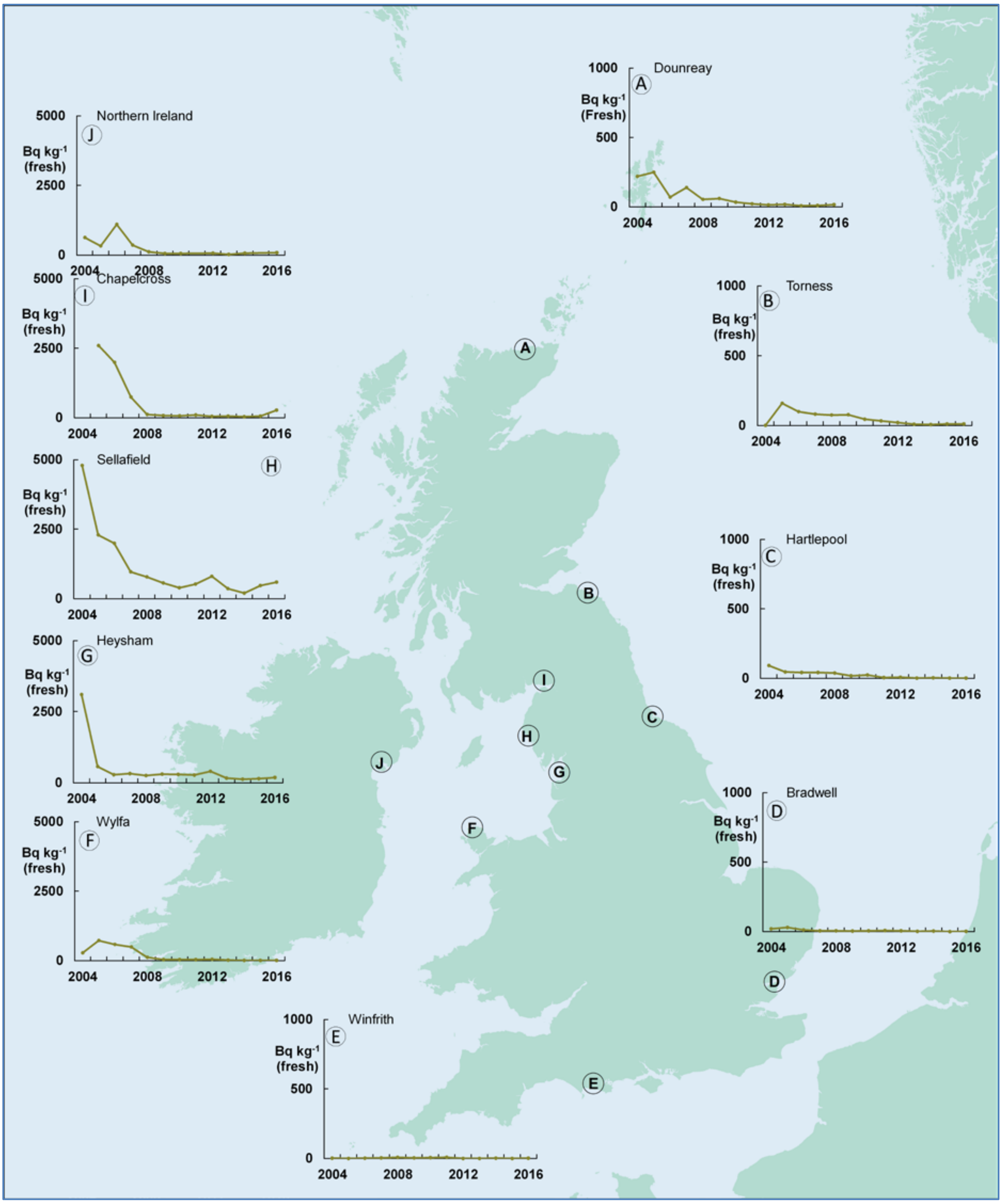

Figure 7.2 Technetium-99 concentrations in seaweed around the UK (2004-2016)

7.3 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 7.1. This gives an indication of the range of doses to the public away from nuclear sites between 2005 and 2016.

Table 7.1 Ranges of estimated dose from radionuclides in drinking water between 2005-2016*

Country	Mean exposure mSv/y		
	Man-made 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	0.017 - 0.062	0.017 - 0.063
Scotland	< 0.001	0.002 - 0.003#	0.002 - 0.003#
UK	< 0.001	0.017 - 0.054	0.017 - 0.054

* No data available in 2004
# Data only available in 2014-2016, inclusive (for K-40 only)

8. Nuclear fuel production and reprocessing

Key points

- All doses were significantly less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.24 mSv 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 2016 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[19] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment. The public's exposure from naturally occurring radionuclides is also considered near Sellafield.

There are three 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.

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

Figure 8.1 provides time trends, between 2004 and 2016, 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 and European limit for members of the public of 1 mSv per year.

Figure 8.1 shows that the highest annual dose from artificial radionuclides (shown in blue) was 0.24 mSv in 2007 near Sellafield. The Sellafield annual doses ranged from 0.083 to 0.24 mSv. 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

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[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 the locations being assessed. This dose, referred to in Sections 8-12, is an exposure that uses a different assessment method to that of *total dose* in Section 7.

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 8.1 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 sea food 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 (2004-2013), Northern Ireland, North Wales and the Isle of Man (2004-2013). 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 0.012 and 0.036 mSv 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 0.037 and 0.16 mSv 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 0.007 and 0.012 mSv 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.

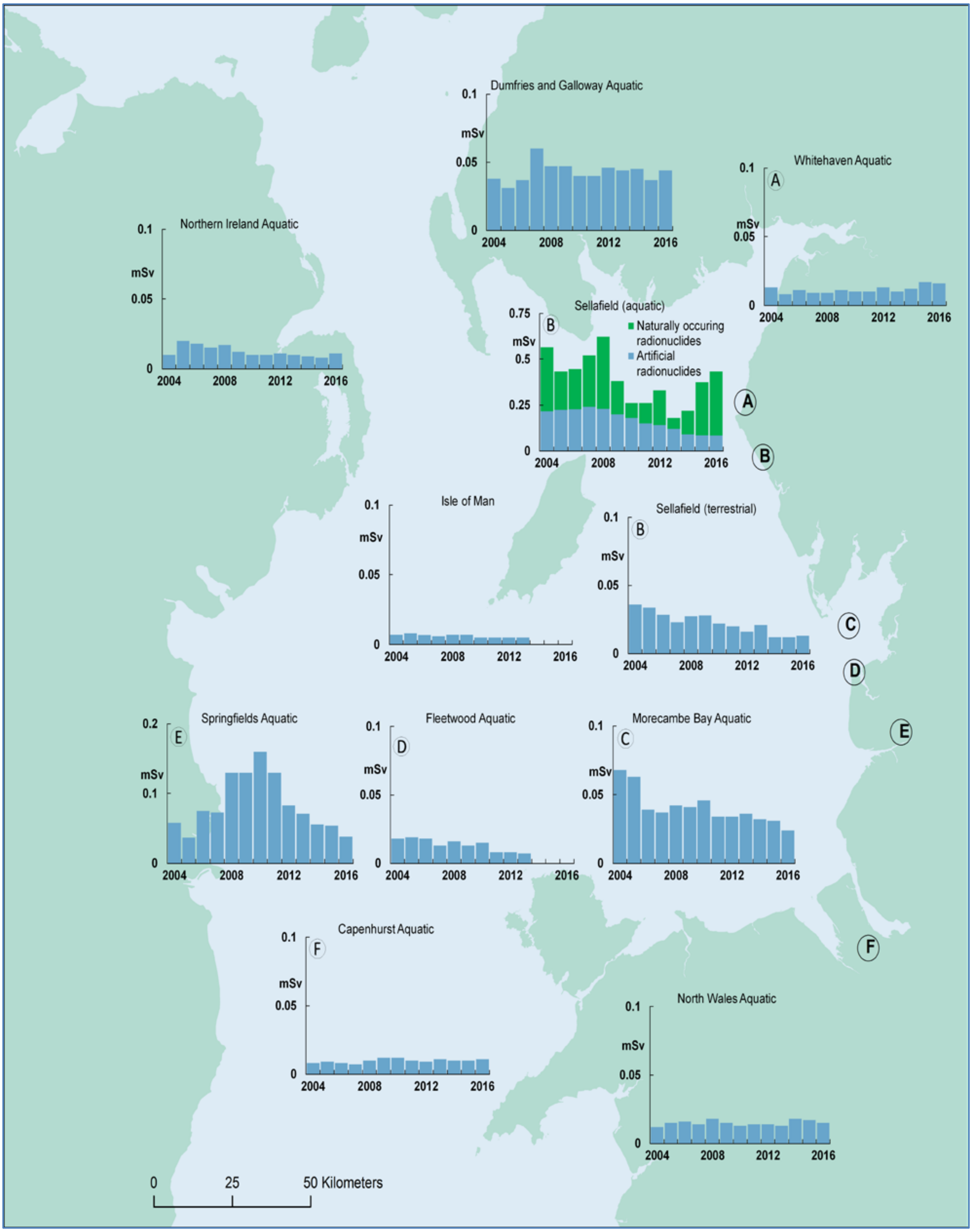

Figure 8.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Irish Sea (2004-2016) (includes exposures from naturally occurring radionuclides near Whitehaven)

8.2 Sellafield, Cumbria

8.2.1 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 8.2 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

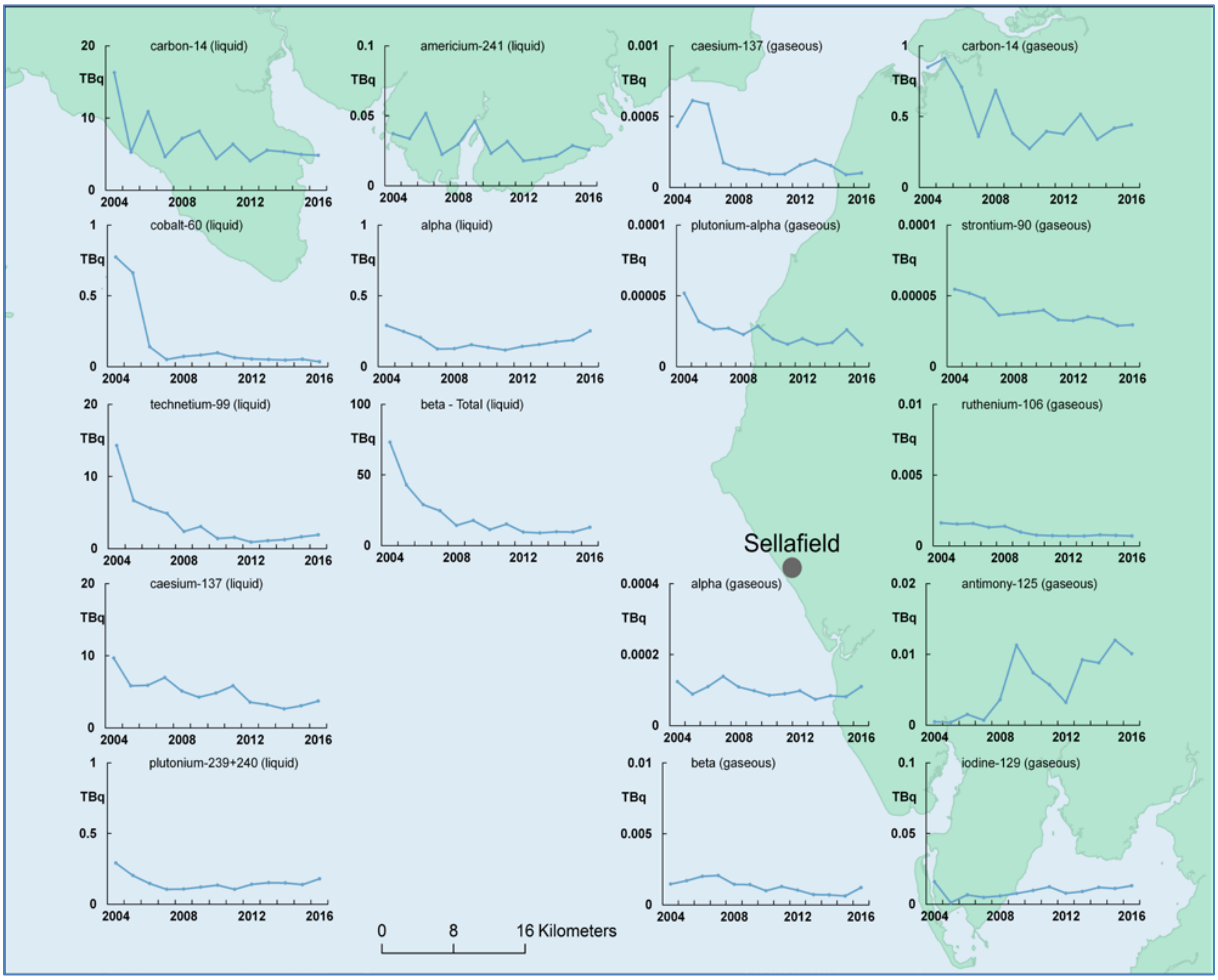

Figure 8.2 Permitted discharges of gaseous and liquid wastes, Sellafield (2004-2016)

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 2016, all liquid discharges generally followed a pattern of overall reduction.

8.2.2 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 8.3 shows the trends of radionuclide concentrations in food (winkles, lobsters, plaice and milk) and the environment (seawater and sediment) near Sellafield between 2004 and 2016. 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.

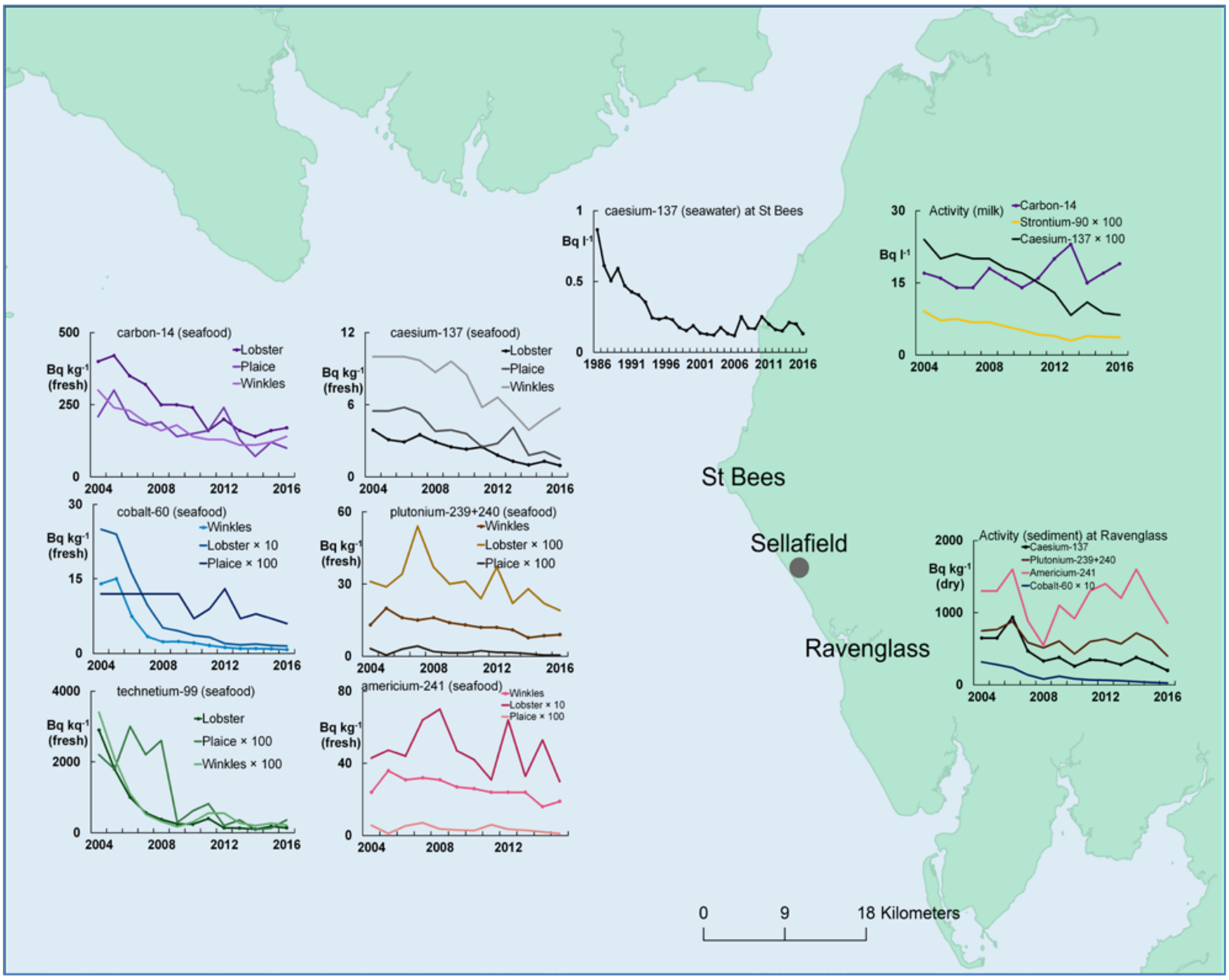

Figure 8.3 Monitoring of the environment from discharges of radioactive wastes, Sellafield (2004-2016)

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 2016, concentrations of caesium-137 in seafood generally declined at a constant rate, 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 five 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 8.3 also shows the trends of caesium-137 in seawater (2014-2016) at St Bees and sediment activity concentrations from Ravenglass. 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 and 2014). 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.

8.3 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). 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 8.4 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

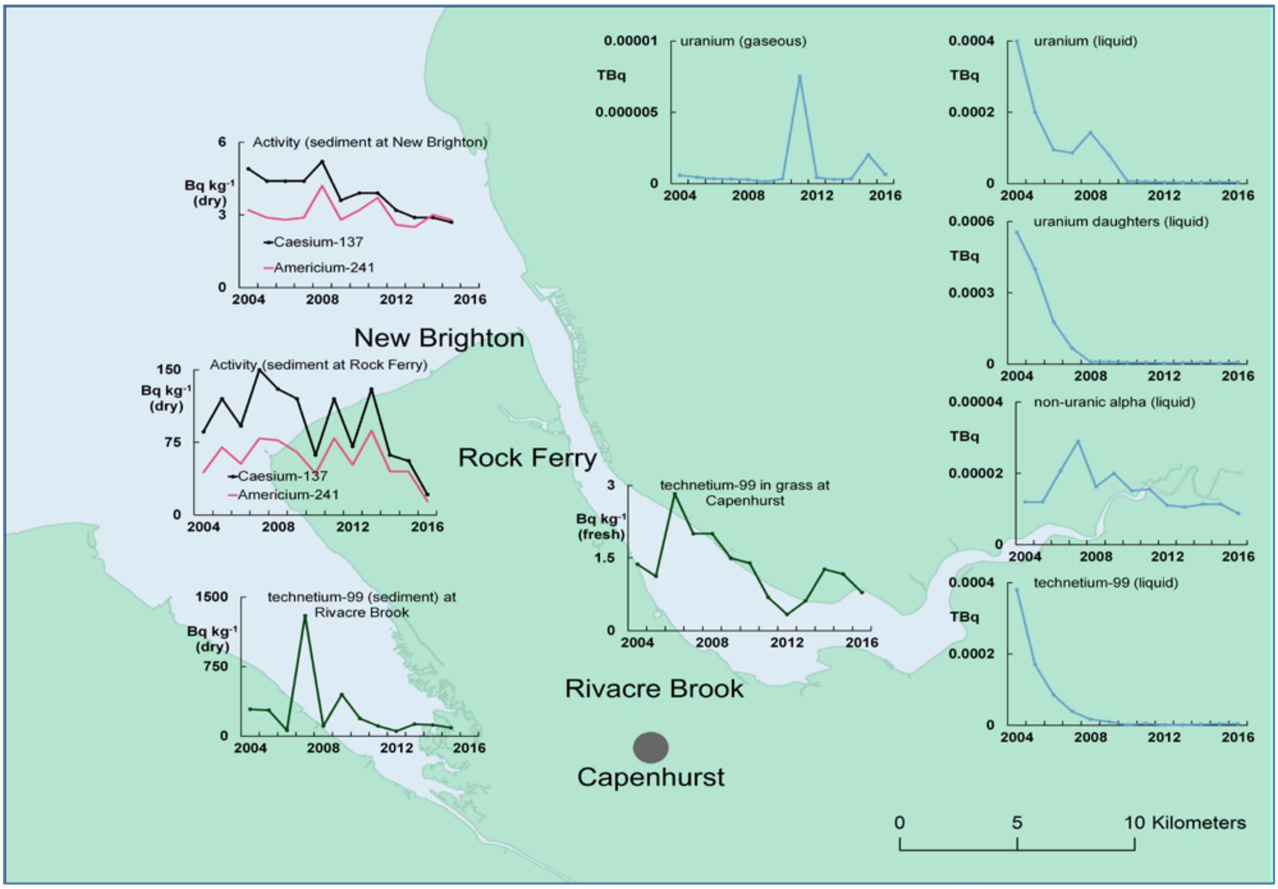

Figure 8.4 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Capenhurst (2004-2016)

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 8.4 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.

8.4 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 two pipelines. The largest discharge for a number of years was of short half-life beta emitting radionuclides (mainly thorium-234).

Figure 8.5 shows the trends of discharges over time (2004-2016) for a number of the permitted radionuclides.

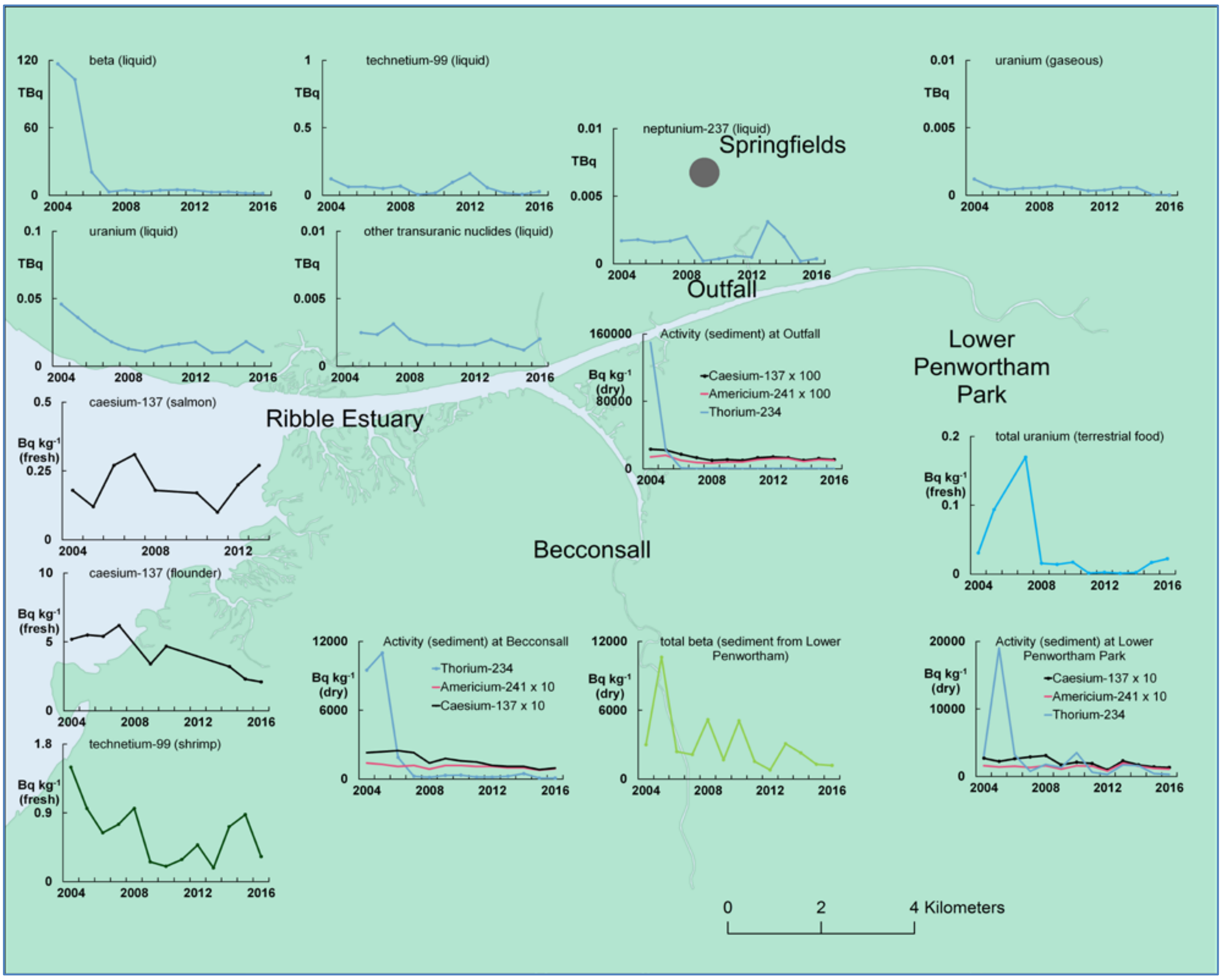

Figure 8.5 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Springfields (2004-2016)

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 8.5 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 peak in 2007 was 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 (e.g. caesium-137 in flounder).

The trends of concentrations in sediments over time from liquid discharges are shown in Figure 8.5 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.

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 nuclear fuel production and reprocessing sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	7	3	1	Majority downward trend
Liquid discharges	16	1	0	Majority downward trend
Overall discharges	23	4	1	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	6	5	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.

9. Research and development

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.047 mSv 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 2016 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[20] (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) and Windscale (Cumbria) which is on the Sellafield site. These latter smaller sites make small discharges overall, and are not considered here.

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 2016, due to the effects of gaseous and liquid waste discharges at the main research sites. All doses were much less than the UK and European limit of 1 mSv per year for members of the public.

Figure 9.1 shows that the highest annual dose was at Dounreay from consuming food produced on land around the site. This ranged between 0.008 and 0.047 mSv 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

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[20] 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 8-12, is an exposure that uses a different assessment method to that of *total dose* in Section 7.

2016 was mostly due to the inclusion of the caesium-137 concentration in game, the activity most likely from historical releases.

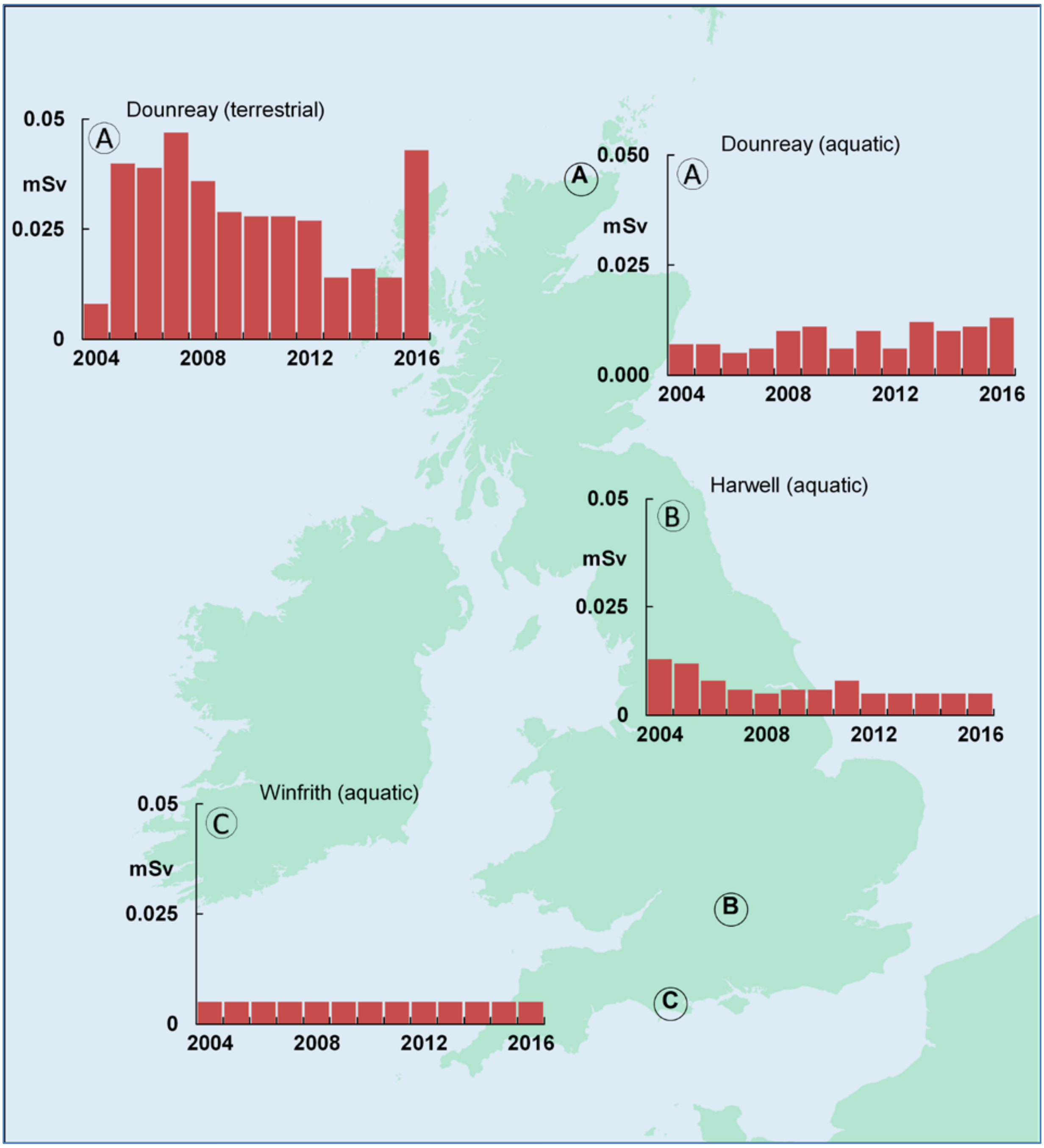

Figure 9.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Dounreay, Harwell and Winfrith (2004-2016)
(Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)

The annual dose from seafood consumption and external exposure over local beaches at Dounreay ranged from less than 0.005 to 0.013 mSv 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.

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 0.013 mSv 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 river bank (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 were well below 0.005 mSv, which is less than 0.5 per cent of the dose limit for members of the public.

9.2 Dounreay – Discharges of radioactive waste and concentrations of radionuclides in food and the environment

Gaseous and liquid discharges are released into the atmosphere and into the sea (Pentland Firth) by a pipeline terminating 600 metres offshore at a depth of about 24 metres.

Figure 9.2 shows the trends of discharges over time (2004-2016) for a number of the authorised radionuclides. The overall trend was a reduction in both gaseous and liquid discharges (2004-2016).

Figure 9.2 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.

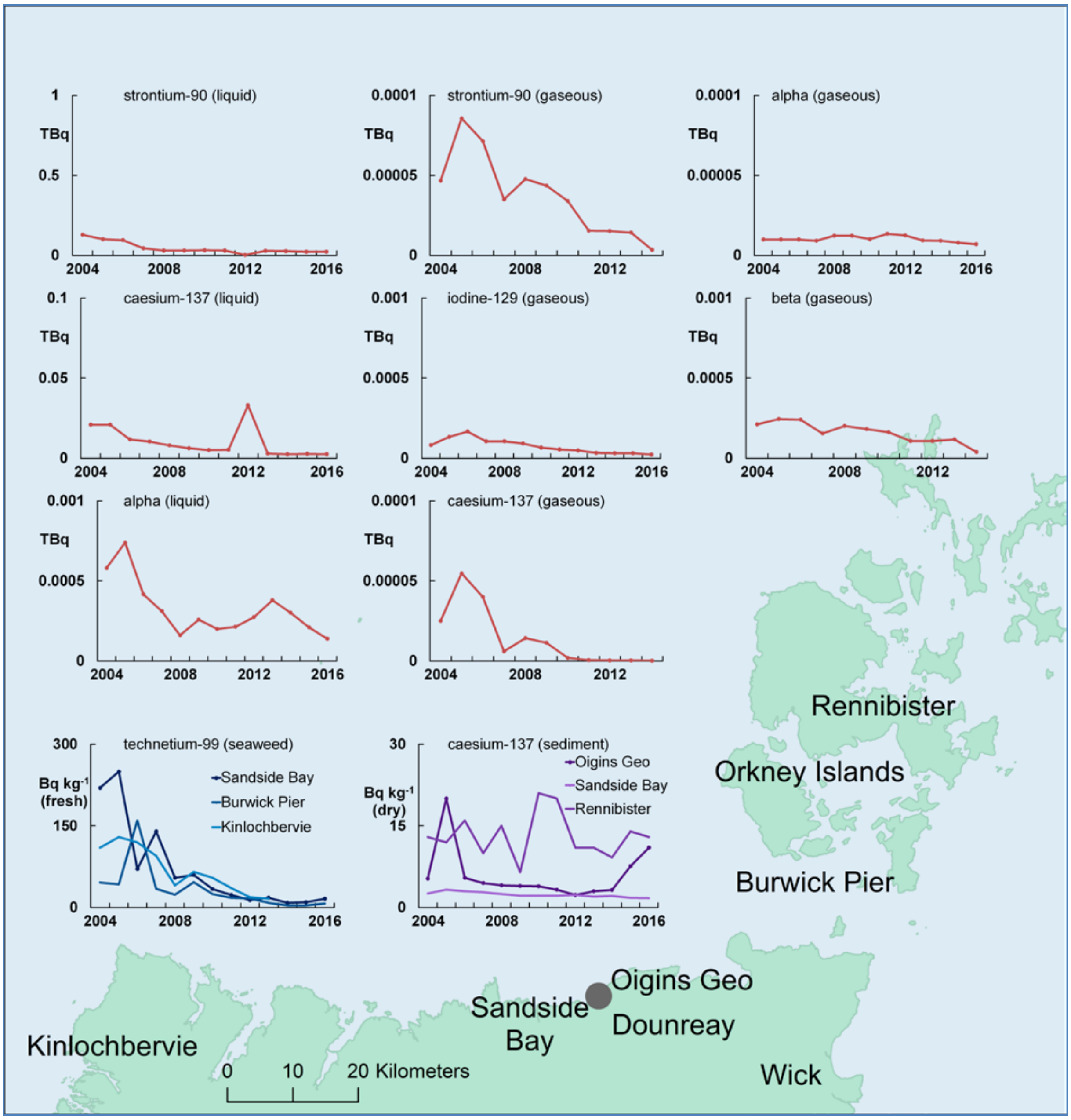

Figure 9.2 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Dounreay (2004-2016)

9.3 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. 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 9.3 shows trends of discharges over time (2004-2016) 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 9.3 also provides monitoring trends from four 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.

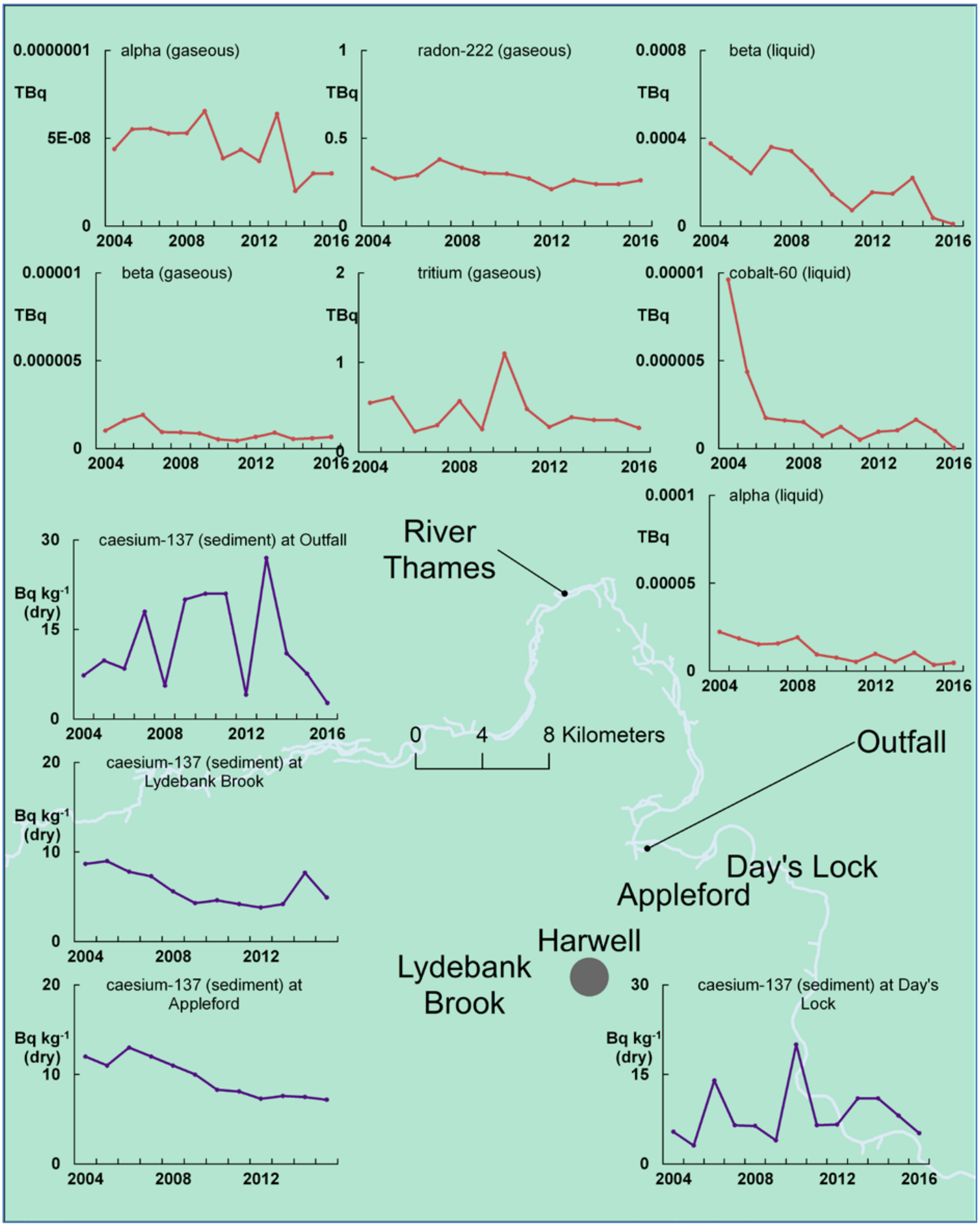

Figure 9.3 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Harwell (2004-2016)

9.4 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 and to the River Frome.

Figure 9.4 shows the trends of discharges over time (2004-2016) 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 per cent of the annual limit in most recent years.

Figure 9.4 also provides radionuclide concentrations from four 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 per cent of the World Health Organisation’s screening levels for drinking water. Since 2006, tritium concentrations have generally declined over time. Plutonium radionuclides and americium-241 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 more recent years. Over the time period there have been some changes in the concentrations of these radionuclides between years, most likely attributable to environmental variability.

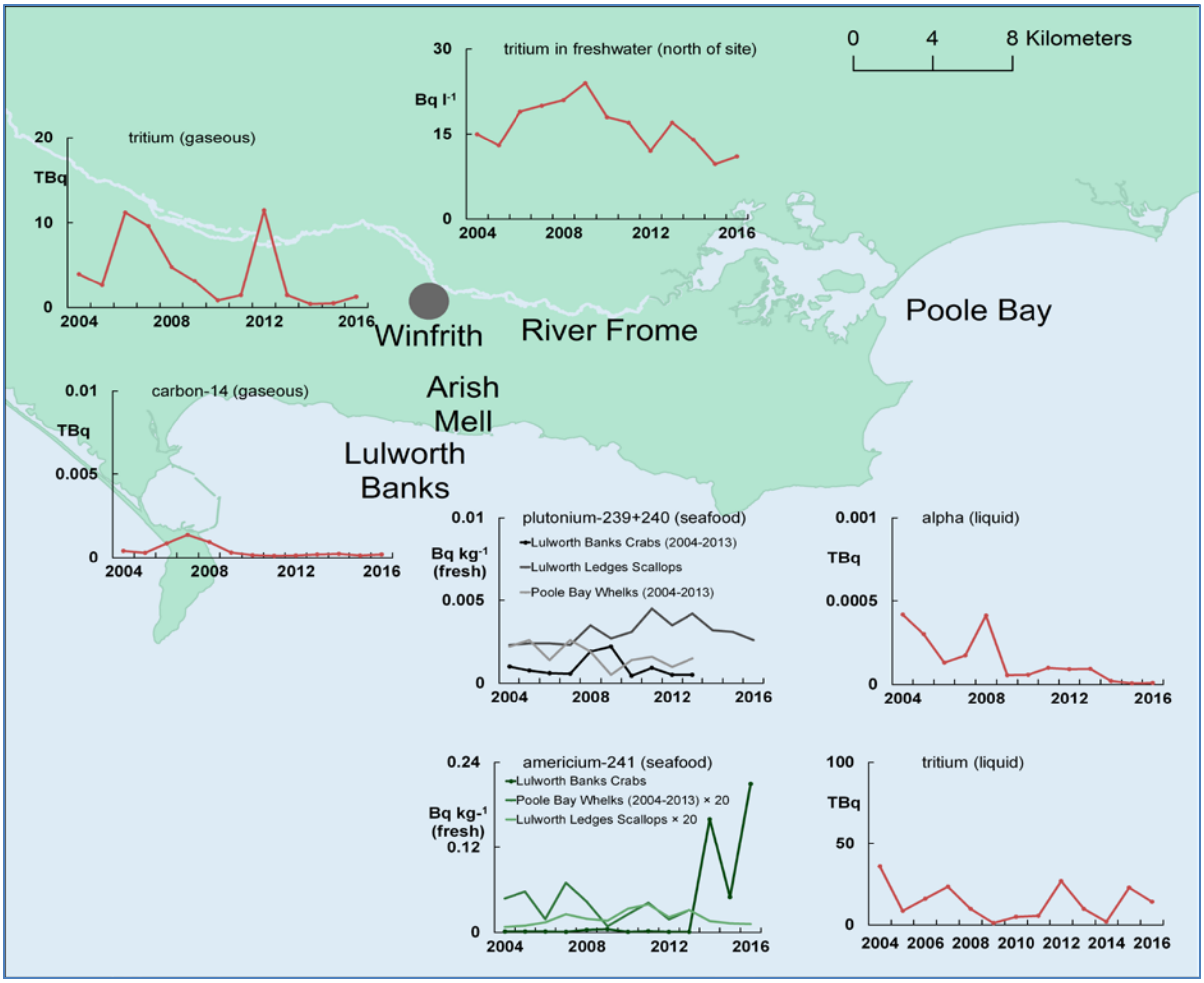

Figure 9.4 Discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Winfrith (2004-2016)

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 research sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	8	3	1	Majority downward trend
Liquid discharges	7	1	0	Majority downward trend
Overall discharges	15	4	0	Majority downward trend
Food and the environment overall	3	6	0	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.

10. Nuclear power generation

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.068 mSv 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 sources.

This section looks at the time trends between 2004 and 2016 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[21] (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, nine in England (Berkeley, Oldbury, Bradwell, Calder Hall, Dungeness, Hartlepool, Heysham, Hinkley Point and Sizewell), three in Scotland (Chapelcross, Hunterston and Torness) and two in Wales (Trawsfynydd and Wylfa). Eleven of the 19 nuclear power stations are first generation Magnox power stations, seven are more recent advanced gas-cooled reactor (AGR) power stations and one 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 stations stopped operating.

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 2016 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 dose where

[21] 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 8-12, is an exposure that uses a different assessment method to that of *total dose* in Section 7.

people spend a lot of time on beach area. At all locations, around these sites, the doses were all less than the UK and European limit for members of the public of 1 mSv per year.

Figure 10.1 shows the annual dose was highest to a group of local fishermen at Heysham. This ranged between 0.024 and 0.068 mSv over the period, and with the highest value in 2004, and generally declined over the 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. 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 between 0.017 and 0.046 mSv 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 GE Healthcare facility at Cardiff. The trend graph shows apparent increases in doses during the period (in 2006, 2009 and 2013). 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 0.031 mSv. 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 fisherman and wildfowl consumers at Chapelcross received annual doses ranging from less than 0.005 to 0.027 mSv 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 0.017 mSv. 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 lead 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 0.019 mSv. The changes in dose were mainly due to the normal variations in concentrations and dose rates in the environment.

At Hartlepool, between 2004 and 2007, the annual dose to a group of local fishermen was assessed to be less than 0.005 mSv. 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 two groups were combined and assessed, due to a revision in the habits information. Small changes in doses in 2015 and 2016 were due to variations in dose rates.

At Hunterston, the annual dose ranged from less than 0.005 to 0.012 mSv. 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 0.005 mSv. In 2012 and 2013, the dose for houseboat dwellers increased due to higher dose rates.

At Trawsfynydd, the annual dose ranged between less than 0.005 and 0.013 mSv 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. Caesium-137 concentrations in sediments have declined over the period so the model predicts a reduction in dose rate. The decrease in dose in 2016 was due to the contribution from caesium-137 in brown trout not being included in the assessment (sample not collected in 2016).

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 0.010 mSv. 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. The dose declined in 2013 due to a revision in the habits information.

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

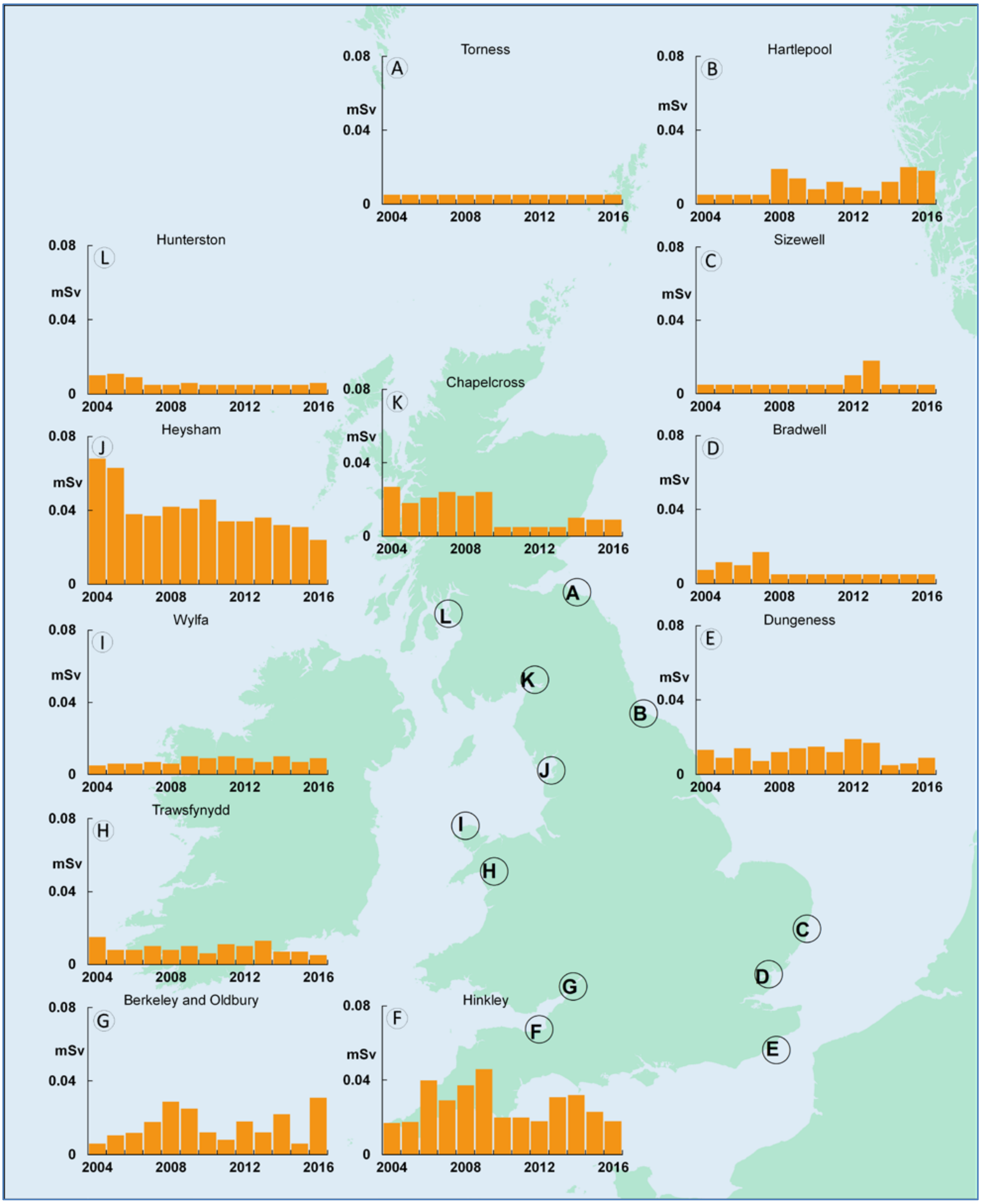

Figure 10.1 Individual radiation exposures around nuclear power stations from aquatic pathways for artificial radionuclides (2004-2016)
(Small doses less than or equal to 0.005mSv are recorded as being 0.005mSv)

10.2 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 10.4 for discharges). Figures 10.2 and 10.3, respectively, show the trends of gaseous and liquid discharges over time (2004-2016) 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 are 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 sites with only Magnox reactors (excluding Trawsfynydd – see section 10.4), 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 tritium and carbon-14 discharges at Bradwell were low. However, a small increase in tritium and gaseous carbon-14 discharges occurred in 2014 and 2015 due to the dissolution of Fuel Element Debris on the Bradwell site.

For the sites with AGR or PWR reactors, the trend was an overall decline in gaseous and liquid discharges over the period 2004-2016, 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 shut down of Heysham 1 and liquid tritium discharges decreased in 2011 from reduced power output at Dungeness B.

10.3 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 10.4 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 10.4 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 two 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 (< 5.8 Bq kg^{-1}).

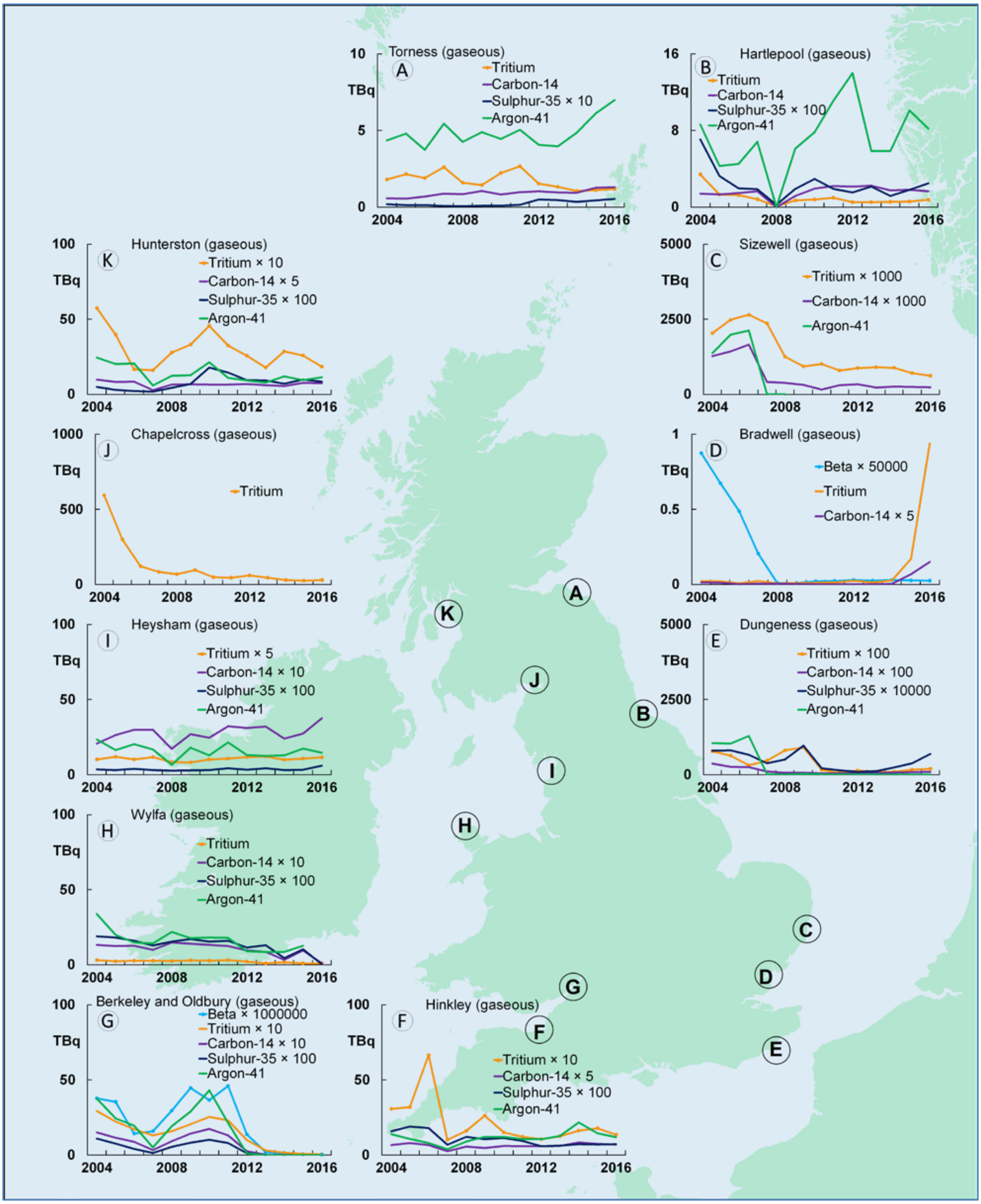

Figure 10.2 Permitted/authorised discharges of gaseous wastes from nuclear power stations (2004-2016)

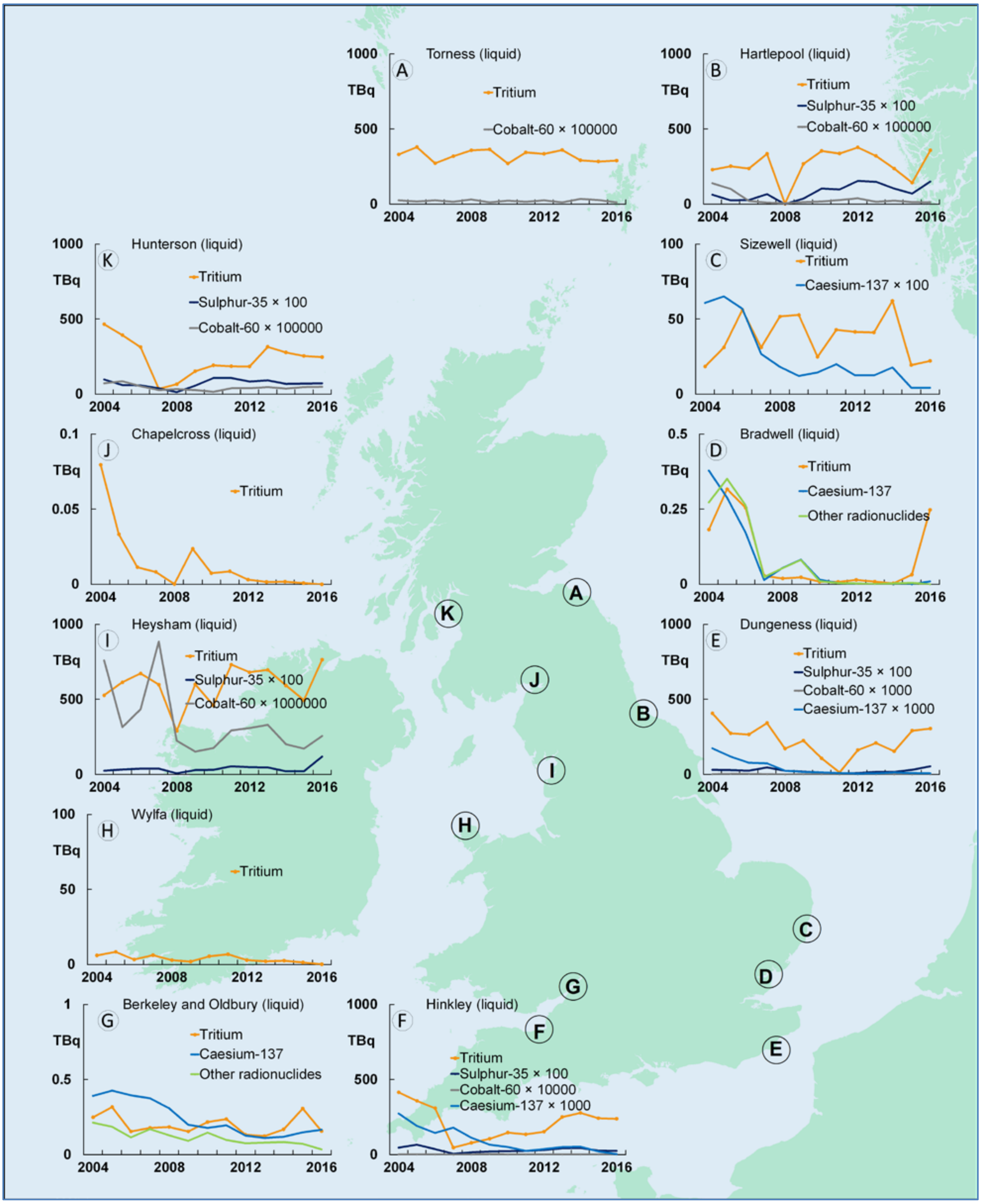

Figure 10.3 Permitted/authorised discharges of liquid wastes from nuclear power stations (2004-2016)

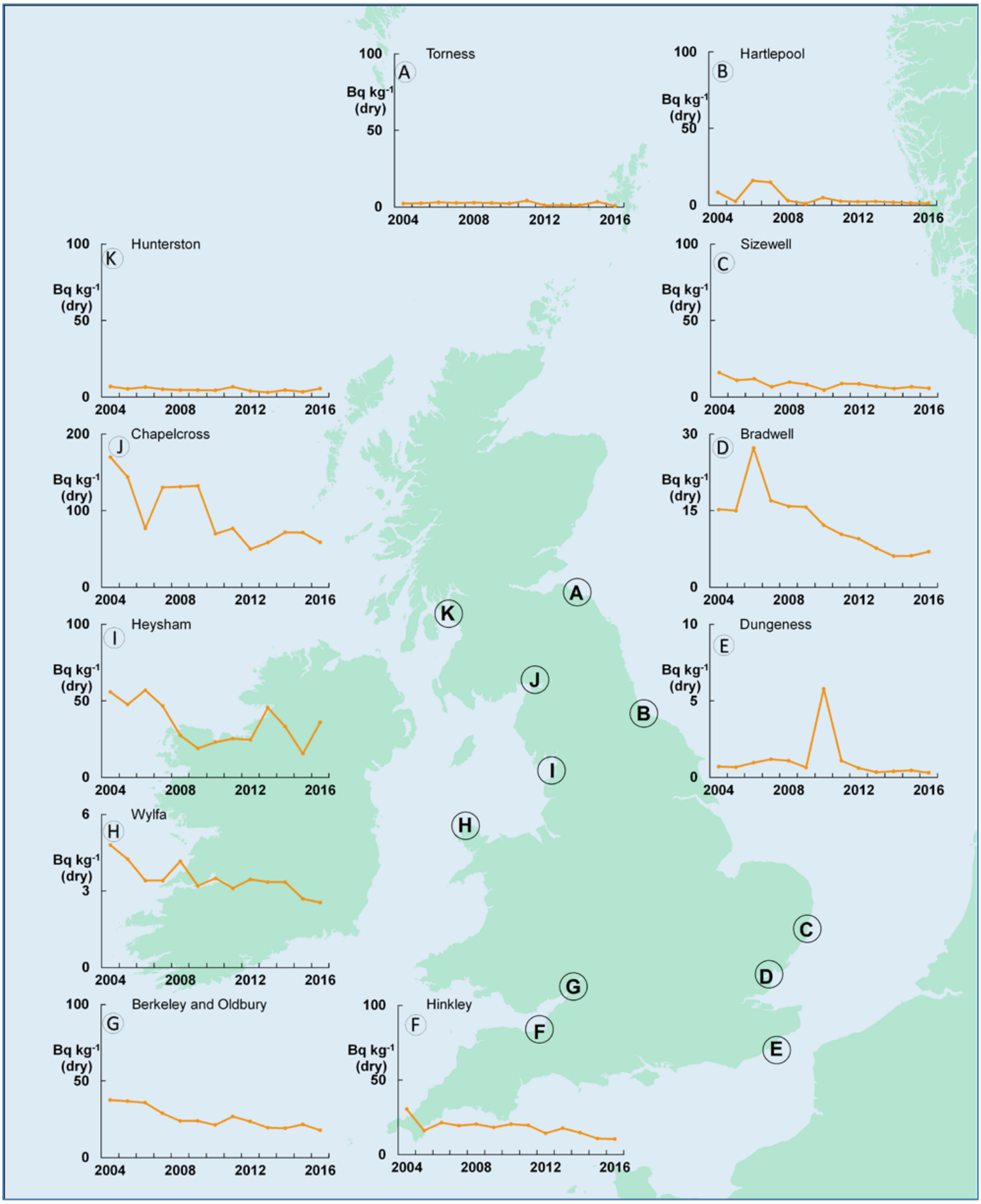

Figure 10.4 Caesium-137 concentrations in marine sediments near nuclear power stations (2004-2016)

10.4 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 10.5 shows the trends of gaseous and liquid discharges over time (2004-2016) 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 10.5 Permitted discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Trawsfynydd (2004-2016)

Figure 10.5 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.

10.5 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 nuclear power sector (2004-2016)*

Trend data	Downwards	No change	Upwards	Overall
Gaseous discharges	8	3	1	Majority downward trend
Liquid discharges	8	4	1	Majority downward trend
Overall discharges	16	7	1	Majority downward trend
Environment overall	11	1	0	Majority downward trend
Overall doses from gaseous and liquid discharges	6	4	2[#]	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

[#] Increase mostly due to revised habits data

11. Defence

Key points

- All doses were significantly less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.017 mSv 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 2016 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[22] (dose) from radioactive waste discharges is assessed using radionuclide concentrations and gamma dose rates in the environment.

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

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

Figure 11.1 shows the time trends of doses between 2004 and 2016, due to the effects of gaseous and liquid waste discharges. All doses were much less than the national UK and European limit for members of the public of 1 mSv per year.

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

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[22] 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 8-12, is an exposure that uses a different assessment method to that of *total dose* in Section 7.

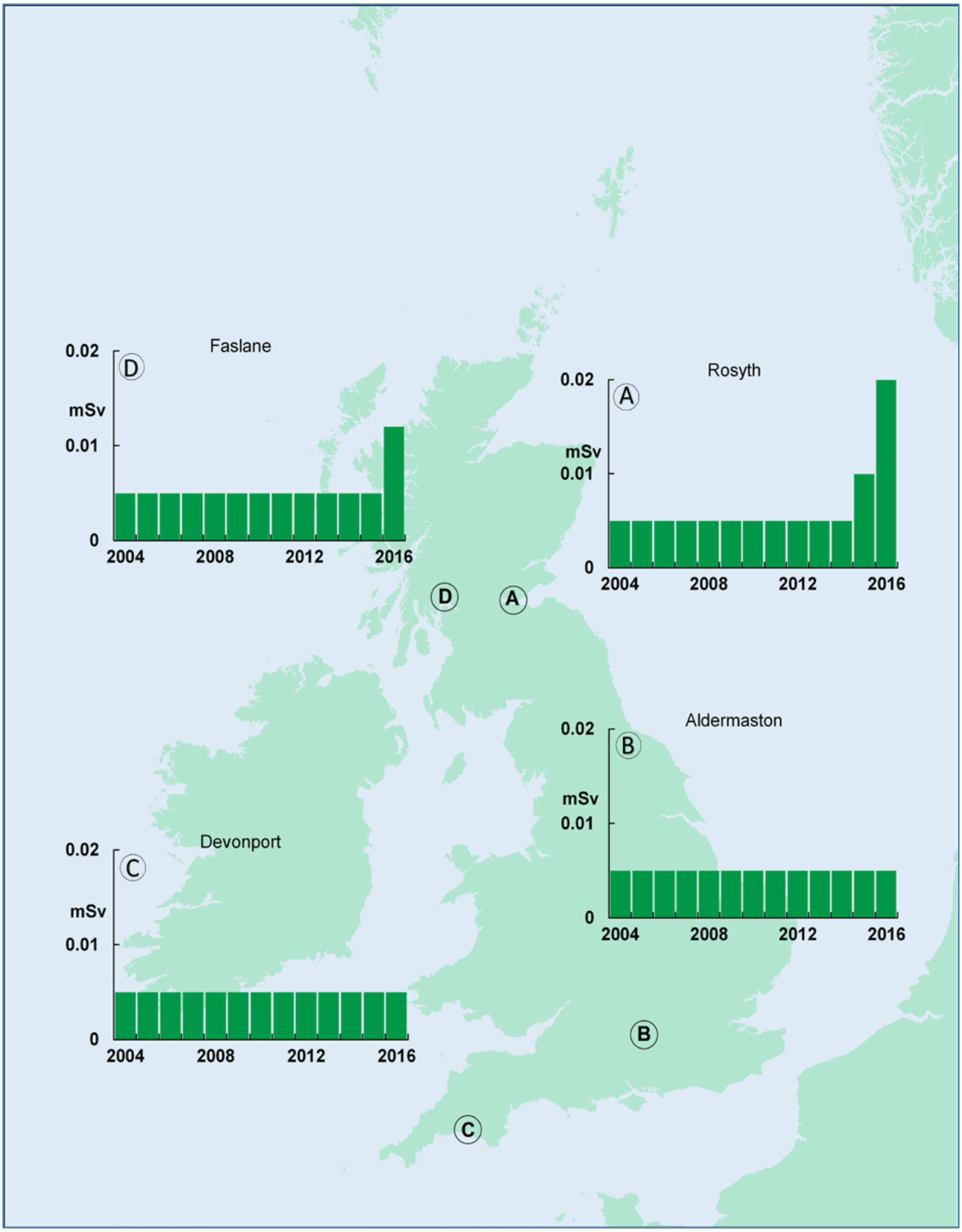

Figure 11.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Aldermaston, Devonport, Faslane and Coulport, and Rosyth (2004-2016) **(Small doses less than 0.005mSv are recorded as being 0.005mSv)**

11.2 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 11.2 shows the trends of discharges over time (2004-2016) 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 per cent 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 and 2012 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.

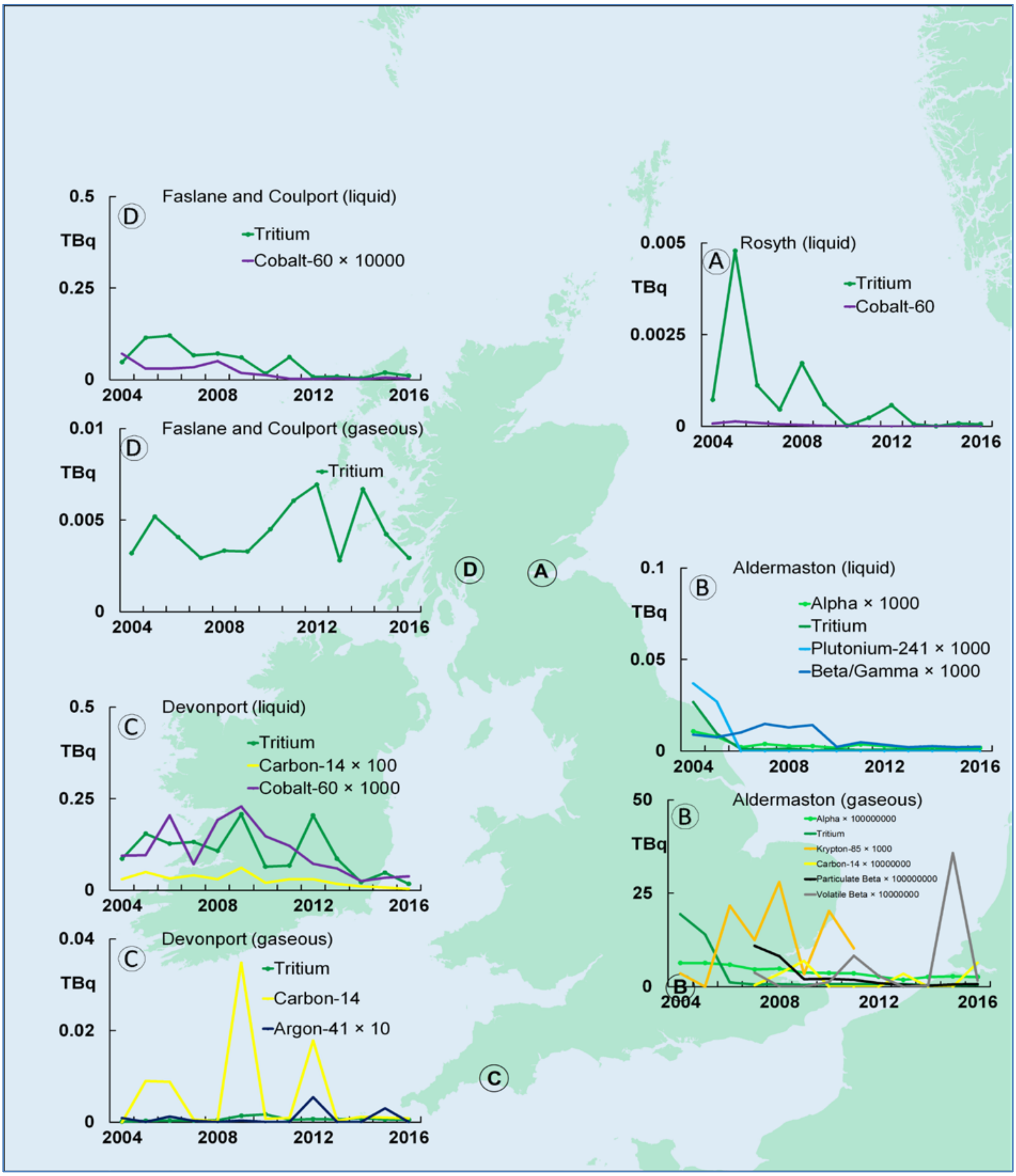

Figure 11.2 Permitted/authorised discharges of gaseous and liquid radioactive wastes, Aldermaston, Devonport, Faslane and Coulport, and Rosyth (2004-2016)

11.3 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 11.3 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.

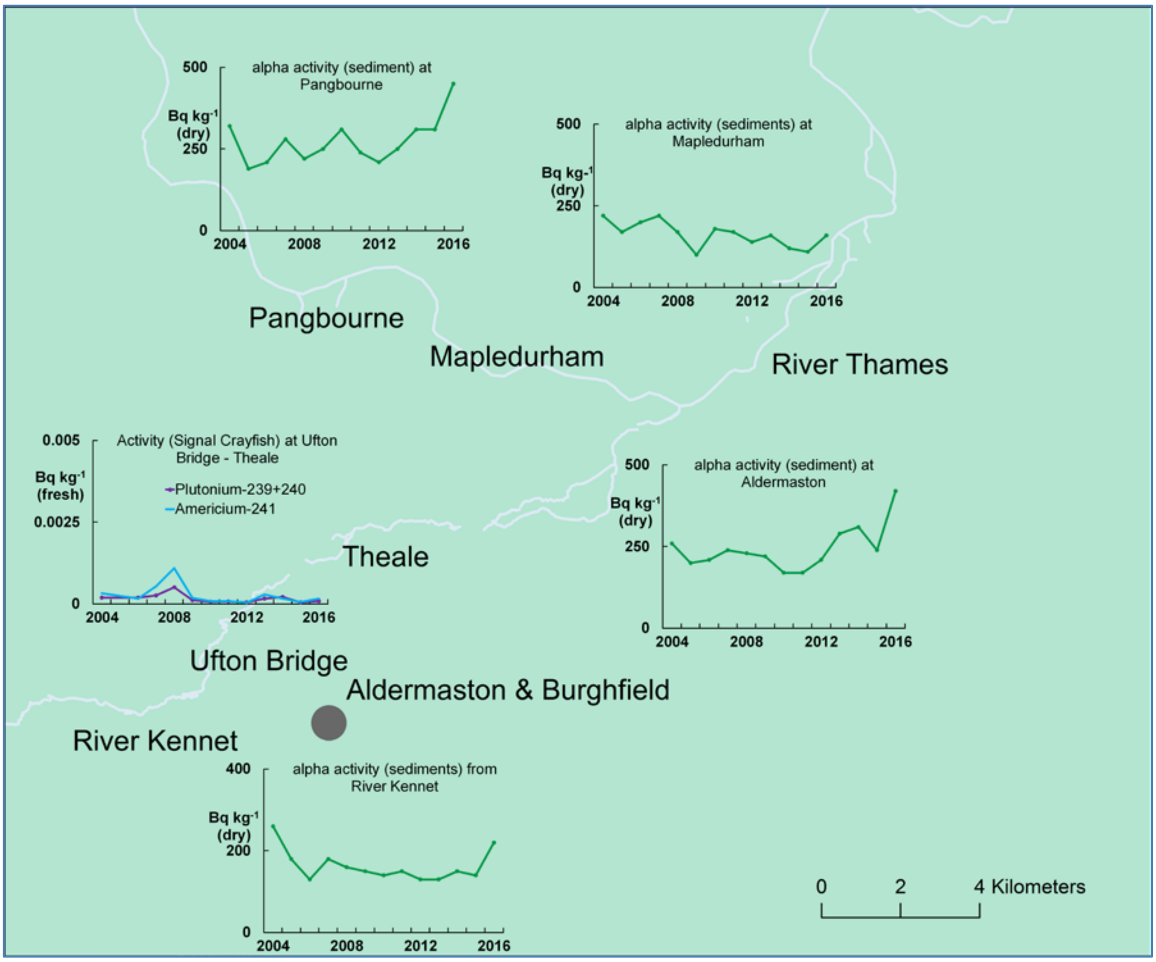

Figure 11.3 Monitoring of the environment from discharges of radioactive wastes, Aldermaston (2004-2016)

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.

11.4 Summary

The information presented in Table 11.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 11.

Table 11.1 Summary of trend data for defence sector (2004-2016)*

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	1	2	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

12. Radiochemical production

Key points

- All doses were less than the dose limit for members of the public of 1 mSv per year.
- Highest annual dose (from artificial radionuclides) was 0.029 mSv 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 2016 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[23] (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 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 per cent of the footprint of the site was de-licensed, following decommissioning and clean-up of the wider Maynard Centre.

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

Figure 12.1 shows the trends of doses of the public's exposure to radiation (2004-2016) due to the effects of gaseous and liquid waste discharges. For locations near both sites, the doses were all much less than the UK and European limit for members of the public of 1 mSv per year.

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[23] 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 8-12, is an exposure that uses a different assessment method to that of *total dose* in Section 7.

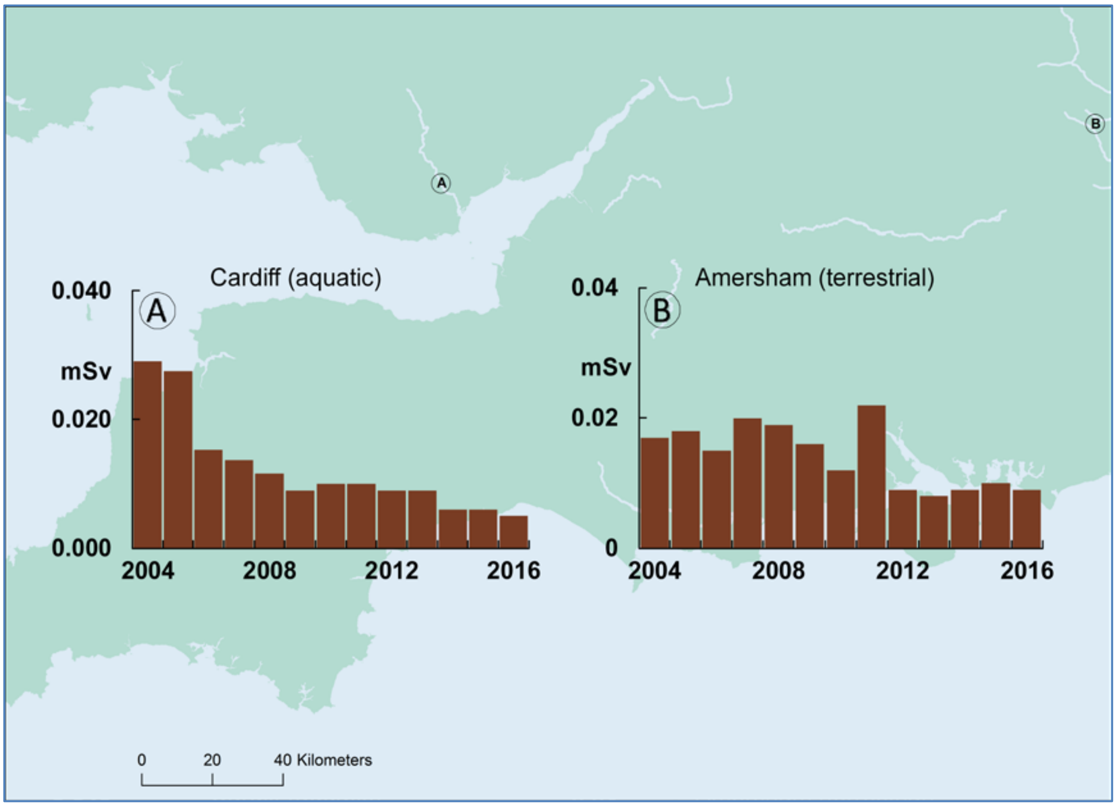

Figure 12.1 Individual radiation exposures to most exposed groups from artificial radionuclides, Amersham and Cardiff (2004-2016)

The annual dose was highest at Cardiff from consuming fish and shellfish (combined with external exposure), and ranged between less than 0.005 and 0.029 mSv 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 0.008 and 0.022 mSv 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 much lower atmospheric discharges of radon-222 between 2012 and 2016.

12.2 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 12.2 shows the trends of discharges over time (2004-2016) 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 12.2 also provides monitoring trends of sulphur-35 and caesium-137 in food and in grass and sediment from three 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 2004-2012), although the activity concentrations were very low. In spinach, sulphur-35 concentrations were significantly less than in grass.

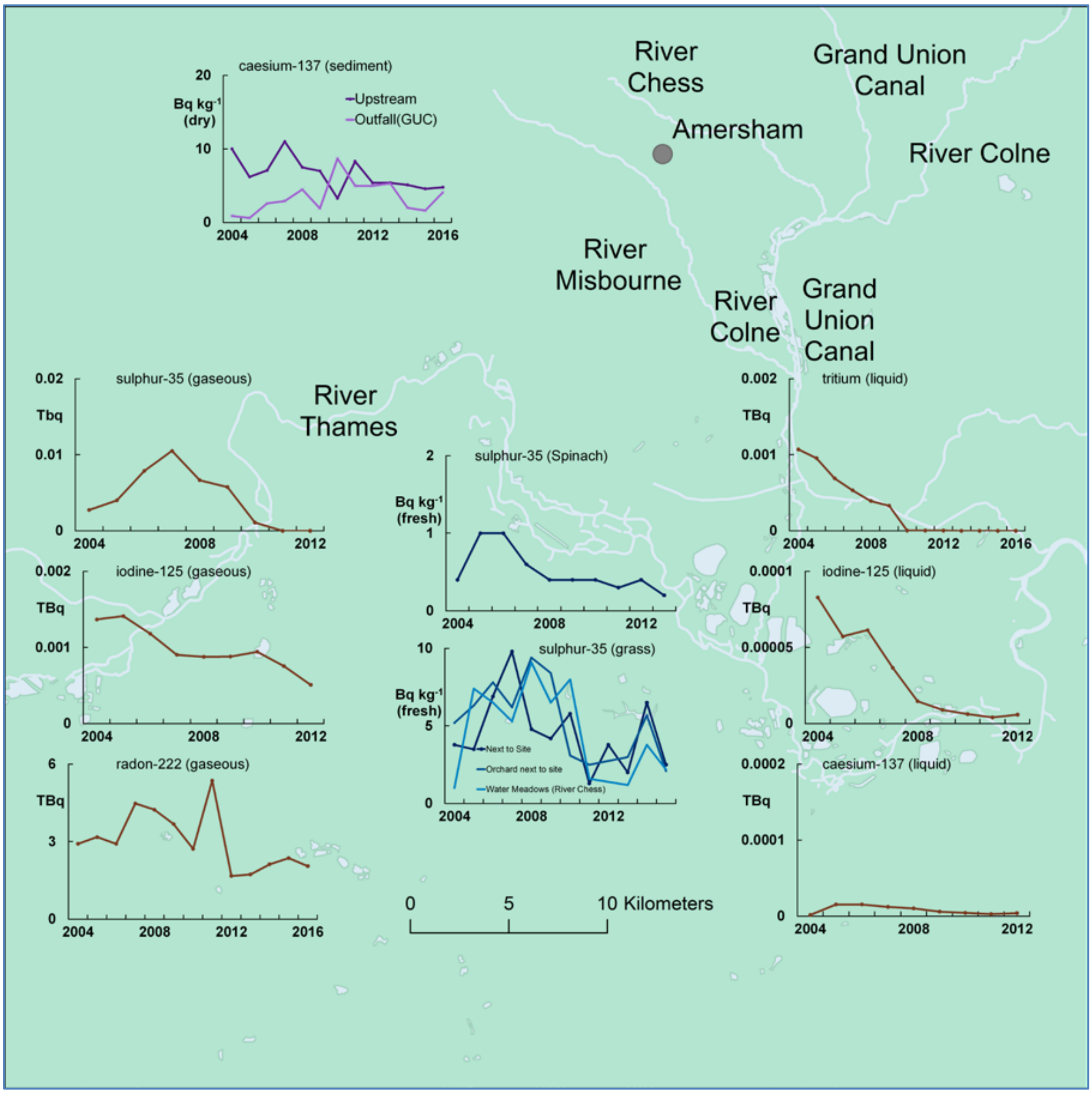

Figure 12.2 Authorised discharges of gaseous and liquid radioactive wastes and monitoring of the environment, Amersham (2004-2016)

12.3 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 (2004-2016) for a number of the permitted radionuclides. Gaseous and liquid discharges of all radionuclides declined over the period.

Figure 12.3 also provides monitoring trends of tritium, carbon-14 and caesium-137 in seafood and from three 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.

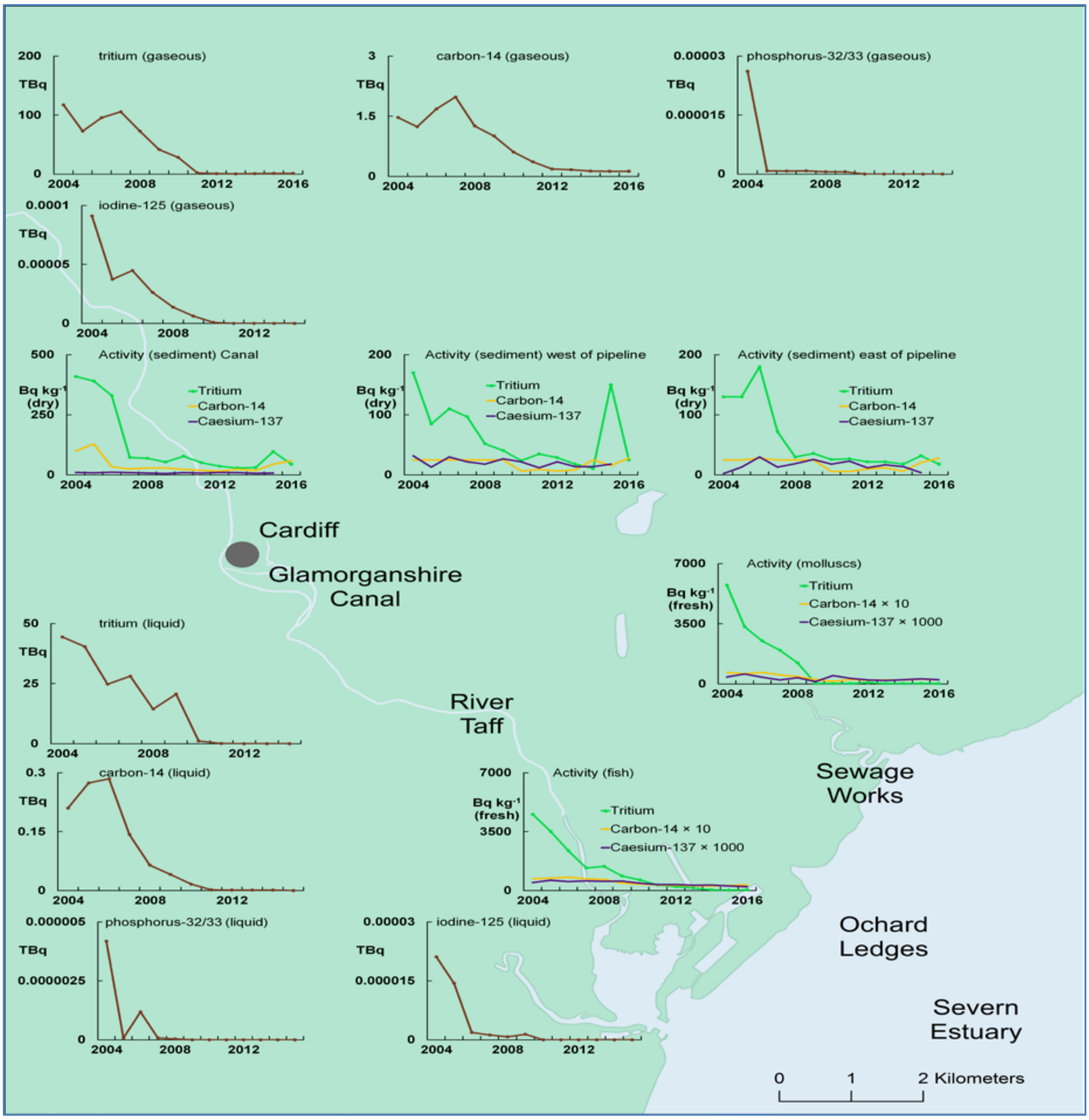

Figure 12.3 Discharges of gaseous and liquid radioactivity wastes and monitoring of the environment, Cardiff (2004-2016)

12.4 Summary

The information presented in Table 12.1 gives an overview of trends associated with doses, discharges and environmental concentrations described in Section 12.

Table 12.1 Summary of trend data for radiochemical production (2004-2016)*

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.

13. Summary and Conclusions

Information presented in Table 13.1 gives an overview of trends associated with discharges and environmental concentrations for each of the five nuclear sectors described in Sections 8-12.

Key points

- Discharge trends were downward in all five sectors.
- Trends of radionuclide concentrations in food and the environment were downward in four of the five sectors with no clear trends in the other sectors.
- Dose trends were downward in four of the five sectors.
- Doses at all sites were less than the dose limit, and in most cases, much less.

It was previously noted, over the period 2004–2008, discharges and environmental concentrations of radionuclides both showed a distinct decline in three of the five sectors (Environment Agency, FSA, NIEA and SEPA, 2010). However, during 2004–2008, environmental concentrations responded relatively slowly to these reductions, part due to the legacy of higher environmental concentrations of radionuclides from past higher discharges. Over the period 2004–2016 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 2004–2016.

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

Table 13.1 Overall summary for nuclear sectors (2004-2016)*

Sector		2004-2016 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**	Majority 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 *Site characteristics*

Nuclear fuel production and reprocessing

- **Table A1. Sellafield Site Characteristics**

Type of facility		Reprocessing Magnox and Oxide Fuels Processing and storage of wastes Clean-up of legacy wastes Special Nuclear Materials management Decommissioning and demolition. Research and Development				
Location		Cumbria				
Date commissioned		Calder Hall -1956 Windscale Piles – 1957 THORP – 1991 MOX – 2001				
Date of cessation of operation		Windscale Piles – 1957 Windscale WAGR – 1981 Calder Hall 2003 MOX – 2012 B205 Magnox reprocessing – in operation THORP – in operation				
Receiving waters and OSPAR catchment area		Irish Sea (OSPAR Region II)				
Volume of effluent discharged into the receiving waters		No information				
Installed electrical generation capacity, MW(e)		50 (per reactor)				
Tonnes of U processed annually		2012	2013	2014	2015	2016
	Magnox	393.7	499.3	435.5	436.2	508.5
	Oxide	213.8	287.3	411.3	397.5	532.2

- **Table A2. Capenhurst Site Characteristics**

Type of facility	Uranium enrichment by centrifuge
Location	Cheshire
Date commissioned	1976
Date of cessation of operation	n/a
Receiving waters and OSPAR catchment area	Rivacre Brook into Mersey Estuary (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed capacity (tonnes)	No information

Tonnes U product per year	2012	2013	2014	2015	2016
	Average of 665				

- **Table A3. Springfields Site Characteristics**

Type of facility	Production of fuel and intermediates (UF_6, UO_2 powder & pellets and AGR fuel)				
Location	Lancashire				
Date commissioned	1949				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	River Ribble (discharges into OSPAR region III)				
Volume of effluent discharged into the receiving waters	No information				
Installed capacity (tonnes)	6,000 MTU (UF_6 production)				
Annual production	2012	2013	2014	2015	2016
Tonnes U in product (UF_6)[1]	5300	5200	3300	0	0
Tonnes U in product (OFC)	450	500	500	550	550

[1] Operational to August 2014

Research and Development

- **Table A4. Dounreay Site Characteristics**

Type of facility	Various decommissioning research reactors
Location	Caithness
Date commissioned	1955
Date of cessation of operation	1994
Receiving waters and OSPAR catchment area	North Atlantic Ocean (OSPAR Region II)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	n/a
Annual electricity generation, GWh(e)	n/a

- **Table A5. Harwell Site Characteristics**

Type of facility	Nuclear power research and development site
Location	Oxfordshire
Date commissioned	1946
Date of cessation of operation	1990

Receiving waters and OSPAR catchment area	River Thames to Thames Estuary (OSPAR Region II)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	n/a
Annual electricity generation, GWh(e)	n/a

- **Table A6. Winfrith Site Characteristics**

Type of facility	Former nuclear research centre, Reactors all now closed
Location	Dorset
Date commissioned	Site opened in 1957, SGHWR commissioned in 1967
Date of cessation of operation	SGHWR closed in 1990. Last reactor shutdown in 1995
Receiving waters and OSPAR catchment area	English Channel (OSPAR region II)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	100 (SGHWR)
Annual electricity generation, GWh(e)	n/a

Nuclear Power generation

Operational sites

- **Table A7. Dungeness B Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)				
Location	Kent				
Date commissioned	1983				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	English Channel (OSPAR Region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1110				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	4079	4760	4388	6656	7700

- **Table A8. Hartlepool Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)

Location	Cleveland				
Date commissioned	1984				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	North Sea (OSPAR region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1210				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	8822	7007	5820	6168	6561

- **Table A9. Heysham 1 Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)				
Location	Lancashire				
Date commissioned	1984				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	Morecombe Bay and Irish Sea (OSPAR Region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1150				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	6641	6852	3847	4624	7589

- **Table A10. Heysham 2 Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)				
Location	Lancashire				
Date commissioned	1988				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	Morecombe Bay and Irish Sea (OSPAR Region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1250				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	9372	8813	10439	944	9581

- **Table A11. Hinkley Point B Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)
Location	Somerset

Date commissioned	1976				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	Bristol Channel (OSPAR Region III)				
Volume of effluent discharged into the receiving waters	No Information				
Installed electrical generation capacity, MW(e)	1220				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	6274	7531	7843	7103	7262

- **Table A12. Hunterston B Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)				
Location	Ayrshire				
Date commissioned	1976				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	Firth of Clyde (OSPAR Region III)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1190				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	6891	7492	6630	7469	7880

- **Table A13. Torness Site Characteristics**

Type of facility	AGR Power Station (2 Reactors)				
Location	East Lothian				
Date commissioned	1988				
Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	North Sea (OSPAR Region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1250				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	8596	9311	8477	8666	9950

- **Table A14. Sizewell B Site Characteristics**

Type of facility	PWR Power Station (1 Reactor)
Location	Suffolk
Date commissioned	1995

Date of cessation of operation	n/a				
Receiving waters and OSPAR catchment area	North Sea (OSPAR Region II)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	1188				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	9346	8715	8828	10507	8627

- **Table A15. Wylfa Site Characteristics**

Type of facility	Magnox Power Station (2 Reactors)				
Location	Anglesey				
Date commissioned	1971				
Date of cessation of operation	2015				
Receiving waters and OSPAR catchment area	Irish Sea (OSPAR Region III)				
Volume of effluent discharged into the receiving waters	No information				
Installed electrical generation capacity, MW(e)	980				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	3718	3649	1594	3266	n/a

Decommissioning Sites

- **Table A16. Berkeley Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Gloucestershire
Date commissioned	1962
Date of cessation of operation	1989
Receiving waters and OSPAR catchment area	River Severn (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	300
Annual electricity generation, GWh(e)	n/a

- **Table A17. Bradwell Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Essex
Date commissioned	1962
Date of cessation of operation	2002
Receiving waters and OSPAR catchment area	Blackwater Estuary (OSPAR Region II)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	246
Annual electricity generation, GWh(e)	n/a

- **Table A18. Chapelcross Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Dumfriesshire
Date commissioned	1959
Date of cessation of operation	2004
Receiving waters and OSPAR catchment area	Solway Firth (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	196
Annual electricity generation, GWh(e)	n/a

- **Table A19. Dungeness A Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Kent
Date commissioned	1995
Date of cessation of operation	2006
Receiving waters and OSPAR catchment area	English Channel (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	550

Annual electricity generation, GWh(e)	n/a

- **Table A20. Hinkley A Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Somerset
Date commissioned	1964
Date of cessation of operation	2000
Receiving waters and OSPAR catchment area	Bristol Channel (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	470
Annual electricity generation, GWh(e)	n/a

- **Table A21. Hunterston A Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Ayrshire
Date commissioned	1964
Date of cessation of operation	1990
Receiving waters and OSPAR catchment area	Firth of Clyde (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	n/a
Annual electricity generation, GWh(e)	n/a

- **Table A22. Oldbury Site Characteristics**

Type of facility	Magnox Power Station (decommissioning from Feb 2012)
Location	Gloucestershire
Date commissioned	1967
Date of cessation of operation	(Feb) 2012
Receiving waters and OSPAR catchment area	Severn Estuary (OSPAR Region III)
Volume of effluent discharged into the receiving waters	No information

Installed electrical generation capacity, MW(e)	434				
Annual electricity generation, GWh(e)	2012	2013	2014	2015	2016
	215	n/a	n/a	n/a	n/a

- **Table A23. Sizewell A Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Suffolk
Date commissioned	1965
Date of cessation of operation	2008
Receiving waters and OSPAR catchment area	North Sea (OSPAR Region II)
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	580
Annual electricity generation, GWh(e)	n/a

- **Table A24. Trawsfynydd Site Characteristics**

Type of facility	Decommissioning Magnox Power Station
Location	Gwynedd
Date commissioned	1965
Date of cessation of operation	1993
Receiving waters and OSPAR catchment area	Lake Trawsfynydd
Volume of effluent discharged into the receiving waters	No information
Installed electrical generation capacity, MW(e)	500
Annual electricity generation, GWh(e)	n/a

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Appendix 3 *Acronyms*

AGR	Advanced Gas-cooled Reactor
ALARA	As Low As Reasonably Achievable
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
BSS	Basic Safety Standards
BSSD	Basic Safety Standards Directive
C&M	Care and Maintenance
CEA	Commissariat à l'énergie atomique
CEC	Commission of the European Communities
CHILW	Contact Handled Intermediate Level Waste
CNS	Capenhurst Nuclear Services Limited
COMARE	Committee on Medical Aspects of Radiation in the Environment
COS	Carbonyl Sulphide
DAERA	Department of Agriculture Environment and Rural Affairs
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DETR	Department of the Environment, Transport and the Regions
DF	Decontamination Factor
DFR	Dounreay Fast Reactor

DPAG	Dounreay Particles Advisory Group
DSRL	Dounreay Site Restoration Limited
EA	Environment Agency
EARP	Enhanced Actinide Removal Plant
EARWG	Environment Agency Requirements Working Group
EBR2	Experimental Breeder Reactor II
EC	European Commission
EDF	Electricité de France
EIA	Environmental Impact Assessment
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
GDA	Generic Design Assessment
GDF	Geological Disposal Facility
GE	General Electric
GES	Good Environmental Status
GSA	General Site Areas
HLW	High Level Waste (waste containing >4 GBq α and/or 12 GBq β/γ and with heat generating properties).
HPA	Health Protection Agency

HSE	Health and Safety Executive
HVLA	High Volume Low Activity
IAEA	International Atomic Energy Agency
ICRP	International Commission for Radiological Protection
ILW	Intermediate Level Waste (as for HLW but not heat generating)
ISO	International Standards Organisation
KMEI	Key Marine Environmental Indicators
LLW	Low Level Waste (<4 GBq α and/or 12 G Bq β/γ)
LLWR	Low Level Waste Repository
LWR	Light Water Reactor
Magnox	Magnox Reprocessing Plant
MCERTS	Environment Agency Monitoring Certification Scheme
MoD	Ministry of Defence
MOX	Mixed Oxide Fuel
NDA	Nuclear Decommissioning Authority
NIEA	Northern Ireland Environment Agency
NNL	National Nuclear Laboratory
NRW	Natural Resources Wales
NWDRF	Nuclear Waste and Decommissioning Research Forum
ONR	Office for Nuclear Regulation
OSPAR	Oslo and Paris Convention
PFR	Prototype Fast Reactor
PARCOM	Paris Commission
PHE	Public Health England

PRAG (D)	Particles Retrieval Advisory Group (Dounreay)
PWR	Pressurised Water Reactor
QA	Quality Assurance
R&D	Research and Development
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
UKAEA	UK Atomic Energy Authority
UKAS	United Kingdom Accreditation Service
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UOC	Uranium Ore Concentrate
UUK	Urenco UK
WAGR	Windscale Advanced Gas-cooled Reactor
YP	Ystradyfodwg and Pontypridd

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