air

EA RADIOACTIVE SUBSTANCES

water

sediment

Radioactivity in the Environment

Report for 1998

A Summary and Radiological Assessment of the Environment Agency's Monitoring Programmes

ENVIRONMENT AGENCY

Forward

The Radioactive Substances Act 1993 provides for controls to be exercised over the keeping and use of radioactive materials and, in particular, on the accumulation and disposal of radioactive wastes. The Environment Agency is responsible for administering and enforcing the act in England and Wales. In support of these regulatory functions and as part of the UK Government's arrangements for providing information to the European Commission under the Euratom Treaty, the Agency commissions independent monitoring of radioactive waste disposals and their impact on the environment, and monitoring of radioactivity in air, rainwater and sources of drinking water.

This report presents the data from these monitoring programmes and comments on their radiological significance. It includes assessments of radiation exposure of members of the public for compliance with the annual dose limit recommended by the International Commission on Radiological Protection. Concentrations of radioactivity in water are also assessed against screening values given in the World Health Organisation guidelines on drinking water quality.

This report for 1998 is one of an annual series published by the Agency. It is being distributed to local authorities as part of the arrangements under the Radioactive Substances Act 1993 for access to environmental information.

The monitoring programmes and preparation of this report are managed by the Agency's National Compliance Assessment Service*.

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Front cover: radiation dose rate monitoring at Ehen Spit, near Sellafield (Dick McReddie, FRPS)

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Executive Summary

The Environment Agency has wide-ranging responsibilities and powers to protect and, where necessary, improve the environment in England and Wales. The Agency is guided by its duty to protect the environment in a way that works towards sustainable development. This involves meeting the needs of the present without compromising the ability of future generations to meet their own needs. One of the Agency's functions is to administer and enforce the Radioactive Substances Act 1993 (RSA 93) in England and Wales. In this role, the Agency seeks to secure continuous improvement in the protection of the public and the environment. During 1998, the OSPAR strategy for radioactive substances was agreed at Sintra, Portugal with the objective of preventing pollution of the North East Atlantic maritime area through progressive and substantial reductions in discharges, emissions and losses of radioactive substances. The Environment Agency will be setting authorisations to discharge radioactive waste within the context of this strategy.

Radiological monitoring programmes are carried out in support of the Agency's regulatory functions under RSA 93 and as part of the UK Government's obligations under the Euratom Treaty. This report presents the results of the Environment Agency's regular monitoring of radioactivity in the environment during 1998 and an assessment of the radiological impact. From time to time, the Agency carries out more detailed studies to investigate areas where enhanced levels of radioactivity in the environment were detected. Two such studies, carried out in 1998, were:

- **Contaminated feral pigeons around Sellafield.** An investigation was carried out into the implications of contaminated feral pigeons congregating in large numbers at a bird sanctuary. Measures were taken to reduce contamination of the pigeons and to remove existing contamination around the houses where the pigeons had gathered. Environmental monitoring in the area has been changed to ensure quick detection of any recurrence.
- **Tritium levels in the Severn Estuary near Cardiff.** Higher-than-expected concentrations of tritium were confirmed in fish, shellfish and sediments near the discharge outfall from the Nycomed Amersham Plant near Cardiff.The radiological implications of the tritium levels were investigated and found to be well below dose limits. The operator was required to reduce plant discharges of aqueous tritium waste as a precaution and is making increased use of recycling and waste minimisation techniques.

The regular monitoring and assessment programme conducted during 1998 was substantially extended as monitoring previously undertaken by the Ministry of Agriculture, Fisheries and Food (MAFF) was transferred to the Agency. The main findings during 1998 were as follows:

- **Radioactivity in liquid and solid wastes from nuclear sites.** Monitoring showed that the majority of levels were being assessed accurately or were being over-estimated by the disposers.
- **Radioactivity in water and sediments around nuclear sites, larger non-nuclear and landfill sites.** Radioactivity levels (both radiation dose-rates and concentrations of radionuclides) were generally consistent with those reported in previous years, with no clear trend. Enhanced levels of artificial radionuclides were found in coastal sediments near Sellafield, declining with increasing distance from the site. Radioactivity levels around other major sites were mostly low or not detectable.
- **Radioactivity levels in air, rainwater and drinking water sources.** Airborne dust and rainwater were sampled continuously at seven locations throughout the UK. As in previous years, concentrations of the radionuclides analysed were very low or undetectable. Samples of water from more than 30 reservoirs, rivers and boreholes were provided by the water companies. The water from all sources, except one in Derbyshire, were consistently well below WHO drinking water guidance levels. Enhanced radioactivity levels in the Derbyshire water are due to the local geology, and were insignificant radiologically.

Doses received by members of the public from drinking water and occupation of beaches, riverbanks and inter-tidal areas around nuclear and major non-nuclear sites have been assessed. In all cases, doses were less than the annual dose limit of 1,000 μSv. Houseboat dwellers on the Ribble Estuary received the highest annual doses of between 100 and 175 μSv. On the Cumbria coast, annual doses were between 5 and 45 μSv, similar to previous years. Elsewhere, annual doses were 1 μSv or less.

Introduction

1.1

The Environment Agency has wide-ranging responsibilities and powers to protect and, where necessary, improve the environment in England and Wales. The Agency is guided by its duty to protect the environment in a way that works towards sustainable development. This involves meeting the needs of the present without compromising the ability of future generations to meet their own needs.

1.2

One of the Agency's functions is to administer and enforce the Radioactive Substances Act 1993 (RSA 93) in England and Wales. In this role, the Agency seeks to secure continuous improvement in the protection of the public and the environment. Discharges of radioactive wastes to the environment may be made (subject to certain Crown exemptions) only in accordance with authorisations issued under RSA 93.

1.3

In support of regulation under RSA 93, the Agency commissions independent monitoring of radioactive waste discharges and assesses their impact on the environment. This report provides a comprehensive summary and radiological assessment of the monitoring results for the 1998 programme. In accordance with a Direction from Government, copies of the report are sent to each local authority in England and Wales so that it can be seen by the public.

2

Background

2.1

The statutory objectives of the Environment Agency are to implement properly a policy and regulatory framework, developed and maintained by the Government, which ensures that:

- radioactive wastes are not created unnecessarily;
- wastes created are managed and treated safely and appropriately;
- those wastes are then safely disposed of appropriately so as to safeguard the interests of existing and future generations and the wider environment, and in a manner that commands public confidence and takes due account of costs.

2.2

These objectives are secured by:

- informing and influencing those who use radioactive substances and create radioactive waste;
- securing high-quality management of radioactive waste in industry;
- enforcing regulations in a systematic and nationally consistent way that weighs both economic and environmental factors, and that allows business to meet the needs of the present without compromising those of the future;
- ensuring that any proposals for solid radioactive waste disposal will provide the necessary high level of protection for people and the environment;
- commissioning research into the potential effects of radioactive wastes entering the environment.

2.3

The Agency authorises radioactive waste discharges from the following:

- **Nuclear licensed sites** – In England and Wales there are more than 30 sites licensed under the Nuclear Installations Act 1965 ('nuclear licensed sites'). They include nuclear power stations, facilities for nuclear fuel manufacture, reprocessing and waste disposal, research, manufacture of radioactive sources and for defence (manufacture, maintenance and decommissioning of weapons and construction, refuelling and refitting of nuclear powered submarines). The major nuclear sites are shown in Figure 1.
- **Non-nuclear sites** – During 1998 there were 861 non-nuclear premises in England and Wales authorised to accumulate and dispose radioactive wastes. The majority consisted of hospitals, universities and industrial, research or manufacturing centres. Details of these authorisations can be viewed at the relevant Agency and local authority offices.

2.4

Discharges from nuclear sites are generally more radiologically significant than those from non-nuclear sites. As well as specifying numerical limits, in authorisations, on the amounts of radioactivity which may be discharged as waste to the environment, the Agency requires nuclear site operators to employ the best practicable means (BPM) to limit the radioactive content of discharges.

2.5

The Agency also requires nuclear site operators to carry out appropriate monitoring of their discharges and the environment near their sites to demonstrate the effectiveness of these controls. Detailed results of the nuclear site operators' monitoring can be viewed at the relevant Agency and local authority offices. A summary of the data on discharges to the environment is presented in Table 1. Further details can also be found in the annual reports published by the nuclear site operators.

2.6

Premises occupied on behalf of the Crown for defence purposes (but not sites managed by defence contractors) are exempt from the requirements of RSA 93. In these cases, discharges are made in accordance with approvals that apply the same standards as authorisations.

2.7

During 1998 there were a number of significant developments affecting the Agency's regulation of

Figure 1 Major nuclear sites

radioactive substances. These included:

- the OSPAR discharge strategy;
- consideration of applications from British Nuclear Fuels plc (BNFL) Sellafield for the operation of a Mixed Oxide Fuel (MOX) plant and applications for variations to the site's discharge authorisations;
- consideration of applications from BNFL for the merger of Magnox Electric;
- consideration of applications for new discharge authorisations for the defence sites at Aldermaston and Burghfield;
- development of regulatory policy on disposals of large numbers of "EXIT" signs containing gaseous tritium light devices (GTLDs) and;
- initiation of research into protection of non human species from radiation exposure.

OSPAR discharge strategy

2.8

In July 1998, the OSPAR strategy for radioactive substances was agreed by Ministers of the signatory countries (known as 'contracting parties') at Sintra, Portugal. The objective of this strategy is to prevent pollution of the North East Atlantic maritime area through progressive and substantial reductions in discharges, emissions and losses of radioactive

substances. The ultimate aim is to achieve, by the year 2020, additional concentrations in the marine environment, above historic levels, which are "near background" for naturally occurring radioactive substances and "close to zero" for artificial radioactive substances.

2.9

Legitimate uses of the sea, technical feasibility and radiological impacts on man and biota are among the issues that are to be taken into account in achieving this objective. To implement the Sintra agreement, the UK Government intends to develop and publish for consultation a national radioactive discharge strategy. Discharge authorisations and variations to them will be set within the context of this national strategy. With its emphasis on environmental concentrations, the OSPAR agreement will mean that environmental monitoring for radioactivity, and reports such as this Agency report, will assume greater importance.

Sellafield authorisations

2.10

British Nuclear Fuels plc submitted applications for the operation of the Mixed Oxide Fuel (MOX) plant and variation of authorisations to dispose of liquid and gaseous wastes from Sellafield in November 1996. In November 1998, after public consultation, the Agency published its proposed decisions on the variations and the "justification" for the operation of the MOX plant.

2.11

Justification entails weighing the benefits of a practice against its detriments. In reaching its proposed decision on justification for MOX, the Agency weighed the radiological and other detriments against the economic benefit of operating the plant, based on an application made after capital cost of £300m had been incurred. The Agency's decision on the application to vary the gaseous and liquid authorisations proposed reductions in discharge limits for technetium-99, carbon-14, tritium, ruthenium-106 and iodine-129. It also requires BNFL to accelerate the introduction of additional abatement technology. The Agency announced its proposed decisions in October 1998, and passed them to the Department of Environment, Transport and the Regions (DETR) and Ministry of Agriculture, Fisheries and Food (MAFF) Ministers for their consideration. In November 1999, Ministers endorsed the Agency's decisions on the variations, and asked it to begin a full review of the authorisations, which is currently underway.

BNFL / Magnox merger

2.12

In January 1998, BNFL submitted 32 applications for authorisation of radioactive waste disposals from the six operational and two decommissioning Magnox nuclear stations in England and Wales. These are currently managed by Magnox Electric plc. New authorisations are a prerequisite for the merger of Magnox Electric into BNFL.

2.13

In determining these applications, the Agency must consider whether continued operation/continued decommissioning of each station is justified, as well as reviewing the limits and conditions in the authorisations.

2.14

The Agency has made several requests for additional information from BNFL. It is preparing documents for public consultation, which will begin in spring 2000.

Aldermaston and Burghfield authorisations

2.15

The contract let by the Ministry of Defence for management of the Aldermaston and Burghfield sites finishes at the end of March 2000, and the Agency has begun determining applications for new authorisations for the sites. The Agency considered these applications and during 1999 held public meetings as part of a public consultation exercise.

Environmental radiation protection

2.16

At present there are no quantitative standards or criteria that provide for protection of species other than humans in the environment, from the impact of incremental radiation exposure. However, Government policy as set out in the Environment Act 1995 requires that radioactive wastes should be managed and disposed of in a manner that provides for the protection of the environment, both now and in the future, in order to meet the objective of sustainable development.

2.17

To address this issue, the Agency has begun a collaborative project with MAFF to study the environmental impact of radioactive discharges on non-human species and is participating in international working groups studying the effects of ionising radiation on flora and fauna. The Agency and seven European partner organisations began preparing a proposal for research to the European Commission. The three year work programme, called FASSET, will lead to a

3

The Agency's monitoring programme

3.1

This chapter outlines the monitoring programme carried out by the Agency. The results of the programme are described in chapter 6.

3.2

The Agency commissions independent monitoring of the authorised discharges of radionuclides to the environment, to provide a check on the monitoring carried out by site operators. In addition, the Agency conducts a comprehensive monitoring programme of radioactivity in the environment resulting from authorised discharges. This environmental monitoring programme also provides an independent assessment of the exposure of the public from non-food pathways. During 1998 the Agency's monitoring programme consisted of:

- monitoring of liquid effluents from nuclear licensed sites;
- quality checking of low-level solid radioactive waste;
- environmental monitoring around nuclear and larger non-nuclear sites;
- environmental monitoring around landfill sites that receive radioactive waste.

3.3

During 1998, the Agency significantly increased its regular environmental monitoring and assessment programme to reflect the transfer of responsibility for non-food pathways from MAFF to the Agency.

3.4

The Agency does not carry out monitoring for radioactivity in foods. In England and Wales, MAFF is responsible for monitoring radioactivity in food, and it carries out a separate surveillance programme complementary to the Agency's programme. A summary of the MAFF programme is published annually[1]. MAFF's responsibilities for monitoring radioactivity in food will pass to the Food Standards Agency after April 2000.

3.5

As well as commissioning its own monitoring, the Agency manages the following programmes on behalf of DETR:

- radioactivity in air and rainwater;
- radioactivity in drinking water sources.

3.6

Together with the Agency's regulatory monitoring, these results form part of the UK Government's arrangements for meeting its obligations under the Euratom Treaty to monitor radioactivity in air, soil and water and to provide data periodically to the European Commission.

3.7

The Agency commissions additional monitoring programmes and assessments from time to time, as needed. During 1998, four programmes were initiated:

- contaminated feral pigeons in Seascale;
- enhanced tritium levels in the Severn Estuary near to Cardiff;
- seawashed turf from the coastal areas of the North East Irish Sea;
- releases of radioactivity from coal-fired power stations

Effluent monitoring

3.8

The Agency requires operators of nuclear licensed sites to provide samples of their liquid effluents for independent radiochemical analysis. The results provide checks on site operators' returns and insights into their quality assurance (QA) procedures and analytical techniques. The sampling consisted of either single-spot samples, or monthly or quarterly bulked samples, as appropriate. During 1998, 266 samples were analysed, resulting in the reporting of results for nearly 1,300 determinands. During 1998 the analyses were undertaken by the Laboratory of the Government Chemist (LGC) at its laboratories in Teddington, Middlesex, using analytical methods that are mostly accredited by the UK Accreditation Service (UKAS). Details of the methods of analysis are given in Appendix 1.

framework for the assessment of the environmental impact of radioactive discharges on non-human biota and ecosystem functions. The work is expected to start in 2000.

Disposal of exit signs containing gaseous tritium light devices (GTLDs)

2.18

At the end of 1998, safety regulations came into force that could result in the mass disposal of 'Exit' and 'Fire Exit' signs. Many of these are self-luminous and contain radioactive tritium in sealed glass tubes. Incorrect disposal with commercial or domestic refuse may lead to radioactive contamination, for example in landfill leachate. Section 6.7 of this report indicates a number of landfill sites that have elevated levels of tritium in leachate.

2.19

GTLDs are currently exempt from the requirement for registration under RSA 93. The Agency has pointed out this deficiency and the exemption order is being reviewed by DETR. In the interim, the Agency has issued a press notice warning that redundant devices should be returned to an authorised disposal contractor. Improper disposal may result in prosecution.

Waste quality checking

3.9

Independent checks are also carried out on solid low-level radioactive waste destined for land disposal at the site operated by British Nuclear Fuels plc (BNFL) at Drigg in Cumbria. Consignments of waste are seized by inspectors and sent to the Agency's Waste Quality Checking Laboratory (WQCL) at Winfrith in Dorset. The results provide checks on the descriptions and radioactive contents of wastes declared by site operators and insights into their quality assurance and monitoring procedures. During 1998, staffing and operation of the laboratory was carried out by NNC Limited.

3.10

In 1998, two consignments of waste were examined at WQCL. The laboratory's analytical methods are accredited by the UKAS and are summarised in Appendix 2. Further details of these and other methods employed during destructive examination are presented in a separate report[2]. One of the techniques used is real time X-ray scanning to examine the contents of drummed waste (see Figure 2).

Figure 2
Real time X-ray scanning of a waste drum at WQCL

Environmental monitoring

3.11

The Agency undertakes a programme of monitoring of radioactivity in the environment, where the radioactivity could lead to exposure of the public from non-food pathways, for example, the occupation of beaches, river banks or other areas. The programme consists of surveys of gamma dose rates and contact beta/gamma dose rates at specified locations, and laboratory analysis of radionuclide concentrations in environmental samples taken from specified locations near nuclear sites and other industrial premises. Samples were also taken from surface waters, some of which are used as sources of drinking water.

3.12

During 1998 all the regular environmental monitoring was carried out by the Synetix Group of ICI Chemical and Polymers Ltd (formerly known as Tracerco), in accordance with Agency specifications. The majority of the methods employed were accredited by UKAS.

3.13

The selection of sampling or measurement points was based on a combination of factors, including measured dose rates and the occupancy of the areas. The principal nuclear sites around which the majority of monitoring was concentrated are shown in Figure 1.

3.14

Samples were normally taken quarterly and analysed by gamma ray spectrometry and, in some cases, chemical extraction and separation followed by beta counting or alpha spectrometry. During 1998 the collection of approximately 630 samples resulted in the reporting of 5,750 determinands.

3.15

Most of the samples were taken and analysed individually, except for samples of water taken from the Thames valley near the nuclear licensed sites of Harwell, Aldermaston and Amersham. These were taken at weekly intervals over 13-week periods and bulked before analysis.

3.16

Measurements of gamma dose rates above beach and river bank areas were made by measuring the absorbed dose rate in air ($\mu Gy\ h^{-1}$) one metre above ground. A Mini-Instruments Environmental Meter type 6-80 fitted with an energy-compensated Geiger-Muller tube type MC-71 was used for this purpose. More than 150 locations were monitored during the year.

Figure 3 Air and rainwater monitoring sites

3.17

Contact beta/gamma monitoring of debris at the most recent strand line on the beach or river bank was also carried out. A Mini-Instruments series 900 mini monitor with a beach monitoring probe was used for this purpose. Any item found with an activity level in excess of 100 cps (taken to be equivalent to 0.01 mSv h^{-1}) would be removed to Synetix's laboratory for further investigation. During 1998, two items were found and removed from the coastal area near Sellafield (paragraph 6.1.5).

Air and rainwater

3.18

Routine measurements of radioactivity in air and rainwater have been carried out for many years. The results provide information on the activity concentrations of radionuclides in air and the levels of radioactivity deposited in rainwater. A detailed description of the programme and the results are published annually[3]. The results are provided to DETR for submission to the European Commission under Article 36 of the Euratom Treaty.

Figure 4 Drinking water sampling sites

3.19

During 1998 this sampling and analysis was undertaken by AEA Technology's National Environmental Technology Centre using methods, most of which are accredited by UKAS. Airborne particulate material was sampled continuously at seven locations at about one metre above ground level. Filters were changed each day at Chilton (Oxfordshire), and each week at Aberporth (Dyfed), Conlig (Co. Down, NI), Dishforth (Yorkshire), Eskdalemuir (Dumfrieshire), Lerwick (Shetland) and Orfordness (Suffolk). Sites are shown in Figure 3.

3.20

All air and rainwater samples were analysed quarterly by gamma-ray spectrometry. Monthly analysis was carried out on air and rain samples from Chilton. Where appropriate, additional samples were also analysed for tritium and/or plutonium and americium. A summary of the analytical methods is given in Appendix 4 and further details can be found elsewhere[4].

Drinking water sources

3.21

Regular monitoring of radioactivity in water sources (rivers, reservoirs and boreholes) used for the supply of drinking water has also been carried out for many years[5]. During 1998 the water companies provided samples of water for analysis by AEA Technology using methods that are mostly accredited by UKAS. The results provide information to the water companies on the activity concentrations of radionuclides in raw water sources and supplementary data to the Agency on exposure of the public. These results are also provided to DETR for submission to the European Commission under Article 36 of the Euratom Treaty.

3.22

Samples of water were taken from 32 sources almost daily, and bulked over three-month periods to provide "quarterly bulks" for analysis. The locations are shown in Figure 4.

3.23

The samples were analysed for total alpha and total beta activities and a range of specific radionuclides. Further details of the analytical methods are given in Appendix 5.

Additional monitoring and assessment programmes

3.24

Contaminated feral pigeons. Feral pigeons contaminated with radioactive material were identified in the village of Seascale (3km south of the Sellafield nuclear site). The pigeons were congregating at a private address with a small bird sanctuary. Work was commissioned in 1998 to identify affected areas and assess the radiological implications. The work was completed during 1999.

3.25

Enhanced levels of tritium in the Severn Estuary near Cardiff. Higher-than-expected concentrations of tritium were found in bottom-dwelling fish caught near the marine liquid effluent outfall from the Nycomed Amersham Plant at Cardiff. During 1998 and 1999, additional monitoring was carried out around the plant and a reassessment of the radiation doses to members of the public was carried out. As a result of the study, the environmental monitoring programme for tritium was extended during 1999 to provide assurance about tritium levels in the environment around other major sites. The results of this additional monitoring activity will be given in the 1999 Radioactivity in the Environment report.

3.26

Seawashed turf. Seawashed land at the margins of the Irish Sea contains a range of radionuclides resulting from historical authorised discharges to the Irish Sea from Sellafield. The last major review of the radiological implications of the cutting of seawashed turf was conducted a number of years ago[6,7]. In 1998, the Agency initiated a further review to provide up-to-date information. A programme of monitoring and an assessment of the radiological implications has begun.

3.27

Coal-fired power stations. Emissions from coal-fired power stations are routinely measured under the Integrated Pollution Control monitoring programme. During 1998, radionuclide levels in the emissions and their implications were also assessed.

Contracting arrangements

3.28

NNC Limited undertook the preparation of this report and Synetix, LGC, NNC and AEA Technology carried out the routine monitoring programmes.

Radiation protection standards

4.1

The radiation protection standards against which the exposures of the public in the UK are judged are set out in the White Paper[8] Cm 2919. Current UK practice is based on the recommendations of the International Commission on Radiological Protection (ICRP), as set out in Publication 60[9] and endorsed by the National Radiological Protection Board (NRPB)[10,11].

4.2

Cm 2919 confirms that radiation doses to the public in the UK from controlled sources should be limited to 1 mSv per year. This limit excludes occupational and medical exposures, and exposure from natural radiation sources. The annual dose limit of 1 mSv should be compared with the sum of the relevant doses over a given year from external exposure and internal exposure from intakes of radionuclides (50 year committed effective doses for adults or up to 70 years committed effective doses for children). For convenience, the sum of the relevant doses is termed 'effective dose' in this report.

4.3

The ICRP also introduced the concept of dose constraint for use in optimisation of protection. When determining applications for authorisations, the Government has accepted that the dose constraint for a single new source should not exceed 0.3 mSv per year and that in general it should be possible for existing plant to be operated within this constraint. Where the constraint cannot be met for existing plant, the operator must demonstrate that the doses resulting from the continued operation of the facility are as low as reasonably achievable (ALARA) and within dose limits. In addition, a "site constraint" of 0.5 mSv per year should apply to the aggregate exposure as a result of discharges from a number of sources with contiguous boundaries at a single location, irrespective of whether different sources on the site are owned or operated by different organisations.

4.4

In practice, the total exposure when estimated from measurements of radiation dose rates and levels of radionuclides in the environment will contain contributions both from current discharges and those that occurred in earlier years, and may also contain contributions from more than one site. Consequently, wherever measured results in this report have been used to estimate the average effective dose to representative members of a critical group, they are compared with the dose limit of 1 mSv per year. For comparison with the average dose from background radiation, see paragraph 5.17.

4.5

For external irradiation, the ICRP further recommends dose limits for individual organs to avoid specific detrimental effects. For members of the public the recommended annual dose limit for irradiation of the skin is 50 mSv and for the lens of the eye 15 mSv.

5 Presentation and assessment of results

SI units and methodology

5.1

Throughout this report, data are presented using the Systeme Internationale (SI) radiological units recommended for use in the UK by the British Committee on Radiation Units and Measurements[12]. The majority of environmental monitoring results, whether liquid or solid, are expressed in activity per unit mass, using the units of Becquerels per kilogramme (Bq kg^{-1}). One kilogramme of water can be considered to have a volume of one litre, within the accuracy of the reported results. Results of environmental monitoring are expressed in other units in the report where this enables comparison with national or international standards. The units used for effective dose (see chapter 4) are milliSievert or microSievert per year (mSv y^{-1} or µSv y^{-1}). Environmental monitoring of external dose rates are expressed as milliGrays or microGrays per hour (mGy h^{-1} or µGy h^{-1}). The approximate numerical relationship between Gy and Sv used is given in paragraph 5.14.

5.2

Methods of sampling and measuring of environmental materials were designed to ensure that any radionuclide would be measured if it were present at sufficient concentration to contribute significantly to the radiation dose to members of the public. Where concentrations were below the limit of detection, zero values have been assumed for the purpose of estimating doses. The alternative is to calculate total dose corresponding to the detection limits. This has not been carried out, as the result would generally be no more than one per cent of the recommended dose limit of 1 mSv y^{-1}.

Assessment of results

Effluent analysis

5.3

The results of effluent analyses undertaken by site operators and by LGC are compared. Where differences greater than 10 per cent (for tritium) and 30 per cent (for all other radionuclides) are observed they are investigated. Meetings of analysts are convened to discuss the differences and, as necessary, further analytical investigations are carried out.

Quality checking of solid radioactive waste

5.4

The results of the analysis are used to check that consignments of waste comply with conditions specified in the consignor's authorisation, the declaration of contents made by the consignor, and with conditions in BNFL's authorisation for disposal of the waste at its site at Drigg. Where non-compliance is indicated, site inspectors take appropriate action.

Radiological effects of environmental radioactivity

5.5

The method of assessing the impact of environmental radioactivity is based on estimation of the effective dose resulting from external radiation and the committed effective dose (CED) from inhalation and/or ingestion, according to the recommendations of ICRP 60[9]. The CED provides an estimate of the risk to an exposed person, making allowances for the residence time of radionuclides in the body, the distribution of radiation dose between different organs of the body and the nature of the radiation. It represents the risk due to the total dose predicted to result from an intake of radionuclides up to the age of 70 years. In general, the terminology used in this report is that defined for use with ICRP 60. The estimation of dose is facilitated by the use of values published by ICRP[13] of the CED predicted to result from a unit intake of each radionuclide occurring at ages one year, 10 years or adult (assumed to be 20 years old).

5.6

The monitoring results are assessed by estimating the effective dose to members of critical groups of the public. Critical groups consist of those individuals whose habits (for example, recreational) make them likely to be the most exposed. Each critical group consists of people of broadly similar habits, so that their radiation exposures can be estimated on the basis of representative information. Exposure to radiation due to radionuclides in foods, whether terrestrial or seafood and whether produced commercially or during recreation, is evaluated by MAFF and is not included here. For the non-food pathways, the principal requirement for habit data is the occupancy of

areas where the public may be exposed to radioactivity in the environment resulting from discharges. The environmental monitoring results may also be compared with the screening values given in the World Health Organisation guidelines on drinking water quality[14] and generalised derived limits[15] (GDLs) for air, sediments, freshwater and soils.

5.7

Habit data are kept under review by the Agency and are usually determined by surveys specific to the vicinity of nuclear establishments, or by the accumulation of observations over time. Where specific occupancy data[16, 17, 18, 19] are available they are used in the dose estimation. Where site-specific data are not available, the habit assumptions and occupancy data shown below, as published by the NRPB[20], are used in the assessments.

Ingestion

5.8

Ingestion of foodstuffs is assessed routinely by MAFF. For the purposes of this report, dose estimates are limited to ingestion of potable water and the inadvertent ingestion of non-potable water and sediments. Inadvertent ingestion of water can occur during bathing and when children are playing on beaches or the banks of rivers and streams.

5.9

Inadvertent ingestion of sediment may also occur on similar occasions. The ingestion rates assumed in the assessment are based on values recommended by the NRPB[20]. In this report it has been assumed that the ingestion occurs during an active period of 10 hours each day, which gives the hourly ingestion rates in the table below. Some children exhibit behaviour described as 'pica', which is the deliberate ingestion of soil and similar materials. This unusual behaviour is not included in this assessment.

5.10

The dose Dig due to radionuclide i resulting from ingestion can be calculated as

$$D_{ig} = C_{ij} H_{ig} g_j O_f \qquad (1)$$

Where:

C_{ij} is the concentration of radionuclide i in medium j (Bq kg^{-1})

H_{ig} is the effective dose coefficient of radionuclide i by ingestion (Sv Bq^{-1})

g_j is the consumption rate of medium j (kg h^{-1})

O_f is the occupancy factor (h y^{-1})

5.11

Water sources were also screened by measurement of total alpha and total beta activities for comparison with WHO screening values[14].

These are:

total alpha activity	0.1 Bq l^{-1}
total beta activity	1.0 Bq l^{-1}

They are based on consideration of the doses that would result for radium-226 and strontium-90 respectively. These were chosen by WHO as representative of the most radiotoxic radionuclides likely to be present in significant quantities. The values represent concentrations below which water can be considered potable without any further radiological examination.

5.12

In most cases, radiochemical analysis for tritium was also carried out. This is a low-energy beta-emitter, which would not be detected by the total beta measurements and is assessed separately using equation (1) above. Where appropriate, other radiochemical analyses were carried out to identify individual radionuclides. Additionally, water samples were analysed by gamma-ray spectrometry. In these cases, doses were also assessed using equation (1).

Inhalation

5.13

The air may contain dust and associated radioactivity raised from local surfaces by wind or other causes of disturbance. It has been estimated that the suspension of surface dusts will result in about 100µg of surface material in each m^3 of air[21]. The dose D_{ih} due to radionuclide i in sediment due to inhalation of re-suspended sediments is calculated as

$$D_{ih} = C_{is} C_{sa} C_m H_{ih} O_f \qquad (2)$$

Where:

C_{is} is the concentration of radionuclide i in sediment (Bq kg^{-1})

C_{sa} is the concentration of sediment suspended in air (kg m^{-3})

C_m is the volume of air inhaled per unit time (m^3 h^{-1})

H_{ih} is the effective dose coefficient by inhalation of radionuclide i (Sv Bq^{-1})

O_f is the occupancy factor (h y^{-1})

External radiation

5.14

The external radiation dose to members of the public is assessed directly from field measurements of the absorbed dose in air, made using the instruments described in

Occupancy and physiological data

Age group	Occupancy		Inhalation rates	Ingestion rates		
	Marine	River banks and lake shores		Drinking water	Inadvertent ingestion	
					Water	Sediment
Years	h y^{-1}	h y^{-1}	m^3 h^{-1}	l d^{-1}	ml y^{-1}	mg h^{-1}
1	30	30	0.216	0.7	50	50
10	30	500	0.648	0.95	100	10
Adult	300	500	0.828	1.65	100	5

paragraph 3.14. Three factors are considered in following this approach to estimating exposure to external radiation due to discharges from nuclear sites. Firstly, the monitoring instrument responds to background radiation as well as any radiation due to discharged radioactivity, and the back-ground radiation dose rate is subtracted. In the absence of site-specific information, the generic back-ground dose rates used for muddy and sandy substrates are 0.07 μGy h^{-1} and 0.05 μGy h^{-1} respectively[22]. Secondly, the effective dose to the whole body differs from the absorbed dose in air, and a factor of 0.86 Sv Gy^{-1} is used to convert the measured absorbed dose in air to the effective dose to the human body[23]. Finally, the appropriate occupancy factor is applied. The Agency's protocol for measurement, inter-pretation and reporting of external dose rates is described in Technical Guidance Note M5[24].

Background radiation

5.15

Background radiation includes contributions from:

(a) terrestrial radioactivity arising from the widespread distribution of naturally occurring uranium, thorium, their daughter products including radon, potassium-40 and minor contributions from other naturally occurring radionuclides;

(b) cosmic radiation;

(c) fallout of man-made radionuclides from nuclear weapon tests and from the Chernobyl accident.

5.16

Most radionuclides discharged in wastes from sites of interest do not occur naturally in significant quantities. Radionuclide-specific determinations can readily detect their presence in the environment. However, measurements of total alpha and beta activity and certain radionuclides may include contributions from discharges from one or more sites, radionuclides of natural origin, residues from weapons testing fallout and the Chernobyl accident.

5.17

In most cases, radiation exposures from natural radioactivity far exceed those from anthropogenic sources. The average annual effective dose to the UK population has been estimated by the NRPB[25] to be 2.6 mSv. Radiation of natural origin accounts for 87 per cent of the exposure and medical procedures for 12 per cent. Discharges of waste from nuclear establishments contribute less than 0.1 per cent.

Assessment of doses

5.18

Total effective dose due to the discharges from nuclear sites, via the pathways of external radiation, inhalation and ingestion, were estimated as described above. It is appropriate to compare these doses with the limit of 1 mSv y^{-1} recommended by the ICRP and adopted for application in the UK by the Government on the recommendation of the NRPB. In making the comparison it should be noted that the doses estimated here do not include direct external radiation from nuclear plants. Further, doses incurred through ingestion of food are reported separately by MAFF.

Air and rainwater

5.19

The monitoring results are compared with the long-running data sets from this programme for unusual occurrences and trend changes over time. Levels are very low and do not currently merit radiological assessment (exposure of the public is insignificant).

Drinking water

5.20

Results for total alpha and total beta activities from the monitoring of drinking water sources are compared with the WHO screening values, as described at 5.11. Radiological assessments are carried out for those results, which occasionally exceed WHO screening values using the radionuclide-specific data. The results are also compared with the long-running data sets from this programme for unusual occurrences and trend changes over time.

Monitoring and assessment results

6.1 Nuclear fuel manufacture, reprocessing and low-level solid waste disposal

6.1.1 BNFL operates three major sites for the manufacture and reprocessing of nuclear fuel (at Springfields in Lancashire, Capenhurst in Cheshire and Sellafield in Cumbria) and one site for low-level solid waste disposal (Drigg in Cumbria). URENCO also operates a site at Capenhurst.

Sellafield

6.1.2 The Sellafield site includes spent fuel storage ponds and the Magnox and THORP reprocessing plants for irradiated nuclear fuel, the Calder Hall Magnox nuclear power station and various support and research facilities. There are also a number of old plant in various stages of decommissioning. The liquid effluent arising from BNFL's operations at the site are routed to sea via the Segregated Effluent Treatment Plant (SETP) and the Enhanced Actinide Removal Plant (EARP). Liquid effluent arising from the Magnox decanning plant and storage ponds is routed to the Site Ion Exchange Effluent Plant (SIXEP) and after treatment is discharged to the sea. Foul drainage from the site, which may contain trace levels of radioactivity, is routed to the on-site sewage works. This is discharged, together with surface water drainage from the non-active areas of the site, via the factory sewer outfall at the confluence of the River Calder and River Ehen. Airborne wastes are emitted to atmosphere via stacks. Low-level solid wastes are transferred to the company's site at Drigg for disposal, except for small quantities of soil excavated during building works, which are used as landfill on approved areas within the site. The Windscale Laboratory of the UK Atomic Energy Authority is co-located with the BNFL facilities on the Sellafield site.

6.1.3 The 1998 programme included:

(a) the analysis of samples of liquid effluents discharged from SETP, EARP and SIXEP and discharges made from the factory sewer outfall;

and monitoring of:

(b) radiation dose rate levels over West Cumbria (see Figures 5 and 6), North and South Cumbria and Lancashire, Merseyside and North Wales coastal areas;

(c) radioactivity in samples of coastal sediments;

(d) radioactivity in samples of water from rivers, surface sources and public water supplies in West Cumbria.

Figure 5
Gamma radiation monitoring at Muncaster Bridge on the Esk Estuary

Effluent monitoring

6.1.4 The comparison of analytical results for liquid effluent samples, determined by BNFL and the Agency's contract laboratory, LGC, was generally satisfactory. However, discrepancies were noted for a number of results, including total alpha, strontium-90, cerium-144, plutonium-241 and promethium-147 in some samples of SIXEP discharges; for total alpha, total beta, plutonium-241, technetium-99 and promethium-147 in samples from SETP discharges; and for total alpha, total beta, carbon-14, plutonium-241, americium-241 and antimony-125 in discharges from EARP. The measured concentrations of curium-242 and curium-(243+244) were, in most cases, very low, and the discrepancies observed can be attributed to analytical uncertainties. Analysts from BNFL and LGC met regularly during 1998 to address observed discrepancies. Measures have been agreed that should lead to more valid comparisons in future.

Figure 6 Monitoring sites – West Cumbria

Gamma dose rate measurement
Sediment sampling location
Water sampling location

Environmental monitoring

Cumbrian coastal areas

6.1.5 Accessible West Cumbrian coastal areas, including beaches, extending from Walney Island in the south to Whitehaven Harbour in the north, were monitored up to four times per year. The locations are shown in Figure 6. Gamma radiation dose rates were measured at each location. Portable instruments were also used to monitor contact beta/gamma radiation dose rates in inter-tidal areas, in order to seek and locate for removal any material with activity levels above 100 cps (see paragraph 3.17). In 1998, two items were found and removed. Both were small particles, one thought to be part of a gasket with a mass of about 200 mg, and one a bead of resin of mass around 5 mg. Similar monitoring was carried out in coastal areas of North and South Cumbria, Lancashire, Merseyside and North Wales.

6.1.6 Locations and measured gamma radiation dose rates are detailed in Tables 2(a), 2(b) and 2(c). The measured gamma dose rates include the contribution from natural background. Natural background dose was

subtracted from the dose rates to enable calculation of annual doses in excess of background. Measurements over sands showed little elevation over background levels, and dose rates were highest over silts. A new measurement site on the River Calder downstream of the factory sewer outfall gave the most elevated results for the year, thought to be from direct radiation emitting from heat exchangers at Calder Hall. The results in 1998 were generally similar to those observed in 1996 and 1997, and slightly lower than those observed between 1991 and 1994.

Sediments

6.1.7 Sediments were sampled from the Sellafield beach, at the Ehen Spit, from Newbiggin in the Esk estuary and at Walney Island, as in previous years. Seventeen further sites were added for the 1998 sampling programme for radiochemical and gamma-ray spectrometric analysis. The trends over the last ten years of mean total alpha and mean total beta concentrations in sediments are shown in Figures 7 and 8. The results for Newbiggin and Walney Island (Table 3) are generally consistent with previously reported levels, although the annual average total alpha results indicate an increase compared to those observed since about 1995. The concentrations of a number of radionuclides at Ehen Spit continue to show a significant reduction compared to 1994, when increased concentrations were reported. The concentrations observed during 1998 are similar to those reported since 1995.

Assessment

6.1.8 The highest gamma radiation dose rates were observed over the banks of the River Calder downstream of the factory sewer outlet, muddy areas in the Esk estuary, located to the south of Sellafield, and over silts in Harrington Harbour. Surveys of occupancy of the West Cumbrian coast have been carried out by MAFF[16] and Research Surveys of Great Britain Limited (RSGB)[17], and these data, where applicable, are shown in Tables 2(a), 2(b) and 2(c). The critical group for leisure activities is considered to be dog walkers[17] with an estimated occupancy of about 300 hours per year. Where occupancy due to employment exceeded that estimated for leisure activities, the higher figure has been used in the dose calculation. Estimates of the external radiation doses received in 1998 by the persons who were found by MAFF and RSGB to make the greatest use of these areas are shown in Tables 2(a), 2(b) and 2(c). The highest estimated external dose was 121 μSv y^{-1} from spending 300 h y^{-1} on the edge of the River Calder. This area is difficult to access and so it is unlikely that the estimated dose would actually be received. Elsewhere on the coast, estimated annual doses ranged from 3 to 43 μSv y^{-1}. The effective dose due to internal exposure from inadvertently ingested sediment and from inhaled dust was estimated to be about 1 μSv y^{-1} for a child at Ehen Spit and 13 μSv y^{-1} at Newbiggin, 22 μSv y^{-1} at River Mite estuary and 7 μSv y^{-1} at Carlton Marsh, using the concentrations observed and the methods described in section 5. Corresponding effective doses for an adult have been

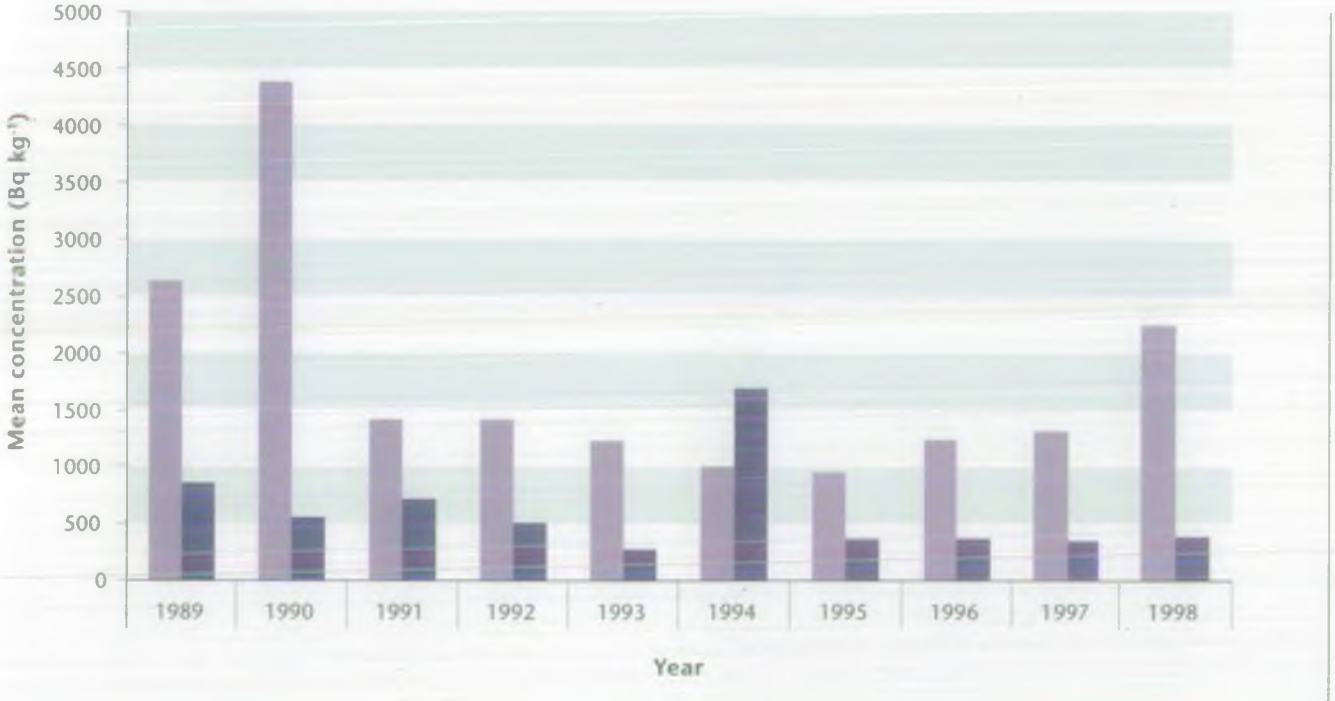

Figure 7 Total alpha in sediments from West Cumbria

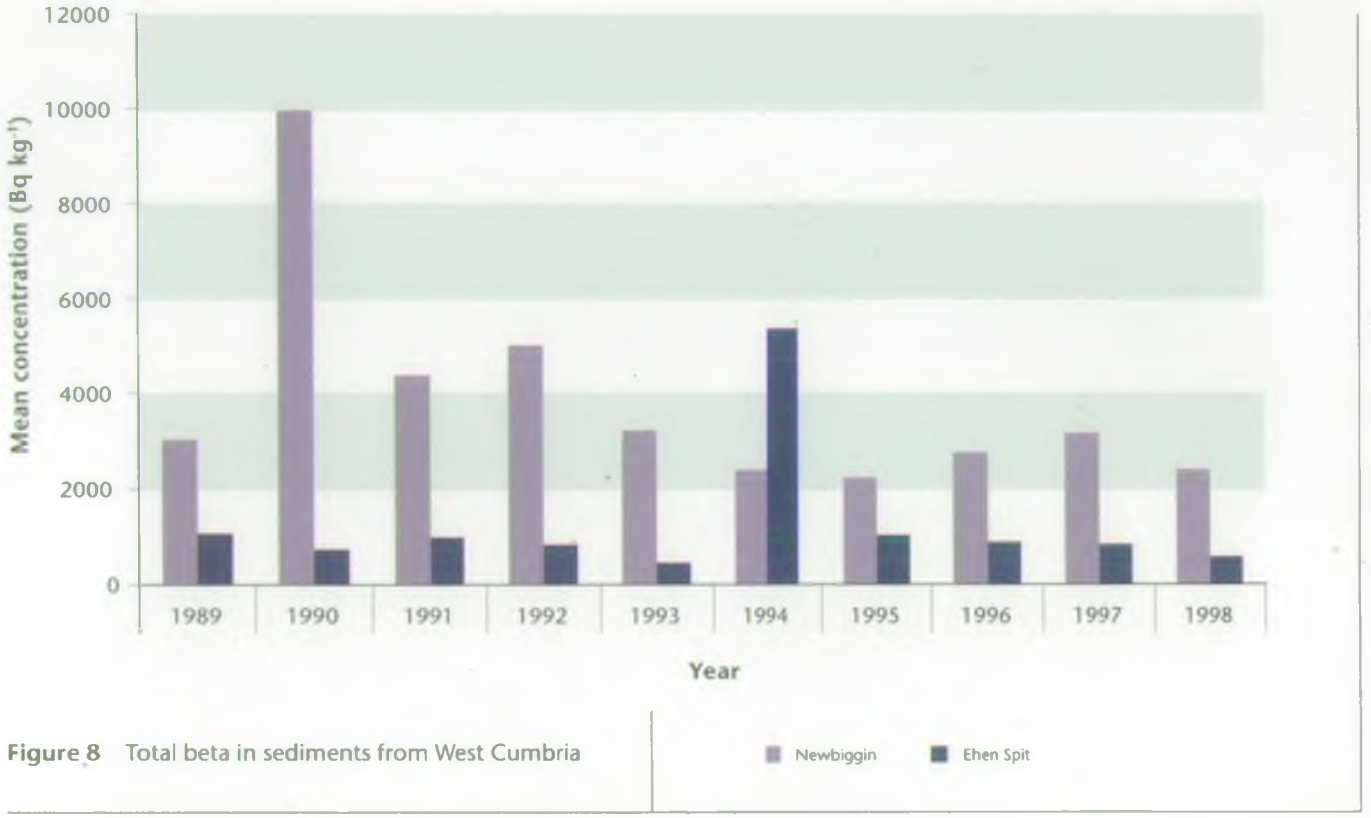

Figure 8 Total beta in sediments from West Cumbria

calculated to be 0.4 μSv y^{-1}, 5.7 μSv y^{-1}, 9.1 μSv y^{-1} and 2.5 μSv y^{-1} at Ehen Spit, Newbiggin, River Mite estuary and Carlton Marsh respectively. As in previous years, the annual total effective dose for a nature warden spending 315 hours per year on the estuary has been calculated. Taking dose rates at Newbiggin to have been typical of those in the estuary, the annual effective dose to a nature warden (including external radiation - see Table 2(a)) would have amounted to about 38 μSv y^{-1}, similar to that reported in 1997. The estimated doses reported at Haverigg and Askam are similar to those reported in 1997. At both these locations the measured dose rates are only marginally above background levels and the doses result from the extended occupancy times.

Surface waters

6.1.9 Analysis of samples of surface water, taken quarterly from Ehen Spit where water issues from the ground at low tide, gave the results shown in Table 4. Because the water is brackish, it will not be used as drinking water, so only inadvertent consumption is likely (if at all). The total alpha levels were below the WHO screening values for drinking water. However, enhanced total beta levels were observed on all occasions when the water was sampled, with concentrations similar to those observed in previous years. The mean annual concentration of tritium during 1998 was similar to that reported in 1997. The annual mean concentration of caesium-137 was raised compared to that reported for 1996 and 1997. Inadvertent consumption of small quantities of water containing the observed caesium-137 and tritium concentrations, for example by children regularly visiting the beach for, say, a total of 300 hours per year, would result in an insignificant effective dose of less than 0.1 μSv y^{-1}.

6.1.10 There was some evidence of tritium from Sellafield at the factory sewer outfall. However, levels were scarcely above those expected in UK surface waters. These waters are not potable and the low concentrations are of no radiological significance. The concentrations of tritium in the River Calder downstream of Sellafield were generally below the limit of detection of 4 Bq kg^{-1}. The only positive value reported (8.4 Bq kg^{-1}) is considered to be so low as to be of no radiological significance.

6.1.11 The levels of tritium, as reported in Table 4, in several other rivers and lakes in West Cumbria, some of which are sources of public drinking water, were all below 10 Bq kg^{-1}. The levels of total alpha and beta activities measured in the samples were below the WHO screening values of 0.1 and 1.0 Bq l^{-1} respectively.

Drigg

6.1.12 BNFL operates the Drigg site for the disposal of solid low-level radioactive waste. Most of the waste that is disposed of at the site arises as a result of operations at Sellafield, but wastes are also received from other nuclear sites and from a wide variety of smaller industrial operators. Suitable wastes are compacted at the Sellafield site, to minimise residual voidage, using the Waste Monitoring and Compaction (WAMAC) facility. In recent

years, a programme of site development has been completed to improve operational arrangements and to minimise contamination of surface water and groundwater draining from the site.

6.1.13 The 1998 programme included:

(a) the analysis of samples of contaminated water routed to sea via the marine pipeline;

(b) the quality checking of waste intended for disposal at Drigg;

and, in the vicinity of Drigg, monitoring of:

(c) radioactivity in the Drigg stream where it passes through public land shortly after leaving the site;

(d) radioactivity in the Railtrack drain which runs parallel to the north-eastern boundary of the site before joining the Drigg stream.

Effluent monitoring

6.1.14 The radionuclide content of effluents discharged to sea via the marine pipeline is restricted by limits on alpha, beta and tritium levels. The comparison of analytical results for the analysis of marine pipeline samples by BNFL and the Agency's contract laboratory was generally satisfactory. However, discrepancies in both the total alpha and total beta results were reported. In both cases, the concentrations reported by BNFL and LGC were close to the limits of detection, and uncertainties in the measured data may account for the poor agreement. For tritium, agreement between the results reported by the two laboratories was generally good.

Quality checking of waste

6.1.15 An ISO container with around 70 drums of low-level radioactive waste originating from Hartlepool Power Station was seized in March by the site inspector, following its acceptance for high-force compaction at Sellafield before disposal by BNFL at Drigg. Upon receipt at the Agency's Waste Quality Checking Laboratory (WQCL), the ISO container was observed to have areas of damage and heavy corrosion around the lifting points. A Lloyd's surveyor inspected the container and a new ISO container was provided by Nuclear Electric for the return of the waste consignment. Examination of the waste by non-destructive testing showed that cobalt-60 made up over 73% of its gamma-emitting radioactivity content. Radiochemical analysis of selected samples found tritium, carbon-14 and sulphur-35, in line with the waste producer's declaration. Analysis of two sub-samples of waste from one drum indicated the presence of around 6 GBq of iron-55 in the drum, which was greater than the declared consignment total of 0.141 GBq. Overall the waste consignment conformed to Hartlepool's authorisations for disposal of LLW by transfer to BNFL. The discrepancy in the quantity of iron-55 in the consignment was followed up with the site operator.

6.1.16 An ISO container of drummed waste originating from Trawsfynydd Power Station was seized in July by the site inspector, following its acceptance for high-force compaction at Sellafield by BNFL before disposal at Drigg. During unloading operations at WQCL, it was observed that the lid of one of the 200-litre waste drums had not been properly secured, causing a temporary breach of containment. Examination of the waste by non-destructive testing showed the principal gamma-emitting radioactive constituents of the waste to be caesium-137 and cobalt-60. The total and individual gamma-emitting radioactive content of the waste as determined by WQCL was less than that declared by the waste producer. The waste consignment conformed to the conditions specified in Trawsfynydd's authorisations, except for the presence of aerosol canisters in one drum. This drum was segregated from the rest of the consignment and returned to the waste producer. The site inspector required improvements to waste disposal procedures at the site to minimise the possibility of recurrence.

Environmental monitoring

Drigg stream

6.1.17 Surface waters drain into the Drigg stream, which leaves the site in the south-east corner and discharges into the inter-tidal region of the River Irt in the Ravenglass estuary. At times of heavy rainfall, storm water drained from the vaults is diverted to the Drigg stream. The site authorisation includes concentration limits on activity in the stream water. The limits which apply to the average concentrations in any one week are:

Alpha activity	9.0×10^{1} Bq l^{-1}
Beta activity	1.2×10^{3} Bq l^{-1}
Tritium	6.0×10^{5} Bq l^{-1}

The results of analyses of spot samples of water and sediment taken each calendar quarter are presented in Table 5. The concentrations of alpha and beta activities and of tritium in stream water were significantly below these limits.

Railtrack drain

6.1.18 It is known that, in the past, ground water moved laterally from some of the trenches towards a Railtrack-owned drain along the East perimeter of the site. BNFL has taken steps to reduce ingress of water into the trenches and built a "curtain wall" to cut off the lateral route. Previously, radionuclides have been

detected over several years in this drain. The results of monitoring presented in Table 5 show that low positive values of total alpha, total beta and tritium were recorded during the annual sampling conducted in the first quarter of 1998. For comparison, no radionuclides were above the limits of detection during 1997.

Assessment

6.1.19 The concentrations of total alpha activity in the Drigg stream and the Railtrack drain during 1998 did not exceed the WHO screening values for drinking water. Concentrations of total beta activity in the Railtrack drain and the Drigg stream during 1998 just exceeded the guidelines for drinking water in the first quarter and third quarter respectively. In the Drigg, stream tritium exceeded the concentration expected to be present in UK surface waters. The average annual measured concentration was lower by a factor of five than that reported during 1997. Although the Drigg stream is not used as a source of drinking water, it is possible that for a short period campers or picnickers could reside nearby. In the unlikely event that they used the stream as a drinking water supply for a two week period and the water was at the maximum tritium activity concentration of 64 Bq l^{-1}, this would result in an effective dose of much less than 1 μSv.

Capenhurst

6.1.20 Capenhurst is split into two nuclear sites: one occupied by Urenco (Capenhurst) Limited and the other by BNFL. Urenco operates centrifuge plants for the isotopic enrichment of uranium. BNFL's operations principally involve the final stages of the decommissioning of the redundant gaseous diffusion plant, and processing of tritium in support of defence activities. Decontamination of this redundant plant is the main source of liquid effluent, which is routed from the site via a culvert and a ditch to Rivacre Brook. A small volume of highly acidic effluent is considered to be special waste within the meaning of the Control of Pollution (Special Waste) Regulations 1980. This effluent, which contains only trace quantities of radioactivity, is disposed of to a licensed landfill site. Airborne wastes are emitted to atmosphere via stacks and roof vents. Solid wastes are disposed of at the Clifton Marsh landfill site operated by Lancashire Waste Services Ltd and at BNFL's disposal site at Drigg.

Effluent monitoring

6.1.21 The 1998 programme included:

(a) the analysis of samples of liquid effluent discharged to Rivacre Brook;

and, in the vicinity of Capenhurst, monitoring of:

(b) radioactivity in samples of water, from Rivacre Brook at four locations downstream of the site, and soils, grass and sediments;

(c) gamma-radiation dose-rate levels on the banks of Rivacre Brook at four locations downstream of the site (see Figure 9).

Figure 9
Gamma radiation monitoring on the banks of Rivacre Brook

6.1.22 The results of analyses carried out by BNFL and LGC of samples of liquid effluent discharged to Rivacre Brook were in all cases close to the limits of detection, and the comparison of data was satisfactory.

Environmental monitoring

Rivacre Brook

6.1.23 Analytical results and details of the monitored locations are presented in Table 6. Only low concentrations of total alpha, total beta, tritium and technetium-99 are observed in the water samples from Rivacre Brook. The mean annual total beta results showed decreases compared to 1996 and 1997. Technetium-99, caesium-137, uranium and low levels of neptunium-237 were detected in samples of sediment. Concentrations generally declined with distance downstream from the site. In most cases, the concentrations in sediment were generally similar to those observed in previous years. The concentrations of total beta in sediment were generally similar to those reported in previous years.

Assessment

6.1.24 There is no known use of Rivacre Brook except as a play area for children living nearby. There is no measurable increase in external radiation over the banks of the brook, and the small areas of exposed mud are not credible sources of resuspended activity. There remains

the possibility of inadvertent ingestion of water and sediment during play. The highest concentrations are observed at the sampling point closest to the BNFL outfall, but this location is relatively inaccessible and not frequented by members of the public. The other sampling points are more representative of the areas where children play. Based on the assumptions set out in section 5, the effective dose due to internal exposure from sediment and water that might be incurred by a child playing in one of these areas is estimated to be less than 1.0 $\mu Sv\ y^{-1}$.

Springfields

6.1.25 BNFL operates chemical plant to extract uranium from ore concentrates and manufactures nuclear fuel and intermediate products at Springfields for use in the UK and abroad. Liquid wastes are discharged by pipelines to the tidal waters of the Ribble Estuary. Airborne wastes are emitted to atmosphere via stacks, and solid wastes are disposed of at the Clifton Marsh landfill site operated by Lancashire Waste Services Ltd or at the company's disposal site at Drigg.

6.1.26 The 1998 programme included:

(a) the analysis of samples of liquid effluent discharged to the tidal waters of the Ribble Estuary;

and, in the vicinity of Springfields, monitoring of:

(b) gamma radiation dose rates over, and activity levels in sediments along, the banks of the River Ribble (see Figure 10);

(c) activity levels in Deepdale Brook at the point where this small stream leaves the site after flowing through its centre. Since 1988 the brook has been isolated from the site by a culvert;

(d) soil and grass samples near the site.

Effluent monitoring

6.1.27 Bulked samples of liquid effluents discharged during the months of March and September 1998 were supplied to the Agency's contract laboratory. Comparisons of results between the BNFL and Agency determinations for both samples were generally poor and variable, with no discernible trends. The short-lived (half-life 24 days) radionuclide thorium-234 and associated daughter product protactinium-234m (half life 1.2 minutes) are the dominating beta-emitting radionuclides in Springfields discharges. The discrepancies in the beta determinations result primarily because it is not possible to correct for radioactive decay in mixed samples containing unknown ratios of these short-lived radionuclides.

Figure 10
Sampling in the River Ribble

Environmental monitoring

Ribble Estuary

6.1.28 Accumulations of radioactivity can be found in various locations in the Ribble Estuary. These result from the direct discharge of radioactive liquid effluent by Springfields to the tidal waters of the estuary and from the marine transport of radioactivity originating from discharges of liquid effluent from BNFL Sellafield to the Irish Sea.

6.1.29 The 1998 programme was largely aimed at monitoring the impact of Springfields and Sellafield discharges in the inter-tidal areas of the upper reaches of the estuary. The main monitoring locations are shown in Figure 11. A significant number of monitoring sites, added to the programme in 1998, were previously monitored by MAFF. The results are presented in Tables 7 and 8.

6.1.30 Discharges from Springfields are dominated by uranium and its decay products. The uranium concentrations observed in sediments fall within the range expected to be present naturally in the UK. As previously reported, thorium-234 and protactinium-234m were found at elevated levels. The high concentrations are transient, being influenced by tidal movements and river flow scouring of the sediments and variations in discharges from Springfields. Although there are large quarterly variations in the observed concentrations, average annual concentrations are generally similar to those observed in recent years.

6.1.31 As in previous years, the gamma dose rates in Table 8 show modest increases over expected background levels. These excesses result mainly from historic discharges from Sellafield.

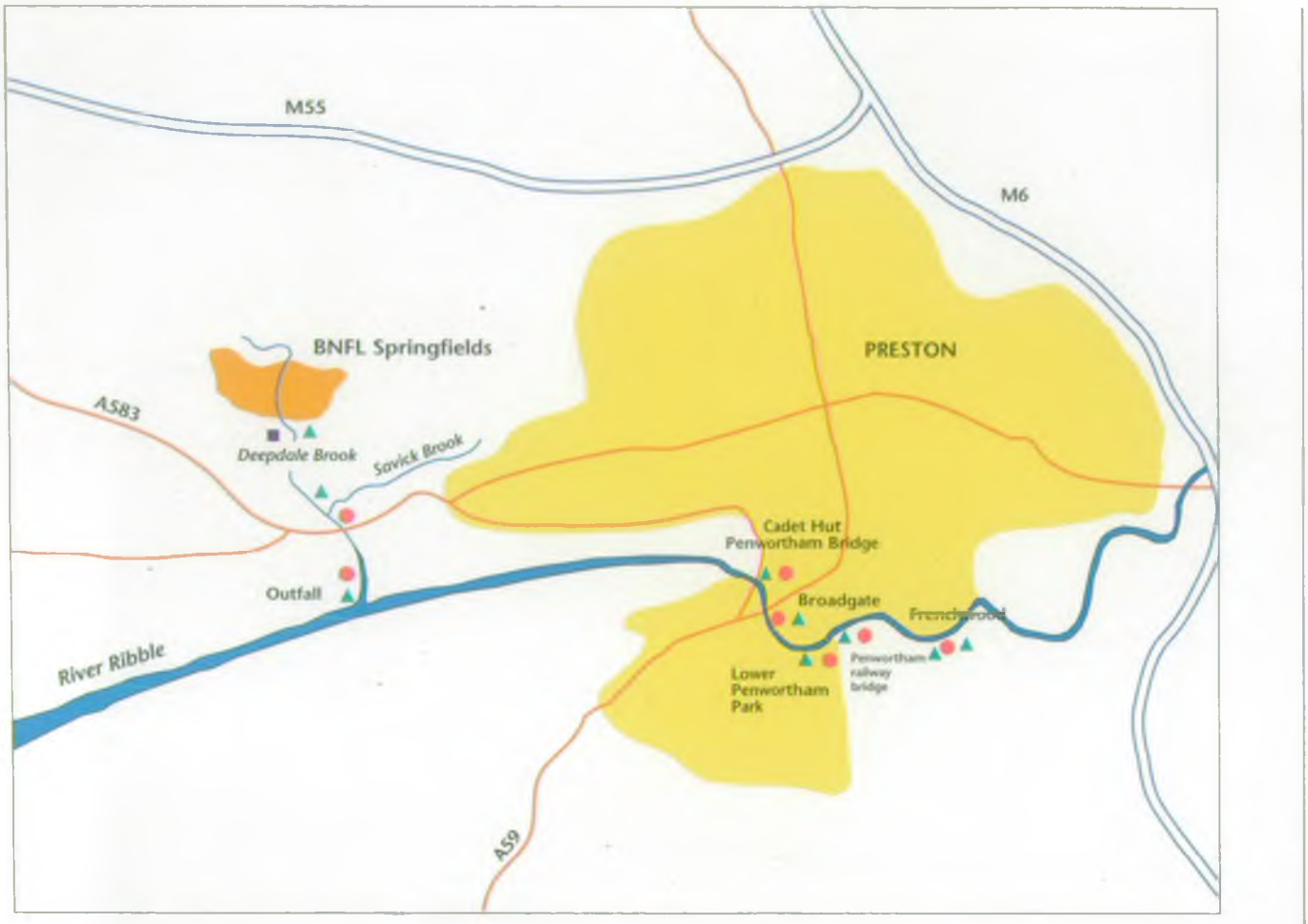

Figure 11 Monitoring sites near BNFL Springfields

Deepdale Brook

6.1.32 Deepdale Brook is a small stream, which passes through the centre of the Springfields site. Historically, groundwater containing uranium has entered the brook, but the engineering of a culvert in 1988 to contain the brook has isolated it from the site except at times of extremely high rainfall. Variable levels of uranium in sediment are present as a result of previous contamination, and occasionally low levels of uranium are detected in the water of the brook. The concentrations of uranium, and other radionuclides, measured in the sediment during 1998 were slightly higher than 1997.

Assessment

6.1.33 Houseboat dwellers are considered to be the most exposed group in the Ribble Estuary, due to their high occupancies. Houseboat dwellers may spend up to 8,000 h y^{-1} on the Ribble. An effective occupancy of 3,300 h y^{-1} has been used for dose assessment, which allows for shielding of doses from mud banks by the water and boat planking. Dose rates on mud banks around areas where houseboats are moored on the Ribble are reported in Table 8. The assessment of dose from external exposure was between 100 and 175 µSv y^{-1} at the mooring locations.

6.1.34 The Agency's predecessor, Her Majesty's Inspectorate of Pollution (HMIP), published a report in 1994 on the distribution of radioactivity in the Ribble Estuary and the recreational use made of this area[19]. The results of the study and other data have been used to assess doses to other groups using the Ribble.

6.1.35 Because of the presence of elevated concentrations of protactinium-234m in sediments in the inter-tidal areas, estimates of external beta dose rates have been considered in addition to the external exposure from gamma-emitting radionuclides and internal doses resulting from inhalation and ingestion of the sediment. Estimates of the exposure of skin to beta radiation have been calculated based on the concentrations of radionuclides measured in the sediment using the dose assessment method proposed by Hunt[26].

6.1.36 The maximum concentrations of protactinium-234m were recorded at Savick Brook. However, this area of the estuary is remote and is rarely visited by members of the public.

6.1.37 The occupancy survey identified anglers as the most potentially exposed members of the public in the inter-tidal areas of the upper estuary. Dose rates at areas where angling occurs on the Ribble Estuary have been measured and are reported in Table 8. The external dose to anglers spending 700 h y^{-1} on the Ribble Estuary was estimated to be approximately 16 µSv y^{-1}. The survey reported that Sea Cadets, who use the estuary for sailing and canoeing, may spend some of their time on the inter-tidal muds. A maximum occupancy of 52 hr y^{-1} was estimated. The survey also reported that children might spend up to 30 hr y^{-1} playing on the inter-tidal muds, although none were observed during the study.

6.1.38 Using the above occupancies and the monitoring results in Tables 7 and 8, the effective doses were estimated to have been 8 µSv y^{-1} for the Sea Cadets and 1 µSv y^{-1} for the children. These estimated doses suggest a slight decrease since 1997, which is mainly due to decreases in the measured gamma radiation dose rates at these sites. The beta radiation skin doses were estimated to have been 0.6 mSv y^{-1} for the Sea Cadets and 0.1 mSv y^{-1} for the children. These skin doses should be compared with the ICRP recommended limit of 50 mSv y^{-1}.

6.1.39 Sediment samples were analysed from locations upstream of Lower Penwortham railway bridge and one location downstream at Lytham Yacht Club. The analysis of the upstream samples indicated concentrations of radionuclides during 1998 were generally somewhat lower than those observed at the railway bridge. As observed during 1996 and 1997, the samples from Lytham Yacht Club contained concentrations of between one-half and one-tenth of those observed around Penwortham. The lower concentrations at Lytham result from the higher tidal flows and subsequent dispersion within the estuary. Caesium-137 concentrations, attributable to the marine transport of material discharged to sea from BNFL Sellafield, were similar at all sampling locations. However, the concentrations of americium-241 attributable to Sellafield showed elevated concentrations near Savick Brook. Figure 12 shows the mean total beta concentrations in sediments in the vicinity of BNFL Springfields for the years 1994 to 1998.

6.1.40 There is no known use of Deepdale Brook by members of the public, and the concentrations of uranium and other radionuclides found are of no radiological significance.

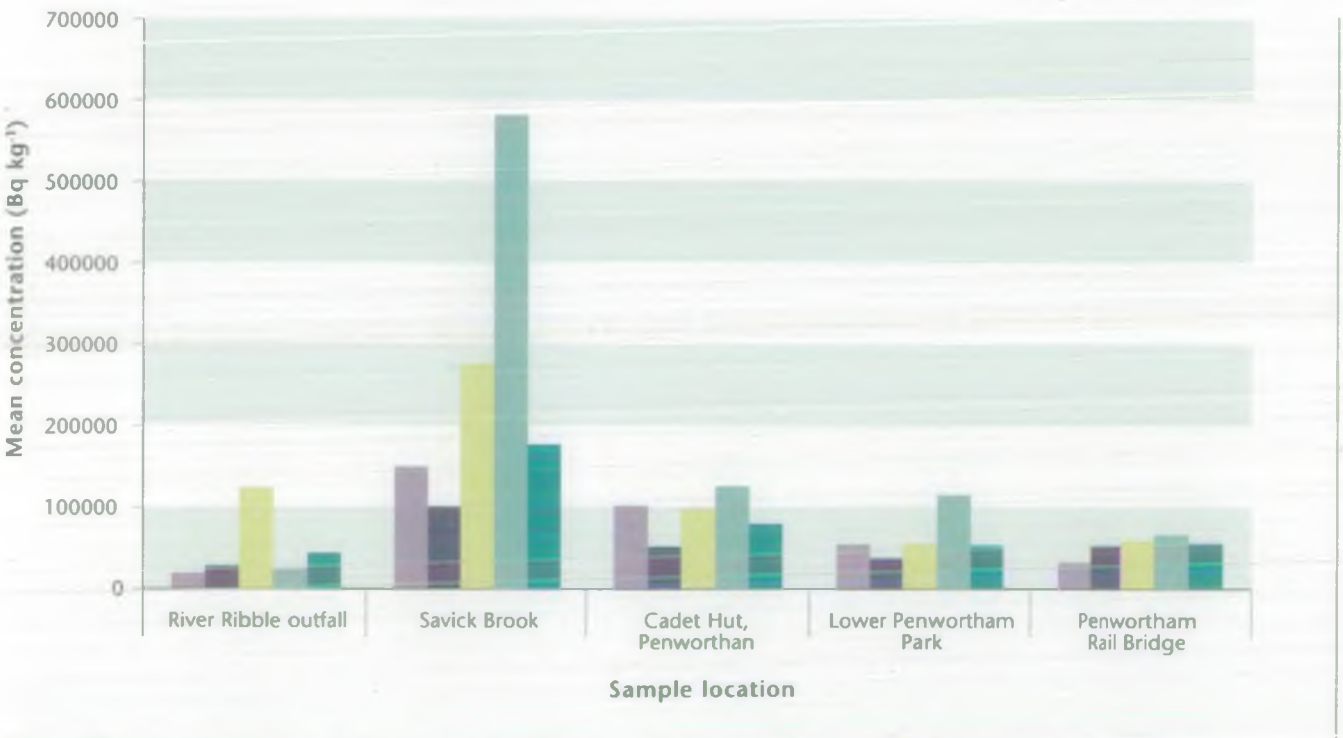

Figure 12 Mean total beta in sediments near Springfields

6.2

Nuclear power stations

6.2.1 Until 31 March 1996, the nuclear power stations in England and Wales were operated by Nuclear Electric plc. On 1 April 1996 responsibility for the operation of the advanced gas cooled reactors (AGRs) and the only pressurised water reactor (PWR) transferred to a new company, Nuclear Electric Ltd, part of British Energy Generation. During 1998, Nuclear Electric changed its name to British Energy Generation. British Energy Generation stations are located at Dungeness (B station), Hartlepool, Hinkley Point (B station), Heysham (two stations) and Sizewell (B station, PWR). In 1998, Magnox Electric, which operated the Magnox stations, became BNFL Magnox Generation, a wholly owned subsidiary of BNFL. Magnox stations are located at Bradwell, Dungeness (A station), Hinkley Point (A station), Oldbury, Sizewell (A station) and Wylfa. Two Magnox reactors at Trawsfynydd and Berkeley are closed. The Agency is currently processing applications for new authorisations which are required as part of the full integration of Magnox operations into BNFL.

6.2.2 For all stations, the principal gaseous radioactive emissions consist of the controlled discharges (called blowdown) of coolant gas, which are made relatively infrequently during operation of the reactor and fuelling machine, together with the small but unavoidable leakage of coolant gas, which occurs whenever the reactors are pressurised. The older Magnox stations, which have steel pressure vessels, also discharge gaseous radioactivity in the form of cooling air that has passed through the space between the pressure vessel and the concrete biological shield. All the principal radioactive emissions are filtered before release to the atmosphere. Some solid wastes and waste lubrication oil are burned in on-site incinerators, and ash and other solid wastes not suitable for incineration are transferred to BNFL's site at Drigg for disposal. Liquid effluents are routed to active effluent treatment plants and, after treatment, collected in final monitoring and delay tanks (FMDT) for monitoring prior to discharge. At AGRs, liquid effluents arising from coolant gas conditioning systems or dryers are routed to tritiated water storage tanks (TWST) before monitoring and discharge. Treated effluents are then discharged to sea (except for those from Trawsfynydd) via pipelines, as summarised below.

6.2.3 The 1998 programme included:

(a) the analysis of FMDT and TWST samples of liquid effluents;

and, near the nuclear power stations, monitoring of:

(b) coastal areas near to discharge outfalls used for liquid effluents (see Figure 13);

(c) radioactivity in samples of surface waters, including some public water supplies and sediment, seaweed, seawater and sea coal.

Figure 13
Monitoring on the beach near Bradwell

Effluent monitoring

6.2.4 The Agency's contract laboratory, LGC, analysed samples of FMDT and TWST discharges quarterly. These samples were also analysed by the stations and by BNFL Magnox Generation Central Radiochemical Laboratory (CRL) as part of the companies' own internal quality assurance procedures. The agreement between results for the analysis of tritium is generally satisfactory and, as has been observed previously, is better for TWST samples than FMDT samples. This probably results from the much lower variation between individual results and also from the higher concentrations being measured. The comparison of results for the analysis of total beta for FMDT samples between all laboratories indicates that agreement is generally satisfactory. Discrepancies in the results of the analyses of TWST samples for sulphur-35 were observed, between LGC and both CRL and the individual stations, particularly where the reported concentrations were low.

Environmental monitoring

Coastal areas

6.2.5 Gamma radiation dose rates were measured over inter-tidal mud flats and beaches. The locations and measured dose rates are presented in Table 9. In most areas, dose rates were indistinguishable from natural background. The local increases in dose rate recorded at Bradwell Beach since 1993 were again evident in 1998. It is likely that this increase has arisen due to direct radiation from external reactor ductwork or cooling air

Power station discharge routes

Power station	Liquid effluent discharge route
Berkeley Oldbury	by pipeline to a common stretch of the Severn Estuary
Bradwell	by pipeline to the estuary of the River Blackwater
Dungeness A and B	by pipelines to adjacent outfalls into the English Channel
Hartlepool	by pipeline into the North Sea
Heysham 1 and 2	by pipelines to adjacent outfalls into Morecambe Bay
Hinkley Point A and B	by pipeline to a common outfall into the Bristol Channel
Sizewell A and B	by pipelines into the North Sea
Trawsfynydd	by pipeline into Lake Trawsfynydd
Wylfa	by pipeline into the Irish Sea at Cemaes Bay

under the influence of specific meteorological conditions. The magnitude and duration of such increases would be related to the amount of power being generated at the station at any one time. The exposure above background, if the mean dose rate recorded at Bradwell Beach in 1998 persisted throughout the year and a person spent 300 hours on the beach, would be approximately 60 μSv y^{-1}. Similarly, increases were measured around Hartlepool in May, which had returned to background levels in October. The corresponding exposure at Hartlepool near Paddy's Hole would be slightly lower, at approximately 40 μSv y^{-1}.

6.2.6 Portable instruments were also used to monitor contact beta/gamma radiation dose rates in inter-tidal areas in order to seek and locate for removal any material with activity levels in excess of 100 cps (see paragraph 3.17). No such material was found in 1998.

Sediments

6.2.7 During 1998, the environmental sampling programme around nuclear power station sites was increased. In addition to the surface water samples already taken at all sites, the extended programme now includes samples of sediments, seaweed and seawater. Samples of sea coal are also taken from beaches around the Hartlepool nuclear power station site. Assessments of dose to members of the public are confined to exposure to the activity concentrations measured in sediments. The seaweed, seawater and sea coal samples are used as environmental indicators. The results of the analysis of samples are presented in tables 10(a) and 10(b). Assessment of the results indicate that if an adult was present at the most radiologically significant location for 300 hours per year, then the predicted effective dose due to inadvertent ingestion and inhalation of sediment is less than 1 μSv y^{-1}.

Surface and public water sources

6.2.8 The results of monitoring samples of surface waters in the vicinity of the power stations are presented in Table 10(a). In general, the total alpha and total beta concentrations were less than the WHO screening values of 0.1 and 1.0 Bq l^{-1} respectively. However, total beta concentrations in excess of 1.0 Bq kg^{-1} were reported for samples obtained from the coastal ditch at Bradwell. Sampling of the coastal ditch at Bradwell was possible at each sampling point only once during 1998; the sampling locations were dry when the sampling programme was undertaken on each of the other occasions. Tritium was generally detected at levels consistent with background values in UK surface waters, with the exception of the coastal ditch at Bradwell, where enhanced levels were observed (Figure 14). The coastal ditch is not used as a drinking water source but, if it were, the dose incurred would be less than 1 μSv y^{-1}. The tritium results for Bradwell, Dungeness, Berkeley and Heysham in 1997 were reported as less than the limit of detection, 10 Bq kg^{-1}. Similarly in 1998 for Sizewell, Bradwell, Dungeness and Heysham, when the detection limit was 4 Bq kg^{-1}. It should be noted that the detection limit figures have been used in Figure 14.

6.3 Research establishments

6.3.1 UKAEA operates two major research establishments in England, at Harwell in Oxfordshire and at Winfrith in Dorset. UKAEA also operates a laboratory at Windscale within the Sellafield site. The laboratory makes minor contributions to discharges of wastes from the Sellafield site and is therefore considered together with Sellafield for the purposes of this report. UKAEA's main activities are now radioactive management waste and the management of decommissioning programmes. AEA Technology also operates on the sites at Harwell and

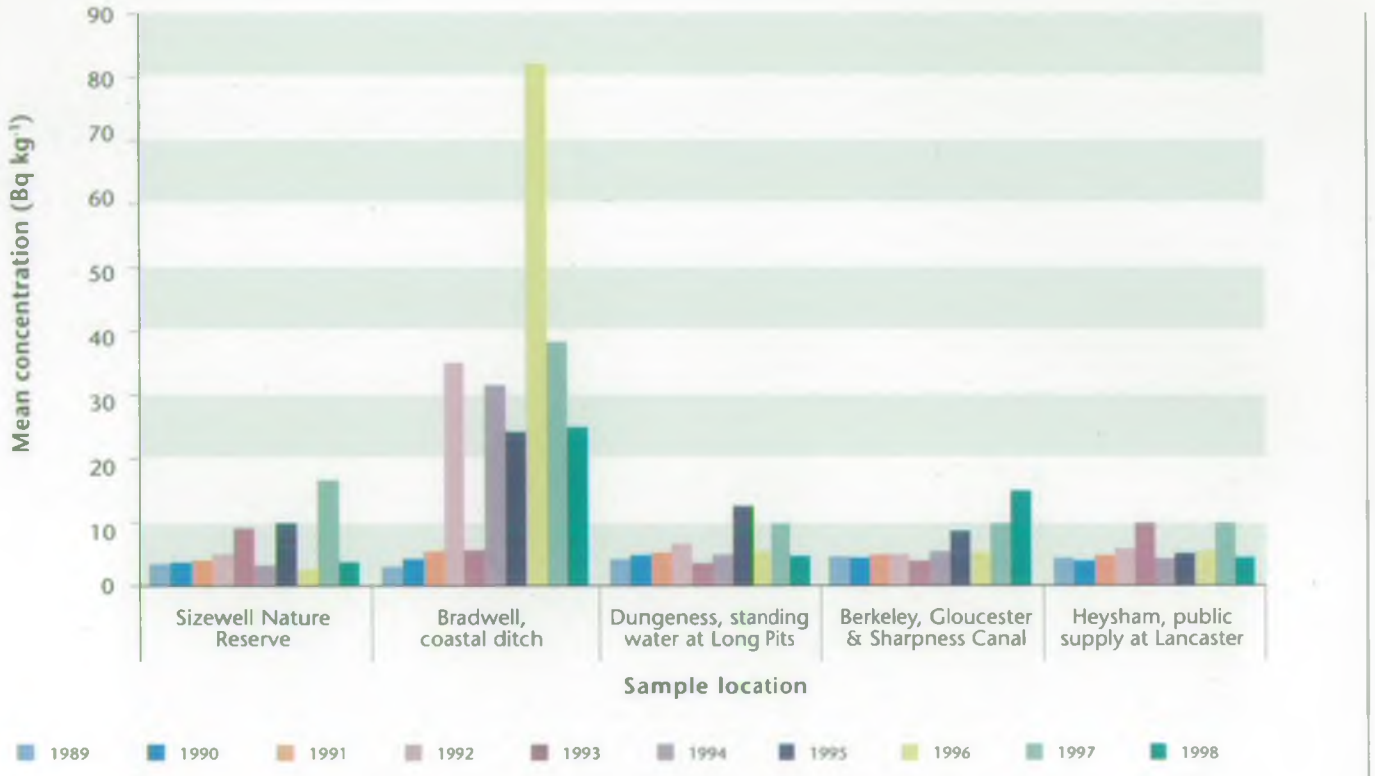

Figure 14 Mean concentration of tritium found in surface waters near nuclear power stations

Winfrith and discharges radioactivity into the environment via UKAEA.

Harwell Laboratory

6.3.2 At UKAEA's Harwell site, operations include radiochemical laboratories and high-active handling facilities. Airborne wastes are emitted to atmosphere via stacks. Liquid effluent arising from the active areas of the site is routed to the site liquid effluent treatment plant (LETP). Liquid effluents from all other areas of the site (known as trade waste) are routed to holding tanks for monitoring before discharge. If necessary, the effluents in the holding tanks can be diverted to the LETP. Effluents from the LETP and trade wastes are discharged, following monitoring, via a pipeline to the River Thames at Sutton Courtenay. Surface drainage and treated water from the on-site sewage system leave the site via Lydebank Brook. Solid low-level waste is transferred to BNFL's site at Drigg for disposal. The Agency is currently determining applications from UKAEA for revised discharge authorisations.

6.3.3 The 1998 programme included:

a) the analysis of samples of liquid effluents from the liquid effluent treatment plant and the trade waste holding tanks;

and, in the vicinity of Harwell, monitoring of:

(b) the banks of the River Thames close to the discharge outfall;

(c) activity levels in samples of water and sediments from the River Thames and other surface waters (see Figure 15).

Effluent monitoring

6.3.4 Discrepancies were noted in the results for total alpha and total beta activities as determined by Harwell and LGC in samples of treatment plant effluents. In the case of the total beta measurements, the discrepancies are considered to result from uncertainties in correcting for radioactive decay due to the presence of short-lived

Figure 15
Collecting water samples from the River Thames

Figure 16 Monitoring locations – Thames Valley area

radionuclides. In all cases, Harwell's results were higher. Where the specific radionuclides caesium-137 and cobalt-60 were reported, agreement between the two laboratories was generally satisfactory. The analysis for total alpha and total beta activity in trade waste samples confirmed that concentrations were low. Some discrepancies were noted for the measurement of tritium concentrations in both the treatment plant effluents and the trade waste samples, although Harwell usually reported the higher concentrations. Analysis of surface water discharged to Lydebank Brook indicated that concentrations of total alpha and total beta were low. In most cases, where comparisons were possible, agreement between the laboratories was satisfactory, although concentrations reported by both laboratories were generally close to the limits of detection. Discrepancies in the concentrations of tritium in the discharges of surface waters to Lydebank Brook were noted; in all cases of discrepancy, the operator reported the higher concentrations.

Environmental monitoring

Banks of the River Thames

6.3.5 Samples of sediment and gamma radiation dose rate measurements were taken at three points on the banks of the river, at varying distances from the discharge outfall. Sediment samples were also collected from Lydebank Brook. The results and sampling locations are shown in Table 11 and Figures 16 and 17 respectively. Caesium-137 and plutonium-(239+240) originating in discharges from Harwell were present in some of the samples.

6.3.6 The banks of the Thames are used by walkers and picnickers, and also by anglers. External and internal exposure due to inadvertent consumption of water and sediment contribute to the resulting radiation exposure of the population. A survey carried out by MAFF[18] has recommended that an occupancy factor of 650 hours per year should be used for the whole body external exposure. The gamma ray dose rates show only a slight increase over background rates expected in the area. This increase is small, and estimates of the potential increase in external radiation dose that results to, for example, a keen angler on the basis of the calculation methods outlined in section 5, are correspondingly low. Taking into account both external and internal exposure, the effective doses are estimated to be about 12 μSv per year. This is similar to the corresponding doses reported for 1997.

6.3.7 Portable instruments were also used to monitor contact beta/gamma radiation dose rates along stretches of the bank of the River Thames in order to seek and locate for removal any material with activity levels in excess of 100 cps (see section 3.11). No such material was found in 1998.

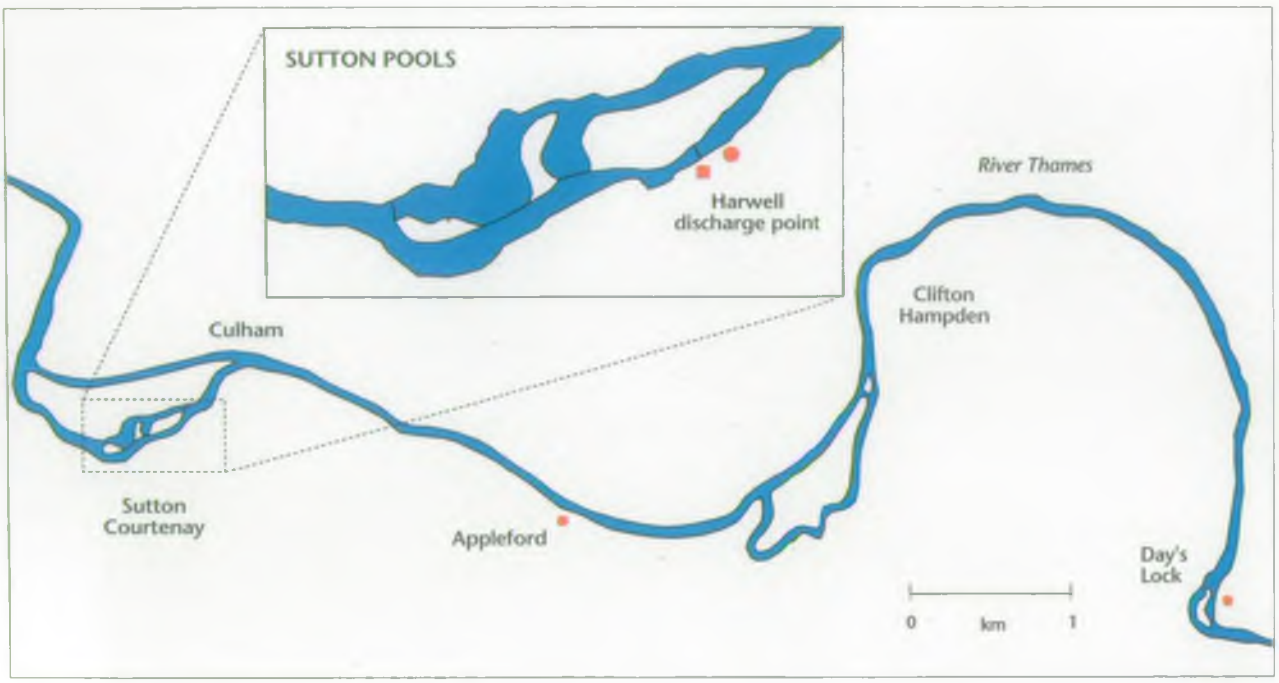

Figure 17 Monitoring locations – Thames Valley area

River Thames and other surface waters

6.3.8 Samples of water collected at weekly intervals from locations upstream and downstream of the discharge point were bulked over 13-week periods. In addition, spot samples were taken from Day's Lock and Lydebank Brook. The results are presented in Table 12. Tritium is a substantial component of Harwell discharges, but the concentrations show there is no significant increase downstream of the discharge point, and generally the results are below the limits of detection. In 1998, the highest concentration observed was 6.8 Bq l^{-1} during the first quarter. If these waters were used continuously as drinking water sources the doses incurred would be less than 0.1μSv y^{-1}. In all cases the concentrations of total alpha and total beta activity were below the WHO screening values.

Winfrith

6.3.9 UKAEA and AEA Technology plc operate engineering and research facilities, including many experimental rigs, laboratories and workshops at Winfrith. A steam-generating heavy water reactor was also operated at the site until 1990; this is now being decommissioned. Airborne wastes are emitted to atmosphere via stacks. Solid wastes are transferred to BNFL's site at Drigg for disposal. Liquid radioactive effluents are routed to holding tanks. Non-active liquid wastes from all other operations at the site (trade wastes) are routed to separate holding tanks. After monitoring, the liquid wastes are discharged to sea at Weymouth Bay via the site pipeline. The site is some distance from the coast, and the pipeline is constructed such that the more active effluents travel along an inner pipe set within an outer pipe carrying the trade wastes.

6.3.10 The 1998 programme included:

(a) the analysis of samples of liquid effluents discharged via the inner pipeline and the outer pipeline;

and, near Winfrith, monitoring of:

(b) coastal areas of Dorset;

(c) surface waters, including the River Frome.

Effluent monitoring

6.3.11 Results reported by UKAEA and LGC for the analysis of liquid effluents from the inner and outer pipelines showed activities close to or below the limits of detection. Where there were any discrepancies between the UKAEA and LGC results, UKAEA usually reported the higher concentrations.

Environmental monitoring

6.3.12 Gamma radiation dose rate measurements, reported in Table 13, were consistent with those observed in previous years, being indistinguishable from natural background.

Surface waters

6.3.13 Samples of water were taken from the River Frome and two streams flowing close to the perimeter of the site, which may receive site storm water. The results are shown in Table 14. The levels of tritium in stream A have continued to decline from the value of 340 Bq l^{-1} reported for the fourth quarter of 1993. The highest concentration of tritium observed in surface waters close to the site in 1998 was 20 Bq l^{-1}. At this concentration the dose to consumers if the stream were used as a drinking water supply would be about 0.2 µSv y^{-1}. The concentrations of tritium in the remaining samples showed only negligible increases above the expected values for UK surface waters. In all cases the total alpha and beta activities were below the WHO screening values, and no radionuclides were detected by gamma-ray spectrometry.

Sediments

6.3.14 Samples of sediments were also taken from the River Frome and the two streams. The results are recorded in Table 14. In most cases, the concentrations observed are similar to those reported in 1997. In all cases where differences were observed relative to 1997, the concentrations are so low that the variations may be attributable to analytical uncertainty. The effective dose due to inadvertent ingestion of sediment (not considered to be likely, as access to the stream is very difficult) is estimated to be very much less than 1 µSv y^{-1} for stream A which, as in previous years, showed the highest concentrations of caesium-137.

6.4

Manufacture of radioactive sources

6.4.1 Nycomed Amersham plc was formed in October 1997 following the merger of Nycomed ASA and Amersham International plc. Nycomed Amersham plc operates two sites in the UK, at Amersham in Buckinghamshire and Cardiff in South Glamorgan.

Amersham

6.4.2 The site at Amersham contains research and production facilities for the manufacture of a wide variety of radioactive sources and radio-labelled compounds for use in research and medicine. Airborne wastes are emitted via stacks to the atmosphere, and solid low-level wastes are transferred to BNFL's site at Drigg for disposal. Liquid effluents are routed so as to keep separate alpha active wastes, non-alpha active wastes and those containing appreciable quantities of short-lived radionuclides. The latter are held in containers in the waste stores, to allow for radioactive decay. The other two effluent streams are treated when activity levels are high. The alpha and non-alpha waste streams are segregated and are routed to one of three holding tanks per stream prior to monitoring and discharge via the public sewer to the Maple Lodge Sewage Treatment Plant, operated by Thames Water.

6.4.3 The 1998 programme included:

(a) the analysis of samples of liquid effluents from the holding tanks;

(b) the analysis of samples of aqueous effluents and sludges from the Maple Lodge Sewage Treatment Plant;

and, near Nycomed Amersham plc, Amersham;

(c) the sampling of water and sediment taken at a point close to the outfall from the sewage works.

Effluent monitoring

6.4.4 The comparison of results from the analysis of liquid effluents by Nycomed Amersham and the Agency's contract laboratory, LGC, showed poor agreement. In nearly all cases where discrepancies were observed, Nycomed Amersham reported higher concentrations. Discrepancies in the total beta results almost certainly result from different methodologies being used by the two laboratories. Nycomed Amersham analyses the individual samples that make up the monthly bulk sample, whereas LGC analyses the monthly bulk. Analysis of the individual samples has the advantage of being able to correct for the decay of short-lived radionuclides from the time of sampling to analysis. This is not possible on the bulk samples analysed by LGC. The sampling and analysis programme was reviewed during 1999 and the protocols will be amended to improve comparability between samples.

Maple Lodge

6.4.5 Maple Lodge Sewage Treatment Plant is operated by Thames Water and receives authorised discharges from Nycomed Amersham. Raw sewage enters the works and, following settlement and biological treatment, is discharged via the Grand Union Canal and River Colne to the River Thames. Sludge solids are produced as a result of settlement and biological treatment and are sent to a digester for microbial breakdown. Following dewatering, the sludge is predominantly put to agricultural use, and around 10% is used as a soil conditioner in land restoration. During 1998 samples of raw sewage, final effluent and digested sludge were analysed each quarter. The results are given in Table 15. A study[27] commissioned by the Agency's predecessor, HMIP, confirmed that the agricultural use of digested sludge at these concentrations would be acceptable on radiological grounds.

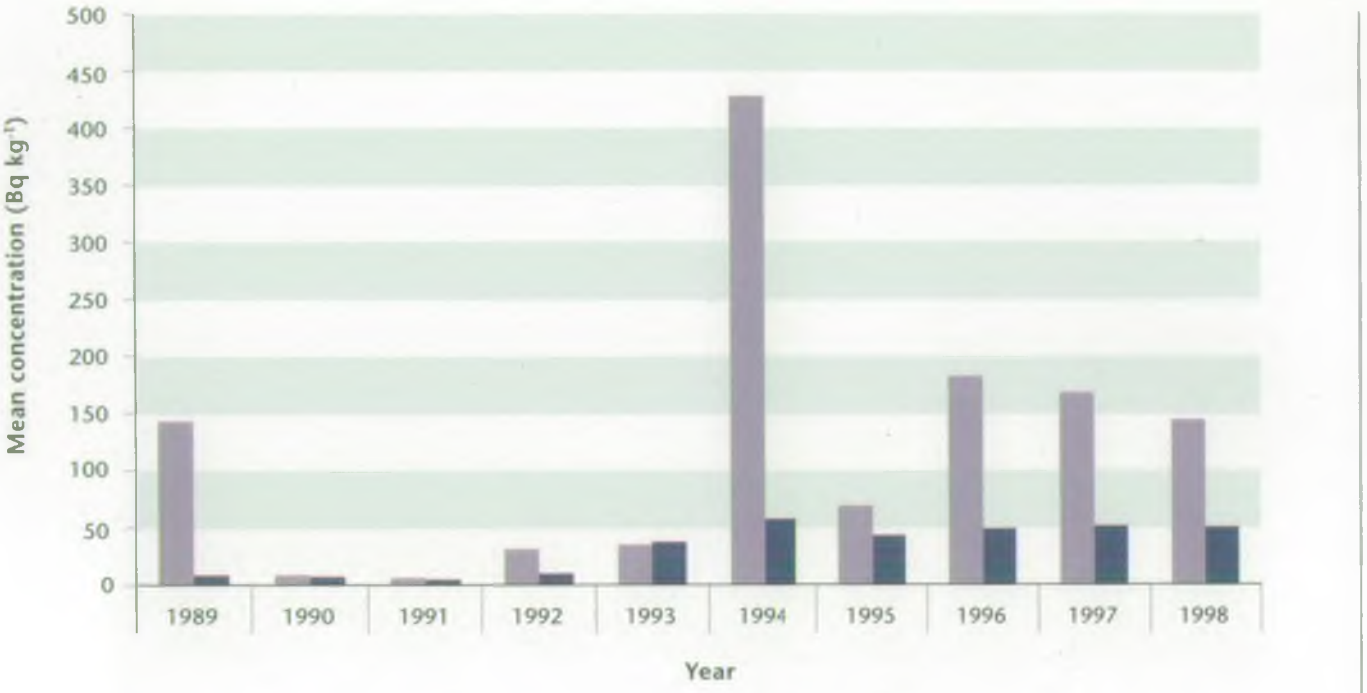

Figure 18 Mean concentration of tritium in surface water near Nycomed-Amersham (Cardiff)

Environmental monitoring

Water and sediment

6.4.6 Samples of water and of sediment were taken at a point close to the outfall from the sewage works. The results are recorded in Table 16. The levels of tritium in water were below the limits of detection throughout 1998. Total alpha and total beta activities were below the WHO screening values of 0.1 Bq l^{-1} and 1.0 Bq l^{-1} respectively throughout 1998. Radiologically insignificant concentrations of cobalt-57, zinc-65 and caesium-137 were again detected in sediment samples from the river during 1998. However, Nycomed Amersham has previously reported similar concentrations in control samples taken upstream of its effluent discharge point. Fishermen or others in close contact with the riverbank may ingest small amounts of sediment, but the resulting effective dose would be much less than 1 μSv y^{-1}.

Cardiff

6.4.7 The site at Cardiff manufactures radio-labelled compounds and diagnostic tests for use in research and medicine. Airborne wastes are discharged to the atmosphere via stacks. Some very low-level solid wastes are disposed of at local landfill sites. Other solid wastes are transferred to BNFL's site at Drigg for disposal. Liquid wastes are pumped automatically from individual building storage tanks to holding tanks for monitoring before discharge to the Bristol Channel via the public sewer and the Eastern pumping station.

6.4.8 The 1998 programme included:

(a) the analysis of samples of final liquid effluents discharged from the holding tanks;

(b) the monitoring of activity levels in the storm water from the site, in the River Taff, which receives the storm water run-off, and in the nearby Glamorganshire Canal.

Effluent monitoring

6.4.9 The comparison of analytical results for the analysis of liquid effluent by Nycomed Amersham plc and the Agency's contract laboratory, LGC, was generally good.

Environmental monitoring

6.4.10 Samples of water were taken during quarters 2 and 3 from points close to the storm water outfall, the River Taff and from the canal. The results recorded in Table 17 show that elevated levels of tritium were reported in the Glamorganshire Canal and the storm-water outfall. The tritium concentrations observed in water from the River Taff throughout 1998 were below the limits of detection. The tritium concentrations observed in water from the storm water outfall during the third quarter of 1998 and the Glamorganshire Canal throughout 1998 were similar to those reported in recent years. Figure 18 shows the mean concentrations of tritium found in surface waters in the vicinity of Nycomed Amersham (Cardiff) for the years 1989 to 1998. An additional programme of monitoring and assessment has been instigated (see paragraph 6.10.3).

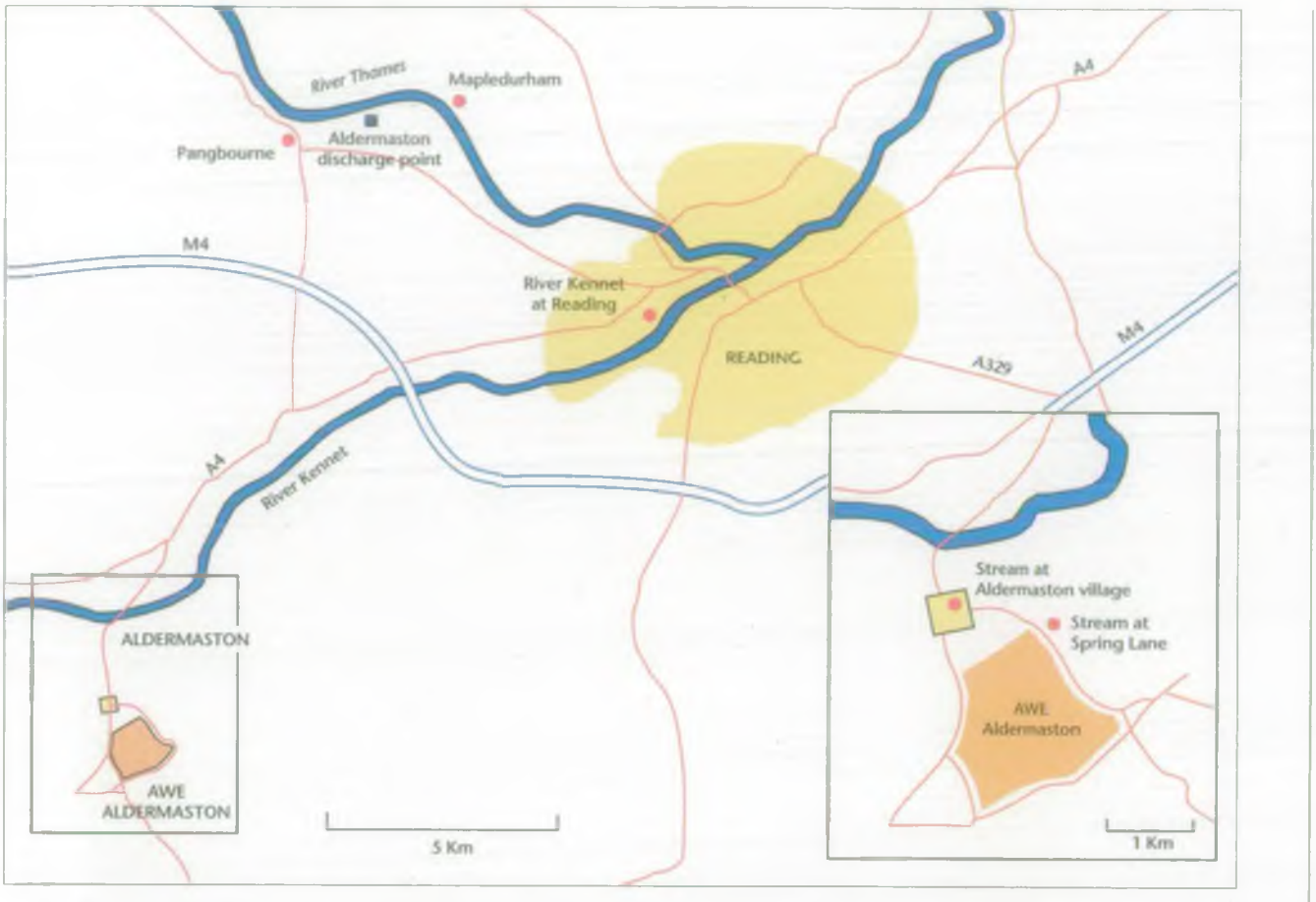

Figure 19 Monitoring locations – AWE Aldermaston

6.5

Nuclear materials for defence purposes

6.5.1 Hunting BRAE Ltd processes nuclear materials in support of the defence programme at the Atomic Weapons Establishment (AWE) at Aldermaston in Berkshire on behalf of the Ministry of Defence. Nuclear materials are used in submarines, which are maintained at Devonport Dockyard in Plymouth in Devon. The Devonport site is operated by Devonport Royal Dockyard Ltd and the Ministry of Defence.

Aldermaston

6.5.2 Active liquid effluents are routed to the on-site active effluent treatment plant and, after treatment by a ferric hydroxide flocculation process, are monitored before discharge by pipeline to the River Thames at Pangbourne (Figure 19). Effluents from facilities undertaking work on depleted uranium are routed with the site's non-active effluents to the trade waste effluent treatment plant and, after monitoring, are discharged to sewer. Active sludges produced from the active effluent treatment plant are stored on site for future treatment and disposal. Sludges from the site trade waste effluent treatment plant are monitored to demonstrate that they contain only exempt levels of radioactivity, then disposed of to a landfill site.

6.5.3 The 1998 programme included:

(a) the analysis of final liquid effluents from the site treatment plant and the trade waste treatment plant, and the analysis of dry sludge cake from the trade waste sludge drying beds;

(b) the monitoring of activity of sediments and surface waters levels in the River Thames, the River Kennet and streams in the vicinity of the site.

Effluent monitoring

6.5.4 Discrepancies between the results of the analysis of total alpha, total beta and tritium activities in samples of treatment plant effluents by AWE and LGC were noted. AWE's and LGC's results of the analysis of total alpha and total beta activities in samples of trade waste effluent were generally close to, or below, the limits of detection for both laboratories. Analyses previously performed by NRPB have shown that the measurement of total alpha and total beta activity is dominated by uranium. LGC's results confirmed that the tritium levels in trade waste effluent were low and close to concentrations normally observed in UK surface waters.

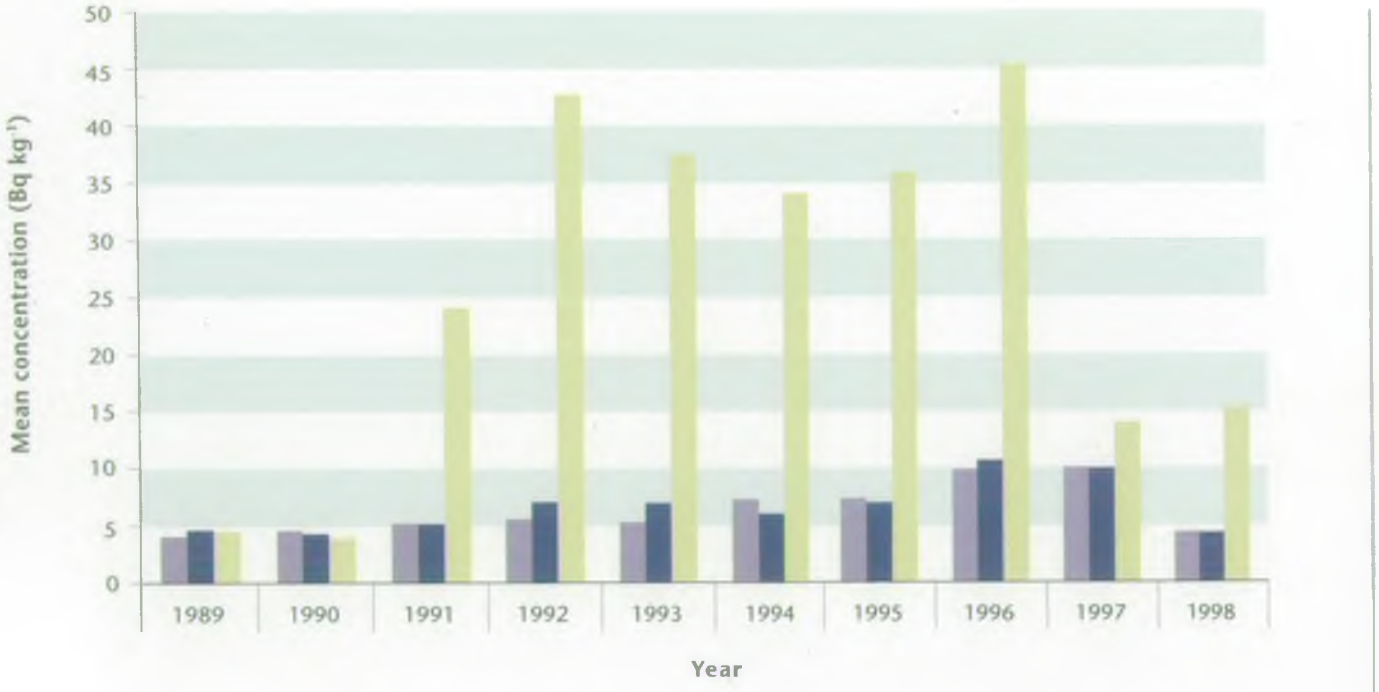

Figure 20 Concentration of tritium in water near AWE Aldermaston

6.5.5 AWE reported low concentrations of total alpha and total beta in two dry sludge cake samples obtained in October 1998.

Environmental monitoring

6.5.6 Samples of water were taken at weekly intervals and bulked over 13-week periods from the River Thames at Pangbourne and Mapledurham, upstream and downstream respectively of the discharge outfall, from the River Kennet at Reading (Figures 16 and 19) and from streams at Aldermaston village and at Spring Lane close to the site. The analytical results recorded in Table 18 show concentrations of tritium measured in the streams at Aldermaston were consistently above the values for general UK waters. The concentrations in the Aldermaston stream were similar to those observed during 1997. Concentrations were low in all cases and the resulting doses would have been negligible to anyone consuming water from the streams. Figure 20 shows the mean concentrations of tritium found in water associated with Aldermaston discharges between 1989 and 1998. The levels of total alpha and total beta activity in all samples were below the WHO screening values of 0.1 Bq l^{-1} and 1.0 Bq l^{-1} respectively. No radionuclides were detected by gamma-ray spectrometry.

6.5.7 Quarterly sediment samples were also taken from these locations and the results are recorded in Table 18. Low levels of caesium-137 were detected in River Thames sediments both upstream and downstream of the discharge outfall, in the River Kennet at Reading and in two streams close to the site. The concentrations measured during 1998 were generally somewhat lower than those observed in recent years. Currently, routine discharges from AWE do not include significant levels of caesium, and its presence in these sediments may be as a result of historical discharges or may include contributions from discharges to the Thames from Harwell further upstream, from nuclear weapon test fallout, or as a result of deposition following the Chernobyl accident. The concentrations of all anthropogenic radionuclides found were small, and inadvertent ingestion of sediment would result in an effective dose of much less than 1 µSv y^{-1}.

Devonport

6.5.8 Liquid effluent containing low activity concentrations of radionuclides is discharged into the Tamar Estuary. The 1998 programme included the analysis of final liquid effluents and monitoring of sediments.

Effluent monitoring

6.5.9 Results of the monitoring conducted on behalf of the Agency showed a good level of agreement with site operator's results.

Environmental monitoring

6.5.10 Gamma dose rates measured above sediments were reported as 0.09 μGy h^{-1} and 0.097 μGy h^{-1} respectively. These were attributed to enhanced regional levels of natural radionuclides, because in the monitored areas, concentrations of artificial radionuclides originating from Devonport were too low to give measurable dose rates. For example, samples of sediments that were analysed for cobalt-60 during the second and fourth quarters of 1998 were below the limit of detection.

6.6 Non-nuclear sites

Surelite Ltd

6.6.1 Surelite Ltd is registered under the Radioactive Substances Act for the keeping and use of large quantities of tritium at its premises at Weldon in Northamptonshire. The tritium is used in the production of light-emitting devices, which are incorporated into signs, instruments and other self-luminous articles.

6.6.2 The principal waste arising from the site is airborne tritium gas emitted to the atmosphere. Trivial amounts of activity are also disposed of locally in solid and liquid wastes. The 1998 programme monitored the impact of emissions to the atmosphere by monitoring tritium levels in nearby surface waters and open grassland.

6.6.3 The water sources from which spot samples were taken and the results of the analysis for tritium are detailed in Table 19. Rutland Water, Eyebrook Water and Pitsford Reservoir are public water sources. The levels of tritium were generally consistent with those for UK surface waters, although slightly elevated concentrations were observed in the samples closest to the site.

6.6.4 No tritium was detected in samples of grass collected from two locations close to the site.

6.7 Landfill sites

6.7.1 Several landfill sites receive solid low-level radioactive wastes for controlled burial. These are wastes that can be disposed of safely, with special precautions, at well-operated landfill sites. Generally disposals are completed on the day the wastes arrive at the site by covering with at least 1.5 m of inactive refuse or soil. Limits on the radioactive content of wastes, the landfill site to be used for disposal and the precautions to be employed when disposing of the wastes are specified in an authorisation issued to the waste producer. Such authorisations are issued for disposal only to landfill sites with the necessary characteristics and after consultation with the appropriate public and local bodies.

6.7.2 The 1998 programme concentrated on monitoring levels of radioactivity in leachates arising from the landfill sites and in groundwaters or local surface waters which might be affected by migration of activity from buried wastes. Bi-annual or quarterly monitoring was carried out at those sites that have exhibited elevated tritium concentrations in past years.

6.7.3 All samples were analysed for total alpha and total beta activity for comparison with the WHO screening values for potable waters. Tritium was determined separately because its low-energy beta emissions mean it cannot be screened satisfactorily by total beta measurement. Specific analyses, such as for uranium, carbon-14 and iodine-125, were undertaken where appropriate to the radionuclide composition of the buried wastes and all samples were screened using gamma-ray spectrometry. The analytical results are presented in Table 20.

6.7.4 At all locations total alpha activities were below the WHO screening value of 0.1 Bq l^{-1}. However, as in previous years total beta activities above the WHO screening value of 1.0 Bq l^{-1} were found in samples from a number of sites. These included borehole waters from the Milton landfill, Northwich tip, Lamby Way tip and Beighton tip, stream water upstream and downstream of the Cowpen Bewley tip, leachate from Crooks Marsh Farm, stream water from Murex Ltd, leachate from Cilgwyn Quarry, borehole waters from Clifton Marsh and Cole Green, local water from Millennium Inorganic Chemicals on-site tip, leachate from Beddingham Quarry (Figure 21), Albright & Wilson and Alco tips and local

Figure 21
Sampling leachate at Beddingham Quarry

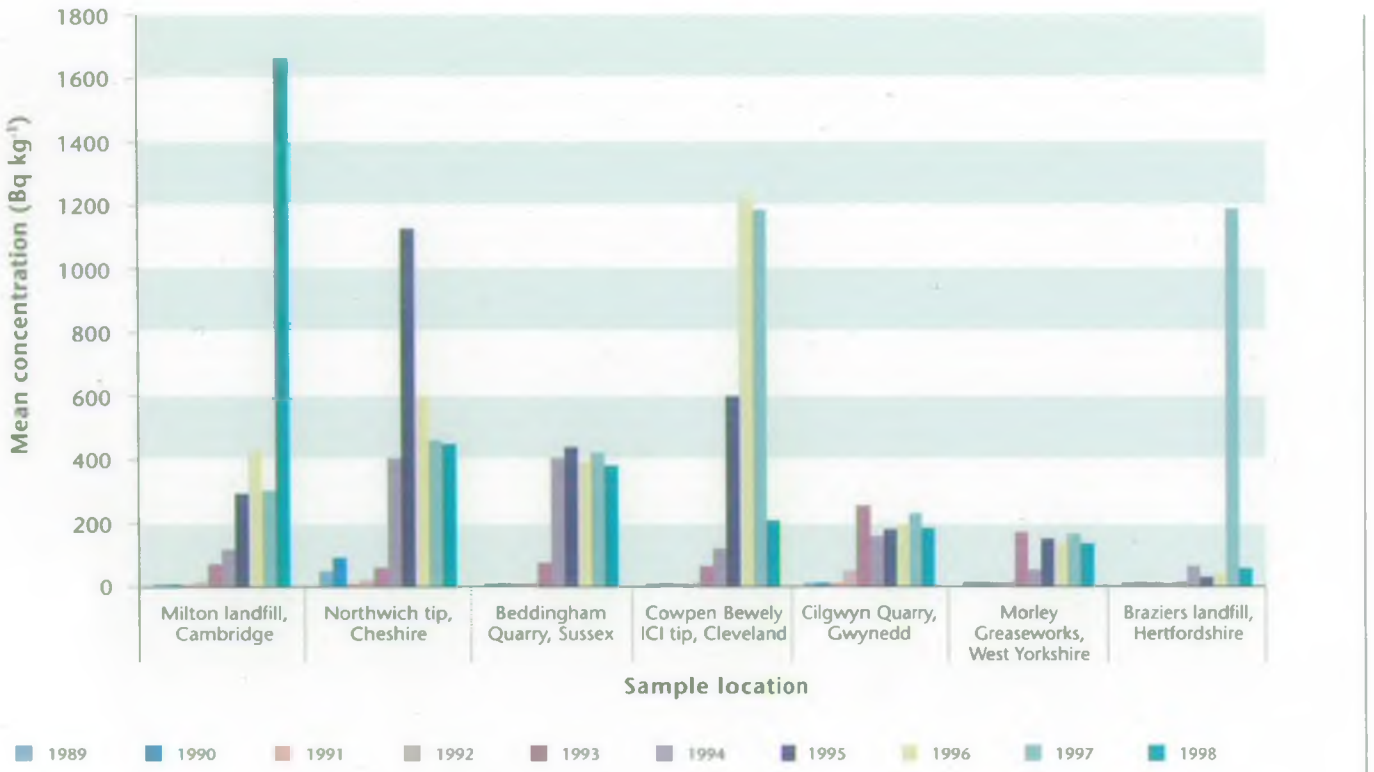

Figure 22 Mean concentration of tritium found at landfill sites

waters from Greaseworks Tip, Wilson Road tip and Dean House Farm. Additional analysis has previously shown that the increased total beta was attributable to enhanced concentrations of potassium-40, a naturally occurring radionuclide present in soils and artificial fertilisers. No other radionuclides were detected by gamma-ray spectrometry.

6.7.5 Elevated concentrations of tritium continued to be observed at a number of landfill sites. These included borehole waters from Milton landfill, Lamby Way tip and Witton tip, stream water downstream of the Cowpen Bewley tip with marginal elevation in upstream river water, leachate from Cilgwyn Quarry, borehole water from Braziers landfill, leachate and borehole water from Beddingham Quarry, and local water at the Greaseworks tip. The reported tritium concentrations vary from year to year. The variation is thought to be related to changes in rainfall quantity and resulting leachate production and the use of different boreholes for sampling. Figure 22 shows the mean concentration of tritium found in association with landfill waters from 1989 to 1998.

6.7.6 Consideration has been given to the possible sources of tritium in landfill site waters. Of the above sites only Crooks Marsh Farm, Milton Landfill and Cowpen Bewley are known to have received gigabecquerel quantities of tritium. At Cilgwyn and Asham (Beddingham) Quarry disposals of megabecquerel quantities have been authorised.

6.7.7 Landfill sites may also receive disposals of very low-level wastes with other refuse from hospitals, universities and research centres. Tritium concentrations up to 4,000 kBq per 0.1 m^3 are permitted. When these wastes are not incinerated with loss of tritium to the atmosphere, they are disposed of at local landfill sites.

6.7.8 Tritium gas is used widely in self-illuminating devices in many proprietary items such as instruments and signs. From 1985, their use has been exempt from registration under the Radioactive Substances Act by SI No 1047, The Radioactive Substances (Gaseous Tritium Light Devices) Exemption Order 1985. This order also exempts the disposal of small GTLDs containing less than 20 GBq of tritium from authorisation under the act, provided that no more than one source is disposed of in any 0.1 m^3 of non-radioactive waste. Consequently, small GTLDs are disposed of with other household and trade wastes to local landfills without further regulatory control.

6.7.9 The conditions under which exemption is granted require users to return large GTLDs containing more than 20 GBq to a manufacturer of such articles or an authorised disposer. However, there is no requirement on the user to inform the Agency of their installation or disposal; consequently there is no means of readily assessing compliance. The Agency has drawn this anomaly to the attention of DETR. Exemption orders are currently being reviewed as part of a wider review of the Radioactive Substances Act 1993. GTLDs containing typically 1,000 GBq were installed widely in the form of EXIT and other warning signs in public buildings during

the 1970s, in response to tighter health and safety legislation. These devices have a working life of about 15 years, during which the radioactivity of the tritium decays to about half of its original value, resulting in diminished luminescence.

6.7.10 The tritium content of authorised disposals including dustbin wastes and small GTLDs is unlikely to be sufficient to result in the observed elevated concentrations of tritium in landfill waters. However, the tritium content of large GTLDs, such as EXIT signs, would be sufficient to produce elevated tritium concentrations. One possible explanation for the increase could be that many of these signs have been disposed of, either deliberately or in ignorance of the regulations, to local landfills instead of being returned to a manufacturer or authorised disposer. To examine this hypothesis further, the Agency commissioned NRPB to carry out a review of the use and disposal of GTLDs and, as part of the review, to investigate the possible sources of elevated tritium levels in landfill waters. The report of this work, published in June 1998, concludes that this is the most likely source of the elevated tritium levels[28].

6.7.11 Although higher than expected, the elevated levels of tritium at the sites concerned do not pose a radiological hazard. The highest concentration observed during 1998 was 2,433 Bq l^{-1} during the first quarter in borehole water from Milton landfill, and concentrations even at this level would result in a dose of about 26 µSv y^{-1} if the borehole were to be used as a drinking water supply. However, the measured concentration at this site fell to 125 Bq l^{-1} in the third quarter of 1998. Assuming that borehole water from Milton landfill was used as a drinking water supply and had tritium concentrations of 2,433 Bq l^{-1} for six months of 1998 and 125 Bq l^{-1} for the remaining six months, the annual mean effective dose would have been about 12 µSv y^{-1}.

6.7.12 Further evidence of the ubiquitous nature of tritium in landfill leachates comes from additional Agency monitoring carried out in the north west of England during 1997. The monitoring programme looked specifically at landfill sites accepting general industrial, commercial and/or domestic waste but not in the main receiving radioactive waste from authorised users. The results of the programme showed that tritium was present in most sites where the waste was of a general nature. Tritium concentrations of up to 1,342 Bq l^{-1} were reported. It was also observed that tritium did not appear in sites devoted to a single operator's waste. This evidence further supports the GTLD hypothesis outlined above.

6.8 Air and rainwater

6.8.1 A summary of the quarterly monitoring data for 1998 from this programme is provided in Tables 21(a), 21(b), and 21(c). Average air concentrations of caesium-137 measured at the seven sampling sites during 1998 were similar to those observed since 1990. The measured concentrations remain less than 0.01 per cent of those observed in 1986, the year of the Chernobyl nuclear power reactor accident, and are of negligible radiological significance. Concentrations of caesium-137 in rainwater was in all cases below analytical limits of detection at the nine rainwater sampling locations.

6.8.2 Concentrations of beryllium-7, a naturally occurring radionuclide formed by cosmic ray reactions in the upper atmosphere, was measured in air during 1998 and was similar at all sampling locations. Over the period 1990 - 1998, peak air concentrations of beryllium-7 tended to occur during spring and early summer at all UK sampling sites. These are attributed to a seasonal variation in the mixing of stratospheric and tropospheric air.

6.8.3 Tritium concentrations measured in rainwater during 1998 were similar to those observed in 1997, and were consistent with those found during the earlier 1990s, particularly at Orfordness and Aberporth. A decline in tritium concentrations has been recorded in rainwater at Eskdalemuir; the annual mean concentration in 1998 was slightly higher than that observed in 1997 but still remained approximately half of that for 1990.

6.9 Drinking water sources

6.9.1 More than 97 per cent of the population in England and Wales obtain their drinking water from the public supply system. The monitoring programme is designed to be representative of the principal sources and includes 14 impounded waters (reservoirs), 12 abstraction sources from rivers and six groundwater boreholes at the locations shown in Figure 4. The monitored sources provide water for more than 10 million people.

6.9.2 The samples are representative of natural waters before treatment and supply to the public water system. Depending on the source type, radioactivity levels may be influenced by local geology, atmospheric fallout or authorised discharges of radioactive wastes. Water treatment would be expected to reduce the levels of radioactivity (except tritium), while the extent of the reduction would depend on the water source and the type of treatment.

6.9.3 The results detailed in Table 22 show that all the monitored sources are generally below the WHO screening values of 0.1 and 1.0 Bq l^{-1} for total alpha and total beta activities respectively. As in 1997, minor exceedances for total alpha activities occurred in samples from the groundwater source at Meerbrook Sough in Derbyshire. Elevated concentrations of uranium are present, indicating that this is caused by the local geology. The concentrations are radiologically insignificant.

6.9.4 Results for the River Thames, which receives authorised discharges from Nycomed Amersham, UKAEA Harwell and MoD Aldermaston, are consistent with those from the Agency's regulatory monitoring near the sites' discharge points. They confirm that the discharges have no detectable influence on activity levels particularly of tritium, the principal component of the discharges, both close to and distant from the discharge points.

6.10 Additional monitoring and assessment

Contaminated feral pigeons

6.10.1 Contaminated feral pigeons were found to be congregating at a private residence with a small bird sanctuary in the village of Seascale (3km south of the Sellafield nuclear site). Elevated levels of artificial radionuclides (plutonium and caesium-137) were measured across much of the garden of the residence, at up to 800 times the typical concentrations for the region. Neighbouring properties were also surveyed where levels of artificial radionuclides were found to be considerably lower. The estimated dose from man-made radionuclides to the residents of the bird sanctuary in the year before remediation was 570 µSv. Doses to inhabitants of neighbouring properties were about 60 µSv y^{-1} or less. Estimated doses were below the annual effective dose limit for members of the public of 1,000 µSv y^{-1}.

6.10.2 A programme of remediation at the affected property was carried out by BNFL, which included removal of the garden top soil and tarmac drive. Limited additional remediation work was also undertaken in response to specific requests from residents. Survey work on the Sellafield site showed that the pigeons had become contaminated by contact with radioactive materials produced by historical practices in older on-site buildings. In response, a series of measures were introduced, which included preventing wildlife access to on-site contamination. Environmental monitoring programmes are also being reviewed and revised to provide reassurance that there is no recurrence of this pathway. The programme carried out to assess the radiological implications of contaminated feral pigeons was completed and published during 1999[29].

Enhanced tritium levels in Cardiff Bay

6.10.3 Activity concentrations of tritium of up to 50,000 Bq kg^{-1} were found in fish caught near the liquid effluent discharge outfall from the plant. Previously it had been assumed, in accordance with international guidance and experience elsewhere, that the tritium concentrations in fish would be low and around the same as in seawater, up to about 200 Bq l^{-1}. High concentrations of tritium were later found in sediments, shellfish and filter feeders. A radiological assessment of tritium ingested in marine foods was commissioned by the Agency during 1998. The initial results from the assessment indicated doses of approximately 38 µSv y^{-1} to the critical group of marine fish consumers, well below the annual dose limit for members of the public of 1,000 µSv. The work is expected to be published shortly.

6.10.4 As a result of the elevated levels of tritium measured around Cardiff, during 1999, the Agency commenced a programme of additional environmental monitoring for tritium in other parts of England and Wales, including the margins of the Irish Sea, parts of the Dorset coast and areas around the Rolls Royce site in Derbyshire. The results of the additional monitoring will be assessed and included in the 1999 report.

Seawashed turf

6.10.5 The need for a programme to assess the exposure pathways arising from artificial radionuclides in sea-washed turf was identified during 1998. The work will assess the extent of the turf cutting industry and current working practices. Monitoring of the sites will also be carried out. The results of the study are expected to be reported in the year 2000.

Coal-fired power stations

6.10.6 All types of coal contain varying activity concentrations of natural radionuclides, principally isotopes and progeny of uranium and thorium. Combustion of coal in a coal-fired power station or coal fired boiler results in releases of radioactive lead, polonium and radon. During 1998, the Agency initiated a study to assess the radioactive content of emissions from coal-fired power stations and the radiological implications. The measured levels were too low to require authorisation under the RSA93.

Summary and conclusions

Effluent monitoring

7.1

Independent monitoring of the radioactive wastes disposed from the major sites was carried out by sampling liquid effluent streams, analysing the radionuclide content and comparing with the operators' own results or declared returns.

7.2

Disposals were monitored from sites carrying out the manufacture, processing and use of radioactive materials, the disposal of solid low-level wastes, nuclear power stations, research establishments, the manufacture of radioactive sources and defence establishments in England and Wales. Approximately 266 effluent samples were taken from 34 liquid effluent streams from the sites. Approximately 1,300 analytical results were reported.

7.3

The operators' measurements of their disposals were consistently in broad agreement with the Agency's monitoring in liquid effluents from 21 sites (BNFL Capenhurst, all the nuclear power stations effluent streams, and Nycomed Cardiff). In effluents from six sites, activity concentrations were near or below limits of detection (Drigg effluents, Harwell trade wastes and final sewage effluent, Winfrith inner and outer pipeline effluents and Aldermaston trade wastes).

7.4

Discrepancies between the Agency's check monitoring and an operator's results were consistently observed for one or more radionuclides in effluents from seven sites (Sellafield EARP, SETP and SIXEP, Springfields, Harwell Trade Wastes, Nycomed Amersham, and Aldermaston treated wastes). The check monitoring indicated that most operators were disposing of less radioactivity than they had declared.

7.5

In effluents from three sites, the agreement between the Agency monitoring and the operator's returns was improved in 1998 compared with 1997. For the remaining sites, the level of agreement between the Agency monitoring and the operators' monitoring was similar in 1997 and 1998.

7.6

The Agency is undertaking a review of the monitoring of effluent carried out where agreement is consistently poor. The review involves the site operator, site inspectors and the laboratories carrying out the monitoring.

7.7

The Agency's effluent monitoring programme provides a means to judge the quality of the operators' own monitoring arrangements. Overall the programme provided evidence that the declarations of disposals made by the operators in 1998 were reasonable and the discharges did not exceed the authorised limits.

Waste quality checking

7.8

Two consignments (140 drums in total) of low-level solid radioactive wastes destined for disposal at BNFL Drigg were seized, the radioactive content assessed by the Agency and compared with the declared content of the consignment. In both cases there was general agreement with the declared content of the wastes. However, the Agency required the replacement of one of the consignment containers, which had become corroded.

Environmental monitoring

7.9

Concentrations of radionuclides in surface waters and sediments around the major sites were monitored. During 1998 a total of approximately 630 environmental samples were taken and analysed and 5,750 results reported.

7.10

As in previous years, the environmental monitoring identified enhanced levels of artificial radionuclides in coastal sediments in Cumbria. The majority of the artificial radionuclides found in the coastal environment arise from

present and past discharges from Sellafield. The highest concentrations are near Sellafield, particularly in fine grain sediments (muds) in the estuaries of West Cumbria. Environmental levels fall off with increasing distance from the Sellafield site. Enhanced activity concentrations of some radionuclides were also found in the Ribble Estuary as a result of discharges from Springfields. In general, concentrations in these coastal environments were in agreement with those reported in previous years and show no clear trend.

7.11

Monitoring of the environments around other sites carrying out storage or processing of nuclear materials or research showed slightly enhanced levels of a few artificial radionuclides in the vicinity of some authorised discharge points. The monitoring showed that the activity concentrations declined with increasing distance from the disposal point. Environmental concentrations measured were broadly in line with those found in previous years.

7.12

Monitoring of the environment around nuclear power stations showed low levels of artificial radionuclides, about half of which were reported as below limits of detection.

Assessment

7.13

The significance of the environmental concentrations measured during monitoring was assessed by determining the effective doses to exposed groups. The external doses were determined by field monitoring in the affected environments combined with estimates of occupancies. Internal exposure was determined using estimated intakes of environmental materials containing radionuclides.

7.14

The external dose monitoring showed that on the West Cumbrian coast and parts of the Ribble estuary, external dose rates were generally no more than twice background. In West Cumbria, these external dose rates gave rise to effective doses of up to 45 $\mu Sv\ y^{-1}$. In the Ribble Estuary, the dose rates are similar to those on the West Cumbrian coast, however, estimated doses for the critical group of houseboat dwellers are higher (between 100 to 175 $\mu Sv\ y^{-1}$) because occupancy of the estuary is higher.

7.15

Dose rates in the coastal areas of North Wales, Lancashire and Merseyside are between 1 and 1.5 times background. For occupancies of around 300 h y^{-1}, effective doses from external exposure in excess of background were between 2 and 20 $\mu Sv\ y^{-1}$. In areas around nuclear power stations, the monitoring found external dose rates mostly less than 1.5 times background. Dose rate monitoring carried out around discharge points from other main sites found background levels only.

7.16

External dose rates measured in the environment around the main nuclear sites have shown little change over the last five years.

7.17

The highest effective doses from intakes of radionuclides in environmental samples were where activity concentrations in the environment are highest and access is possible. The highest effective doses were on the Cumbrian Coast, where inadvertent ingestion of sediment and inhalation gave rise to estimated effective doses of between 1 and 22 $\mu Sv\ y^{-1}$. In the Ribble Estuary, doses from internal exposure of between 1 and 8 $\mu Sv\ y^{-1}$ are estimated. Around other nuclear sites, internal doses from intakes of radionuclides in sediments and waters are estimated to be between 0.1 and 1 $\mu Sv\ y^{-1}$.

7.18

The estimated effective doses around all the sites are well below the public dose limit of 1,000 $\mu Sv\ y^{-1}$.

Conclusions

7.19

The Agency has carried out an extensive programme of monitoring of effluent discharges from major nuclear sites.

7.20

Discharges of radioactivity into the environment reported by the operators of the major sites during 1998 were well below the authorised discharge levels.

7.21

The Agency has carried out an extensive programme of environmental monitoring around major nuclear sites. The results of the monitoring show that environmental concentrations of discharged radionuclides were broadly similar to previous years.

7.22

The Agency has assessed the effective doses to members of the public around all the sites. All the estimated doses were below the public dose limit and in many cases the estimated doses were much less than 1% of the dose limit.

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Table 1

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
British Nuclear Fuels plc, Capenhurst				
Rivacre Brook	Tritium	8.75E+01	1.50E-04	0.0
	Technetium-99	1.00E-01	1.35E-03	0.0
	Uranium	2.00E-02	1.25E-03	6.3
	Uranium daughters	2.00E-02	2.90E-03	15
	Non-uranic alpha	3.00E-03	1.45E-05	0.5
Gaseous	Tritium	1.6E+03	5.00E+01	0.3
	Uranium	(c)	6.15E-06	
Drigg				
Sea pipeline	Alpha	1.00E-01	1.14E-04	0.1
	Beta (d)	3.00E-01	1.63E-03	0.5
	Tritium	1.20E+02	4.99E-01	0.4
Stream (e)	Alpha	9.00E+04	6.90E+01	0.8
	Beta (d)	1.20E+06	8.40E+02	0.9
	Tritium	6.00E+08	5.10E+04	0.0
Sellafield				
Sea pipelines	Alpha	1.00E+00	1.74E-01	17
	Beta	4.00E+02	8.55E+01	21
	Tritium	2.50E+04	2.31E+03	9.2
	Carbon-14	2.08E+01	3.75E+00	18
	Cobalt-60	1.30E+01	2.41E+00	19
	Strontium-90	4.80E+01	1.77E+01	37
	Zirconium-95 & Niobium-95	9.00E+00	6.47E-01	7.2
	Technetium-99	2.00E+02	5.27E+01	26
	Ruthenium-106	6.30E+01	5.58E+00	8.8
	Iodine-129	1.60E+00	5.53E-01	35
	Caesium-134	6.60E+00	3.19E-01	4.8
	Caesium-137	7.50E+01	7.54E+00	10
	Cerium-144	8.00E+00	7.62E-01	9.5
	Plutonium alpha	7.00E-01	1.40E-01	20
	Plutonium-241	2.70E+01	3.54E+00	13
	Americum-241	3.00E-01	4.72E-02	16
	Uranium (f)	2.04E+03	5.54E+02	27
Factory sewer	Alpha	3.30E-03	3.20E-05	1.0
	Beta	1.35E-02	4.70E-04	3.5
	Tritium	1.32E-01	1.73E-02	13

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Sellafield (cont)				
Gaseous (g, h)	Alpha	1.96E-03	8.33E-05	4.3
	Beta	3.28E-01	1.64E-03	0.5
	Tritium	1.45E+03	2.50E+02	17
	Carbon-14	8.62E+00	2.60E+00	30
	Sulphur-35	2.10E-01	1.54E-01	73
	Argon-41	3.70E+03	2.53E+03	68
	Cobalt-60	9.20E-04	5.30E-05	5.8
	Krypton-85	4.70E+05	9.89E+04	21
	Strontium-90	9.40E-03	6.00E-05	0.6
	Ruthenium-106	9.60E-02	1.10E-03	1.1
	Antimony-125	5.00E-03	1.84E-04	3.7
	Iodine-129	6.30E-02	2.64E-02	42
	Iodine-131	5.50E-02	3.18E-03	5.8
	Caesium-137	1.83E-02	4.41E-04	2.4
	Plutonium (alpha)	1.22E-03	3.43E-05	2.8
	Plutonium-241	1.74E-02	2.67E-04	1.5
	Americium-241 & Curium-242	7.40E-04	4.99E-05	6.7
Springfields				
Liquid	Alpha	4.00E+00	1.95E-01	4.9
	Beta	2.40E+02	1.50E+02	63
	Technetium-99	6.00E-01	2.73E-02	4.6
	Thorium-230	2.00E+00	8.50E-02	4.3
	Thorium-232	2.00E-01	1.20E-03	0.6
	Neptunium-237	4.00E-02	2.00E-04	0.5
	Uranium	1.50E-01	4.67E-02	31
Gaseous	Uranium	6.00E-03	1.54E-03	26
BNFL Magnox Generation Berkeley Power Station and Technology Centre				
Liquid	Tritium	8.00E+00	3.42E-02	0.4
	Caesium-137	2.00E-01	1.43E-02	7.2
	Other radionuclides	4.00E-01	7.34E-02	18
Gaseous (i)	Alpha and beta	2.00E-04	1.87E-06	0.9
	Tritium	2.00E+00	2.17E-03	0.1
	Carbon-14	2.00E-01	2.31E-04	0.1
	Sulphur-35	6.00E-03	0.00E+00	0.0

Table 1 continued

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Bradwell				
Liquid	Tritium	3.00E+01	1.79E+00	6.0
	Caesium-137	7.50E-01	3.23E-01	43
	Other radionuclides	1.00E+00	3.59E-01	36
Gaseous	Beta particulate	1.00E-03	2.62E-04	26
	Tritium	1.50E+00	8.39E-01	56
	Carbon-14	6.00E-01	3.79E-01	63
	Sulphur-35	2.00E-01	5.80E-02	29
	Argon-41	1.00E+03	7.24E+02	72
Dungeness 'A' Station				
Liquid	Tritium	3.50E+01	4.21E-01	1.2
	Caesium-137	1.20E+00	7.08E-01	59
	Other radionuclides	1.40E+00	3.86E-01	28
Gaseous	Beta particulate	1.00E-03	3.60E-04	36
	Tritium	2.00E+00	5.70E-01	29
	Carbon-14	5.00E+00	3.00E+00	60
	Sulphur-35	4.00E-01	6.30E-02	16
	Argon-41	2.00E+03	1.30E+03	65
Hinkley Point 'A' Station				
Liquid	Tritium	2.50E+01	7.08E-01	2.8
	Caesium-137	1.50E+00	4.93E-01	33
	Other radionuclides	1.00E+00	2.84E-01	28
Gaseous	Alpha and beta	1.00E-03	1.05E-04	11
	Tritium	2.50E+01	2.53E+00	10
	Carbon-14	4.00E+00	1.42E+00	36
	Sulphur-35	2.00E-01	5.72E-02	29
	Argon-41	4.50E+03	2.70E+03	60
Oldbury				
Liquid	Tritium	2.50E+01	1.73E-01	0.7
	Caesium-137	7.00E-01	6.20E-02	8.9
	Other radionuclides	1.30E+00	1.75E-01	14
Gaseous	Beta particulate	1.00E-03	1.03E-04	10
	Tritium	5.00E+00	2.39E+00	48
	Carbon-14	6.00E+00	3.72E+00	62
	Sulphur-35	7.50E-01	3.11E-01	42
	Argon-41	5.00E+02	1.80E+02	36

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Sizewell 'A' Station				
Liquid	Tritium	3.50E+01	2.91E+00	8.3
	Caesium-137	1.00E+00	7.06E-02	7.1
	Other radionuclides	7.00E-01	1.45E-01	21
Gaseous	Beta	1.00E-03	5.62E-05	5.6
	Tritium	7.00E+00	5.15E-01	7.4
	Carbon-14	1.50E+00	4.65E-01	31
	Sulphur-35	6.00E-01	1.90E-02	3.2
	Argon-41	3.00E+03	8.42E+02	28
Trawsfyndd				
Liquid	Total activity (e,j,k)	7.20E-01	1.77E-02	2.5
	Tritium	1.20E+01	6.28E-02	0.5
	Strontium-90	8.00E-02	1.03E-02	13
	Caesium-137	5.00E-02	6.51E-03	13
Gaseous	Beta	2.00E-03	1.51E-06	0.1
	Tritium	1.00E+01	1.37E-01	1.4
	Carbon-14	5.00E+00	1.55E-03	0.0
	Sulphur-35	4.00E-01	0.00E+00	0.0
	Argon-41	3.50E+03	0.00E+00	0.0
Wylfa				
Liquid	Tritium	4.00E+01	9.64E+00	24
	Other radionuclides	1.50E-01	7.01E-02	47
Gaseous	Beta	1.00E-03	6.35E-05	6.4
	Tritium	2.00E+01	8.25E+00	41
	Carbon-14	2.40E+00	1.47E+00	61
	Sulphur-35	5.00E-01	2.96E-01	59
	Argon-41	1.20E+02	6.06E+01	51
British Energy Generation Ltd				
Dungeness 'B' Station				
Liquid	Tritium	6.50E+02	1.72E+02	27
	Sulphur-35	2.00E+00	2.02E-01	10
	Cobalt-60	3.00E-02	1.26E-03	4.2
	Other radionuclides	2.50E-01	1.65E-02	6.6
Gaseous	Beta particulate	1.00E-03	1.61E-05	1.6
	Tritium	1.50E+01	3.32E+00	22
	Carbon-14	5.00E+00	4.05E-01	8.1
	Sulphur-35	4.50E-01	2.30E-02	5.1
	Argon-41	1.50E+02	2.31E+01	15
	Iodine-131	5.00E-03	4.22E-06	0.1

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Hartlepool				
Liquid	Tritium	1.20E+03	3.29E+02	27
	Sulphur-35	3.00E+00	3.25E-01	11
	Cobalt-60	3.00E-02	3.27E-03	11
	Other radionuclides	3.00E-01	2.55E-03	0.9
Gaseous	Beta particulate	1.00E-03	4.43E-06	0.4
	Tritium	6.00E+00	1.51E+00	25
	Carbon-14	5.00E+00	1.91E+00	38
	Sulphur-35	1.60E-01	2.27E-02	14
	Argon-41	6.00E+01	1.16E+01	19
	Iodine-131	5.00E-03	2.87E-05	0.6
Heysham Station 1				
Liquid	Tritium	1.20E+03	3.96E+02	33
	Sulphur-35	2.80E+00	2.41E-01	8.6
	Cobalt-60	3.00E-02	1.00E-03	3.3
	Other radionuclides	3.00E-01	9.17E-03	3.1
Gaseous	Beta particulate	1.00E-03	3.63E-05	3.6
	Tritium	6.00E+00	1.42E+00	24
	Carbon-14	4.00E+00	1.16E+00	29
	Sulphur-35	1.20E-01	1.45E-02	12
	Argon-41	6.00E+01	1.26E+01	21
	Iodine-131	5.00E-03	7.47E-04	15
Heysham Station 2				
Liquid	Tritium	1.20E+03	3.07E+02	26
	Sulphur-35	2.30E+00	3.39E-02	1.5
	Cobalt-60	3.00E-02	1.09E-03	3.6
	Other radionuclides	3.00E-01	1.71E-02	5.7
Gaseous	Beta particulate	1.00E-03	1.46E-05	1.5
	Tritium	1.50E+01	2.18E+00	15
	Carbon-14	3.00E+00	1.05E+00	35
	Sulphur-35	3.00E-01	1.53E-02	5.1
	Argon-41	8.50E+01	1.63E+01	19
	Iodine-131	5.00E-03	1.89E-04	3.8
Hinkley Point 'B' Station				
Liquid	Tritium	6.20E+02	3.87E+02	62
	Sulphur-35	5.00E+00	5.78E-01	12
	Cobalt-60	3.30E-02	4.40E-04	1.3
	Other radionuclides	2.35E-01	1.90E-02	8.1

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Hinkley Point 'B' Station (cont)				
Gaseous	Beta particulate	1.00E-03	5.16E-05	5.2
	Tritium	3.00E+01	1.72E+00	5.7
	Carbon-14	8.00E+00	1.92E+00	24
	Sulphur-35	4.00E-01	1.01E-01	25
	Argon-41	3.00E+02	3.67E+01	12
	Iodine-131	5.00E-03	1.25E-05	0.3
Sizewell 'B' Station				
Liquid	Tritium	8.00E+01	4.83E+01	60
	Other radionuclides	2.00E-01	1.78E-02	8.9
Gaseous	Noble gases	3.00E+02	1.57E+01	5.2
	Halogens	3.00E-03	5.95E-05	2.0
	Beta particulate	1.00E-02	1.06E-05	0.1
	Tritium	8.00E+00	1.39E+00	17
	Carbon-14	6.00E-01	2.30E-01	38
Devonport Royal Dockyard Ltd, Devonport				
Sewer (l)	Beta	(m)	6.56E-06	N/A
	Tritium	(m)	5.27E-06	N/A
	Cobalt-60	(m)	3.06E-07	N/A
River (l)	Beta	(m)	0.00E+00	N/A
	Tritium	(m)	0.00E+00	N/A
	Cobalt	(m)	0.00E+00	N/A
Sewer (n)	Total activity	(m)	9.09E-04	N/A
Pipeline (n)	Total activity (o)	1.00E-03	2.31E-05	2.3
	Tritium	1.20E-01	1.13E-01	94
	Cobalt-60	6.00E-03	1.24E-04	2.1
Hunting-BRAE Ltd, Aldermaston				
Pipeline	Alpha	1.50E-04	1.89E-05	13
	Tritium	5.00E-02	1.43E-03	2.9
	Plutonium-241	6.00E-04	7.57E-05	13
	Other radionuclides	1.50E-04	1.19E-05	7.9
Silchester – Liquid	Alpha	1.00E-04	5.59E-06	5.6
	Beta	3.00E-04	2.45E-05	8.2
Gaseous (g)	Alpha	9.00E-07	1.31E-07	15
	Beta (p)	4.60E-06	1.51E-07	3.3
	Tritium	3.40E+02	2.54E+00	0.7
	Krypton-85	4.00E-01	2.56E-03	0.6

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Burghfield				
Liquid	Alpha	2.00E-06	5.92E-08	3.0
	Other radionuclides	1.20E-05	1.18E-07	1.0
Gaseous (g)	Alpha	2.00E-08	7.90E-10	4.0
	Tritium	3.50E-01	1.26E-04	0.0
	Krypton-85	1.00E+00	0.00E+00	0.0
Marconi Marine (VSEL) Ltd, Barrow				
Liquid	Tritium	2.00E-02	0.00E+00	0.0
	Manganese-54	2.50E-07	0.00E+00	0.0
	Cobalt-58	7.00E-07	0.00E+00	0.0
	Cobalt-60	7.00E-08	0.00E+00	0.0
	Tin-113	2.50E-07	0.00E+00	0.0
	Antimony-124	2.00E-06	0.00E+00	0.0
	Other radionuclides	3.50E-06	0.00E+00	0.0
Gaseous	Tritium	3.20E-06	0.00E+00	0.0
	Argon-41	8.00E-02	0.00E+00	0.0
Nycomed-Amersham plc, Amersham				
Liquid	Alpha	3.00E-04	4.20E-05	14
	Beta > 0.4 MeV	1.00E-01	7.66E-03	7.7
	Tritium	2.00E-01	2.29E-03	1.1
	Iodine-125	2.00E-01	2.15E-03	1.1
	Caesium-137	5.00E-03	3.56E-05	0.7
	Other radionuclides	3.00E-01	5.63E-02	19
Gaseous	Alpha	2.00E-06	1.70E-07	8.5
	Tritium	4.00E+01	0.00E+00	0.0
	Selenium-75	3.00E-02	2.80E-04	0.9
	Iodine-125	1.00E-01	1.40E-02	14
	Iodine-131	5.00E-02	5.50E-04	1.1
	Radon-222	1.00E+01	1.60E+00	16
	Other (penetrating)	5.00E-02	8.10E-05	0.2
	Other (non-penetrating)	5.00E-01	1.30E-02	2.6
Cardiff				
Liquid	Tritium	9.00E+02	2.77E+02	31
	Carbon-14	2.00E+00	1.15E+00	58
	Phosphorus-32/33	1.00E-02	4.44E-06	0.0
	Iodine-125	5.00E-02	8.12E-03	16
	Other radionuclides	5.00E-04	1.20E-05	2.4

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
Cardiff (cont)				
Gaseous	Soluble tritium	4.00E+02	1.53E+02	38
	Insoluble tritium	1.00E+03	4.07E+02	41
	Carbon-14	6.00E+00	2.63E+00	44
	Phosphorus-32/33	2.00E-04	3.07E-06	1.5
	Iodine-125	5.00E-04	1.17E-04	23
	Other radionuclides	4.00E-02	0.00E+00	0.0
United Kingdom Atomic Energy Authority, Harwell (q)				
Pipeline	Alpha	1.00E-03	5.12E-05	5.1
	Beta (d)	2.00E-02	2.98E-03	15
	Tritium	4.00E+00	8.79E-02	2.2
	Cobalt-60	7.00E-03	4.57E-05	0.7
	Caesium-137	7.00E-03	4.90E-04	7.0
Lydebank Brook	Alpha	5.00E-04	2.56E-05	5.1
	Beta (d)	2.00E-03	2.12E-04	11
	Tritium	1.00E-01	2.63E-02	26
Gaseous	Alpha	7.00E-06	1.68E-07	2.4
	Beta	4.50E-04	4.27E-06	0.9
	Tritium	1.50E+02	2.69E+00	1.8
Windscale				
Gaseous	Alpha	1.20E-05	3.09E-07	2.6
	Beta	5.00E-03	4.97E-06	0.1
	Tritium	2.30E+00	4.40E-03	0.2
	Krypton-85	1.40E+01	1.77E-01	1.3
	Iodine-131	1.20E-03	2.45E-06	0.2
Winfrith				
Liquid – Inner pipeline	Alpha	3.00E-01	1.33E-03	0.4
	Tritium	6.50E+02	3.42E+00	0.5
	Cobalt-60	1.00E+01	3.11E-04	0.0
	Zinc-65	6.00E+00	3.20E-04	0.0
	Other radionuclides	8.00E+01	8.14E-03	0.0
Liquid – Outer pipeline	Alpha	4.00E-03	6.30E-05	1.6
	Tritium	1.00E+00	9.48E-03	0.9
	Other radionuclides	1.00E-02	9.98E-05	1.0
Gaseous	Alpha	2.20E-06	2.05E-09	0.1
	Beta	5.00E-05	8.10E-06	16
	Tritium	1.50E+01	3.22E+00	21
	Carbon-14	3.00E-01	6.46E-04	0.2
	Krypton-85	1.50E+02	0.00E+00	0.0

Table 1 *continued*

Principal discharges of radioactive waste from nuclear establishments in 1998

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1998 TBq (a)	1998 discharge % of annual limit (b)
URENCO, Capenhurst				
Gaseous	Uranium	2.50E-06	6.87E-08	2.7

Notes

(a) Some discharges are upper estimates because they include 'less than' data derived from analyses of effluents at limits of detection. Data quoted to three significant figures except where fewer significant figures are provided in source documents.

(b) Data quoted to two significant figures except when values are less than one per cent.

(c) There are no numerical limits for this discharge. However, the authorisation stipulates that the best practicable means should be used to control the discharge.

(d) Excluding tritium.

(e) Discharges and limits are expressed in terms of concentrations of activity in Bq m^{-3}.

(f) The limit and discharge data are expressed in kg.

(g) Discharge limits and discharges are aggregated from data for individual locations on site. Percentages are given as a general guide to usage of the limits but should strictly be calculated for individual locations. Discharges were below the appropriate limit at each location.

(h) Some limits are related to the operation of the THORP plant and may thus vary from year to year.

(i) Limit for site includes Berkeley centre.

(j) Excluding caesium-137.

(k) Excluding strontium-90.

(l) Discharges are made by the Ministry of Defence.

(m) The authorisation includes a limit on concentration of total activity of 4.0E-06 TBq m^{-3}. At no time did the concentration exceed the limit.

(n) Discharges are made by Devonport Royal Dockyard Ltd.

(o) Excluding cobalt-60.

(p) Excluding tritium, plutonium-241, krypton-85 and volatile beta-emitters (no releases in this category during the year).

(q) Includes discharges from other operators on each site.

Table 2(a)

Mean gamma radiation dose rates at 1 metre over inter-tidal areas of the West Cumbrian coast

Location	Ground type	Dose rate μGy h^{-1}				Occupancy $h\ y^{-1}$	Estimated Annual Dose in excess of background μSv y^{-1}
		Q1	Q2	Q3	Q4		
St. Bees	Sand	0.080	0.117	0.085	0.081	300	11
Whitehaven Harbour Yacht Basin	Silt	0.124	0.137	0.177	0.130	470	29
Whitehaven Harbour Outer	Silt	0.129	0.118	0.119	-	470	21
Whitehaven Harbour Inner	Silt	0.105	0.094	0.149	-	470	19
Workington Harbour	Pebbles	-	0.123	-	0.125	300	19
Nethertown Beach	Sand	-	0.129	-	0.085	300	15
Harrington Harbour	Silt	-	0.186	-	0.185	300	30
Braystones	Sand	-	0.116	-	0.089	300	14
Pipeline on foreshore	Pebbles	-	0.190	-	0.143	300	30
Sellafield (Ehen spit)	Sand	-	0.122	-	-	300	19
Sellafield Beach	Sand	-	0.123	-	0.126	300	19
Ehen Spit Seashore	Sand	-	0.122	-	0.079	300	13
River Calder Downstream	Rocks	-	0.510	-	0.527	300	121
Maryport Harbour	Silt	-	0.105	-	0.105	300	9
River Calder Upstream	Grass/sand	-	0.116	-	0.111	300	16
Seascale	Sand	0.090	0.081	0.083	0.100	300	10
Carlton Marsh	Salt marsh	0.173	0.208	0.195	0.182	300	31
Tarn Bay	Pebbles	-	0.113	-	0.102	300	15
Eskmeals Nature Reserve	Salt marsh	0.188	0.178	0.126	0.201	300	27
Boat Area	Silt	0.116	0.116	0.076	0.110	300	9
Ford	Silt	0.130	0.126	0.111	0.119	300	13
Raven Villa	Silt	0.139	0.147	0.132	0.119	300	17
Newbiggin/Eskmeals 2	Silt	0.162	0.156	0.154	0.201	315	27
Salmon Garth	Mussels	0.125	0.129	0.100	0.128	300	18
Newbiggin/Eskmeals 1	Silt	0.208	0.228	0.171	0.159	315	33
River Mite Estuary	Salt marsh	0.160	0.159	0.197	0.174	300	26
Muncaster Bridge	Salt marsh	0.188	0.180	0.139	0.172	300	26
Silecroft	Pebbles	-	0.113	-	0.105	300	15
Haverigg	Sand	-	0.112	-	0.097	920	43
Tumner Hill Marsh	Silt/grass	-	0.177	-	0.097	300	17
Walney Channel East	Silt	-	0.104	-	0.102	300	9
Millom	Sand	-	0.076	-	0.110	300	11
Walney Channel West	Silt	-	0.114	-	0.103	300	10
Low Shaw	Silt	-	0.092	-	0.091	300	6
Askam	Sand	-	0.083	-	0.080	960	26
Roa Island	Silt	-	0.100	-	0.088	300	6

Table 2(b)

Mean gamma radiation dose rates at 1 metre over inter-tidal areas of the North and South Cumbrian coast

Location	Ground type	Dose rate μGy h^{-1}				Occupancy $h\ y^{-1}$	Estimated Annual Dose in excess of background μSv y^{-1}
		Q1	Q2	Q3	Q4		
Allonby	Sand	0.080	0.100	0.089	0.107	300	11
Silloth Harbour	Silt	0.105	0.106	0.091	0.114	300	9
Cardurnock Marsh	Salt marsh	0.077	0.125	0.092	0.101	300	7
Newton Arlosh	Salt marsh	0.088	0.124	0.108	0.111	300	10
Greenend 2	Silt	0.085	0.094	0.084	0.087	300	5
Greenend 1	Salt marsh	0.086	0.088	0.084	0.089	300	4
Greenend 3	Silt	0.083	0.091	0.094	0.088	300	5
Port Carlisle 1	Salt marsh	0.086	0.090	0.090	0.095	300	5
Port Carlisle 2	Silt	0.090	0.108	0.079	0.096	300	6
Burgh Marsh	Silt/grass	-	0.092	-	0.087	300	5
Rockcliffe Marsh	Silt/grass	-	0.097	-	0.094	300	7
Greenodd Salt Marsh	Saltmarsh	-	0.091	-	0.084	300	5
Sand Gate Marsh	Salt marsh	0.098	0.105	0.111	0.097	300	8
Flookburgh	Silt	0.098	0.091	0.081	0.095	300	5
Arnside 1	Silt	0.095	0.098	0.118	0.083	300	7
Arnside 2	Salt marsh	0.102	0.102	0.084	0.116	300	8
High Foulshaw	Salt marsh	0.092	0.103	0.100	0.097	300	7

Table 2(c)

Mean gamma radiation dose rates at 1 metre over inter-tidal areas of Lancashire, Merseyside and North Wales coast

Location	Ground type	Dose rate μGy h^{-1}				Occupancy h y^{-1}	Estimated Annual Dose in excess of background μSv y^{-1}
		Q1	Q2	Q3	Q4		
Ainsdale	Sand	0.056	0.066	0.064	0.062	300	3
Blackpool	Sand	0.075	0.071	0.072	0.072	300	6
Fleetwood shore 1	Sand	0.087	0.079	0.077	0.076	300	8
Fleetwood shore 2	Salt marsh	0.123	0.125	0.143	0.139	300	16
Heads – River Wyre	Salt marsh	0.114	0.125	0.118	0.113	300	12
Skippool Creek 2	Silt	0.119	0.143	0.122	0.115	300	14
Height o'th Hill	Salt marsh	0.121	0.135	0.104	0.118	300	13
Skippool Creek 1	Salt marsh	0.091	0.11	0.121	0.13	300	11
Crossens Marsh	Salt marsh	0.102	0.129	0.116	0.114	300	12
Hambleton	Salt marsh	0.143	0.124	0.127	0.127	300	16
Sunderland Point	Silt	0.097	0.105	0.104	0.109	300	9
Sunderland	Salt marsh	0.111	0.116	0.12	0.139	300	13
Cockerham Marsh	Salt marsh	0.106	0.098	0.102	0.124	300	10
Colloway Marsh	Salt marsh	0.131	0.138	0.131	0.133	300	16
Conder Green	Silt	0.100	0.102	0.105	0.101	300	8
Aldcliffe Marsh	Salt marsh	0.130	0.131	0.13	0.126	300	15
Lancaster	Salt marsh	0.091	0.079	0.089	0.091	300	5
Llanfairfechan	Grass	-	0.102	-	0.102	300	13
Caerhun	Grass	-	0.107	-	0.105	300	14
Llandudno	Sand	-	0.091	-	0.073	300	8
Rhyl	Sand	-	0.091	-	0.090	300	10
Prestatyn	Sand	-	0.066	-	0.062	300	4
West Kirby	Silt	0.077	0.084	0.068	0.081	300	2
Flint 1	Silt	-	0.103	-	0.091	300	7
Flint 2	Grass	-	0.116	-	0.098	300	15
Little Neston Marsh 1	Salt marsh	-	0.102	-	0.122	300	11
Little Neston Marsh 2	Salt marsh	-	-	-	0.130	300	15
New Brighton	Sand	0.074	0.069	0.07	0.070	300	5
Rock Ferry	Silt/sand	0.095	0.087	0.082	0.087	300	10

Notes

1. Each result is the mean of three individual measurements.
2. Occupancy data were obtained from studies by MAFF[1] and RSGB[12] for some locations.
3. The dose rates shown include a contribution from background radiation.

Site	Quarter	Total alpha	Total beta	Co-60	Sr-90
Carlton Marsh	1	2455	2150	29	-
	2	1999	2040	25	-
	3	2530	2717	24	-
	4	2506	2663	76	-
Ehen Spit	2	420	600	3.1	-
	4	364	526	5.1	-
Flookburgh	1	136	725	-	-
	2	184	697	-	-
	3	233	798	-	-
	4	305	918	-	-
Harrington Harbour	2	945	1397	12	-
	4	1282	2181	19	-
Haverigg	2	364	658	2.9	-
	4	333	606	3.2	-
Low Shaw	2	209	750	-	-
	4	248	855	-	-
Maryport Outer Harbour	2	885	1206	6.8	<100
	4	558	957	3.5	<100
Millom	2	160	502	<0.6	-
	4	458	823	17	-
Newbiggin	1	1930	2334	40	223
	2	2732	2531	34	296
	3	1841	1932	26	150
	4	2440	2561	84	197
Newton Arlosh	1	350	962	-	-
	2	482	1101	-	-
	3	536	1219	-	-
	4	544	1301	-	-

Table 3

Radioactivity in sediments from West Cumbria (Bq kg^{-1})

Nb-95	Zr-95	Ru-106	Cs-137	Ce-144	Pu-238	Pu-239 /240	Pu-241	Am-241
24	12	273	439	35	-	-	-	793
14	7.4	231	396	33	-	-	-	581
11	14	230	572	27	-	-	-	1204
4.1	4.3	147	529	19	-	-	-	1154
-	-	-	92	-	-	-	-	133
-	-	-	77	-	-	-	-	147
-	-	-	98	-	-	-	-	35
-	-	-	93	-	-	-	-	29
-	-	-	97	-	-	-	-	43
-	-	-	156	-	-	-	-	72
-	-	64	323	-	-	-	-	285
-	-	97	461	-	-	-	-	660
-	-	18	80	-	-	-	-	68
-	-	8.7	56	-	-	-	-	77
-	-	-	110	-	-	-	-	62
-	-	-	142	-	-	-	-	104
-	-	52	215	-	36	161	1830	213
-	-	16	148	-	22	129	1543	161
-	-	<2.9	30	-	-	-	-	41
-	-	19	106	-	-	-	-	161
11	5.6	251	582	22	124	603	6950	864
21	9.5	300	528	45	171	836	9390	861
4.5	4.2	161	354	17	99	467	5400	587
9.5	5.2	237	582	27	136	694	8334	1179
-	-	-	275	-	-	-	-	64
-	-	-	295	-	-	-	-	130
-	-	-	318	-	-	-	-	150
-	-	-	339	-	-	-	-	152

Site	Quarter	Total alpha	Total beta	Co-60	Sr-90	Nb-95
Raven Villa	1	1217	1389	21	-	11
	2	1145	1335	20	-	5.9
	3	1585	1550	20	-	2.5
	4	1602	1549	41	-	1.7
River Calder, Upstream	2	325	1537	-	-	-
	4	257	1311	-	-	-
River Calder, Downstream	2	317	1515	3.2	-	-
	4	219	1181	<0.7	-	-
River Mite Estuary	1	1998	3650	49	357	31
	2	2073	3856	54	387	32
	3	1983	1705	14	165	16
	4	5478	3430	41	155	<3.1
Sand Gate Marsh	1	218	894	-	-	-
	2	290	952	-	-	-
	3	326	894	-	-	-
	4	175	832	-	-	-
Seascale Beach	1	810	859	2	-	-
	2	480	542	4.6	-	-
	3	656	722	4.1	-	-
	4	327	566	2.7	-	-
St Bees Beach	1	217	<500	<1.6	-	-
	2	255	557	1.5	-	-
	3	405	593	2.2	-	-
	4	307	526	2.8	-	-
Walney Channel East	2	580	1021	4.5	-	1.4
	4	1009	1329	12	-	<0.8
Walney Channel West	2	636	1019	5.8	-	3.1
	4	322	694	3.7	-	<0.5

Table 3 continued

Radioactivity in sediments from West Cumbria (Bq kg^{-1})

Zr-95	Ru-106	Cs-137	Ce-144	Pu-238	Pu-239 /240	Pu-241	Am-241
8.4	93	225	<10	-	-	-	420
2.8	109	215	14	-	-	-	340
4.5	111	301	11	-	-	-	703
<1.2	64	249	9.2	-	-	-	461
-	-	97	-	-	-	-	-
-	-	54	-	-	-	-	-
-	-	140	-	-	-	-	-
-	-	50	-	-	-	-	-
10	624	888	88	160	798	8640	1245
13	658	916	98	171	836	9390	1403
8.1	108	290	8.1	68	330	4010	514
<4.1	117	1367	14	476	2300	27570	2830
-	-	197	-	-	-	-	62
-	-	200	-	-	-	-	64
-	-	175	-	-	-	-	48
-	-	126	-	-	-	-	41
-	-	50	-	-	-	-	116
-	-	47	-	-	-	-	176
-	-	49	-	-	-	-	187
-	-	54	-	-	-	-	111
-	-	55	-	-	-	-	49
-	-	57	-	-	-	-	43
-	-	82	-	-	-	-	139
-	-	86	-	-	-	-	128
<1	39	130	5.1	-	-	-	118
<1.4	37	232	<3.5	-	-	-	299
<3.5	50	149	4.9	-	-	-	149
<0.6	<3	57	<2	-	-	-	52

Site	Quarter	Total alpha	Total beta	Co-60	Sr-90
Whitehaven Harbour	1	1643	1838	17	185
(Yacht Basin)	2	1648	4121	30	248
	3	2286	3801	25	401
Whitehaven Harbour	4	374	725	1.7	<100
(Outer Harbour)					
Workington Harbour	2	1657	2918	38	-
	4	1589	2111	12	-

Notes

1. Cs-134 levels are below the limit of detection of 1.5 Bq kg^{-1}.
2. Ag-110m levels are below the limit of detection of 1.1 Bq kg^{-1}.

Table 3 *continued*

Radioactivity in sediments from West Cumbria (Bq kg^{-1})

Nb-95	Zr-95	Ru-106	Cs-137	Ce-144	Pu-238	Pu-239 /240	Pu-241	Am-241
15	8	213	445	19	62	305	3450	541
26	15	380	847	35	143	725	8000	909
29	10	344	953	27	150	757	7960	1254
-	-	-	114	-	13	83	<100	114
11	8.1	200	658	15	-	-	-	640
<2.9	<5.2	66	536	<8.4	-	-	-	683

Table 4

Radioactivity in surface waters from West Cumbria (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Ehen Spit Issue	Total alpha	0.12	-	-	-
	Total beta	11	11	22	9.1
	Tritium	183	660	455	433
	Caesium-137	0.49	0.66	1.1	0.4
Seaburn Sewer Outfall	Tritium	14	17	8.3	13
	Strontium-90	<1	<1	<1	<1
	Plutonium-239+240	<0.1	<0.1	<0.1	<0.1
River Calder Downstream	Tritium	8.4	<4	<4	<4
	Strontium-90	<0.1	<1	<1	<1
River Calder Upstream	Tritium	<4	<4	<4	<4
	Strontium-90	<0.1	<1	<1	<1
Wast Water	Tritium	-	4.7	-	-
Ennerdale Water	Tritium	-	<4	-	-
Devoke Water	Tritium	-	7	-	-
Thirlmere	Tritium	-	10	-	-

Notes

1. Except where specified, for all samples:

(a) total alpha activities were less than 0.1 Bq kg^{-1};

(b) total beta activities were less than 1.0 Bq kg^{-1};

(c) no other radionucludes were detected by gamma-ray spectrometry.

Table 5

Radioactivity in water and sediments near BNFL Drigg (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Drigg Stream Sediment	Total alpha	292	301	277	227
	Total beta	930	934	1122	886
	Cobalt-60	<0.24	1.8	2.4	3
	Caesium-134	<0.3	1.9	<0.46	1.1
	Caesium-137	<83	303	<369	395
	Americium-241	5.2	22	19	51
Drigg Stream Water	Total alpha	0.05	0.1	0.06	0.04
	Total beta	<0.5	<0.5	4.6	0.8
	Tritium	7.8	21	64	15
British Rail Drain Water	Total alpha	0.09	-	-	-
	Total beta	2.2	-	-	-
	Tritium	29	-	-	-

Notes

1. All water samples:

(a) plutonium-238, plutonium-241, americium-241 and thorium-228 were less than 0.1 Bq kg^{-1} and plutonium-(239+240) less than 10 Bq kg^{-1};

(b) strontium-90, uranium-234, uranium-235 and uranium-238 were less than 1.0 Bq kg^{-1};

(c) no radionuclides were detected by gamma-ray spectrometry.

2. All sediment samples:

(a) plutonium-238, plutonium-239/240, polonium-210, thorium-228, uranium-234, uranium-235 and uranium-238 were less than 100 Bq kg^{-1} and strontium-90 was less than 10 Bq kg^{-1}.

3. The Railtrack drain was sampled in the first quarter only of 1998.

Table 6

Radioactivity in water and sediment samples from Rivacre Brook downstream of BNFL Capenhurst (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	3
At outfall 0.7 km downstream			
Water	Total alpha	0.72	0.05
	Total beta	1.0	<0.5
	Tritium	52	42
	Technetium-99	1.1	0.1
	Uranium-234	<1	<1
	Uranium-235	<1	<1
	Uranium-238	<1	<1
	Neptunium-237	<0.1	<0.1
Sediment	Total alpha	687	403
	Total beta	1878	1458
	Technetium-99	1093	250
	Caesium-137	11	3.1
	Uranium-234	230	45
	Uranium-235	<10	<10
	Uranium-238	200	38
	Neptunium-237	33	28
1.6 km downstream			
Water	Total alpha	0.25	0.04
	Total beta	0.69	<0.5
	Tritium	23	10
	Technetium-99	0.3	<0.1
	Uranium-234	<1	<1
	Uranium-235	<1	<1
	Uranium-238	<1	<1
	Neptunium-237	<0.1	<0.1
Sediment	Total alpha	255	953
	Total beta	752	2510
	Technetium-99	373	1490
	Caesium-137	6.2	18
	Uranium-234	59	137
	Uranium-235	<10	<10
	Uranium-238	58	101
	Neptunium-237	17	60

Table 6 *continued*

Radioactivity in water and sediment samples from Rivacre Brook downstream of BNFL Capenhurst (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	3
3.1 km downstream			
Water	Total alpha	0.15	0.04
	Total beta	0.51	<0.5
	Tritium	9.4	9.4
	Technetium-99	<0.1	<0.1
	Uranium-234	<1	<1
	Uranium-235	<1	<1
	Uranium-238	<1	<1
	Neptunium-237	<0.1	<0.1
Sediment	Total alpha	675	397
	Total beta	1846	1228
	Technetium-99	400	830
	Caesium-137	16	7.7
	Uranium-234	147	101
	Uranium-235	<6	<10
	Uranium-238	112	65
	Neptunium-237	22	17
4.3km downstream			
Water	Total alpha	0.18	0.05
	Total beta	0.38	<0.5
	Tritium	8.3	9.6
	Technetium-99	<0.1	<0.1
	Uranium-234	<1	<1
	Uranium-235	<1	<1
	Uranium-238	<1	<1
	Neptunium-237	<0.1	<0.1
Sediment	Total alpha	<100	191
	Total beta	386	583
	Technetium-99	39	81
	Caesium-137	1.4	0.89
	Uranium-234	18	20
	Uranium-235	<5	<5
	Uranium-238	17	14
	Neptunium-237	3.1	2.9

Notes

1. Gamma radiation dose rates, including a contribution from background, measured each quarter at each location, did not exceed 0.1 μGy h^{-1}.
2. No monitoring was undertaken in quarter 1 and quarter 4.

Table 7

Radioactivity in water and sediments near BNFL Springfields (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Becconsall Boatyard					
Sediment	Total alpha	<1000	<1000	<1000	<1000
	Total beta	10326	<10000	<10000	<10000
	Caesium-137*	275	210	411	320
	Thorium-228	<30	<30	37	<30
	Thorium-230	97	104	100	100
	Thorium-232	<30	<30	<30	<30
	Thorium-234	17950	15270	14457	1722
	Protactinium-234m	20980	21120	16353	<1800
	Uranium-234	<100	<100	<100	<100
	Uranium-235	<100	<100	<100	<100
	Uranium-238	<100	<100	<100	<100
	Americium-241*	175	123	188	152
Cadet Hut Penwortham					
Sediment	Total alpha	-	1083	-	<1000
	Total beta	-	155200	-	<10000
	Caesium-137*	-	450	-	342
	Thorium-228	-	<30	-	<30
	Thorium-230	-	145	-	89
	Thorium-232	-	<30	-	<30
	Thorium-234	-	143000	-	10088
	Protactinium-234	-	185	-	<87
	Protactinium-234m	-	191000	-	10495
	Uranium-234	-	<100	-	<100
	Uranium-235	-	<100	-	<100
	Uranium-238	-	<100	-	<100
	Americium-241*	-	760	-	169
Deepdale Brook					
Sediment	Total alpha	-	<1000	-	1355
	Total beta	-	<10000	-	<10000
	Caesium-137*	-	3.9	-	6.5
	Thorium-228	-	<30	-	<30
	Thorium-230	-	177	-	126
	Thorium-234	-	<221	-	1293
	Protactinium-233	-	<100	-	<100
	Protactinium-234m	-	<291	-	1419
	Uranium-234	-	<100	-	113
	Uranium-235	-	<100	-	<100
	Uranium-238	-	<100	-	106

* It is considered that the presence of these nuclides in the Ribble Estuary results from the marine transport of material discharged to sea from BNFL Sellafield.

Table 7 *continued*

Radioactivity in water and sediments near BNFL Springfields (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Deepdale Brook					
Water	Total alpha	1.5	0.22	0.38	1.6
	Total beta	1.4	<0.5	0.8	2.1
	Uranium-234	1.4	<1	<1	1.1
	Uranium-235	<1	<1	<1	<1
	Uranium-238	1.4	<1	<1	1.2
Freckleton					
Sediment	Total alpha	-	-	1077	-
	Total beta	-	-	35171	-
	Cobalt-60*	-	-	4.4	-
	Caesium-137*	-	-	556	-
	Thorium-228	-	-	42	-
	Thorium-230	-	-	136	-
	Thorium-232	-	-	<30	-
	Thorium-234	-	-	62424	-
	Protactinium-234m	-	-	68014	-
	Uranium-234	-	-	<100	-
	Uranium-235	-	-	<100	-
	Uranium-238	-	-	<100	-
	Americium-241*	-	-	265	-
Lea Gate					
Sediment	Total alpha	-	1541	-	<1000
	Total beta	-	267300	-	10278
	Caesium-137*	-	374	-	505
	Thorium-228	-	31	-	<30
	Thorium-230	-	187	-	129
	Thorium-232	-	<30	-	<30
	Thorium-234	-	241000	-	24787
	Protactinium-234	-	331	-	<72
	Protactinium-234m	-	333000	-	23579
	Uranium-234	-	<100	-	<100
	Uranium-235	-	<100	-	<100
	Uranium-238	-	<100	-	<100
	Americium-241*	-	927	-	268

* It is considered that the presence of these nuclides in the Ribble Estuary results from the marine transport of material discharged to sea from BNFL Sellafield.

Table 7 continued

Radioactivity in water and sediments near BNFL Springfields (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Longton Marsh					
Sediment	Total alpha	-	<1000	-	-
	Total beta	-	<10000	-	-
	Caesium-137*	-	674	-	-
	Thorium-228	-	43	-	-
	Thorium-230	-	227	-	-
	Thorium-232	-	32	-	-
	Thorium-234	-	17050	-	-
	Protactinium-234m	-	22630	-	-
	Uranium-234	-	<100	-	-
	Uranium-235	-	<100	-	-
	Uranium-238	-	<100	-	-
	Americium-241*	-	253	-	-
Lower Penwortham Park					
Sediment	Total alpha	1914	1225	1284	<1000
	Total beta	<10000	170300	15602	<10000
	Caesium-137*	591	538	359	498
	Thorium-228	90	<30	31	34
	Thorium-230	707	185	118	110
	Thorium-232	88	<30	<30	<30
	Thorium-234	969	159000	23120	11078
	Protactinium-234	<7.5	162	<40	<111
	Protactinium-234m	1026	210000	25077	9806
	Uranium-234	<100	<100	<100	<100
	Uranium-235	<100	<100	<100	<100
	Uranium-238	<100	<100	<100	<100
	Americium-241*	241	660	178	256
Lytham Yacht Club					
Sediment	Total alpha	-	-	<1000	-
	Total beta	-	-	21384	-
	Cobalt-60*	-	-	4.3	-
	Caesium-137*	-	-	549	-
	Thorium-228	-	-	37	-
	Thorium-230	-	-	101	-
	Thorium-232	-	-	<30	-
	Thorium-234	-	-	33910	-
	Protactinium-234m	-	-	36724	-
	Uranium-234	-	-	<100	-
	Uranium-235	-	-	<100	-
	Uranium-238	-	-	<100	-
	Americium-241*	-	-	267	-

* It is considered that the presence of these nuclides in the Ribble Estuary results from the marine transport of material discharged to sea from BNFL Sellafield.

Table 7 *continued*

Radioactivity in water and sediments near BNFL Springfields (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Penwortham Position 1					
Sediment	Total alpha	<1000	1208	<1000	<1000
	Total beta	<10000	166000	<10000	<10000
	Caesium-137*	6.3	562	293	270
	Thorium-228	<30	34	41	<30
	Thorium-230	<30	170	223	67
	Thorium-232	<30	<30	37	<30
	Thorium-234	44	190600	2911	1413
	Protactinium-234m	<40	189800	3186	<1900
	Uranium-234	<100	<100	<100	<100
	Uranium-235	<100	<100	<100	<100
	Uranium-238	<100	<100	<100	<100
	Americium-241*	<1.9	964	116	128
Penwortham Position 2					
Sediment	Total alpha	1257	-	-	-
	Total beta	162000	-	-	-
	Caesium-137*	552	-	-	-
	Thorium-228	33	-	-	-
	Thorium-230	161	-	-	-
	Thorium-232	<30	-	-	-
	Thorium-234	175000	-	-	-
	Protactinium-234	364	-	-	-
	Protactinium-234m	184300	-	-	-
	Uranium-234	<100	-	-	-
	Uranium-235	<100	-	-	-
	Uranium-238	<100	-	-	-
	Americium-241*	1077	-	-	-
Penwortham Rail Bridge					
Sediment	Total alpha	<1000	1107	1183	<1000
	Total beta	<10000	178400	12970	<10000
	Caesium-137*	103	580	405	389
	Thorium-228	<30	31	31	<30
	Thorium-230	37	169	157	98
	Thorium-232	<30	<30	<30	<30
	Thorium-234	67	195800	22285	3228
	Uranium-234	<100	<100	<100	<100
	Uranium-235	<100	<100	<100	<100
	Uranium-238	<100	<100	<100	<100
	Americium-241*	42	993	207	183

* It is considered that the presence of these nuclides in the Ribble Estuary results from the marine transport of material discharged to sea from BNFL Sellafield.

Table 7 *continued*

Radioactivity in water and sediments near BNFL Springfields (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
River Ribble Outfall					
Sediment	Total alpha	<1000	<1000	<1000	<1000
	Total beta	31995	50064	13740	36823
	Caesium-137*	14	106	446	117
	Thorium-228	<30	<30	36	<30
	Thorium-230	81	36	102	75
	Thorium-232	<30	<30	<30	<30
	Thorium-234	64120	47060	20896	102310
	Protactinium-233	<100	<100	<100	<100
	Protactinium-234m	72620	49190	23859	118590
	Uranium-234	<100	<100	<100	<100
	Uranium-235	<100	<100	<100	<100
	Uranium-238	<100	<100	<100	<100
	Americium-241*	<15	237	194	51
Savick Brook					
Sediment	Total alpha	-	1830	-	1150
	Total beta	-	346000	-	15602
	Caesium-137*	-	453	-	558
	Thorium-228	-	34	-	31
	Thorium-230	-	292	-	164
	Thorium-232	-	<30	-	<30
	Thorium-234	-	326000	-	41574
	Protactinium-234	-	453	-	93
	Protactinium-234m	-	433000	-	44544
	Uranium-234	-	<100	-	<100
	Uranium-235	-	<100	-	<100
	Uranium-238	-	<100	-	<100
	Americium-241*	-	1205	-	279

Notes

1. * It is considered that the presence of these nuclides in the Ribble Estuary results from the marine transport of material discharged to sea from BNFL Sellafield.
2. All protactinium-234m results are calculated using an abundance value of 0.90 per cent. The low thorium-234 concentrations relative to the protactinium-234m concentrations probably result from self-absorption in the sample during analysis.

Table 8

Mean gamma radiation dose rates at 1 metre over inter-tidal areas near BNFL Springfields (μGy h^{-1})

Location	Ground Type	Quarter			
		1	2	3	4
Banks Marsh	Silt	-	0.161	-	0.123
Becconsall Boatyard	Silt	0.097	0.096	0.091	0.120
Becconsall Boatyard, Houseboats	Silt	-	0.108	-	0.113
Freckleton	Silt	-	-	0.132	-
Hesketh Bank	Silt	-	0.149	-	0.123
Longton Marsh	Silt	-	0.148	-	-
Lower Penwortham Railway Bridge	Silt	0.110	0.178	0.095	0.099
Lower Penwortham Park	Silt	0.092	0.123	0.094	0.091
Penwortham Cadet Hut	Silt	-	0.176	-	0.093
Lytham Yacht Club	Silt	-	-	0.114	-
Naze Point	Silt	-	0.144	-	0.118
River Bank Angler 1	Silt	0.090	0.114	0.081	0.094
Angler Location 2	Silt	-	0.103	-	-
River Darwen	Silt	0.081	0.107	0.068	0.082
River Ribble Outfall	Silt	0.152	0.137	0.091	0.162
Savick Brook, Tidal Limit	Silt	-	0.317	-	0.154
Savick Brook, Lea Gate	Silt	-	0.317	-	0.147
Savick Brook, Confluence	Silt	-	0.123	-	0.083
Warton Mud Marsh	Silt	-	0.148	-	0.156
Warton Salt Marsh	Silt	-	0.133	-	0.134

Notes

1. Each result shown for the bank of the Ribble Estuary is the mean of three readings obtained using a Mini-Instruments Environmental Meter type 6-80.
2. The dose rates shown include a contribution from background radiation of 0.05 μGy h^{-1} for sand and 0.07 μGy h^{-1} for other substrates.

Table 9

Mean gamma radiation dose rates at 1 metre over inter-tidal areas near nuclear power stations ($\mu Gy\ h^{-1}$)

Location	Ground Type	Quarter	
		2	4
Sizewell			
Sizewell Beach	Sand	0.061	0.056
Southwold Harbour	Silt	0.068	0.075
Aldeburgh	Pebbles	0.054	0.056
Dunwich	Pebbles	0.058	0.049
Rifle Range	Pebbles	0.054	0.057
Bradwell			
1.5 km east of pipeline	Silt	0.067	0.056
Bradwell Beach	Sand	0.456	0.091
Beach (opposite power station on north side of estuary)	Sand	0.075	0.072
Maldon	Silt	0.078	0.069
Waterside	Silt	0.067	0.060
West Mersea	Silt	0.080	0.073
Dungeness			
Dungeness East Coast	Pebbles	0.050	0.048
Dungeness South Coast	Pebbles	0.056	0.050
Greatstone on Sea	Pebbles	0.054	0.057
Jury Gap	Pebbles	0.056	0.057
Littlestone on Sea	Pebbles	0.052	0.051
Rye Bay	Sand	0.067	0.056
Hinkley Point			
Blue Anchor Bay Beach	Sand	0.075	0.065
Burnham Beach	Sand	0.066	0.071
Hinkley Point Beach	Sand	0.090	0.088
Kilve Beach	Rocks	0.097	0.101
Steart Flats (Wall Common)	Sand	0.066	0.072
Stolford	Sand	0.075	0.082
Watchet Harbour	Silt	0.090	0.097
Weston-super-Mare Beach	Sand	0.063	0.067
Oldbury and Berkeley			
1 km south of Oldbury	Silt	0.095	0.088
2 km south west of Oldbury	Silt	0.074	0.085
Guscar Rocks	Silt	0.096	0.091
Hills Flats	Silt	0.076	0.094
Lydney Rocks	Silt	0.076	0.082
Sharpness	Silt	0.084	0.084
Heysham			
Beach at Middleton Sands	Sand	0.081	0.081
Between the two pipelines	Sand	0.085	0.090
Central Pier Morecambe	Sand	0.076	0.083
Half Moon Bay	Sand	0.083	0.083

Table 9 *continued*

Mean gamma radiation dose rates at 1 metre over inter-tidal areas near nuclear power stations ($\mu Gy\ h^{-1}$)

Location	Ground Type	Quarter	
		2	4
Hartlepool			
Carr House	Sand	0.126	0.062
Greatham Creek Bird Hide	Sand	0.113	0.094
Hartlepool North Sands	Sand	0.060	0.061
North Gare	Sand	0.205	0.111
Paddys Hole	Silt	0.344	0.152
Seaton Carew	Sand	0.124	0.058
Seaton Sands	Sand	0.129	0.056
Trawsfynydd			
Bailey Bridge	Stones	0.102	0.106
Cae Adda	Stones	0.085	0.089
Fish Farm	Stones	0.101	0.098
Footbridge	Stones	0.099	0.112
Trawsfynydd Lake Shore	Stones	0.135	0.104
Wylfa			
Cemaes Bay	Sand	0.071	0.074
Cemlyn Bay	Sand	0.071	0.069

Notes

1. Each result shown is the mean of three readings obtained using a Mini-Instruments Environmental Meter type 6-80.
2. The dose rates shown include a contribution from background radiation of 0.05 $\mu Gy\ h^{-1}$ for sand and 0.07 $\mu Gy\ h^{-1}$ for other substrates.

Table 10 (a)

Radioactivity in surface waters near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Sizewell			
Leisure Park	Total alpha	0.05	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Nature Reserve	Total alpha	0.06	<0.02
	Total beta	0.75	<0.5
	Tritium	<4	<4
The Meare	Total alpha	0.05	<0.02
	Total beta	0.5	0.7
	Tritium	<4	<4
Wylfa			
Public Supply	Total alpha	0.08	-
	Total beta	<0.5	-
	Tritium	<4	-
Bradwell			
Coastal Ditch 1	Total alpha	0.85	-
	Total beta	6.2	-
	Tritium	6.8	-
Coastal Ditch 2	Total alpha	0.53	-
	Total beta	6.3	-
	Tritium	6.5	-
Coastal Ditch 3	Total alpha	0.4	0.08
	Total beta	8.8	5.8
	Tritium	64	16
Coastal Ditch 4	Total alpha	0.44	0.1
	Total beta	16	10
	Tritium	65	49
Public Supply near Bradwell	Total alpha	0.05	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Dungeness			
Pumping Station Well 1	Total alpha	0.07	-
	Total beta	<0.5	-
	Tritium	<4	-
Pumping Station Well 2	Total alpha	0.07	0.08
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Standing Water at Long Pits	Total alpha	0.04	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Reservoir	Total alpha	-	<0.02
	Total beta	-	<0.5
	Tritium	-	<4

Table 10 (a) continued

Radioactivity in surface waters near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Hinkley Point			
Ashford Reservoir	Total alpha	0.04	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Durleigh Reservoir	Total alpha	0.04	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Oldbury and Berkeley			
Gloucester and Sharpness Canal	Total alpha	<0.02	<0.02
	Total beta	<0.5	<0.5
	Tritium	16	14
Public Supply	Total alpha	<0.02	0.08
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Heysham			
Lancaster Public Supply	Total alpha	<0.02	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Hartlepool			
Dalton Piercy Boreholes	Total alpha	0.06	0.07
	Total beta	<0.5	<0.5
	Tritium	<4	<4
Public Supply	Total alpha	0.03	0.06
	Total beta	<0.5	<0.5
	Tritium	<4	<4

Table 10 (a) *continued*

Radioactivity in surface waters near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Trawsfynydd			
Afon Prysor	Total alpha	0.04	<0.02
	Total beta	<0.5	1
	Tritium	<4	<4
	Sulphur-35	<1	<1
Diversion Culvert	Total alpha	0.14	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
	Sulphur-35	<1	<1
Gwylan Stream	Total alpha	3.4	3.1
	Total beta	8.2	4.5
	Tritium	<4	<4
	Sulphur-35	<1	<1
Hot Lagoon	Total alpha	0.05	<0.02
	Total beta	<0.5	0.7
	Tritium	<4	<4
	Sulphur-35	<1	<1
Lake Trawsfynydd	Total alpha	0.08	<0.02
	Total beta	<0.5	<0.5
	Tritium	<4	<4
	Sulphur-35	<1	<1
Public Supply	Total alpha	0.08	0.08
	Total beta	<0.5	0.9
	Tritium	<4	<4
	Sulphur-35	<1	<1

Notes

1. (a) Except where shown the total alpha and total beta activity was less than 0.1 and 0.5 Bq kg^{-1} respectively;

   (b) The concentration of sulphur-35 was less than 1.0 Bq kg^{-1}.

2. Monitoring undertaken for quarters 2 and 4 only in 1998.

   Samples were obtained from Dungeness Reservoir, Wylfa and Bradwell only once during 1998.

Table 10 (b)

Radioactivity in sediments near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Sizewell			
Aldeburgh	Caesium-137	<0.6	14
Southwold Harbour	Total beta	946	113
	Cobalt-60	1.3	0.62
	Caesium-137	19	<0.35
Wylfa			
Cemaes Bay	Caesium-137	7.3	5.6
Cemlyn Bay	Caesium-137	4.8	4.7
Bradwell			
Maldon	Cobalt-60	1.9	<2.9
	Caesium-134	10	5.5
	Caesium-137	74	58
West Mersea	Caesium-134	1.9	2.1
	Caesium-137	12	33
Waterside	Caesium-134	5.2	5.6
	Caesium-137	34	48
Pipeline	Caesium-134	1.5	<0.32
	Caesium-137	6.3	0.8
1.5 km east of pipeline	Cobalt-60	5.2	<0.3
	Caesium-134	4.6	<0.2
	Caesium-137	27	0.6
Dungeness			
Rye Harbour 1	Total beta	800	642
	Cobalt-60	3.0	2.3
	Caesium-137	2.0	1.7
Rye Harbour 2	Total beta	525	350
	Cobalt-60	2.2	1.3
	Caesium-137	1.1	0.47
Hinkley Point			
1,600 m east of pipeline	Caesium-134	-	10
	Caesium-137	-	48
800 m east of pipeline	Caesium-137	3.3	3.0
At the pipeline	Caesium-137	4.2	6.7
River Parrott	Caesium-134	4.1	3.2
	Caesium-137	28	41
Stolford	Caesium-134	0.81	3.9
	Caesium-137	10	25
Steart Flatts	Caesium-137	3.8	5.1

Table 10 (b) *continued*

Radioactivity in sediments near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Oldbury and Berkeley			
1 km south of Oldbury	Caesium-134	<1.0	1.2
	Caesium-137	21	29
2 km south west of Berkeley	Caesium-137	27	3.1
Hill Flats	Caesium-137	16	116
Sharpness	Caesium-137	19	26
Heysham			
Half Moon Bay	Cobalt-60	<0.8	29
	Ruthenium-106	<5.3	34
	Caesium-137	13	253
	Americium-241	7.1	208
Pott's Corner	Caesium-137	22	51
	Americium-241	10	8.7
Between the two pipelines	Caesium-137	38	27
	Americium-241	17	11
Central Pier at Morecambe	Caesium-137	8.0	37
	Americium-241	4.1	21
Hartlepool			
Paddy's Hole	Caesium-137	11	6.1
North Gare	Caesium-137	0.59	<0.34
Trawsfynydd			
Lake Shore near Yacht Club	Cobalt-60	6.8	5.0
	Strontium-90	<25 (annual bulked sample)	
	Antimony-125	25	19
	Caesium-134	31	21
	Caesium-137	2338	2334
	Plutonium-238	2.4	2.6
	Plutonium-239/240	5.6	5.4
	Americium-241	9.7	6.8
Bailey Bridge	Cobalt-60	<0.82	2.8
	Strontium-90	<25 (annual bulked sample)	
	Caesium-134	6.2	6.6
	Caesium-137	439	536
	Plutonium-238	18	1.4
	Plutonium-239/240	85	2.5
	Americium-241	21	2.8

Table 10 (b) *continued*

Radioactivity in sediments near nuclear power stations (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
Trawsfynydd *continued*			
Fish Farm	Cobalt-60	31	<5.7
	Strontium-90	<25 (annual bulked sample)	
	Antimony-125	43	<7.2
	Caesium-134	51	15
	Caesium-137	2587	739
	Plutonium-238	71	3.6
	Plutonium-239/240	355	6.4
	Americium-241	49	10
Footbridge	Cobalt-60	2.6	<1.6
	Strontium-90	<25 (annual bulked sample)	
	Caesium-134	6.8	2.9
	Caesium-137	526	306
	Plutonium-238	86	0.9
	Plutonium-239/240	412	1.1
	Americium-241	11	2.1
Cae Adda	Strontium-90	<25 (annual bulked sample)	
	Caesium-134	4.7	2.7
	Caesium-137	440	417
	Plutonium-238	54	0.7
	Plutonium-239/240	267	2.2
	Americium-241	2.8	3.2

Notes

1. Monitoring undertaken for quarters 2 and 4 only in 1998.

Table 11

Radioactivity in sediments from the River Thames near UKAEA Harwell (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
River Thames bank					
Appleford	Total alpha	258	169	133	120
	Total beta	555	394	350	398
	Caesium-137	12	19	24	24
	Plutonium-238	<2 (annual bulked sample)			
	Plutonium-239+240	0.5 (annual bulked sample)			
	Americium-241	<0.2 (annual bulked sample)			
Day's Lock	Total alpha	285	270	169	225
	Total beta	459	490	408	449
	Caesium-137	16	6.1	7.7	16
	Plutonium-238	<2 (annual bulked sample)			
	Plutonium-239+240	0.4 (annual bulked sample)			
	Americium-241	<0.2 (annual bulked sample)			
Sutton Courtenay	Total alpha	269	309	225	313
	Total beta	546	652	408	759
	Caesium-137	60	87	41	2.9
	Plutonium-238	<2 (annual bulked sample)			
	Plutonium-239+240	1 (annual bulked sample)			
	Americium-241	<0.2 (annual bulked sample)			
Lydebank Brook	Total alpha	164	158	176	182
	Total beta	438	473	542	600
	Caesium-137	16	14	16	20
	Plutonium-238	<2 (annual bulked sample)			
	Plutonium-239+240	0.7 (annual bulked sample)			
	Americium-241	<0.2 (annual bulked sample)			

Notes

1. All results expressed as dry weight.

Table 12

Radioactivity in surface waters of the River Thames near UKAEA Harwell (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Day's Lock	Total beta	<0.5	<0.5	<0.5	0.6
	Tritium	<4	<4	<4	<4
Lydebank Brook	Tritium	6.8	<4	<4	<4
River Thames, above discharge point	Tritium	<4	<4	<4	<4
River Thames, below discharge point	Tritium	<4	<4	<4	<4
River Thames, above discharge point, Culham	Tritium	-	<4	-	<4
River Thames, below discharge point, Culham	Tritium	-	<4	-	<4

Notes

1. All samples:

(a) total alpha concentrations were less than 0.1 Bq kg^{-1} unless specified, total beta concentrations were less than 0.5 Bq kg^{-1};

(b) no radionuclides were detected by gamma-ray spectrometry.

Table 13

Mean gamma radiation dose rates at 1 metre over inter-tidal areas of the Dorset coast near UKAEA Winfrith (μGy h^{-1})

Location	Ground Type	Quarter
		2
Kimmeridge Bay	Silt	0.066
Poole Harbour	Silt	0.056
Weymouth Bay	Sand/Shingle	0.053
Ringstead Bay	Pebbles	0.055
Durdle Door	Sand/Shingle	0.050
Arish Mell	Sand/Shingle	0.055
Swanage Bay	Sand	0.063
Red Cliffe Point to Black Head	Shingle/Rock	0.082
St Oswalds Head	Sand/Shingle	0.056
Lulworth Cove	Shingle	0.057

Notes

1. Each result shown is the mean of three readings obtained using a Mini-Instruments Environmental Meter type 6-80.
2. The dose rates shown include a contribution from background radiation of 0.05 μGy h^{-1} for sand and 0.07 μGy h^{-1} for other substrates.

Table 14

Radioactivity in surface water and associated sediments near UKAEA Winfrith (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	4
River Win			
Natural Water Sources	Tritium	<4	6.9
Sediment	Total alpha	119	151
	Total beta	135	162
	Caesium-137	1.0	1.6
River Frome at Winfrith			
Natural Water Sources	Tritium	<4	<4
Sediment	Total alpha	112	<100
	Total beta	138	111
	Caesium-137	1.6	<3.9
River Frome at Wool			
Natural Water Sources	Tritium	<4	<4
River Frome Downstream			
Sediment	Total alpha	174	179
	Total beta	275	306
	Caesium-137	4.8	7.1
Stream A North of Site			
Natural Water Sources	Tritium	20	16
Sediment	Total alpha	155	<100
	Total beta	144	149
	Cobalt-60	3.3	1.4
	Caesium-137	14	13
Stream B East of Site			
Natural Water Sources	Tritium	<4	6.9
Sediment	Total alpha	119	151
	Total beta	135	162
	Caesium-137	1	1.6

Notes

1. All water samples: total alpha and total beta activities were below 0.1 Bq kg^{-1} and 0.5 Bq kg^{-1} respectively.

Table 15

Radioactivity in sewage at Maple Lodge sewage treatment plant (Bq kg^{-1})

Sample Type	Radionuclide	Quarter			
		1	2	3	4
Crude Effluent	Total alpha	<0.1	<0.1	<0.1	<0.1
	Total beta	0.71	0.5	2	0.6
	Tritium	<5	<5	<5	<5
	Aqueous Tritium	-	<5	<5	<5
	Organic Tritium	-	<10	<10	<10
	Carbon-14	<0.3	<0.5	-	-
	Iodine-125	<1	<1	0.89	<0.5
Digested Sludge	Total alpha	1.11	3.94	2.72	2.73
	Total beta	10.13	11.34	26.11	11.3
	Tritium	<5	<5	17.3	<5
	Aqueous Tritium	-	<5	14.3	<5
	Organic Tritium	-	<10	<10	<10
	Carbon-14	1	<0.5	0.5	<0.3
	Cobalt-57	-	<1.2	1.2	1.22
	Cobalt-58	-	<1	<1	<1
	Zinc-65	-	<3.19	3.2	3.45
	Iodine-125	5.9	<1	0.67	2.28
	Total Solids Unit = g/l	22.8	25.2	22.2	23.8
Final Effluent	Total alpha	<0.1	<0.1	<0.1	<0.1
	Total beta	0.63	0.58	0.87	0.54
	Tritium	<5	<5	<5	<5
	Aqueous Tritium	-	<5	<5	<5
	Organic Tritium	-	<10	<10	<10
	Carbon-14	<0.5	<5	-	-
	Iodine-125	<1	1.5	<0.15	3.32

Notes

1. All results expressed as dry weight.

Table 16

Radioactivity in surface waters and associated sediments near Nycomed Amersham (Amersham) (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Grand Union Canal					
Water	Total alpha	0.06	0.02	0.05	<0.02
	Total beta	0.43	<0.5	0.60	<0.5
	Tritium	<4	<4	<4	<4
	Carbon-14	<0.1	<0.1	<0.1	<0.1
	Iodine-125	<0.1	<0.1	<0.1	<0.1
Grand Union Canal					
Sediment	Total alpha	210	236	163	177
	Total beta	396	452	347	406
	Carbon-14	<100	<100	<100	<100
	Cobalt-57	1.0	1.5	1.0	0.8
	Iodine-125	<100	<100	<100	<100
	Caesium-137	3.0	4.8	4.4	1.4

Table 17

Radioactivity in surface waters near Nycomed Amersham (Cardiff) (Bq kg^{-1})

Location	Radionuclide	Quarter	
		2	3
Glamorganshire Canal	Total alpha	0.08	0.47
	Tritium	51	51
	Organic Tritium	<10	<10
	Carbon-14	0.2	<0.1
	Iodine-125	<0.1	<0.1
River Taff	Total alpha	<0.02	0.40
	Tritium	<4	<4
	Organic Tritium	<10	<10
	Carbon-14	<0.1	<0.1
	Iodine-125	<0.1	<0.1
Surface Water Outfall to River Taff	Tritium	55	233
	Organic Tritium	<10	<10
	Carbon-14	<0.1	<0.1
	Iodine-125	<0.1	<0.1

Notes

1. Unless specified total alpha and total beta activities were less than 0.1 Bq l^{-1} and 0.5 Bq l^{-1} respectively.

Table 18

Radioactivity in water and associated sediments near AWE (Aldermaston) (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
River Thames, Pangbourne	Total alpha	0.03	<0.02	0.05	<0.02
Natural Water Sources	Total beta	0.22	<0.5	<0.5	<0.5
	Tritium	<4	<4	<4	<4
	Uranium-234	<2	<2	<2	<2
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	<2	<2	<2	<2
	Plutonium-238	<0.2	<0.2	<0.2	<0.2
	Plutonium-239+240	<0.2	<0.2	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
River Thames at Mapledurham	Total alpha	0.02	<0.02	0.05	<0.02
Natural Water Sources	Total beta	0.29	<0.5	<0.5	<0.5
	Tritium	<4	<4	<4	<4
	Uranium-234	<2	<2	<2	<2
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	<2	<2	<2	<2
	Plutonium-238	<0.2	<0.2	<0.2	<0.2
	Plutonium-239+240	<0.2	<0.2	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
River Kennet, Reading	Total alpha	0.05	<0.02	0.05	<0.02
Natural Water Sources	Total beta	0.21	<0.5	<0.5	<0.5
	Tritium	<4	<4	<4	<4
	Uranium-234	<2	<2	<2	<2
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	<2	<2	<2	<2
	Plutonium-238	<0.2	<0.2	<0.2	<0.2
	Plutonium-239+240	<0.2	<0.2	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
Stream at Aldermaston	Total alpha	0.06	<0.02	0.07	<0.02
Natural Water Sources	Total beta	0.26	<0.5	1.4	<0.5
	Tritium	16	16	14	15
	Uranium-234	<2	<2	<2	<2
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	<2	<2	<2	<2
	Plutonium-238	<0.2	<0.2	<0.2	<0.2
	Plutonium-239+240	<0.2	<0.2	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2

Table 18 *continued*

Radioactivity in water and associated sediments near AWE (Aldermaston) (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
Stream at Spring Lane	Total alpha	0.05	<0.02	0.09	<0.02
Natural Water Sources	Total beta	0.56	<0.5	<0.5	<0.5
	Tritium	<4	<4	<4	<4
	Uranium-234	<2	<2	<2	<2
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	<2	<2	<2	<2
	Plutonium-238	<0.2	<0.2	<0.2	<0.2
	Plutonium-239+240	<0.2	<0.2	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
Stream Draining South*	Total alpha	0.06	-	-	-
Natural Water Sources	Total beta	0.23	-	-	-
	Tritium	<4	-	-	-
	Uranium-234	<2	-	-	-
	Uranium-235	<0.2	-	-	-
	Uranium-238	<2	-	-	-
	Plutonium-238	<0.2	-	-	-
	Plutonium-239+240	<0.2	-	-	-
	Americium-241	<0.2	-	-	-
River Kennet, Reading	Total alpha	161	180	234	90
Sediment	Total beta	278	341	487	292
	Caesium-137	1.7	2.3	<0.6	<0.6
	Uranium-234	3.6	5.7	4	3.8
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	3.2	5.4	3.7	3.0
	Plutonium-238	<0.2	2.3	<0.2	0.3
	Plutonium-239+240	0.45	8.3	0.6	0.4
	Americium-241	<0.2	<0.2	<0.2	<0.2
River Thames, Mapledurham	Total alpha	239	201	171	146
Sediment	Total beta	435	406	456	363
	Caesium-137	40	30	34	20
	Uranium-234	2.7	6.3	6.6	6.6
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	2.6	6.1	6.3	6.2
	Plutonium-238	<0.2	1.5	<0.2	0.3
	Plutonium-239+240	0.5	6.3	0.6	0.5
	Americium-241	<0.2	<0.2	<0.2	<0.2

Table 18 continued

Radioactivity in water and associated sediments near AWE (Aldermaston) (Bq kg^{-1})

Location	Radionuclide	Quarter			
		1	2	3	4
River Thames, Pangbourne	Total alpha	398	398	383	341
Sediment	Total beta	656	610	593	725
	Caesium-137	1.7	<0.6	11	1.0
	Uranium-234	2.9	5.1	4.6	4.9
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	2.3	5.1	4.3	4.6
	Plutonium-238	<0.2	0.6	0.7	0.2
	Plutonium-239+240	0.26	1.1	1.2	1.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
Stream at Aldermaston	Total alpha	175	208	200	224
Sediment	Total beta	282	392	434	582
	Caesium-137	3.4	4.0	3.1	5.4
	Uranium-234	4.6	7.4	6.0	6.5
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	3.6	6.4	5.0	5.8
	Plutonium-238	<0.2	0.4	1.2	0.3
	Plutonium-239+240	1.9	3.6	6.2	3.7
	Americium-241	<0.2	<0.2	<0.2	<0.2
Stream at Spring Lane	Total alpha	168	233	205	222
Sediment	Total beta	192	517	524	594
	Caesium-137	1.8	3.5	2.6	6.2
	Uranium-234	1.8	5.2	7.4	5.1
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	2.0	4.2	7.4	5.0
	Plutonium-238	<0.2	0.4	2.2	0.6
	Plutonium-239+240	0.38	0.6	12	3.2
	Americium-241	<0.2	0.32	<0.2	<0.2
Stream Draining South	Total alpha	184	213	340	172
Sediment	Total beta	220	391	555	328
	Caesium-137	4.7	8.0	15	5.2
	Uranium-234	1.4	5.7	4.5	4.0
	Uranium-235	<0.2	<0.2	<0.2	<0.2
	Uranium-238	1.3	6.5	4.5	4.3
	Plutonium-238	<0.2	0.6	<0.2	1.0
	Plutonium-239+240	0.56	0.6	0.4	0.7
	Americium-241	<0.2	0.54	<0.2	<0.2

Notes

1. * no longer being monitored.

Table 19

Radioactivity in surface water near Surelite's site (Bq kg^{-1})

Location	Distance from site (km)	Radionuclide	Sample Concentration
Stream at Weldon	1	Total beta	1.0
		Tritium	16
Stream at Weldon Lodge, Weldon	2	Total beta	0.6
		Tritium	42
Harpers Brook, Brigstock	5	Total beta	<0.5
		Tritium	<4
River Welland, Rockingham	6	Total beta	0.5
		Tritium	<4
Harpers Brook, on A6014	7	Total beta	<0.5
		Tritium	<4
Eyebrook Water	10	Total beta	0.3
		Tritium	<4
Rutland Water	16	Total beta	0.2
		Tritium	<4
Pitsford Reservoir	24	Total beta	0.3
		Tritium	8.6

Notes

1. All samples: Total alpha activities were below 0.1 Bq kg^{-1}.

Table 20

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region / Regional Office	Sample source	Radionuclide	Quarter 1	Quarter 2	Quarter 3	Quarter 4
North West (South Area)						
Northwich Tip	Borehole WM20G	Total alpha	0.02	-	<0.02	-
		Total beta	2.2	-	3.6	-
		Tritium	11	-	7	-
	Borehole WM5G	Total alpha	0.04	-	<0.02	-
		Total beta	9.9	-	18	-
		Tritium	29	-	22	-
	Borehole WM6G	Total alpha	0.11	-	<0.02	-
		Total beta	17	-	24	-
		Tritium	441	-	413	-
		Organic tritium	N/A	-	7.2	-
Magnesium Elektron	Local water	Total alpha	0.04	-	-	-
Swinton		Total beta	0.5	-	-	-
		Tritium	23	-	-	-
Arpley Landfill	Local water	Total alpha	0.03	-	0.25	-
		Total beta	0.07	-	0.8	-
		Tritium	<4	-	<4	-
		Carbon-14	0.11	-	<0.1	-
Sefton Meadows Tip	Local water	Total alpha	0.02	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	<4	-	-	-
North West (North Area)						
Albright & Wilson	Ufex	Total alpha	-	-	-	0.09
	Local water	Total beta	-	-	-	24
		Tritium	-	-	-	<4
		Uranium-234	-	-	-	0.4
		Uranium-238	-	-	-	0.4
Alco	Hut Bank Quarry	Total alpha	-	-	-	<0.02
	Local water	Total beta	-	-	-	3
		Tritium	-	-	-	<4
	Manhole 4	Total alpha	-	-	-	0.04
	Local water	Total beta	-	-	-	2.4
		Tritium	-	-	-	<4
Walney Island	Vickers waste ponds	Total alpha	-	-	-	0.02
	Water	Total beta	-	-	-	<0.5
		Tritium	-	-	-	<4

Table 20 *continued*

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region / Regional Office	Sample source	Radionuclide	Quarter			
			1	2	3	4
North West (Central Area)						
Birkacre Mine Shaft	Local water	Total alpha	0.05	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	<4	-	-	-
Belthorne Mine Shaft	Lottice Brook	Total alpha	<0.02	-	0.11	-
		Total beta	0.61	-	0.6	-
		Tritium	6.9	-	<4	-
	River Lostock	Total alpha	0.02	-	0.14	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-
	River Yarrow	Total alpha	0.03	-	<0.02	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-
Clifton Marsh	Site Borehole 6	Total alpha	0.05	-	<0.02	-
		Total beta	1.6	-	1.9	-
		Tritium	12	-	14	-
	Site Borehole 9	Total alpha	0.05	-	0.06	-
		Total beta	1.4	-	1.1	-
		Tritium	11	-	16	-
	Site Borehole 19	Total alpha	0.04	-	0.02	-
		Total beta	1.2	-	1.8	-
		Tritium	6.2	-	9.4	-
	Site Borehole 40	Total alpha	<0.02	-	0.19	-
		Total beta	1.7	-	3.3	-
		Tritium	<4	-	<4	-
	Site Borehole 59	Total alpha	<0.02	-	0.03	-
		Total beta	2.4	-	2.6	-
		Tritium	21	-	32	-
Ulnes Water	River Lostock 1	Total alpha	0.07	-	-	-
	River Lostock 2	Total alpha	0.03	-	-	-
Thames (North East Area)						
Braziers Landfill	Borehole 1	Total alpha	<0.02	-	<0.02	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-
	Borehole 5	Total alpha	0.03	-	<0.02	-
		Total beta	<0.5	-	<0.5	-
		Tritium	55	-	<4	-
	Borehole 9	Total alpha	0.02	-	0.04	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-

Table 20 *continued*

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region / Regional Office	Sample source	Radionuclide	Quarter 1	2	3	4
Thames (North East Area) *continued*						
Cole Green Landfill	Stream	Total alpha	0.02	-	0.04	-
		Total beta	<0.5	-	<0.5	-
		Tritium	13	-	<4	-
		Organic tritium	N/A	-	<4	-
	Static borehole	Total alpha	0.04	-	0.05	-
		Total beta	7.2	-	6.8	-
		Tritium	57	-	38	-
Thames (South East Area)						
Murex Ltd	Water, stream east	Total alpha	0.15	-	-	-
		Total beta	0.99	-	-	-
		Tritium	<4	-	-	-
	Water, stream west	Total alpha	0.06	-	-	-
		Total beta	0.77	-	-	-
		Tritium	<4	-	-	-
Thames (West Area)						
Stanford in the Vale	Borehole 15	Total alpha	0.04	-	<0.02	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-
	Local water	Total alpha	0.02	-	0.08	-
		Total beta	<0.5	-	<0.5	-
		Tritium	<4	-	<4	-
Anglian (Eastern Area)						
Strumpshaw	Borehole BH3	Total alpha	-	<0.02	-	<0.02
		Total beta	-	<0.5	-	<0.5
		Tritium	-	<4	-	<4
	Borehole BH2	Total alpha	-	<0.02	-	<0.02
		Total beta	-	<0.5	-	<0.5
		Tritium	-	<4	-	<4
	Reservoir	Total alpha	-	<0.02	-	<0.02
		Total beta	-	<0.5	-	<0.5
		Tritium	-	<4	-	<4
	Water abstraction	Total alpha	-	<0.02	-	<0.02
		Total beta	-	<0.5	-	<0.5
		Tritium	-	<4	-	<4
Anglian (Central Area)						
Cambridge	Site borehole	Total alpha	0.12	-	<0.02	-
Milton Landfill		Total beta	24	-	22	-
		Tritium	241	-	413	-

Table 20 *continued*

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region / Regional Office	Sample source	Radionuclide	Quarter 1	Quarter 2	Quarter 3	Quarter 4
Anglian (Central Area) *continued*						
Milton Landfill	Site drainage	Total alpha	0.3	-	dry	-
		Total beta	<0.5	-	dry	-
		Tritium	27	-	dry	-
	Ground water	Total alpha	0.03	-	<0.02	-
		Total beta	0.63	-	<0.5	-
		Tritium	<4	-	<4	-
	Phase 2	Total alpha	0.12	-	<0.02	-
	Borehole L10	Total beta	30	-	6.3	-
		Tritium	2433	-	125	-
	Phase 2	Total alpha	0.69	-	<0.02	-
	Borehole L12	Total beta	4.8	-	15	-
		Tritium	20	-	24	-
Wales (South East Area)						
Lamby Way tip	Borehole 1A	Total alpha	-	<0.02	-	<0.02
		Total beta	-	1.2	-	7.4
		Tritium	-	17	-	31
		Organic tritium	-	N/A	-	<4
Wales (Northern Area)						
Quarry, Caernarfon	Leachate,	Total alpha	-	<0.02	-	0.03
	Cilgwyn 1	Total beta	-	1.7	-	2.3
		Tritium	-	188	-	279
	Leachate,	Total alpha	-	<0.02	-	0.05
	Cilgwyn 2	Total beta	-	<0.5	-	<0.5
		Tritium	-	<4	-	<4
Southern (Sussex Area)						
Beddingham Quarry	Site 1 leachate	Total alpha	-	<0.02	-	0.03
		Total beta	-	11	-	17
		Tritium	-	278	-	319
		Organic tritium	-	<4	-	5.8
	Site 2 leachate	Total alpha	-	<0.02	-	dry
		Total beta	-	0.7	-	dry
		Tritium	-	13	-	dry
	Site 3 leachate	Total alpha	-	<0.02	-	<0.02
		Total beta	-	23	-	<0.5
		Tritium	-	90	-	38
North East (Dales Area)						
ICI	River Stell	Total alpha	0.08	-	<0.02	-
Cowpen Bewley tip	Downstream	Total beta	13	-	17	-
		Tritium	239	-	175	-

Table 20 *continued*

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region / Regional Office	Sample source	Radionuclide	Quarter 1	2	3	4
North East (Dales Area) *continued*						
Cowpen Bewley tip	River Stell	Total alpha	0.03	-	0.06	-
	Upstream	Total beta	5.4	-	21	-
		Tritium	<4	-	<4	-
North East (Northumbrian Area)						
High Urpeth Tip	Local water	Total alpha	0.03	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	<4	-	-	-
Kibblesworth Colliery	Local water	Total alpha	0.03	-	-	-
		Total beta	0.67	-	-	-
		Tritium	<4	-	-	-
Ryton tip, Gateshead	Local water	Total alpha	0.06	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	9.1	-	-	-
North East (Ridings Area)						
Gelderd Road, Leeds	Local water	Total alpha	<0.02	-	0.09	-
		Total beta	1.2	-	3.1	-
		Tritium	12	-	14	-
Farm Tip, Dean House	Local water	Total alpha	0.04	-	0.05	-
		Total beta	1.2	-	3.9	-
		Tritium	<4	-	18	-
Greaseworks tip, Morley	Local water	Total alpha	<0.02	-	<0.02	-
		Total beta	4.4	-	5.0	-
		Tritium	99	-	133	-
Wilson Road tip, Leeds	Local water	Total alpha	0.03	-	<0.02	-
		Total beta	1.3	-	3.1	-
		Tritium	<4	-	<4	-
Beighton tip	Borehole	Total alpha	0.14	-	-	-
		Total beta	6.6	-	-	-
		Tritium	9.6	-	-	-
	Local water	Total alpha	0.05	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	10	-	-	-
SCM Chemicals	Local water	Total alpha	0.05	-	-	-
		Total beta	4.6	-	-	-
		Tritium	<4	-	-	-
Midlands (Lower Severn Area)						
Crooks Marsh Farm	Avonmouth	Total alpha	-	<0.02	-	<0.02
	Local water	Total beta	-	0.5	-	1.9
		Tritium	-	19	-	17

Table 20 *continued*

Radioactivity in leachates, ground and surface waters near landfill sites (Bq kg^{-1})

Agency Region Regional Office	Sample source	Radionuclide	Quarter			
			1	2	3	4
Midlands (Lower Trent Area)						
School of Agriculture, Nottingham	Local water	Total alpha	0.04	-	-	-
		Total beta	<0.5	-	-	-
		Tritium	<4	-	-	-
Hilts Quarry	Fritchley Brook	Total alpha	0.03	-	-	-
		Total beta	0.5	-	-	-
		Tritium	<4	-	-	-

Notes

1. N/A Not available.
2. - No monitoring undertaken.
3. Unless specified, thorium-228, thorium-232, uranium-234, uranium-235, uranium-238, carbon-14 and iodine-125, where measured, were found to be <0.1 Bq kg^{-1}.

Table 21(a)

Quarterly concentrations of caesium-137 (μBq kg^{-1}) and beryllium-7 (mBq kg^{-1}) in air

Station	Radionuclide	Quarter			
		1	2	3	4
Lerwick	Beryllium-7	2.4	2.3	1.6	2.1
	Caesium-137	<0.3	<0.5	<0.4	<0.5
Glasgow (NRPB)	Beryllium-7	2.1	1.6	1.8	2.1
	Caesium-137	<1.5	<1.5	<1.5	<1.5
Eskdalemuir	Beryllium-7	3.4	1.9	1.4	1.3
	Caesium-137	<0.4	<0.5	<0.4	<0.4
Conlig	Beryllium-7	3.0	1.9	1.7	1.5
	Caesium-137	<0.3	<0.5	<0.4	<0.4
Dishforth	Beryllium-7	2.7	2.1	1.4	1.6
	Caesium-137	<0.3	<0.5	<0.4	<0.7
Orfordness	Beryllium-7	3.2	2.0	2.0	2.8
	Caesium-137	<0.3	<0.5	<0.5	<0.5
Aberporth	Beryllium-7	3.1	1.8	1.8	2.2
	Caesium-137	<0.3	<0.5	<0.4	<0.5
Chilton	Beryllium-7	2.7	2.6	2.4	2.4
	Caesium-137	<0.3	<0.2	<0.2	<0.1
Guernsey (NRPB)	Beryllium-7	2.1	2.0	1.8	2.4
	Caesium-137	<1.5	<1.5	<1.5	<1.5

Table 21(b)

Quarterly concentrations of caesium-137 (mBq kg^{-1}) and beryllium-7 (Bq l^{-1}) in rain

Station	Radionuclide	Quarter			
		1	2	3	4
Lerwick	Beryllium-7	1.6	2.0	2.2	1.3
	Caesium-137	<12	<18	<15	<7
Eskdalemuir	Beryllium-7	1.8	1.1	1.2	1.4
	Caesium-137	<6	<8	<9	<5
Aldergrove	Beryllium-7	0.8	1.3	0.7	0.9
	Caesium-137	<13	<12	<15	<9
Conlig	Beryllium-7	1.7	1.8	1.5	1.4
	Caesium-137	<16	<12	<17	<11
Dishforth	Beryllium-7	0.7	1.0	2.1	0.8
	Caesium-137	<20	<11	<22	<18
Orfordness	Beryllium-7	3.1	1.7	1.7	1.5
	Caesium 137	<35	<27	<20	<19
Aberporth	Beryllium-7	1.1	1.4	1.8	0.8
	Caesium-137	<15	<16	<35	<14
Snowdon	Beryllium-7	0.9	<0.7	1.9	1.9
	Caesium-137	<18	<24	<23	<15
Chilton	Beryllium-7	0.9	1.6	1.8	1.0
	Caesium-137	<20	<12	<23	<11

Table 21(c)

Concentrations of tritium in rainwater (Bq l^{-1})

Station	Radionuclide	Quarter			
		1	2	3	4
Eskdalemuir	Tritium	4.9	2.4	7.8	4.0
Orfordness	Tritium	1.2	1.6	1.9	1.1
Aberporth	Tritium	0.7	1.0	1.0	0.5

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Elan Valley Reservoir, Powys, Wales (Severn Trent Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	9	3.4	< 12	< 1	1.1	< 10	< 10	< 10	< 10	< 10	0.3	52	1.7
q2	< 0.02	< 0.05	< 0.05	< 4	18	9.1	< 12	< 1	1	< 10	< 10	< 10	< 10	< 10	0.6	1.9	< 0.1
q3	< 0.02	< 0.05	< 0.05	< 4	< 3	13.9	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	< 0.1	2.2	< 0.1
q4	< 0.02	< 0.05	< 0.05	< 4	9	< 1	< 16	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.3	1.6	< 0.1
River Severn (Tewkesbury) Gloucestershire (Severn Trent Water)																	
q1	0.04	0.165	0.144	< 4	121	5.8	< 42 (low volume)	< 1	< 1	< 10	< 10	20	< 10	13	4	120	1.7
q2	0.044	0.245	0.172	< 4	127	10.7	< 12	< 1	< 1	< 10	< 10	21.8	< 10	11.4	4.2	53	0.2
q3	0.033	0.26	0.187	< 4	133	16	< 6	< 1	< 1	< 10	< 10	17.4	< 10	< 10	4.4	51	0.2
q4	0.031	0.205	0.16	< 4	118	< 1	< 15	< 1	< 1	< 10	< 10	13.5	< 10	< 10	3.9	71	0.2
Derbyshire, Groundwater (Severn Trent Water)																	
q1	0.089	< 0.05	< 0.05	< 4	30	9.6	< 12	< 1	< 1	< 10	15.6	43	< 10	22	1	160	0.7
q2	0.084	0.103	0.067	< 4	39	11.5	< 12	< 1	< 1	< 10	14.8	38	< 10	21	1.3	89	0.5
q3	0.13	0.106	0.086	< 4	21	14.4	-	< 1	< 1	< 10	15.9	40.3	< 10	21.5	0.7	77	0.5
q4	0.129	0.106	0.082	< 4	30	1	< 13	< 1	< 1	< 10	16.7	38	< 10	20	1	110	0.5
River Tees, County Durham (Northumbrian Water)																	
q1	< 0.02	0.089	0.074	< 4	30	2.3	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	34	0.14
q2	< 0.02	0.07	0.055	< 4	54	3.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.8	32	0.3
q3	< 0.02	< 0.05	0.054	< 4	21	10.2	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.7	23	0.1
q4	0.022	0.079	0.064	< 4	61	1.9	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	99	0.3
Kielder Reservoir, Northumbria (Northumbrian Water)																	
q1	0.022	< 0.05	< 0.05	8.3	12	5.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.4	9.3	0.42
q2	< 0.02	0.05	< 0.05	5	24	3.7	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	8.5	1.3
q3	< 0.02	< 0.05	< 0.05	4.5	9	10.5	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.3	8.1	< 0.1
q4	0.022	0.06	< 0.05	5.2	24	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	16	< 0.1

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Tunstall Reservoir, County Durham (Northumbrian Water)																	
q1	0.043	0.061	0.053	5.9	30	6.1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	20	0.1
q2	< 0.02	0.055	< 0.05	< 4	39	9.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.3	8.9	< 0.1
q3	< 0.02	0.072	0.053	< 4	27	7	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	14	< 0.1
q4	< 0.02	0.093	0.068	< 4	30	6.3	< 17	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	13	< 0.1
Haweswater Reservoir, Cumbria (North West Water)																	
q1	< 0.02	0.065	0.057	4.2	30	2.8	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	27	0.19
q2	< 0.02	0.086	0.061	< 4	45	3.9	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.5	39	0.1
q3	0.02	0.089	0.064	< 4	30	8	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	28	< 0.1
q4	< 0.02	0.083	0.065	< 4	61	1.6	< 16	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	39	0.11
River Lune, Halton, Lancashire (North West Water)																	
q1	< 0.02	< 0.05	< 0.05	5	9	4.4	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.3	6.9	<0.1
q2	< 0.02	< 0.05	< 0.05	< 4	27	5.6	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	13	<0.1
q3	< 0.02	< 0.05	< 0.05	< 4	< 3	7.1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	<0.1	7.4	<0.1
q4	< 0.02	< 0.05	< 0.05	< 4	< 3	< 1	< 15	< 1	< 1	< 10	< 10	< 10	< 10	< 10	<0.1	7.3	<0.1
Arnfield Water Treatment Plant, Derbyshire (North West Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	18	2.7	< 12	< 1	1.6	< 10	< 10	< 10	< 10	< 10	0.6	6.7	0.21
q2	< 0.02	< 0.05	< 0.05	< 4	27	4.8	< 12	< 1	1.3	< 10	< 10	< 10	< 10	< 10	0.9	13	< 0.1
q3	< 0.02	< 0.05	< 0.05	< 4	12	3.9	-	< 1	1.2	< 10	< 10	< 10	< 10	< 10	0.4	5.4	< 0.1
q4	0.027	0.075	0.053	< 4	19	1	< 12	< 1	2.8	< 10	< 10	< 10	< 10	< 10	0.62	85	0.2
Ennerdale Water, Cumbria (North West Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	6	4.3	< 12	< 1	1.9	< 10	< 10	< 10	< 10	< 10	0.2	2.5	0.22
q2	< 0.02	< 0.05	< 0.05	4	15	6.2	-	< 1	1.4	< 10	< 10	< 10	< 10	< 10	0.5	5.9	< 0.1
q3	< 0.02	< 0.05	< 0.05	< 4	< 3	6.5	< 6	< 1	1.1	< 10	< 10	< 10	< 10	< 10	< 0.1	5.1	< 0.1
q4	< 0.02	< 0.05	< 0.05	< 4	< 3	< 1	< 9	< 1	1.6	< 10	< 10	< 10	< 10	< 10	< 0.1	3.7	< 0.1
Corn Close, Groundwater, Lancashire (North West Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	27	1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	28	< 0.1
q2	< 0.02	0.074	0.052	< 4	54	< 1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.8	30	0.2
q3	< 0.02	0.121	0.083	< 4	61	< 1	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	28	0.2
q4	< 0.02	< 0.05	< 0.05	< 4	29	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.95	83	0.3

Table 22 continued

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Denge, Shallow Groundwater, Folkestone, Kent (Folkstone and Dover Water)																	
q1	< 0.02	0.137	0.12	< 4	115	2.4	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.8	62	1.4
q2	< 0.02	0.227	0.181	< 4	151	5.6	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5	43	0.3
q3	0.023	0.271	0.208	< 4	203	4.6	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	6.7	49	0.3
q4	< 0.02	0.219	0.164	< 4	142	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.7	35	0.2
Kent, Deep Groundwater (Southern Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	30	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	110	0.52
q2	< 0.02	0.093	0.059	< 4	36	1.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.2	100	0.3
q3	0.023	0.081	0.071	< 4	30	3.4	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	110	0.2
q4	< 0.02	< 0.05	< 0.05	< 4	30	1	< 18	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	130	0.2
River Dee, Cheshire (Welsh Water)																	
q1	< 0.02	0.146	0.12	< 4	103	3.3	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.4	31	0.21
q2	< 0.02	0.179	0.135	< 4	124	5.7	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.1	31	0.2
q3	< 0.02	0.248	0.178	< 4	148	8.5	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.9	130	0.3
q4	< 0.02	0.138	0.105	< 4	91	3.5	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3	23	< 0.1
Llwyn-on Reservoir, Mid-Glamorgan (Welsh Water)																	
q1	< 0.02	< 0.05	<0.05	< 4	9	4.9	< 15	< 1	2.3	< 10	< 10	< 10	< 10	< 10	0.3	9.9	0.19
q2	< 0.05	0.053	< 0.02	< 4	27	5.3	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	16	< 0.1
q3	0.071	0.083	0.067	< 4	15	8.1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.5	14	< 0.1
q4	0.058	0.095	0.071	< 4	< 3	< 1	< 16	< 1	4.4	10	< 10	< 10	< 10	< 10	< 0.1	12	< 0.1
Cwm Ystradllyn Treatment Works, Gwynedd, Wales (Welsh Water)																	
q1	0.028	0.089	0.077	< 4	14	7.5	< 12	< 1	3.9	28	< 10	< 10	< 10	< 10	0.45	5.3	0.19
q2	< 0.02	< 0.05	< 0.05	< 4	12	8.7	< 12	< 1	2.8	16.5	< 10	< 10	< 10	< 10	0.4	1.9	< 0.1
q3	< 0.02	< 0.05	< 0.05	< 4	9	9.5	-	< 1	1.4	< 10	< 10	< 10	< 10	< 10	0.3	4.1	< 0.1
q4	0.021	0.068	0.05	< 4	16	7.5	< 13	< 1	4.8	10.2	< 10	< 10	< 10	< 10	0.54	10	< 0.1
Ashford Reservoir, Bridgwater, Somerset (Wessex Water)																	
q1	< 0.02	0.06	0.053	< 4	61	1.7	< 12	< 1	< 1	< 10	<10	10	< 10	< 10	2	60	0.24
q2	< 0.02	0.075	0.057	< 4	67	3.5	< 12	< 1	1.1	< 10	< 10	< 10	< 10	< 10	2.2	56	0.1
q3	0.027	0.078	0.059	< 4	70	4	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	52	0.1
q4	< 0.02	0.11	0.081	< 4	61	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	52	0.1

Table 22 continued

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Chew Valley Lake Reservoir, Bristol (Bristol Water)																	
q1	< 0.02	0.142	0.119	< 4	118	4.5	< 12	< 1	< 1	< 10	< 10	12	< 10	< 10	3.9	75	2
q2	0.021	0.195	0.136	< 4	112	5.2	< 12	< 1	< 1	< 10	< 10	11	< 10	< 10	3.7	64	1.6
q3	0.02	0.191	0.14	< 4	115	11.6	-	< 1	< 1	< 10	< 10	12	< 10	< 10	3.8	64	1.7
q4	0.022	0.189	0.14	< 4	124	2	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.1	67	1.8
River Avon, Christchurch, Hampshire (Bournemouth Water)																	
q1	-	-	-	< 4	-	< 1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	-	-	-
q2	0.05	0.115	0.079	< 4	61	5.8	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	91	0.3
q3	< 0.02	0.099	0.071	< 4	73	4.2	-	<1	< 1	< 10	< 10	< 10	< 10	< 10	2.4	120	0.5
q4	< 0.02	0.117	0.078	< 4	91	1.9	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3	90	0.2
River Fowey, Cornwall (South West Water)																	
q1	0.032	0.085	0.078	< 4	61	1.4	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	8.8	0.26
q2	0.036	0.085	0.07	< 4	51	4.1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.7	8.5	< 0.1
q3	0.043	0.088	0.067	< 4	61	6.2	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	12	< 0.1
q4	0.043	0.133	0.098	< 4	61	< 1	< 15	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	7.8	< 0.1
River Exe, Devon (South West Water)																	
q1	< 0.02	0.066	0.06	< 4	61	< 1	<12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	21	0.22
q2	< 0.02	0.083	0.062	< 4	61	3.7	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	18	< 0.1
q3	0.025	0.107	0.082	< 4	61	< 1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	18	< 0.1
q4	< 0.02	0.062	0.049	< 4	61	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	20	< 0.1
Grafham Reservoir, Cambridgeshire (Anglian Water)																	
q1	0.045	0.342	0.3	< 4	303	2.3	< 12	< 1	< 1	< 10	< 10	9.3	< 10	10.4	10	150	0.71
q2	< 0.02	0.443	0.32	< 4	269	7.3	< 12	< 1	< 1	< 10	< 10	12	< 10	9.2	8.9	130	1.9
q3	< 0.02	0.415	0.299	< 4	284	6.6	-	< 1	< 1	< 10	< 10	13.2	< 10	< 10	9.4	140	0.6
q4	0.051	0.376	0.277	< 4	270	< 1	< 12	< 1	< 1	< 10	< 10	11.2	< 10	< 10	8.9	130	0.5
Stoke-Ferry River, Norfolk (Anglian Water)																	
q1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
q2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
q3	-	-	-	< 4	76	2.8	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.5	110	0.2
q4	0.051	0.142	0.111	< 4	112	1.6	< 10	< 1	< 1	< 10	< 10	11.8	< 10	9.9	3.7	140	0.3

Table 22 continued

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Littlecoates (Grimsby), Groundwater, S. Humberside (Anglian Water)																	
q1	< 0.02	0.104	0.091	< 4	82	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.7	120	0.57
q2	< 0.02	0.152	0.101	< 4	88	3.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.9	120	0.5
q3	< 0.02	0.112	0.08	< 4	79	3.9	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.6	110	0.5
q4	0.032	0.103	0.089	< 4	91	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3	190	0.8
River Thames (Oxford), Oxfordshire (Thames Water)																	
q1	< 0.02	0.047	0.042	< 4	106	< 1	< 12	< 1	< 1	< 10	< 10	11.1	< 10	< 10	3.5	130	0.52
q2	0.021	0.179	0.155	< 4	115	5.3	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.8	110	0.3
q3	< 0.02	0.269	0.184	< 4	160	< 1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5.3	100	0.3
q4	0.042	0.203	0.152	< 4	127	< 1	< 14	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.2	110	0.3
River Thames (Walton), Surrey (Thames Water)																	
q1	< 0.02	0.21	0.179	8.8	163	4.1	<12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5.4	120	0.48
q2	0.04	0.172	0.129	< 4	163	3.9	-	< 1	< 1	< 10	< 10	9.9	< 10	< 10	5.4	100	0.4
q3	< 0.02	0.299	0.229	< 4	218	3.6	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	7.2	100	0.4
q4	0.038	0.248	0.183	< 4	182	5.6	< 13	< 1	< 1	< 10	< 10	< 10	< 10	< 10	6	100	0.3
Bourne End: Groundwater, Buckinghamshire (Thames Water)																	
q1	< 0.02	< 0.05	< 0.05	< 4	30	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	220	0.48
q2	0.022	< 0.05	< 0.05	< 4	45	2.4	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.5	110	0.3
q3	< 0.02	0.08	0.057	< 4	24	4.8	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	110	0.3
q4	< 0.02	0.058	< 0.05	< 4	3	1.4	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.1	100	0.3
River Lee (Chingford), Waltham Forest, London (Thames Water)																	
q1	< 0.02	0.304	0.262	4.1	294	4.3	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	9.7	130	0.68
q2	0.039	0.378	0.267	< 4	245	5.3	< 12	< 1	< 1	< 10	< 10	9.7	< 10	< 10	8.1	120	0.4
q3	0.026	0.368	0.297	< 4	300	< 1	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	9.9	110	0.5
q4	< 0.02	0.346	0.255	4.8	254	3.3	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	8.4	110	0.4
River Thames (Chertsey), Surrey (North Surrey Water)																	
q1	< 0.02	0.179	0.158	< 4	145	3.2	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.8	120	0.38
q2	< 0.02	0.139	0.111	< 4	154	5.9	< 12	< 1	1	< 10	< 10	9.8	< 10	< 10	5.1	100	0.4
q3	< 0.02	0.303	0.231	< 4	209	4.2	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	6.9	120	0.4
q4	0.034	0.248	0.164	< 4	166	3.8	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5.5	110	0.5

Table 22 continued

Calendar quarter	Gross alpha[a] Bq l^{-1}	Gross beta[b] Bq l^{-1}	Gross beta[c] Bq l^{-1}	H-3 Bq l^{-1}	K-40[d] mBq l^{-1}	Sr-90 mBq l^{-1}	I-125 mBq l^{-1}	Cs-134 mBq l^{-1}	Cs-137 mBq l^{-1}	Po-210 mBq l^{-1}	Ra-226 mBq l^{-1}	U-234 mBq l^{-1}	U-235 mBq l^{-1}	U-238 mBq l^{-1}	K mg l^{-1}	Ca mg l^{-1}	Sr mg l^{-1}
Eccup Reservoir, Leeds, Yorkshire (Yorkshire Water)																	
q1	< 0.02	0.101	0.084	< 4	61	17	< 12	< 1	1.3	< 10	< 10	< 10	< 10	< 10	2	24	0.17
q2	< 0.02	0.109	0.078	< 4	54	5.6	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.8	14	< 0.1
q3	< 0.02	0.112	0.083	< 4	61	8.1	< 6	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.6	13	< 0.1
q4	< 0.02	0.091	0.067	< 4	61	< 1	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	15	< 0.1
Chellow Heights, Bradford, Yorkshire (Yorkshire Water)																	
q1	< 0.02	0.077	0.062	< 4	23	5.6	< 12	< 1	1.8	< 10	< 10	< 10	< 10	< 10	0.77	25	< 0.1
q2	< 0.02	0.058	< 0.05	< 4	36	5.4	< 12	< 1	1.5	< 10	< 10	< 10	< 10	< 10	1.2	31	< 0.1
q3	< 0.02	< 0.05	< 0.05	< 4	12	< 1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.4	67	0.2
q4	0.021	0.06	< 0.05	< 4	9	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.3	59	0.7
Roadsford Reservoir, Dowrglann, St Austell, Cornwall (South West Water)																	
q1	0.021	0.065	0.056	< 4	67	7.4	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.2	110	0.22
q2	< 0.02	0.09	0.074	< 4	67	4.5	< 12	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.2	9.7	< 0.1
q3	< 0.02	0.114	0.084	< 4	64	6.1	-	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.1	11	0.4
q4	< 0.02	0.094	0.073	< 4	30	< 1	< 10	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	26	0.5

Notes

(a) measured using a plutonium-242 standard;

(b) measured using a caesium-137 standard;

(c) measured using a potassium-40 standard;

(d) the potassium-40 concentration is calculated from the stable potassium concentration using a potassium-40 specific activity of 31 mBq mg^{-1} stable potassium (0.0118% potassium-40 natural abundance)

Appendix 1 : Discharge monitoring

A1.1

Total

(a) Aqueous samples

A source is prepared by evaporating an aliquot of the sample to dryness on a two-inch diameter stainless steel planchette. The source is counted using an efficiency/source weight calibrated zinc sulphide scintillation detector.

(b) Solid samples

A source is prepared by drying and grinding a portion of the sample supplied, and passing it through a 30-micron mesh sieve. A standard geometry source is prepared on a two-inch diameter stainless steel planchette from the homogenised sample, and counted on a gas-flow proportional counter calibrated against standard sources prepared in a sodium chloride matrix.

A1.2

Total beta

Source preparation follows the procedures above.

(a) Aqueous samples

The source is counted using an efficiency/source weight calibrated Geiger Muller Detector.

(b) Solid samples

A standard geometry source is prepared on a two-inch diameter stainless steel planchette from the homogenised sample, and counted on a gas-flow proportional counter calibrated against standard sources prepared in a sodium chloride matrix.

A1.3

Total activity (excluding tritium) by liquid scintillation counting

The sample is transferred to a glass scintillation vial and evaporated to dryness in the presence of nitric acid and hydrogen peroxide. The residue is dissolved in dilute nitric acid and a suitable scintillation cocktail is added. The sample is counted using a dual-label twin-channel counting technique using either carbon-14/caesium-137 or iron-55/carbon-14 standards.

A1.4

Gamma-ray spectrometry

Sources are prepared by placing samples into standard geometry counting vessels, that is 250 ml capacity polyethylene bottles for liquids, 50 g capacity plastic containers for solids. Pre-treatment may include acidification, dilution, filtration etc for liquids, and drying, grinding etc for solids, dependent on sample origin. The sources are counted on a high-purity germanium detector system linked to a multi-channel spectrum/data analyser. The system is calibrated against traceable multi-element standards prepared into standard geometries, and nuclide identification made by software reference to gamma centroid energy libraries.

A1.5

Dual-label liquid scintillation counting for tritium/carbon-14 or tritium/sulphur-35

An aliquot of the sample is added to a suitable liquid scintillation cocktail, and the activities measured by means of a dual-label twin-channel counting technique using either tritium/carbon-14 or tritium/sulphur-35 standards.

A1.6

Specific nuclide methods

(a) Tritium

The sample is distilled from alkaline medium (sodium carbonate) and an aliquot of the distillate mixed with a suitable scintillation cocktail, and liquid scintillation counted.

For samples with organic content, the sample is distilled from a strong oxidant mix of phosphorus pentoxide and chromium trioxide before treating as above.

For low-activity samples, the sample volume is reduced by electrolysis, the enriched sample is then redistilled (from alkaline medium) and the activity determined by liquid scintillation counting.

(b) Carbon-14

Two methods are used, the choice depending on the particular sample being analysed.

Wet oxidation method

The sample is boiled with sulphuric acid and chromium trioxide, and the carbon dioxide produced is swept by nitrogen through a sulphur trap and absorbed into a 1:1 v/v phenylethylamine:methanol solution. The absorber solution is mixed with a suitable liquid scintillation cocktail, and the carbon-14 activity measured by liquid scintillation counting.

Combustion method

The sample is placed in a combustion thimble in a combustion tube and heated to 600 °C in an oxygen stream. The evolved carbon dioxide is passed through a pre-filtered saturated calcium hydroxide solution, and the precipitate produced dried and mixed to form a gel with a suitable liquid scintillation cocktail and counted.

(c) Sulphur-35

The sample is evaporated to dryness from a nitric acid and hydrogen peroxide medium in order to convert sulphur to sulphate. After an iron (III) hydroxide scavenge, the sulphate is separated on an ion exchange column. The sulphate is precipitated as barium sulphate and counted as a gel with a suitable liquid scintillation cocktail. The yield is determined from spiked samples.

(d) Iodine-125/129

All forms of iodine in the sample are initially converted to iodite by alkaline oxidation. The iodite ions are then reduced to iodine under acidic conditions, the liberated iodine being separated by solvent extraction using carbon tetrachloride. A purification and concentration procedure is carried out by reducing the iodine to iodide and re-oxidation to iodine. It is once more reduced to iodide and precipitated as silver iodide. It is then counted in this form on a sodium iodide (thallium activated) detector, or a high-purity germanium gamma detector.

(e) Strontium-90

The principle of the method is to separate strontium-90 and yttrium-90, which exist in radioactive equilibrium from the bulk of the sample prior to separation of yttrium-90. A pure source of strontium-90 is then prepared and this is counted twice to determine the activity of the strontium-90 via measurements of the yttrium-90 ingrowth, and also to check on source purity.

Initially strontium is concentrated by the precipitation of alkaline earth metal carbonates and hydroxides. Purification is achieved by selective precipitation of interfering radioisotopes. Yttrium is removed by precipitation of yttrium hydroxide. The purified strontium is converted to a suitable form for counting and measurement of the yttrium-90 ingrowth obtained by counting twice on a liquid scintillation counter, using the phenomenon of Cherenkov radiation. A chemical yield is obtained by initially spiking the samples with the gamma-emitting radioisotope strontium-85, and gamma-counting the final solution.

(f) Radium-226

Aqueous samples

The method is based on the original method by Rosholt. The basis of the method is a series of co-precipitations to remove bismuth, polonium and thorium, finally co-precipitating the radium with barium sulphate. The precipitate is mounted onto a planchette, and then counted initially on a zinc sulphide screen scintillation counter. The radium-226 daughters are then allowed to ingrow for at least 10 days, and then re-counted on the zinc sulphide screen scintillation counter.

Solid samples

Standard geometry (50 g where available) sources are prepared for gamma-ray spectrometry (see above).

(g) Plutonium, americium and curium

Separation of plutonium, americium and curium is accomplished by using plutonium's absorption properties from nitric acid onto strong anion exchange resin. Americium and curium (trivalent actinides) are not absorbed at the nitric acid concentration used, and so pass through the column. The raffinate is evaporated to dryness and the residue dissolved in 12M nitric acid. A solvent extraction with DDCP (dibutyl-N, N-diethylcarbamyl-phosphonate) is performed, and the americium and curium extract further purified by ion exchange chromatography. Plutonium is eluted from the column using a concentrated hydrochloric acid/hydriodic acid mixture. The elute is evaporated to dryness, and purified by repeated evaporations with nitric acid.

The appropriate solutions are then electroplated onto stainless steel discs from an ammonium sulphate medium, followed by counting on silicon surface barrier detectors (alpha spectrometry).

Chemical yields and counting efficiencies are determined by using plutonium-236, americium-243 and curium-244 tracers as appropriate.

Where plutonium-241 is also required, prior to electroplating the plutonium solution is split into two: one half for electroplating, the other for liquid scintillation counting to determine the beta-emitting plutonium-241 isotope.

(h) Uranium and thorium

Uranium and thorium isotopes are precipitated from solution with iron (III) hydroxide. The precipitate is dissolved in hydrochloric acid and uranium separated from thorium by anion exchange chromatography.

Following this initial separation, the uranium and thorium isotopes are further purified by additional ion exchange chromatographic techniques, before electroplating onto stainless steel discs for counting by alpha spectrometry. Chemical yields and counting efficiencies are determined by using uranium-236 and thorium-229 tracers as appropriate.

(i) Neptunium-237

Neptunium is obtained by a modification of the technique used above for the plutonium separation. Following elution of the plutonium with the hydrochloric/hydroiodic acid mixture, further washing of the column is carried out with concentrated hydrochloric acid to remove iodide, followed by elution of neptunium with 4.5M hydrochloric acid.

Following this initial separation, the neptunium-237 is further purified by additional ion exchange chromatographic techniques, before electroplating onto stainless steel discs for counting by alpha spectrometry.

Chemical yield is determined by using the beta emitting neptunium-239 tracer.

(j) Technetium-99

The sample is preconcentrated by evaporation from strongly alkaline media, ruthenium is removed by precipitation with alcohol and the supernatent acidified prior to removal of iron by precipitation with ammonia. Technetium is further purified by coprecipitation with copper sulphide, and the precipitate dissolved in xylene from a sulphuric acid medium in the presence of hydrogen peroxide.

Technetium is extracted from the solution with TIOA (Tri-isooctylamine) and back-extracted into sodium hydroxide, from which it is electrodeposited onto a stainless steel disc. Technetium-99m tracer is used to determine the yield by gamma counting. The technetium-99m is allowed to decay before the technetium-99 activity is measured by beta counting.

(k) Strontium-89/90, calcium-45, nickel-63, iron-55, yttrium-91 and promethium-147

Preliminary separation

The sample is centrifuged and the solids fused with sodium hydroxide; these dissolved solids are returned to the supernatant. Carrier and tracer solutions are added, and the volume reduced in the presence of hydrogen peroxide to assist isotopic exchange. Preliminary separation of the nuclides is performed by pH critical precipitation with ammonium hydroxide. The supernate produced (A) is reserved for strontium-89/90 (and calcium-45 and nickel-63) analysis. The precipitate is dissolved in 8M HCl and scavenged for antimony by saturation with hydrogen sulphide. Iron-55 is then separated from this supernate by extraction into di-isopropyl ether (B). The aqueous phase is evaporated to dryness and the residue dissolved in nitric acid, an extraction with D2EHPA (Di-(2-ethlylhexyl)) phosphate is carried out and the organic phase (C) is reserved for yttrium-91 separation and the aqueous phase (D) for promethium-147.

Supernate A: nickel-63, strontium-89/90, calcium-45

Nickel-63
The supernate containing nickel (as its dimethylglyoxime complex) is extracted into chloroform (the aqueous phase being retained for determination of Sr-89/90 and Ca-45), and then back-extracted into hydrochloric acid. The complexation and back-extraction is repeated, and the resulting purified solution evaporated to dryness. The solids are dissolved in water and bulked to a known volume before an aliquot is removed for nickel-63 activity determination by liquid scintillation counting.

Strontium-89/90
The retained aqueous phase from the nickel-63 methodology is used for the determination of activity concentrations for strontium-89/90. The method used is summarised above.

Calcium-45
Following the counting of the vial for strontium-89/90, the solution is treated to a number of controlled pH precipitations to remove strontium and yttrium, before the remaining supernate is acidified and an aliquot is taken, mixed with liquid scintillation cocktail and counted.

Extractant B: Iron-55
The organic extractant (di-isopropyl ether) is washed with hydrochloric acid, and the aqueous phase transferred to a centrifuge tube. Iron is precipitated by the addition of ammonium hydroxide, the precipitate centrifuged and then re-dissolved in hydrochloric acid. The extraction procedure is repeated to concentrate the iron-55 before an aliquot of the final solution is taken and mixed with a liquid scintillation cocktail and counted.

Extractant C: Yttrium-91
The organic phase is washed with nitric acid, and then the yttrium extracted into hydrochloric acid. Yttrium is then precipitated from the solution using sodium hydroxide, centrifuged, washed with water and then dissolved in the minimum volume of dilute hydrochloric acid. A known volume aliquot is taken, mixed with a liquid scintillation cocktail and counted.

Supernate D: Promethium-147
The supernate containing promethium is purified using D2EHP, and from the aqueous solution rare-earth hydroxides are precipitated. The precipitate is washed, re-dissolved in dilute acid and any ruthenium removed by extraction into carbon tetrachloride. The rare-earth hydroxides are re-precipitated, washed and then re-dissolved in a known volume of dilute acid. An aliquot of this solution is then mixed with liquid scintillation cocktail and counted.

Counting and yield determination

The purified fractions are prepared for liquid scintillation counting by mixing with suitable scintillant cocktails (strontium is prepared in an aqueous medium to utilise the Cherenkov phenomenon). Yields are determined by a variety of techniques that include gamma counting for tracers (strontium-85), inductively coupled plasma-optical emission spectrometry (calcium) and complex colorimetric analysis against calibration graphs (promethium/iron/yttrium).

Appendix 2: Waste quality checking laboratory

A2.1

Non-destructive testing of solid radioactive waste

A2.1.1 X-radiography

Each 200 litre drum is X-radiographed from three points around the circumference of the drum and three levels covering the length of the drum, producing nine radiographs per drum. The radiographs are visually examined and information on the contents of the drums is deduced.

A2.1.2 Segmented gamma scanning

The gamma-emitting radioisotopes in each drum are identified and quantified by Segmented Gamma Scanning (SGS). The SGS rotates the drum at a speed of 6 rpm and the radioactive content of each drum is detected by a high-purity drifted germanium detector and is corrected for attenuation by the use of a europium-152 transmission source.

A2.2

Destructive testing of solid radioactive waste

Solutions are first prepared from representative samples taken from the solid low-level radioactive waste. The radioactivity content of the solution is then determined using the following methods.

A2.2.1 Determination of total alpha radioactivity

This method uses alpha spectrometry to determine the total alpha-emitting radioactivity contained within a specified volume of liquid. A measured aliquot of the liquid to be analysed is evaporated onto a stainless steel counting tray and allowed to cool before analysis by alpha spectrometry in a pre-calibrated geometry. The counting efficiency of the alpha spectrometer is determined by counting a mixed alpha reference standard source.

A2.2.2 Determination of total beta radioactivity

This method uses liquid scintillation counting to determine the total beta-emitting radioactivity contained within a specific volume of liquid. A measured aliquot of the liquid to be analysed is added to a known volume of a scintillation cocktail. The sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The counting efficiency of the sample is determined by internal standardisation using a caesium-137 reference standard solution.

A2.2.3 Determination of gamma radioactivity

This method uses gamma-ray spectrometry to determine the gamma-emitting radioisotopes contained within a specified volume of liquid. A 50 ml aliquot of the liquid to be analysed is counted in a pre-calibrated geometry by gamma-ray spectrometry using an instrument capable of measuring energies between 50 and 1900 keV. The counting efficiencies of the gamma-ray spectrometer are determined by counting a mixed gamma reference standard solution.

A2.2.4 Determination of specific radionuclides

(a) Tritium

In this method, tritium is extracted as tritiated water by distillation from a known volume of sample solution, after first being treated with an alkaline reducing agent to prevent volatilisation of ruthenium and iodine radioisotopes. A measured aliquot of the condensate is added to a known volume of a scintillation cocktail. The sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The method efficiency is determined by analysing a tritium reference standard solution as per the sample. The counting efficiency of the sample is determined by internal standardisation using a tritium reference standard solution.

(b) Technetium-99

In this method technetium-99 is separated by solvent extraction from a known volume of sample solution. A measured aliquot of the sample is heated with concentrated nitric acid, hydrogen peroxide and iron carrier, to ensure that the technetium is in solution as the pertechnetate. Impurities are co-precipitated with iron (III) hydroxide, by the addition of concentrated ammonia solution, and removed by centrifugation. The supernatant is

acidified with concentrated sulphuric acid, and the technetium-99 is extracted into a measured aliquot of five per cent tri-n-octylamine in xylene. A measured aliquot of the organic phase is added to a known volume of a scintillation cocktail. The sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The method efficiency is determined by analysing a technetium-99 reference standard solution as per the sample. The counting efficiency of the sample is determined by internal standardisation using a technetium-99 reference standard solution.

(c) Strontium-90 and calcium-45

In this method, strontium-90 and calcium-45 are separated from a known volume of sample solution using fuming nitric acid. A measured aliquot of the sample is heated with oxalic acid solution, calcium and strontium carriers. The solution is adjusted to pH4 to precipitate strontium-90 and calcium-45 as their oxalates, removed by centrifugation, and ashed to their oxides. The oxides are dissolved in acid, and ruthenium, antimony, and cobalt carriers added. Impurities are co-precipitated as sulphides, by the addition of hydrogen sulphide gas, and removed by centrifugation. The supernatant is heated with ammonium carbonate to precipitate strontium-90 and calcium-45 as their carbonates, and removed by centrifugation. The carbonates are dissolved in acid, and the strontium-90 and calcium-45 separated by the addition of fuming nitric acid, and cooling in an ice bath. The precipitate containing the strontium-90 is dissolved in water, while the supernatant contains the calcium-45. Impurities are removed by co-precipitation with barium chromate, and centrifugation. The carbonate precipitation and acid dissolution are repeated. Further impurities are removed by co-precipitation with iron (III) hydroxide.

Yttrium-90 is separated from the strontium-90 fraction by precipitation with yttrium carrier and concentrated ammonia solution, followed by centrifugation, and the date and time noted. The carbonate precipitation is repeated and the carrier recoveries calculated. The carbonate is dissolved in a known volume of dilute acid, and the yttrium-90 in the strontium-90 sample is allowed to grow-in. A measured aliquot of the acid phase is added to a known volume of scintillation cocktail. The sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The method efficiencies are determined by analysing strontium-90 and calcium-45 reference standard solutions as per the sample. The counting efficiency of the sample is determined by internal standardisation using the appropriate reference standard solution.

(d) Iodine-125 and Iodine-129

In this method, iodine radioisotopes are separated from a known volume of sample solution using anion exchange chromatography. A measured aliquot of the sample is mixed with iron, cobalt and iodide carriers. Impurities are co-precipitated with iron (III) hydroxide, by the addition of concentrated ammonia solution, and removed by centrifugation. Further impurities are co-precipitated with cobalt hydroxide, by the addition of sodium hydroxide solution, and removed by centrifugation. The supernatant is mixed with sodium hypochlorite solution to ensure that the iodine is in solution as the periodate.

The iodine in solution is then reduced to the iodide form by the addition of nitric acid, hydroxylamine hydrochloride solution, and then di-sodium disulphate solution. The solution is adjusted to pH 6.5 prior to passing through an anion exchange column to adsorb the iodine radioisotopes as the iodide. The column is washed with de-ionised water, and sodium chloride solution to remove impurities. The iodine radioisotopes are eluted with sodium hypochlorite solution, and made up to a known volume in a calibrated volumetric flask. A 50ml aliquot of the solution is analysed in a pre-calibrated geometry on a low energy gamma and X-ray spectrometer capable of measuring energies between 3 and 100 keV. The counting efficiencies of the spectrometer are determined by counting reference standard solutions. The method efficiency is determined by analysing a mixed iodine-125/iodine-129 reference standard solution as per the sample.

(e) Actinides (Am/Cm, Pu, U and Th)

In this method, actinide radioisotopes are separated from a known volume of sample solution using anion exchange chromatography. A measured aliquot of the sample is heated with iron carrier, and actinide reference standard solutions. The actinide radioisotopes are co-precipitated with iron (III) hydroxide, by the addition of concentrated ammonia solution, and removed by centrifugation, leaving impurities in the supernatant. The precipitate is dissolved in hydrochloric acid, and the iron removed by shaking with di-isopropyl ether. The aqueous phase is evaporated to dryness and the residue dissolved in hydrochloric acid. Concentrated nitric acid is added to ensure that the plutonium is in the correct oxidation state.

The solution is passed through an anion exchange column and washed with hydrochloric acid to remove the americium, curium and thorium radioisotopes in the eluate, and retain the plutonium and uranium radioisotopes on the resin. Impurities are removed from the column by washing with nitric acid and hydrogen peroxide, and the uranium radioisotopes are eluted with dilute nitric acid.

Plutonium radioisotopes are eluted with two per cent hydriodic acid in concentrated hydrochloric acid. The americium, curium and thorium radioisotopes are evaporated to dryness with concentrated nitric acid, and the residue dissolved in nitric acid. Methanol is added and the solution is passed through an anion exchange column to remove impurities.

Americium and curium radioisotopes are eluted with nitric acid, and thorium radioisotopes are eluted with concentrated hydrochloric acid. All eluted fractions are evaporated to dryness with concentrated hydrochloric acid, before electro-deposition onto stainless steel counting trays from ammonium oxalate or ammonium chloride solutions in hydrochloric acid. The counting trays are analysed by alpha spectrometry in a pre-calibrated geometry. The method efficiencies are determined from the internal reference standard solutions.

(f) Plutonium-241

The counting tray from the plutonium analysis is washed with nitric and hydrochloric acids to dissolve the plutonium radioisotopes. The solution is evaporated to dryness and the residue is dissolved in dilute nitric acid. A known volume of a scintillation cocktail is added, and the sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The counting efficiency of the sample is determined by internal standardisation using a plutonium-241 reference standard solution.

(g) Carbon-14

In this method, carbon-14 is separated as carbon dioxide by wet oxidation from a known volume or weight of sample. A measured aliquot or weight of the sample is refluxed with potassium dichromate, concentrated sulphuric and phosphoric acids. Air is passed through the reaction vessel and the gasses are bubbled through dilute nitric acid to remove impurities, and then through an amine solution to dissolve the carbon dioxide. The amine solution is made up to a known volume in a calibrated volumetric flask. A measured aliquot of the amine solution is added to a known volume of a scintillation cocktail.

The sample is thoroughly shaken and allowed to equilibrate before analysis by liquid scintillation counting. The method efficiency is determined by analysing a carbon-14 reference standard solution as per the sample. The counting efficiency of the sample is determined by internal standardisation using a carbon-14 reference standard solution.

(h) Sulphur-35

In this method, sulphur-35 is separated from a known volume of sample solution using cation exchange chromatography. A measured aliquot of the sample is taken in duplicate, one of which is dosed with a measured aliquot of sulphur-35 reference standard solution. Antimony, ruthenium and sulphate carriers are added and the sample is evaporated to dryness. The residue is dissolved in concentrated hydrochloric acid. Impurities are co-precipitated with iron (III) hydroxide, by the addition of concentrated ammonia solution, and removed by centrifugation. The supernatant is adjusted to pH 7 prior to passing through a cation exchange column to remove impurities. The eluate containing the sulphur-35 is heated with concentrated hydrochloric acid and barium chloride solution to precipitate the sulphur-35 as the sulphate.

The sulphate is slurried with a known aliquot of de-ionised water and shaken with a known volume of a gelling scintillation cocktail. The sample is allowed to equilibrate before analysis by liquid scintillation counting. The sulphur-35 activity of the sample is determined from the duplicate dosed with the reference standard solution, and the method efficiency is determined by analysing a sulphur-35 reference standard solution as per the sample.

(i) Iron-55

In this method, iron-55 is separated by solvent extraction from a known volume of sample solution. A measured aliquot of the sample is heated with iron, nickel and cobalt carriers, hydrogen peroxide and ammonium chloride. Concentrated ammonia solution is added to precipitate iron (III) hydroxide and impurities removed by centrifugation. The precipitate is dissolved in hydrochloric acid, and the iron-55 is extracted into di-isopropyl ether. The iron-55 is back-extracted into de-ionised water which is heated to remove any residual ether. The iron (III) hydroxide precipitation is repeated, the precipitate is dissolved in dilute hydrochloric acid and is made up to a known volume in a calibrated volumetric flask.

A 50 ml aliquot of the solution is analysed in a pre-calibrated geometry on a low energy gamma and X-ray spectrometer capable of measuring energies between 3 and 100 keV. The counting efficiency of the spectrometer is determined by counting an iron-55 reference standard solution. The method efficiency is determined by analysing an iron-55 reference standard solution as per the sample.

Appendix 3: Environmental monitoring

3.1

Total or total alpha activity

Samples are extracted with acids (where necessary) to obtain a solution and, after the addition of plutonium-236 as a yield tracer, are filtered. Samples are prepared as electro-deposited sources and counted under vacuum using silicon surface barrier detectors. Total alpha values are obtained by summing all counts obtained over eight hours (less a standard subtraction for background) in the energy range 3-8 MeV after corrections for radiochemical yield and counting efficiency.

3.2

Total or total beta activity

All total beta values are measured after removal of tritium. Samples (liquid) are reduced to dryness and re-dissolved in aqueous solution. The products are counted by liquid scintillation counting using caesium-137 as a calibration standard.

3.3

Gamma-ray spectrometry

The determination of gamma-emitting nuclides is carried out using gamma-ray spectrometry. The equipment consists of a number of high resolution germanium detector systems, linked to a multi-tasking hard disc multi-channel analyser assembly for spectrum recording and data processing. Nuclide identification is based on gamma photon centroid energy evaluation, and quantitative measurements are made using energy-related efficiency calibrations. These calibrations provide an energy and counting efficiency relationship for a given sample matrix and volume, and are established using traceable multi-component gamma standards.

3.4

Alpha spectrometry

The determination of alpha-emitting nuclides is carried out using a combination of radiochemical separation procedures combined with alpha spectrometry. The complexity of the radiochemical separation procedure chosen depends on the precise analytical requirements for nuclide identification (see below). All samples are prepared for analysis in the form of an electrodeposited source, and are counted under vacuum using silicon surface barrier detectors.

Counting periods are chosen to be in the range one to four days. Yield tracers are used to calculate chemical recovery and counting efficiency and are selected on the basis of low environmental occurrence. The alpha counting chambers are routed via a multi-channel buffer to a personal computer for the analysis of data by a suitable software package. Nuclide identification is based on alpha peak centroid energy and quantitative determination based on nett peak area after correction for counting efficiency and radiochemical recovery.

3.5

Analysis of grass samples for organically bound tritium

A suitable weight of dried grass sample is ashed slowly in a copper oxide furnace tube with a bleed of carrier gas. The effluent gases are passed through a cooled condenser and the resultant condensate is counted for tritium on a liquid scintillation counter.

3.6

Specific nuclide methods

(a) Plutonium, americium, thorium, uranium, curium

Samples are ashed, extracted with boiling hydrochloric acid and filtered (rejecting the insoluble residue). To the filtrate is added oxalic acid and sodium sulphite, and the pH is adjusted. The supernatant is rejected after centrifuging the material. The oxalic acid precipitation is repeated and the resulting precipitate filtered. The precipitate is ashed, dissolved in acid and, after adding iron carrier, the pH is adjusted. The precipitate is retained, dissolved in an acid mixture and passed through an ion-exchange column. A number of eluants are used to remove specific radionuclides from the column. Each eluant is subjected to electro-chemical deposition and alpha spectrometry as described above. Appropriate yield tracers, including plutonium-243, americium-243, thorium-229 and uranium-232, are used.

(b) Neptunium-237

Samples are ashed, extracted with hydrochloric acid and, where necessary, iron (III) carrier is added. The solution is made alkaline and the resulting precipitate centrifuged and collected. This precipitate is dissolved in acid and reduced to incipient dryness. After the addition of further acid, the sample is diluted with methanol. Recoveries are determined by the standard addition technique.

(c) Sulphur-35

Sulphate carrier is added to the sample, which is allowed to stand overnight in the presence of nitric acid. The resultant solution is evaporated to incipient dryness, cooled and magnesium nitrate solution added. After dissolution in hot water, the material is transferred to a crucible, evaporated to dryness and ignited to 500 °C. The residue is dissolved in aqueous acid and filtered, collecting the filtrate and washings. The pH of the solution is adjusted and subjected to ion-exchange chromatography. The column is eluted and the resulting eluant raised to boiling point. Barium chloride solution is added and the material centrifuged. The supernatant liquor is removed and the residual solid transferred to a gel scintillator and counted by liquid scintillation spectrometry. Yields are determined by the standard addition technique.

(d) Technetium-99

Hydrogen peroxide is added to the sample (in liquid form) before passing the material down an ion-exchange column. The column is washed with water and eluted. The fraction of interest is extracted into cyclohexanone and the aqueous phase discarded. The organic phase is washed with 1M HCl, water and partitioned with a cyclohexane/water mixture. The aqueous phase is reduced in volume and counted using liquid scintillation spectrometry.

(e) Strontium-90

Strontium and calcium carriers are added to the sample, followed by oxalic acid solution. The pH of the solution is adjusted and, after warming, the resulting precipitate is recovered by centrifuging. The precipitate is dissolved in acid and oxalic acid precipitation repeated. The oxalate is destroyed by heating to 600 °C, and the resulting residue dissolved in acid. Hydrogen sulphide is passed through the solution in the presence of a number of carriers. The supernatant is made alkaline and the hydrogen sulphide treatment repeated.

Ammonium carbonate is added to the supernatant and the solution centrifuged. The supernatant is discarded, the carbonates dissolved in acid and the precipitation repeated. The precipitate is dissolved in acid and fuming nitric acid added. The solution is cooled in ice and the precipitate retained. The fuming nitric acid step is repeated and the precipitate dissolved in water. Barium carrier is added and the pH adjusted. The solution is warmed, chromate added and, after centrifuging, the supernatant liquor retained. A precipitation procedure is carried out using fuming nitric acid, and the resulting solid dissolved in water. Iron carrier is added and the solution made alkaline, heated and filtered into a clean tube. Yttrium carrier is added and the solution made acidic. Yttrium-90 daughter product is allowed to grow-in and the precipitate retained. The precipitate is dissolved in acid and the hydroxide precipitation repeated twice. The precipitate is recovered and washed with water and methanol. The purified solid is suspended in gel scintillator and counted by liquid scintillation spectrometry.

(f) Tritium by electrolysis

A suitable volume of sample is distilled and electrolyte added to the distillate. The material is subjected to electrolysis until the required level of pre-concentration is achieved. The remaining solution is distilled and the distillate counted by liquid scintillation spectrometry. Recoveries are determined using low level tritium standard solutions.

(g) Uranium analysis

The radionuclide uranium-238 is determined using non-destructive thermal neutron activation analysis. An independent measurement of uranium-235 is performed using delayed neutron analysis. Where appropriate, the measurement of uranium-235 and uranium-238 (from an assumption of equilibrium with the decay product thorium-234) is carried out by gamma-ray spectrometry.

This latter technique is inherently less sensitive than those methods involving neutron activation reactions, and its application for the measurement of uranium isotopes is limited accordingly.

Appendix 4: Radioactivity in air and rainwater

4.1

Sample preparation

(a) Rainwater

The sample volume is measured and the rainwater evaporated. The concentrated sample is then transferred to a polystyrene pot for analysis.

When zirconium-95 is thought to be present in the rainwater sample, it is first passed through an ion-exchange column. The filtrate is evaporated and added to the resin which has been placed in a polystyrene pot.

When necessary, special rainwater samples for radio-iodine analysis only are passed through an ion-exchange column, the resin is shaken out into a polystyrene pot and counted without further processing; the filtrate is discarded.

(b) Airborne dust filters samples for analysis by gamma-ray spectrometry

The filter material is compressed to form a sample with a suitable geometry for counting. When it is required to compound a large number of filters, these are ashed and the resulting ash placed in a polystyrene pot for counting.

4.2

Analysis of samples

(a) Gamma-ray spectrometry

The determination of activities of gamma-emitting radionuclides in samples is undertaken using conventional gamma-ray spectrometry techniques. Several standard textbooks describe the methods used in depth, and these should be referred to if more detailed knowledge is sought.

The specific gamma-ray activities in the samples are determined by comparison with mixed radionuclide gamma-ray reference standardised solutions in identical geometries. The activities of radionuclides present in the sample are then determined using the efficiency-energy response functions derived from the standardised solutions.

(b) Plutonium isotopes and strontium-90

Sample pre-treatment

Air filters

The air filter is spiked with strontium carrier and plutonium-242 to act as an internal tracer. The sample is then ashed and the resultant ash is leached with dilute nitric acid. The acid leachate is then ready for analysis of plutonium isotopes and strontium-90.

Rainwater

The rainwater, whose container has previously had carriers added, is evaporated to dryness. The residue is then ashed in a muffle furnace and the residue is leached with nitric acid. The resultant solution is then ready for analysis of plutonium isotopes and strontium-90.

(c) Analysis

Plutonium isotopes

The plutonium isotopes are purified by adsorption onto an anion-exchange column in nitric acid medium. The eluant and further nitric acid washes are then retained for the strontium-90 analysis.

The plutonium fraction is solubilised in water and electrodeposited onto a stainless steel disc for alpha spectroscopic determination of the plutonium-239/240 and plutonium-238 activities by reference to the plutonium-242 internal tracer.

Strontium-90 analysis

The eluant from the anion-exchange column is boiled to dryness. The residue is dissolved in demineralised water and strontium and yttrium carriers added. Yttrium is then precipitated and the yttrium-90 activity is corrected for decay from the time of its separation from the strontium-90 parent and hence the strontium-90 activity of the sample can be calculated.

Tritium in rainwater

Sample pre-treatment

The rainwater sample is distilled to dryness in a closed distillation unit to remove salts and particulate contamination.

Electrolytic enrichment

Electrolytic enrichment of 100 ml of the distillate from the original sample allows an enrichment of tritium by a factor of about 18 to be achieved.

Liquid scintillation counting

Following electrolytic enrichment of the sample, it is counted using a proprietary emulsion scintillant (Packard Instagel) and a conventional liquid scintillation spectrometer tuned for optimum low-level counting. Each sample is counted for either 10 periods of 100 minutes or 10 periods sufficient to collect 2,000 counts, depending on the count rate of the sample. Batches of samples are processed to allow background and calibration samples to be counted at the same time as samples. In general there is a ratio of about one background and one calibration standard to every five samples.

Appendix 5: Drinking water sources

5.1

Total alpha / beta in water

An acidified water sample is concentrated by evaporation and sulphuric acid added. The resulting precipitate is dried and ashed in a muffle furnace. An aliquot of the ground residue is used to prepare a source which is counted on a Berthold low-level proportional counter.

5.2

Tritium

Each sample is distilled in a closed system and an aliquot of the distillate is measured in the pre-calibrated window of an LKB 1220 Quantulus low-level liquid scintillation counter. Distilled deep groundwater (negligible tritium content) is also counted as a tritium background.

5.3

Potassium-40

The potassium-40 activity concentrations are calculated from the stable potassium concentrations using a potassium-40 specific activity of 31 $mBq\ mg^{-1}$ stable potassium.

5.4

Strontium-90

The water sample containing strontium carrier is concentrated by evaporation, and undergoes purification by selective precipitation. Following purification, a small fraction is taken from the stock solution and analysed by ICP-MS to determine the strontium carrier concentration. The stock solution is left to ingrow yttrium-90. The yttrium is extracted into a toluene/di-ethylhexylphosphate solution and then back-extracted into hydrochloric acid. The sample is reprecipitated and filtered onto a preweighed filter paper. The source is counted immediately on a Tennelec low-level proportional counter. Chemical recovery is determined by the strontium carrier concentration result and from the weight of yttrium oxalate.

5.5

Iodine-125

The water sample containing iodide carrier is filtered and then treated with sodium hydrogensulphite to convert any iodine species to iodide. The iodide is concentrated onto an anion-exchange resin and then eluted by oxidation to iodine using sodium hypochlorite. The iodine is extracted into chloroform and then back-extracted into aqueous solution, following reduction to iodide using sodium hydrogensulphite. The iodine-125 is measured by liquid scintillation counting, and the chemical recovery of iodide is then determined by gravimetry as silver iodide.

5.6

Caesium-137

Following concentration by evaporation and adjustment to pH 2, caesium is concentrated onto ammonium molybdophosphate (AMP) in batches. The caesium-AMP complex is isolated and measured by high resolution gamma-ray spectrometry using a well-type germanium detector. The detector is calibrated using a traceable caesium-137 source in the same geometry.

5.7

Uranium

An acidified aliquot of a sample is spiked with a relevant tracer and iron carrier, and allowed to equilibrate. The sample then undergoes a series of separation steps by ferric oxyhydroxide precipitation and anion exchange. The uranium is finally eluted and electrodeposited onto a stainless steel disc. The source is measured on an alpha spectrometry system. The chemical recovery is derived from the tracer.

5.8

Polonium

An acidified aliquot of sample is spiked with a relevant tracer and iron carrier, and allowed to equilibrate. The sample is precipitated and the supernate discarded. The precipitate is redissolved with hydrochloric acid and ascorbic acid added. The polonium is autodeposited onto

silver discs, and measured on an alpha spectrometry system. The chemical recovery is derived from the tracer.

5.9

Radium-226 by gamma-ray spectrometry

The radium isotopes are co-precipitated with lead and barium sulphates from a faintly acid water sample. After the precipitate is isolated and redissolved, the radium isotopes are then co-precipitated with barium sulphate. The sample is dissolved in alkaline EDTA, and measured by high resolution gamma-ray spectrometry using a well-type germanium detector. The detector is calibrated using a traceable radium-226 source in the same geometry.

5.10

Stable calcium, strontium and potassium

An aliquot of the sample is taken, and the stable calcium, strontium and potassium are measured using ICP-MS.

5.11

Gamma-ray spectrometry

Following concentration by evaporation, the sample is measured using germanium detectors coupled to a computerised analytical system. The detectors are calibrated for efficiency using a mixed radionuclide standard which covers an energy range of approximately 120-2000 keV. Efficiencies at lower energies are determined on an individual basis. Stored spectra are analysed using the in-house software SUPER SABRE for photopeak identification and subsequent quantification.

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