

The Information Centre  
Environment Agency  
Waterwise Drive  
Barnes Waller  
Barnes Waller  
Barnes Waller  
Barnes Waller

# RADIOACTIVITY IN THE ENVIRONMENT

A summary and radiological assessment of the  
Environment Agency's Monitoring Programmes

Report for 1996



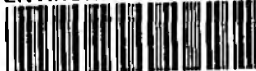
ENVIRONMENT AGENCY

## CONTENTS

FOREWORD	1
EXECUTIVE SUMMARY	2
1. INTRODUCTION	4
2. BACKGROUND	4
3. AGENCY MONITORING	4
4. RADIATION PROTECTION STANDARDS	10
5. PRESENTATION AND ASSESSMENT OF RESULTS	10
6. RESULTS	14
6.1 British Nuclear Fuels plc	14
6.2 Nuclear power stations	23
6.3 United Kingdom Atomic Energy Authority	25
6.4 Amersham International plc	29
6.5 Ministry of Defence	31
6.6 Non-nuclear sites	33
6.7 Landfill sites	33
6.8 Air and rainwater	35
6.9 Drinking water sources	35
7. SUMMARY AND CONCLUSIONS	36
REFERENCES	37
TABLES	39
APPENDICES	77

Environment Agency  
Information Centre

ENVIRONMENT AGENCY



128630

EA RAS-Box 2

## **FOREWORD**

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 administration and enforcement of 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 drinking water sources.

This report presents the data from these monitoring programmes and provides a commentary on their 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 in relation to the guidelines on drinking water quality recommended by the World Health Organisation.

This report for 1996 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 provision of access to environmental information.

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

**Dr Allan Duncan**  
**Director of Environmental Protection**

*\* National Compliance Assessment Service, Cameron House, White Cross Industrial Estate, South Road, Lancaster LA1 4XQ*

## **EXECUTIVE SUMMARY**

This report presents the results from the Environment Agency's monitoring of radioactivity in the environment during 1996. Monitoring programmes were carried out in support of the Agency's regulatory functions under the Radioactive Substances Act 1993 and as part of the UK Government's obligations under the Euratom Treaty.

The programmes included:

- effluent monitoring;
- the quality checking of solid waste disposals ;
- environmental monitoring;
- the monitoring of radioactivity in air and rainwater;
- the monitoring of radioactivity in drinking water sources.

A total of 160 effluent samples were analysed for nearly 900 determinands, two consignments of solid radioactive waste destined for disposal at British Nuclear Fuels' site at Drigg were checked, direct instrumental monitoring was carried out at 150 locations within the vicinity of nuclear sites, and 532 environmental samples were analysed for over 2,000 determinands.

### **Effluent monitoring**

The Agency requires operators of certain sites to provide samples of their liquid effluents for independent analysis. The results are compared with reports submitted by site operators. The majority of results showed satisfactory agreement; operators' values were frequently higher than the Agency's measurements indicating that they were not under-reporting. However, some discrepancies were found and are being investigated.

### **Quality checking of solid waste disposals.**

Consignments of solid low level radioactive waste are seized by inspectors for examination at the Agency's Waste Quality Checking Laboratory. Sophisticated non-destructive and destructive analytical techniques are used at the laboratory to check the radioactive content and description of the wastes. Consignments of waste from the Atomic Weapons Establishment at Aldermaston and Amersham International at Amersham were examined. In both cases the operators reported higher activity than the Agency's laboratory. The consignments also conformed with the operators' disposal authorisations except for the presence of aerosol canisters in waste from both sites and a small quantity of free liquid in the Amersham waste.

### **Environment monitoring**

Instrumental surveys of radiation levels and laboratory analyses of samples collected mainly within the vicinity of nuclear sites are carried out. The results are used to assess the exposure of members of the public to radiation from non-food pathways, such as might arise from the occupation of beaches, river banks and inter-tidal areas. (MAFF undertake monitoring of radioactivity in foodstuffs.) Radiological assessment of the results confirmed that exposures remained similar to those in previous years and in all cases were substantially less than the dose limit of 1 milliSievert per year. As in previous years elevated levels of tritium were observed in leachates from a number of landfill sites. Although higher than expected the elevated levels do not pose a radiological hazard.

### **Radioactivity in air and rainwater**

This routine monitoring programme has been carried out for many years to provide information on radioactivity in air and deposited in rainwater. Airborne dust and rainwater were sampled continuously at locations throughout the UK. The concentrations in air of beryllium-7, a naturally occurring radionuclide formed by cosmic rays in the upper atmosphere, caesium-137, plutonium 239+240 and americium-241 were very low and similar to results recorded since 1990. Caesium-137 was undetectable in rainwater, and the concentration of tritium, plutonium 239+240 and americium-241 were at low levels, as expected.

### **Radioactivity in drinking water sources**

This routine monitoring programme has also been carried out for many years. Samples of water were provided by the water companies from 32 sources comprising reservoirs, rivers and groundwater boreholes providing drinking water to over 10 million people. The results show that all the monitored sources are generally below the World Health Organisation's (WHO) guideline values for radioactivity in potable water. In the few cases where slight exceedance of the WHO values were found, further assessments showed that these were attributable to the local geology, or were of a transitory nature not confirmed by other analyses, and were radiologically insignificant.

## **1. INTRODUCTION**

1.1 The Radioactive Substances Act 1993 provides for controls to be exercised over the use and keeping of radioactive materials and the accumulation and disposal of radioactive wastes. The Environment Agency (the Agency)\* is responsible for administration and enforcement of the Act in England and Wales. In support of these regulatory functions the Agency commissions independent monitoring of radioactive waste disposals and their impact on the environment.

1.2 The Agency also manages programmes monitoring radioactivity in air and rainwater, and in water sources used for public water supplies. These programmes are managed on behalf of the Department of the Environment, Transport and the Regions (DETR). Together with the Agency's regulatory monitoring they 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 provide data periodically to the European Commission.

1.3 This report presents a comprehensive summary and radiological assessment of the results from monitoring undertaken in 1996.

## **2. BACKGROUND**

2.1 Discharges of radioactive wastes to the environment may only be made (subject to certain exemptions) in accordance with authorisations issued under the Radioactive Substances Act. Certain premises are exempt from this requirement, notably those occupied on behalf of the Crown for defence purposes. In these cases discharges are made in accordance with approvals which apply the same standards as authorisations.

2.2 During 1996 there were over 1,100 premises in England and Wales authorised to discharge radioactive wastes. Details of these authorisations can be viewed at the relevant

Agency and local authority offices. The majority consisted of hospitals, universities and industrial, research or manufacturing centres.

### **Nuclear sites**

2.3 Sites licensed under the Nuclear Installations Act 1965 and known as nuclear sites are also authorised to discharge radioactive wastes. They include nuclear power stations, nuclear fuel fabrication and reprocessing plants, research establishments and isotope production centres. Discharges from these sites are generally more radiologically significant than for the premises referred to at 2.2.

2.4 In addition to specifying numerical limits, in authorisations, on the amounts of radioactivity which may be discharged as waste to the environment, the Agency requires operators to employ the best practicable means (bpm) to limit the radioactive content of discharges. The Agency also requires operators to carry out appropriate monitoring of their discharges and the environment in the vicinity of their sites to demonstrate the effectiveness of these controls. Detailed results from this monitoring can be viewed at the relevant Agency and local authority offices. A summary of the data on discharges to the environment is reproduced in Table 1. Further details can also be found in the annual reports published by the nuclear site operators.

## **3. AGENCY MONITORING**

3.1 The Agency commissions its own monitoring to provide checks on site operators' data and an independent assessment of the exposure of the public from non-food pathways. (When determining its monitoring programmes the Agency takes into account monitoring of radioactivity in foodstuffs and the foodchain carried out by MAFF(1).) The Agency's programmes consist of:

*\*The Environment Agency was established on 1 April 1996 by bringing together Her Majesty's Inspectorate of Pollution, the National Rivers Authority, the Waste Regulation Authorities of England and Wales and elements of the Department of the Environment.*



- effluent monitoring involving the analyses of effluents
- the quality checking of solid waste disposals
- environmental monitoring.

The Agency also manages the following monitoring programmes on behalf of the DETR:

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

### Effluent monitoring

3.2 The Agency requires operators of certain sites to provide samples of their liquid effluents for independent radiochemical analysis. The results provided checks on site operators' returns and insights into their quality assurance (QA) procedures and analytical techniques. During 1996 the analyses were undertaken by the Laboratory of the Government Chemist (LGC) at its laboratories in Teddington, Middlesex. Details of the methods of analysis are given in Appendix 1. The sampling consisted of either single spot samples or monthly or quarterly bulked samples as appropriate. During 1996 a total of 160 samples were analysed resulting in the reporting of results for nearly 900 determinands.

### Waste quality checking

3.3 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. During 1996 the laboratory was staffed and operated by Taywood Environmental Consultancy (TEC) on behalf of the Agency. The results provide checks on the descriptions and radioactive contents of wastes declared by site operators and insights into their QA and monitoring procedures. During 1996 two consignments of waste were seized by inspectors and sent for examination at WQCL. The laboratory's

analytical methods are summarised in Appendix 2, with further details of these and other methods employed during destructive examination presented in reference 2.

### Environmental monitoring

3.4 A programme of monitoring of radioactivity in the environment which could lead to exposure of the public from non-food pathways such as might arise from the occupation of beaches, river banks or other areas is also carried out. The programme consists of a survey of radiation levels and radiochemical and gamma-ray spectrometric analysis of samples collected at specified locations in the vicinity of certain nuclear sites and industrial premises. During 1996 this monitoring was undertaken by the Tracerco Group of ICI Chemicals and Polymers Ltd in accordance with detailed specifications.

3.5 Samples of environmental materials were taken and direct instrumental monitoring carried out at predetermined locations, normally on a quarterly basis as follows:

Quarter 1	1 January	to	31 March
Quarter 2	1 April	to	30 June
Quarter 3	1 July	to	30 September
Quarter 4	1 October	to	31 December

The locations of the major nuclear sites around which the majority of monitoring was concentrated are shown in Figure 1.

3.6 The 1996 programme concentrated on sampling environmental materials such as water and associated sediments from ponds, lakes, streams and rivers, in areas which may be used by the public for leisure activities. Samples were also taken from surface waters, some of which are used as sources of potable water, located in the vicinity of the major nuclear sites.

3.7 Most of the samples were taken on a spot basis, except for samples of water taken



Figure 1 Major nuclear sites



from the Thames Valley in the vicinity of Harwell, Aldermaston and Amersham. These were taken at weekly intervals over 13-week periods and bulked prior to analysis. During 1996 the collection of a total of 340 samples resulted in nearly 1,250 analyses being performed, and the reporting of nearly 1,600 determinands.

3.8 The 1996 programme also included monitoring of certain beaches and river banks. A total of 154 locations were monitored during the year resulting in the reporting of nearly 300 individual results.

3.9 Contact beta/gamma monitoring of debris at the most recent strand line was carried out using a Mini-Instruments series 900 mini monitor with a beach monitoring probe. Any item found with an activity level in excess of 100 cps (taken to be equivalent to 0.01 mSv h<sup>-1</sup>) would be removed to Tracerco's laboratory for further investigation.

3.10 Gamma radiation dose rates were also monitored by measuring the absorbed dose rate in air ( $\mu\text{Gy h}^{-1}$ ) at one metre above ground using a Mini-Instruments Environmental Meter type 6-80 fitted with an energy-compensated Geiger-Muller tube type MC-71. The instrument had been calibrated against a standard reference radium-226 source.

3.11 Analysis of the samples was carried out by Tracerco at its laboratories at Billingham. Total alpha and total beta activities were measured and in many cases these were supplemented by a range of other analyses including gamma-ray spectrometry, alpha spectrometry and specific radionuclide determinations as appropriate. Further details of the analytical methods are given in Appendix 3.

#### **Air and rainwater**

3.12 Routine monitoring of radioactivity in air and rainwater has been carried out for many years. Samples of airborne particulate material and rainwater are collected and analysed. During 1996 this sampling and analysis was undertaken by AEA Technology's

National Environmental Technology Centre. 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 is published annually<sup>(3)</sup>. The results are provided to the DETR for submission to the European Commission under Article 36 of the Euratom Treaty.

3.13 Airborne dust was sampled continuously at seven locations at about one metre above ground level. Filters are changed each day at Chilton (Oxfordshire) and each week at Aberporth (Dyfed), Conlig (Co Down, NI), Dishforth (Yorkshire), Eskdalemuir (Dumfriesshire), Lerwick (Shetland) and Orfordness (Suffolk). Samples of rainwater are collected at each of the seven air sampling locations and at two additional locations at Aldergrove (Co Antrim, NI) and Snowdon (Gwynedd). The sampling locations are shown in Figure 2.

3.14 All samples were analysed quarterly by gamma-ray spectrometry. Monthly analysis was carried out on air and rain samples from Chilton. Where appropriate, additional samples are 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 in reference 4.

#### **Drinking water sources**

3.15 Routine monitoring of radioactivity in water sources used for the supply of drinking water has also been carried out for many years<sup>(5)</sup>. During 1996 samples of water were provided by the water companies for analysis by AEA Technology at Harwell laboratory under its contract to the Agency. 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 the DETR for submission to the European Commission under Article 36 of the Euratom Treaty.



Figure 2. Air and rainwater sampling sites

3.16 Samples of water were taken from 32 sources on a near-daily basis and bulked over three-month periods to provide "quarterly bulks" for analysis. The "quarters" coincided with those detailed at 3.5 for the Agency's environmental monitoring

programme. The locations of the 32 sources are shown in Figure 3.

3.17 The samples were analysed for gross alpha and gross beta activities and a range of specific radionuclides. Further details of the





Figure 3. Drinking water sampling sites

analytical methods are given in Appendix 5.

#### Contracting arrangements

3.18 The assessment of results and the

preparation of this report were undertaken on behalf of the Agency by AEA Technology. The Tracerco Group, LGC, TEC and AEA Technology were awarded contracts following competitive tendering.

#### **4. 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<sup>(6)</sup> Cm 2919. Current UK practice is based on the recommendations of the International Commission on Radiological Protection (ICRP) as set out in Publications 60<sup>(7)</sup> and endorsed by the National Radiological Protection Board (NRPB)<sup>(8,9)</sup>.

4.2 Cm 2919 confirms that doses to members of the public in the UK should be limited to 1 mSv per year.

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 the advice of the NRPB 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 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 from both 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 5.17.

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

#### **5. PRESENTATION AND ASSESSMENT OF RESULTS**

##### **SI units and methodology**

5.1 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<sup>(10)</sup>. However, because of the requirements specified by the United Kingdom Accreditation Service (UKAS) all results, whether liquid or solid, are expressed in activity per kilogramme. In practice one kilogramme of water can be considered to have a volume of one litre within the accuracy of the reported results.

5.2 Results for solid samples are presented as activity per unit dry weight (Bq kg<sup>-1</sup>) unless otherwise specified. Methods of sampling and measurement 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 dose estimation. In such instances, the total dose corresponding to the detection limits is generally no more than about one per cent of the recommended dose limit of 1 mSv y<sup>-1</sup>.

##### **Assessment of results**

###### **Effluent analysis**

5.3 The analytical results of effluent analysis 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. Initially meetings of analysts are convened to discuss the differences and, as necessary, 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 repository site at Drigg.

#### Environmental monitoring

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<sup>(7)</sup>. 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<sup>(11)</sup> of the committed effective dose predicted to result from a unit intake of each radionuclide occurring at ages one, 10 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 discharged radioactivity may be present.

5.7 Habit data are kept under review by MAFF and 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<sup>(12, 13, 14, 15)</sup> are available these are used in the dose estimation. These specific data record that a small number of people engage in occupations which lead them to spend up to about 1,300 hours per year on beaches, saltmarshes and estuarine mud banks in North West England. A further small group regularly use such areas recreationally for about 300 hours per year. Where site-specific data are not available the following habit assumptions and occupancy data as published by the NRPB<sup>(16)</sup> are used in the assessments presented here.

Age group	Occupancy		Inhalation rates	Ingestion rates		
	Marine	River banks and lake shores		Drinking water	Inadvertent ingestion	
years	h y <sup>-1</sup>	h y <sup>-1</sup>	m <sup>3</sup> h <sup>-1</sup>	l h <sup>-1</sup>	Water ml y <sup>-1</sup>	Sediment mg h <sup>-1</sup>
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



## Ingestion

5.8 As ingestion of foodstuffs is assessed routinely by MAFF, 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<sup>(16)</sup>. 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 above table. Some children exhibit a 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  $D_{ig}$  due to radionuclide  $i$  resulting from ingestion can be calculated as

$$D_{ig} = C_{ij} H_{ig} g_j O_i \quad (1)$$

Where

$C_{ij}$  is the concentration of radionuclide  $i$  in medium  $j$  (Bq kg<sup>-1</sup>)

$H_{ig}$  is the effective dose per unit intake of radionuclide  $i$  by ingestion (Sv Bq<sup>-1</sup>)

$g_j$  is the consumption rate of medium  $j$  (kg h<sup>-1</sup>)

$O_i$  is the occupancy factor (h y<sup>-1</sup>)

5.11 Water sources were also screened by measurement of gross alpha and gross beta activities for comparison with World Health Organisation (WHO) guideline values<sup>(17)</sup>.

These are:

gross alpha activity: 0.1 Bq l<sup>-1</sup>.  
gross beta activity: 1.0 Bq l<sup>-1</sup>.

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 gross 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 the wind or by 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<sup>3</sup> of air. The dose  $D_{in}$  due to radionuclide  $i$  in sediment due to inhalation of re-suspended sediments is calculated as

$$D_{in} = C_{is} C_{sa} C_m H_{ih} O_i \quad (2)$$

Where

$C_{is}$  is the concentration of radionuclide  $i$  in sediment (Bq kg<sup>-1</sup>)

$C_{sa}$  is the concentration of sediment suspended in air (kg m<sup>-3</sup>)

$C_m$  is the volume of air inhaled per unit time (m<sup>3</sup> h<sup>-1</sup>)

$H_{ih}$  is the effective dose per unit intake by inhalation of radionuclide  $i$  (Sv Bq<sup>-1</sup>)

$O_i$  is the occupancy factor (h y<sup>-1</sup>)

## 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 3.10. 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 background radiation dose rate is subtracted. In the absence of site-specific information the generic background dose rates used for muddy and sandy substrates are  $0.07 \text{ (Gy h}^{-1}\text{)}$  and  $0.05 \text{ (Gy h}^{-1}\text{)}$  respectively<sup>(18)</sup>. Secondly, the effective dose to the whole body differs from the absorbed dose in air, and a factor of 0.87 ( $\text{Sv Gy}^{-1}$ ) is used to convert the measured absorbed dose in air to the effective dose to the human body. Finally, the appropriate occupancy factor is applied. The Agency's protocol for the measurement, interpretation and reporting of external dose rates is described in Technical Guidance Note M5<sup>(19)</sup>.

#### 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 originating from outer space;
- (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 and therefore radionuclide-specific determinations can readily detect their presence in the environment. However, measurements of gross alpha and beta activity concentrations and of certain radionuclides can include contributions from terrestrial radioactivity as

described above and from worldwide fallout, including that from 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<sup>(20)</sup> to be 2.6 mSv. Radiation of natural origin accounts for 87 per cent of the exposure. Of the remaining 13 per cent, 12 per cent is accounted for by medical procedures. Discharges of waste from nuclear establishments contribute less than 0.1 percent.

#### Assessment of doses

5.18 Total doses (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  $1 \text{ mSv y}^{-1}$  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 recalled that the doses estimated here do not include doses incurred through food, which 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.

#### Drinking water

5.20 Results for gross alpha and gross beta activities from the monitoring of drinking water sources are compared with the WHO guideline values as described at 5.11. Radiological assessments are carried out for the occasional exceedances 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.

## 6. RESULTS

### 6.1 BRITISH NUCLEAR FUELS PLC

6.1.1 BNFL operates four major sites in England. These are located at Sellafield and Drigg in Cumbria, Springfields in Lancashire and Capenhurst in Cheshire.

#### SELLAFIELD

6.1.2 The Sellafield site includes storage ponds and the Magnox and THORP reprocessing plants for irradiated nuclear fuel, the Calder Hall Magnox nuclear power station and various support facilities. Prior to 1994 the majority of the liquid effluent arising from BNFL's operations at the site were routed to sentencing tanks from which discharges to sea were made. During 1994 the Segregated Effluent Treatment Plant (SETP) and the Enhanced Actinide Removal Plant (EARP) were commissioned and the effluent from these plants is now discharged to sea via separate monitoring tanks. 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 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 a large proportion 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 is tipped on approved tipping 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 1996 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, in the vicinity of Sellafield, monitoring of:

- (b) radiation dose rate levels over West Cumbria 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.

#### 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 gross beta, cerium-144, carbon-14, americium-241 and promethium-147 in some samples of SIXEP discharges; for gross beta, ruthenium-106, iodine-129, cerium-144, zirconium-95, niobium-95, curium-242 and curium-(243+244) in samples from the SETP discharges; and for gross beta, strontium-90, technetium-99, carbon-14, plutonium-238, plutonium-(239+240), americium-241, curium-242, curium-(243+244) and promethium-147 in discharges from the EARP. As has been reported previously discrepancies in the reported values of ruthenium-106 are not uncommon and are probably attributable to analytical interference from the 511 keV annihilation peak which is co-incident with the primary gamma energy of ruthenium-106. 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. However, given the number of discrepancies observed for other radionuclides, a meeting was held with LGC and BNFL during 1996 to try to identify the reasons for the discrepancies and improve the reliability of the comparisons. A number of areas for further investigation were identified and analysts from BNFL and LGC are expected to report back towards the end of 1997.

## 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 in the spring and autumn. 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 in excess of 100 cps (see section 3.9). In 1996 no such material was found.

6.1.6 Locations and measured gamma radiation dose rates are detailed at Table 2. The locations are also shown in Figure 4. Measurements over sands showed little elevation over background levels and dose rates were highest over silts. Similar measurements made by BNFL(21) in 1996 show general agreement to those in Table 2. The radiation dose rates reported here may also be compared with those found by MAFF<sup>(1)</sup> for 1996. The results cannot be compared in detail, since the sampling locations were not identical. However the results of the two surveys extend over similar areas. In both surveys the highest levels were observed in the Esk, Mite and Irt estuaries and at Whitehaven Harbour; in the 1996 MAFF survey<sup>(1)</sup> dose rates of 0.07 to 0.27  $\mu\text{Gy h}^{-1}$  were recorded over saltmarshes in this area, while in the survey described here, levels exceeding 0.14  $\mu\text{Gy h}^{-1}$  were observed only over mud in the Esk estuary (Newbiggin) and Whitehaven Harbour, Table 2. The results in 1996 were generally similar to those observed in 1995 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 for radiochemical and gamma-ray spectrometric analysis. The results for Newbiggin and Walney Island (Table 3) are generally consistent with previously reported levels, although the annual average gross

beta and gross alpha results indicate a slight increase compared to 1994 and 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 1996 are similar to those reported in 1995.

### Assessment

6.1.8 The highest gamma radiation dose rates were observed over the muddy areas in the Esk estuary, located to the south of Sellafield, and over silts in Whitehaven Harbour. Surveys of occupancy, of the West Cumbrian coast, have been carried out by MAFF<sup>(12)</sup> and Research Surveys of Great Britain Limited (RSGB)<sup>(13)</sup> and these data, where applicable, are shown in Table 2. The critical group for leisure activities is considered to be dog walkers<sup>(13)</sup> 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 1996 by the persons who were found by MAFF and RSGB to make the greatest use of these areas are shown in Table 2. The effective dose due to internal exposure from inadvertently ingested sediment and from inhaled dust was estimated to be about 0.8  $\mu\text{Sv y}^{-1}$  for an infant at Ehen Spit and 2.5  $\mu\text{Sv y}^{-1}$  at Newbiggin using the concentrations observed and the methods described in section 5. Corresponding effective doses for an adult have been calculated to be 1.5  $\mu\text{Sv y}^{-1}$  and 5  $\mu\text{Sv y}^{-1}$  at Ehen Spit and Newbiggin 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 levels at Newbiggin to have been typical of his exposure, his annual effective dose (including external radiation - see Table 2) would have amounted to about 24  $\mu\text{Sv y}^{-1}$ . This would suggest a decrease in estimated dose relative to 1995. In 1996 the doses received by bait diggers and fishermen at Haverigg and Askam were estimated to have been higher than the dose to the nature warden, at about 29  $\mu\text{Sv y}^{-1}$  and 36  $\mu\text{Sv y}^{-1}$  respectively. The estimated dose reported at



Figure 4. Monitoring locations - Cumbrian coastal area



Haverigg shows a decrease compared to 1995 and those at Askam are similar to those reported in 1995. At both these locations the measured dose rates are only marginally above background levels (see Table 2) 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, at low tide, water issues from the ground, gave the results shown in Table 4. The water is brackish, so only inadvertent consumption is likely. The gross alpha levels observed were below the WHO guideline values. However, enhanced gross beta levels were observed on all occasions when the water was sampled, with concentrations similar to those observed since 1992. The mean annual concentration of tritium during 1996 indicates a marginal decrease in tritium levels compared to 1995 with reported concentrations similar to those observed during the period 1990 to 1993. The annual mean concentration of caesium-137 is similar to that reported for 1995. 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 a committed effective dose of much less than  $0.1 \mu\text{Sv y}^{-1}$ .

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 in the River Calder downstream of Sellafield also indicated the likely presence of tritium from Sellafield. However, the maximum concentration reported of  $16 \text{ Bq l}^{-1}$  is similar to the maximum concentration observed in 1995 and 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 consistent with

expected values for UK surface waters and would result in a committed dose of very much less than  $0.1 \mu\text{Sv y}^{-1}$  to water consumers. The levels of gross alpha and beta activities measured in the samples were below the WHO's guidance values of 0.1 and  $1.0 \text{ Bq l}^{-1}$  respectively.

#### DRIGG

6.1.12 BNFL operates the Drigg site for the disposal of solid low level radioactive waste. Most of the waste 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. In recent years, a programme of site development has been undertaken to improve operational arrangements and to minimise contamination of surface and ground water draining from the site. Much of this work has now been completed. Disposal by tumble tipping of loose wastes into clay-lined trenches has now ceased. Instead, suitable wastes are compacted at the Sellafield site, to minimise residual voidage, using the Waste Monitoring and Compaction (WAMAC) facility.

6.1.13 The 1996 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 poor. The gross alpha results reported by both BNFL and LGC are close to the limits of detection and uncertainties in the analysis may account for the poor agreement. Analyses previously carried out by NRPB have shown that the major contributions to alpha and beta levels are uranium and strontium-90 respectively. Discrepancies were also observed for tritium during both January and July 1996.

### Quality checking of waste

6.1.15 An ISO-container of drummed low level radioactive waste originating from the Atomic Weapons Establishment (AWE), Aldermaston, was seized in March by the Site Inspector, following its acceptance for high force compaction and disposal by BNFL, at Drigg. Examination at the Agency's WQCL showed that the predominant gamma-ray emitting radioactive constituent of the waste was U-235 which comprised over 60 per cent of the radioactivity found by gamma scanning. The total and individual gamma emitting radioisotopic content of the consignment as determined by WQCL was similar to that declared by the waste producer. Samples taken from selected drums for detailed radiochemical analysis showed quantities of uranium and plutonium to be present. However, in all cases the AWE declared activities were higher than those found by WQCL. The waste consignment conformed to the conditions specified in AWE's and Drigg's authorisations except for the presence of two aerosol canisters. These were isolated and returned to the waste producer.

6.1.16 An ISO-container of drummed waste originating from Amersham International plc was seized in December by the Site Inspector prior to high force compaction and disposal by BNFL at Drigg. Examination of the waste by non-destructive testing showed the presence of a large number of gamma emitting radionuclides consistent with the waste producer's activities in isotope

production. In all cases the declared radioactivities were higher than those found by WQCL. The waste consignment conformed to Amersham's authorisations for disposal except for the presence of aerosol canisters and a small quantity of free liquid. These were isolated and returned to the waste producer.

### 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. Also, 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	$9.0 \times 10^1 \text{ Bq l}^{-1}$
Beta activity	$1.2 \times 10^3 \text{ Bq l}^{-1}$
Tritium	$6.0 \times 10^5 \text{ Bq l}^{-1}$

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 Ground water was known to move laterally from some of the trenches towards the Railtrack drain. Some radionuclides have been detected over several years in this drain. The results of monitoring presented in Table 5 show that no radionuclides were above the limits of detection during 1996. The Railtrack drain was sampled only during the first quarter of 1996.

#### Assessment

6.1.19 The concentrations of gross alpha activity and gross beta activity in the Drigg stream and the Railtrack drain during 1996 did not exceed the WHO guidelines for drinking water. In the Drigg stream only tritium exceeded the concentrations

expected to be present in UK surface waters. Although the Drigg stream is not used as a source of drinking water it is possible that for a short period a camper or picnicker could reside in the vicinity of the stream. In the unlikely event that they drew drinking water supply from the stream, they would have to drink more than 390,000 litres of stream water to incur a committed effective dose of 1.0 mSv.

## CAPENHURST

6.1.20 BNFL and Urenco (Capenhurst) Limited operate centrifuge plants for the isotopic enrichment of uranium at the Capenhurst site. The original diffusion plant was decommissioned in 1983 and continues to be dismantled. Decontamination of this obsolete 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 to BNFL's disposal site at Drigg.

6.1.21 The 1996 programme included:

- (a) the analysis of samples of liquid effluent discharged to Rivacre Brook and samples of special waste;

and, in the vicinity of Capenhurst, monitoring of:

- (b) radioactivity in samples of water and sediments taken during spring and summer from Rivacre Brook at four locations downstream of the site;
- (c) gamma-radiation dose-rate levels on the banks of Rivacre Brook at four locations downstream of the site.

## Effluent monitoring

6.1.22 The results of analyses, carried out by BNFL and the 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 gross beta and technetium-99 are observed in the water samples from Rivacre Brook. At all sampling points the mean annual gross beta results show some decreases compared to 1995 although the concentrations are still slightly higher than those observed in 1994. Uranium, caesium, technetium-99 and trace levels of neptunium-237 were detected in samples of sediment. Concentrations generally declined with distance downstream from the site. In all cases the concentrations in sediment were generally similar to those observed in 1995. However, the concentrations of technetium-99 appear to indicate a two-fold increase compared to those reported in 1995. The concentrations of gross beta in sediment, where observed, were generally similar to those reported for 1994 and 1995.

### 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. On the assumptions set out in section 5, the committed effective dose that might be incurred by a child playing in one

of these areas is estimated to be much less than 1.0  $\mu\text{Sv y}^{-1}$ .

## **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 to the company's disposal site at Drigg.

6.1.26 The 1996 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;
- (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.

## **Effluent monitoring**

6.1.27 Bulk samples of liquid effluents discharged during the months of March and September 1996 were supplied to the Agency's contract laboratory. Comparison of results for the March sample were generally good. Discrepancies in the results for total beta and thorium-230 were noted for the September sample. However, in all cases where a significant discrepancy was observed BNFL reported the higher results. 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 discrepancy in the beta determination is thought to result primarily from the uncertainties in correcting for radioactive decay for these short-lived radionuclides.

## **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 1996 programme concentrated on monitoring the impact of Springfields and Sellafield discharges in the inter-tidal areas of the upper reaches of the estuary at the locations shown in Figure 5. 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. Except for the presence of low concentrations of caesium-134, which is usually reported below the limits of detection, observed concentrations are 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.

6.1.32 The house boat dwellers monitored frequently by MAFF are considered to be the

Figure 5. Monitoring locations - BNFL Springfields







most exposed group occupying the Ribble Estuary, due mainly to these historic discharges. Their radiation exposure is reported in detail by MAFF<sup>(1)</sup> and is not considered further in this report.

#### Assessment

6.1.33 HMIP published a report in 1994 on the distribution of radioactivity in the Ribble Estuary and the recreational use made of this area<sup>(15)</sup>. The results of the occupancy survey and other data have been used in the radiological assessments in this report.

6.1.34 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<sup>(22)</sup>.

6.1.35 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.

6.1.36 The occupancy survey identified anglers as the most potentially exposed members of the public in the inter-tidal areas of the upper estuary. As with the house boat dwellers, their radiation exposure is reported by MAFF<sup>(1)</sup> and is not considered further in this report. 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<sup>-1</sup> was estimated. The survey also reported that children may spend up to 30 hr y<sup>-1</sup> playing on the inter-tidal muds, although none was observed during the study.

6.1.37 Using the above occupancies and the monitoring results in Tables 7 and 8, the exposures which may have been incurred were estimated to have been 11.2  $\mu\text{Sv y}^{-1}$  for

the Sea Cadets and 5.8  $\mu\text{Sv y}^{-1}$  for the children. These estimated doses suggest a slight increase to 1994 and 1995 which seem to be entirely attributable to slight increases in the measured gamma radiation dose rates at these sites. The beta radiation skin doses were estimated to have been 0.55 mSv y<sup>-1</sup> for the Sea Cadets and 0.31 mSv y<sup>-1</sup> for the children. These doses should be compared with the ICRP recommended limit of 50 mSv y<sup>-1</sup>. Sediment samples were analysed from two 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 1996 were generally somewhat lower than those observed at the railway bridge. As observed during 1995 the sample from Lytham Yacht Club contained concentrations of between one-half and one-tenth of those observed around Penwortham. The lower concentrations at Lytham presumably 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 the same source shows elevated concentration near Savick Brook.

#### Deepdale Brook

6.1.38 Deepdale Brook is a small stream which passes through the centre of the Springfields site. Historically 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 occasional low levels of uranium are detected in the water of the brook. The concentrations of uranium, and other radionuclides, measured in the sediment during 1996 were slightly lower than those measured in 1995 but generally remain similar those recorded since about 1990. There is no known use of the brook by members of the public and these levels are of no radiological significance.

## 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 pressurised water reactor (PWR) transferred to a new company, Nuclear Electric Ltd. Nuclear Electric plc continued to operate the magnox stations under the new name Magnox Electric plc. Magnox Electric stations are located at Bradwell, Dungeness (A station), Hinkley Point (A station), Oldbury, Sizewell (A station) and Wylfa. Two further magnox reactors at Berkeley and Trawsfynydd are closed. Nuclear Electric stations are located at Dungeness (B station), Hartlepool, Heysham (two stations), Hinkley Point (B station) and Sizewell (B station, PWR).

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 which 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 driers are routed to Tritiated Water Storage Tanks (TWST) prior to monitoring and discharge. Treated effluents are then discharged to sea (except for those from Trawsfynydd) via pipelines, as summarised below.

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

6.2.3 The 1996 programme included:

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

and, in the vicinity of the nuclear power stations, monitoring of:

- (b) coastal areas near to discharge outfalls used for liquid effluents;
- (c) radioactivity in samples of surface waters, including some public water supplies.

### **Effluent monitoring**

6.2.4 The Agency's contract laboratory, LGC, analysed samples of FMDT and TWST discharges on a quarterly basis. These samples were also analysed by the stations and by Magnox Electric's Central Radiochemical Laboratory (CRL) as part of the companies' own internal QA procedures. The agreement between results for the analysis of tritium is generally good 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 the higher concentrations being measured. The comparison of results for the analysis of total beta for FMDT samples between all laboratories indicate 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. In every case LGC reported the higher results.

### **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 slight local increase in dose rate recorded at Bradwell Beach since

1993 was again evident in 1996. A similar increase is also evident during the fourth quarter of 1996 at Hinkley Point Beach although no increase was observed during the second quarter of 1996. It is likely that these increases have arisen due to direct radiation from external reactor ductwork or cooling air under the influence of specific meteorological conditions. In both cases 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, if the mean dose rate recorded at Bradwell Beach in 1996 persisted throughout the year and a person spent, say, 300 hours on the beach would be about  $60 \mu\text{Sv y}^{-1}$ . The corresponding exposure at Hinkley Point Beach would be lower at about  $27 \mu\text{Sv y}^{-1}$ .

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 section 3.9). In 1996 no such material was found.

#### **Surface and public water sources**

6.2.7 The results of monitoring samples of surface waters in the vicinity of the power stations are presented in Table 10. In general the gross alpha and gross beta concentrations were less than the WHO guidance values of  $0.1$  and  $1.0 \text{ Bq l}^{-1}$  respectively. However, total beta concentrations in excess of  $1.0 \text{ Bq l}^{-1}$  were reported for samples obtained from the coastal ditch at Bradwell. Sampling of water from some sampling points at the coastal ditch at Bradwell was not possible during 1996; the sampling locations were dry when sampling was undertaken. Only at sampling point 4 were specific radionuclides detected which might in part account for the increased total beta†. Tritium was generally detected at levels consistent with background values in UK surface waters with again the exception of the coastal ditch (Bradwell) where slightly enhanced levels were observed. At both sampling point 3 and sampling point 4 tritium concentrations

† The total beta results reported exclude low energy beta activity attributable to the presence of tritium.



observed in the second quarter of 1996 were somewhat higher than those observed in 1995. However those observed in the fourth quarter of 1996 at sampling point 4 were barely distinguishable from background levels (no sampling was possible at sampling point three during the fourth quarter as it was dry). The coastal ditch is not used as a source of drinking water but, if it were, the dose incurred would be less than  $1 \mu\text{Sv y}^{-1}$ .

### 6.3 UNITED KINGDOM ATOMIC ENERGY AUTHORITY

6.3.1 UKAEA operates two major research establishments in England, at Harwell in Oxfordshire and at Winfrith in Dorset. (UKAEA's Windscale Laboratory is co-located with BNFL's plant at Sellafield. It makes minor contributions to discharges of wastes from the site and is therefore considered together with Sellafield for the purposes of this report.)

#### 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 one of four holding tanks for monitoring prior to 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 leaves the site via Lydebank Brook. Solid low level waste is transferred to BNFL's site at Drigg for disposal.

6.3.3 The 1996 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 from the River Thames and other surface waters.

#### Effluent monitoring

6.3.4 Discrepancies in the results for total alpha and total beta activities as determined by Harwell and LGC in samples of treatment plant effluents were noted. Harwell's results were generally higher. In the case of the total beta measurements the discrepancies are thought to result from uncertainties in correcting for radioactive decay due to the presence of short-lived radionuclides. Where the specific radionuclides caesium-137 and cobalt-60 were reported, agreement between the two laboratories was generally good. The analysis for total alpha and total beta activity in trade waste samples confirmed that concentrations were low. Discrepancies were noted for the measurement of tritium concentrations in both the treatment plant effluents and the trade waste samples although Harwell generally reported the higher concentrations. Analysis of surface water discharged to Lydebank Brook indicated that all concentrations of total alpha, total beta and tritium were low. In most cases agreement between the laboratories was satisfactory although concentrations, reported by both laboratories, were generally close to the limits of detection.

#### 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 6 and 7 respectively. Caesium-137, cobalt-60 and plutonium-(239+240) originating in discharges from Harwell were present in some of the samples.



Figure 6. Monitoring locations - Thames Valley area

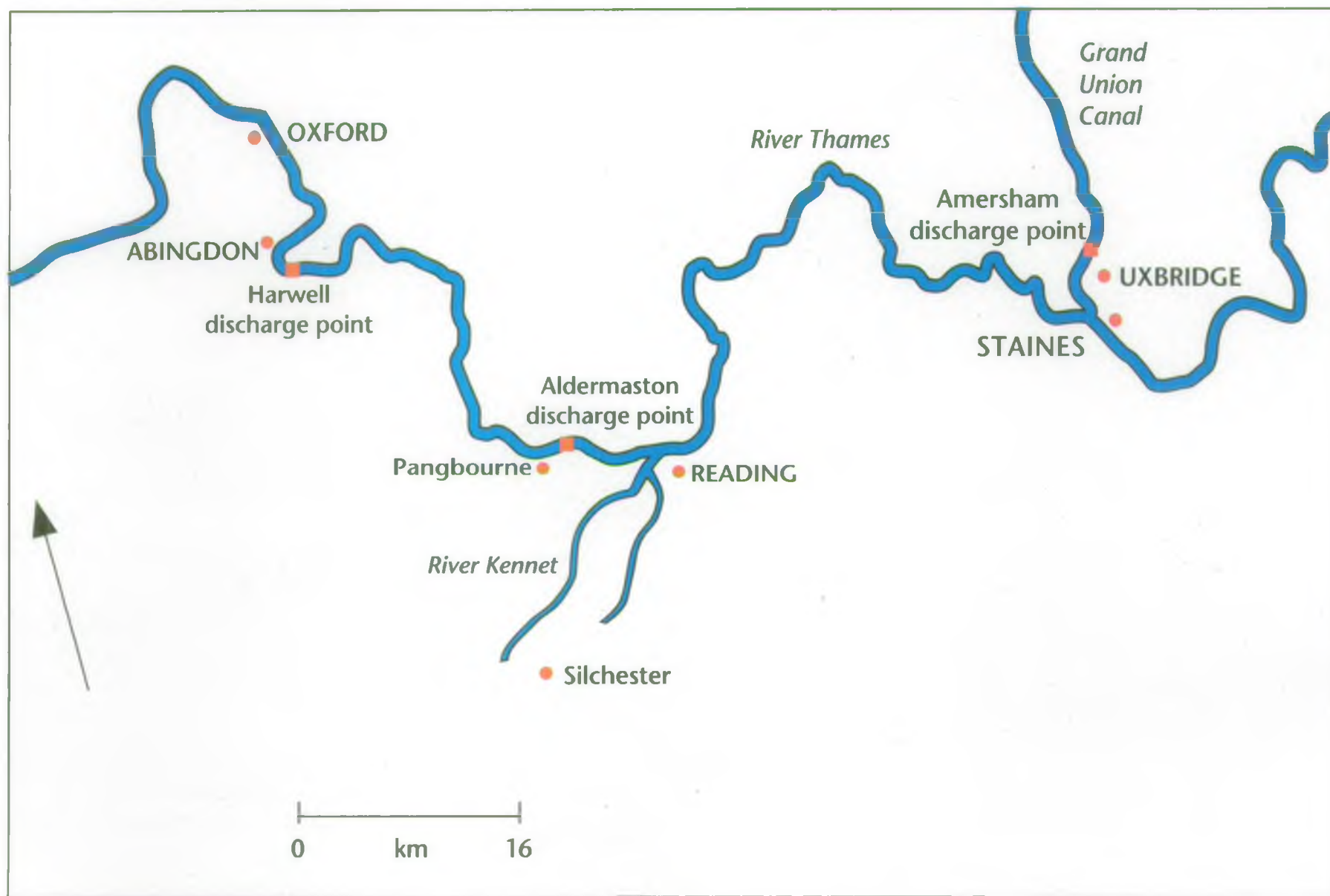
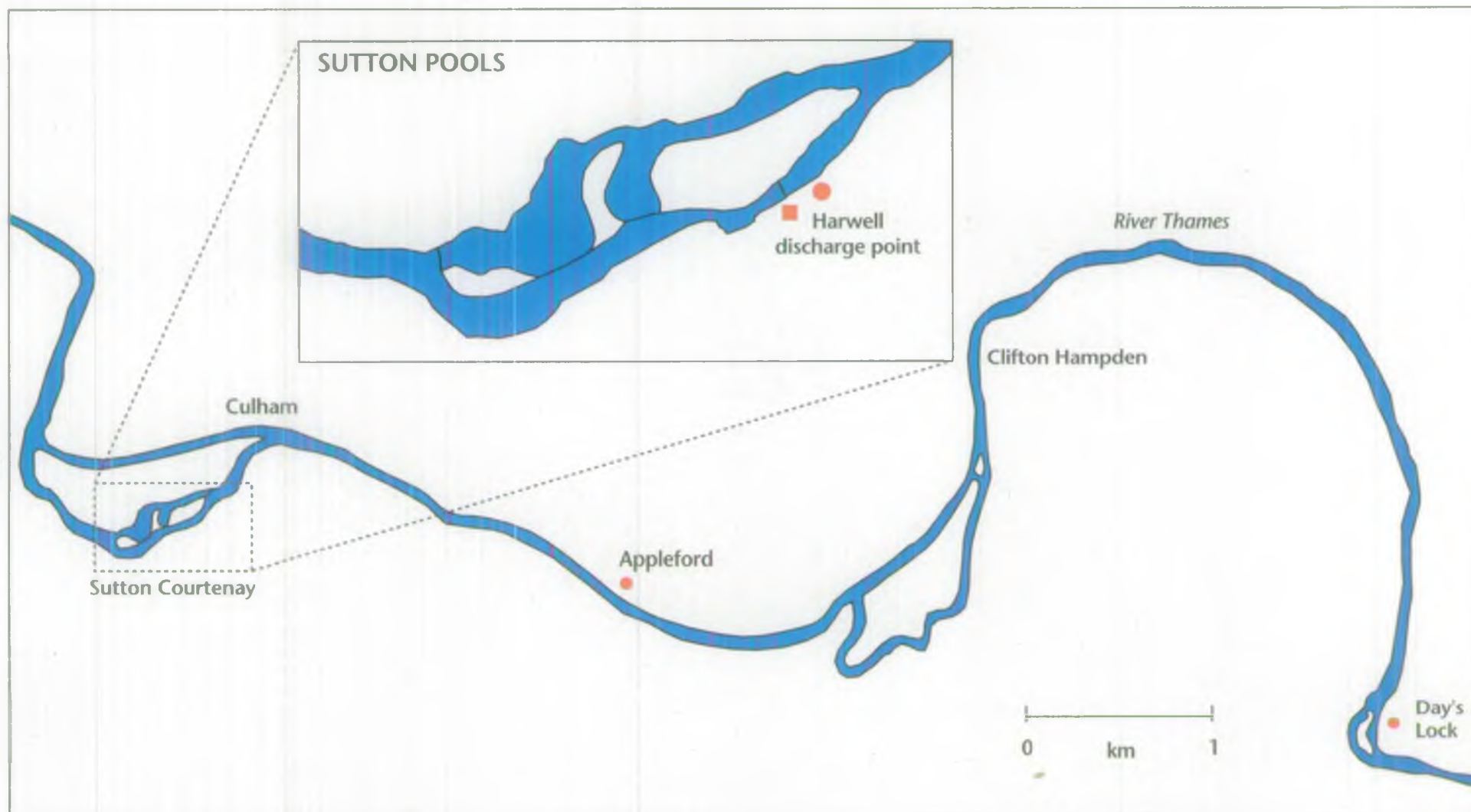


Figure 7. Monitoring locations - UKAEA Harwell



6.3.6 The banks of the Thames are used by walkers and picnickers, and also by anglers. External exposure 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(14) 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, say, 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 16  $\mu\text{Sv}$  per year. This is slightly higher than corresponding doses reported since about 1993 and is entirely attributable to higher dose rates reported in the fourth quarter of 1996. Results reported in the second quarter of 1996 were consistent with previous years and would have resulted in estimated doses similar to those previously reported.

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 3.9). In 1996 no such material was found.

#### 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 that there is no significant increase downstream of the discharge point, and generally the results are within the normal range of tritium concentration in surface waters in the UK. In 1996 the highest concentration observed was 15.0 Bq l<sup>-1</sup>

during the third quarter. If these waters were used continuously as drinking water sources the doses incurred would be only about 0.1  $\mu\text{Sv y}^{-1}$ . In all cases the concentrations of gross alpha and gross beta activity were below the WHO guidance values.

#### WINFRITH

6.3.9 The UKAEA operates engineering and research facilities including many experimental rigs, laboratories and workshops at Winfrith. These include those operated by AEA Technology plc. 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 such that the more active effluents travel along an inner pipe set within an outer pipe carrying the trade wastes.

6.3.10 The 1996 programme included:

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

and, in the vicinity of 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.

## Environmental monitoring

### Beach monitoring

6.3.12 Comprehensive monitoring of accessible coastal areas in Dorset, including beaches, extending from Swanage Bay in the east to Weymouth Harbour in the west, was undertaken in the spring. Gamma-radiation dose rates were measured at each location and portable instruments were used to monitor contact beta/gamma radiation dose rates over inter-tidal areas in order to locate, for removal, any material with activity levels in excess of 100 cps (see section 3.9). In 1996 no such material was found.

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

### Surface waters

6.3.14 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 declined significantly from the value of 340 Bq l<sup>-1</sup> reported for the fourth quarter of 1993. The highest concentration of tritium observed in surface waters close to the site in 1996 was 19 Bq l<sup>-1</sup>. At this concentration the dose to consumers if the stream was used as a drinking water supply would be less than 0.3 (Sv y<sup>-1</sup>). The concentrations of tritium in the remaining samples showed only negligible increases above the expected values for UK surface waters. In all cases the gross alpha and beta activities were below the WHO's guideline values and no radionuclides were detected by gamma-ray spectrometry.

### Sediments

6.3.15 Samples of sediments were also taken from the River Frome and the two streams. The results are recorded at Table 14. In most cases the concentrations observed are somewhat lower than those reported in 1994 and 1995. Only at Stream B to the east of the site was any increase observed. However,

here the concentrations are so low that the observed increase may be attributable to analytical uncertainty. The committed 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  $\mu$ Sv y<sup>-1</sup> for Stream A which, as in previous years, showed the highest concentrations for caesium-137.

## 6.4 AMERSHAM INTERNATIONAL PLC

6.4.1 Amersham International operates two sites, one at Amersham in Buckinghamshire and one at Cardiff in South Glamorgan.

### AMERSHAM INTERNATIONAL (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 decay tanks to allow for radioactive decay. The other two effluent streams are treated when activity levels are high. The three waste streams are routed to holding tanks prior to monitoring and discharge via the public sewer to the Maple Lodge Sewage Treatment Plant, operated by Thames Water plc.

6.4.3 The 1996 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, in the vicinity of Amersham International, 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 analytical results for the analysis of liquid effluent by Amersham International and the Agency's contract laboratory, LGC, showed poor agreement. Discrepancies in the gross beta analyses almost certainly result from the analysis by Amersham International of the individual samples that make up the monthly bulk sample supplied to LGC. The former gives a more accurate estimate of the short-lived radionuclides by reducing the uncertainty in correcting for radioactive decay between the time of sampling and the analysis. In nearly all cases where discrepancies were observed the Agency's contract laboratory reported concentrations lower than those reported by Amersham International.

#### **Maple Lodge**

6.4.5 Maple Lodge Sewage Treatment Plant is operated by Thames Water plc. It receives authorised discharges from Amersham International. 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 of long chain molecules. Following dewatering, the sludge is disposed of to a landfill site, used for land reclamation or put to agricultural use. During 1996 samples of raw sewage, final effluent and digested sludge were analysed each quarter. The results are given in Table 15. A study(23) commissioned by Her Majesty's Inspectorate of Pollution has confirmed that the agricultural use of digested sludge at these concentrations would be acceptable on radiological grounds.

#### **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 at Table 16. The levels of tritium in water were consistent with expected values for general UK waters. Gross alpha activities were below the WHO's guidance values of 0.1 Bq l<sup>-1</sup>. Gross beta activities marginally exceed the WHO's guidance values of 1.0 Bq l<sup>-1</sup> during the first and second quarters of 1996 when concentrations of 1.2 Bq l<sup>-1</sup> were recorded. Radiologically insignificant concentrations of cobalt-57 and isotopes of caesium were again detected in sediment samples from the river during 1996. However, Amersham International 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 committed effective dose would be much less than 1 µSv y<sup>-1</sup>.

#### **AMERSHAM INTERNATIONAL (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 prior to discharge via the public sewer and the Eastern pumping station to the Bristol Channel.

6.4.8 The 1996 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 Amersham International and the Agency's contract laboratory, LGC, was generally good.

#### **Environmental monitoring**

6.4.10 Samples of water were taken quarterly from points close to the storm-water outfall, the River Taff and from the canal. The results recorded at 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 storm-water outfall during the second and fourth quarters of 1996 were generally similar to those reported in 1995. However one elevated concentration of 460 Bq l<sup>-1</sup> was reported for the third quarter of 1996 and no sample was available for the first quarter of 1996, as the outfall was dry. Concentrations in the Glamorganshire Canal, although slightly lower, were similar to those observed in 1994 and 1995 and the concentrations in the River Taff, as for previous years, were similar to those observed in UK surface waters. Levels of gross alpha and gross beta activities were below the WHO's guidance values of 0.1 and 1.0 Bq l<sup>-1</sup> respectively and no radionuclides were detected by gamma-ray spectrometry. Overall, the levels of activity found in 1996 were radiologically insignificant

### **6.5 MINISTRY OF DEFENCE (PROCUREMENT EXECUTIVE)**

6.5.1 The Atomic Weapons Establishment (AWE) at Aldermaston in Berkshire is operated on behalf of the Ministry of Defence (Procurement Executive) by Hunting BRAE Ltd. The facilities at AWE are used for the processing of nuclear materials in support of the defence programme. Active liquid

effluents are routed to the on-site active effluent treatment plant and, after treatment by a ferric hydroxide flocculation process, are monitored prior to discharge by pipeline to the River Thames at Purley (Figure 8). 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 disposed of to a landfill site by a contractor following monitoring to demonstrate that they contain only exempt levels of radioactivity.

6.5.2 The 1996 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;

and, in the vicinity of AWE;

- (b) the monitoring of activity levels in the River Thames, the River Kennet and nearby streams.

#### **Effluent monitoring**

6.5.3 Discrepancies between the results of the analysis of total alpha activities in samples of treatment plant effluents by AWE and LGC were noted, and comparison of total beta and tritium results was generally satisfactory. 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 8. Monitoring locations - AWE Aldermaston





6.5.4 AWE reported low concentrations of total alpha and total beta in dry sludge cake samples obtained in February and August 1996. The results reported by LGC confirm that activity levels were low.

### **Environmental monitoring**

6.5.5 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, and from the River Kennet at Reading (Figures 6 and 8) and from streams at Aldermaston village and at Spring Lane close to the site. The analytical results recorded at Table 18 show concentrations of tritium measured in the streams at Aldermaston and, to a lesser extent, Spring Lane were consistently above the values for general UK waters during 1996. Similar concentrations have been observed since 1992 and are consistent with those observed by AWE. Concentrations were small and the resulting doses would have been negligible to anyone consuming water from the streams. The levels of gross alpha and gross beta activity in all samples were below the WHO's guidance values of 0.1 Bq l<sup>-1</sup> and 1.0 Bq l<sup>-1</sup> respectively. No radionuclides were detected by gamma-ray spectrometry.

6.5.6 Quarterly sediment samples were also taken from these locations and the results are recorded at Table 18. Low levels of caesium isotopes 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. 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 a committed effective dose much less than 1 µSv y<sup>-1</sup>.

### **6.6 NON-NUCLEAR SITES**

6.6.1 In 1996 only one company, Surelite Ltd, was 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 this site was airborne tritium gas emitted to the atmosphere. Trivial amounts of activity were also disposed of locally in solid and liquid wastes. The 1996 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 consistent with those for general UK surface waters although slightly elevated concentrations of tritium are observed in the samples closest to the site.

6.6.4 No organically bound 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 which can be disposed of safely, with special precautions, at many 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 1996 programme concentrated on monitoring levels of radioactivity in leachates, arising from the landfill sites and in ground waters or local surface waters which might be affected by migration of activity from buried wastes. Bi-annual monitoring was carried out at those sites which have exhibited elevated tritium concentrations in past years.

6.7.3 All samples were analysed for gross alpha and gross beta activity for comparison with the WHO guideline values for potable waters. Tritium, which because of its soft beta emissions cannot be screened satisfactorily by gross beta measurement, was determined separately. 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 gross alpha activities were below the WHO's guidance value of  $0.1 \text{ Bq l}^{-1}$ . However, as in previous years gross beta activities in excess of the WHO's guidance value of  $1.0 \text{ Bq l}^{-1}$  were found in samples from a number of sites. These included leachate from Crooks Marsh Farm, borehole water from the Milton Landfill, borehole water from Northwich Tip, stream water upstream and downstream of the Cowpen Bewley Tip, borehole water from Cole Green Landfill, local water from Millennium Inorganic Chemicals on-site tip, borehole waters from Clifton Marsh, leachate from Beddingham Quarry, local waters from Gelderd Road Tip, Greaseworks Tip, Wilson Road Tip and Dean House Farm and borehole water from Lamby Way Tip. Additional analysis showed that the increased gross beta was attributable to enhanced concentrations of potassium-40, a naturally occurring radionuclide present in soils and artificial fertilisers. With the exception of potassium-40 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 leachate from Crooks Marsh Farm, borehole waters from the Milton Landfill, borehole water from the Witton Tip, stream water downstream of the Cowpen Bewley Tip with marginal elevation in upstream river water, leachate from Cilgwyn Quarry, borehole water from Cole Green Landfill, borehole water from Clifton Marsh landfill, leachate and borehole water from Beddingham Quarry, local water at the

Greaseworks Tip, local water from Wilson Road Tip, local water from the Dean House Farm Tip and borehole water from Lamby Way Tip.

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  $4000 \text{ kBq per } 0.1 \text{ m}^3$  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  $20 \text{ GBq}$  of tritium from authorisation under the Act provided that no more than one source is disposed of in any  $0.1 \text{ m}^3$  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  $20 \text{ GBq}$  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. GTLDs containing typically  $1000 \text{ GBq}$  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 efficiency.

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(24) and as part of the review to investigate the possible sources of elevated tritium levels in landfill waters. The report of this work supports this hypothesis and is being prepared for publication.

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 1996 was 1220 Bq l<sup>-1</sup> in streamwater downstream of Cowpen Bewley Tip, Cleveland, and concentrations even at this level would result in a dose of only about 14 µSv y<sup>-1</sup> if the stream were to be used as a drinking water supply.

## **6.8 AIR AND RAINWATER**

6.8.1 A summary of the quarterly monitoring data for 1996 from this programme is provided in Table 21. Average air concentrations of caesium-137 measured at the seven sampling sites during 1996 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 were usually 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, measured in air during 1996 were similar at all sampling locations. Over the period 1990-1996, peak air concentrations of beryllium-7 have 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 Annual average concentrations of plutonium-239+240 and americium-241 in air and rainwater measured at Aberporth were a very small fraction of NRPB's Generalised Derived Limits<sup>(25)</sup> for members of the public for air, freshwater and drinking water.

6.8.4 Tritium concentrations measured in rainwater during 1996 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; annual mean concentrations in 1996 were approximately half of those 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 3. The monitored sources provide water for over 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, while the extent of 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 guideline values of 0.1 and 1.0 Bq l<sup>-1</sup> for gross alpha and gross beta activities respectively. Minor exceedances for gross alpha activities occurred in samples from the groundwater source at Meerbrook Sough in Derbyshire. Elevated concentrations of uranium confirm that this is caused by the local geology. The concentrations are radiologically insignificant. The few minor exceedances in samples from some of the other locations are inconsequential, being transitory and not confirmed by the other analyses.

6.9.4 Results for the River Thames which receives authorised discharges from Amersham International, UKAEA Harwell and MoD Aldermaston are consistent with those from the Agency's regulatory monitoring in the vicinity of 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.

## 7. SUMMARY AND CONCLUSIONS

7.1 The 1996 programme of monitoring was completed satisfactorily. The programme included the analysis of a total of 160 effluent samples, the analysis of solid radioactive waste destined for disposal at the BNFL Drigg site, direct monitoring at over 150 locations in the vicinity of nuclear sites and the analysis of a total of 532 environmental samples.

7.2 The programme acts as a check on site operators' returns and provides independent data on the environmental impact of authorised disposals of radioactive wastes and on radiation doses to critical groups of the public.

7.3 The environmental monitoring programme concentrates on monitoring activity levels in environmental materials which might result in radiation exposure of the public from non-food pathways.

7.4 In summary, radiation exposures from these pathways which may have been incurred by members of the public in 1996 remain similar to those in previous years and, in all cases, are estimated to have been substantially less than the principal dose limit of 1 mSv per year.

## REFERENCES

1. Radioactivity in Food and the Environment (RIFE). Ministry of Agriculture, Fisheries and Food, Radiological Safety and Nutrition Division, London.
2. Quality Checking of Radioactive and Hazardous Waste. Taylor Woodrow. HMIP Research Report DoE/HMIP/RR/92/007.
3. Radioactivity in Air and Rainwater: UK Results to the End of 1996. AEA Technology plc. Report DETR/RAS/97.004.
4. Radioactivity in Air and Rainwater: Results to the End of 1991. AEA Technology. Report DoE/RAS/93.003.
5. Monitoring Radioactivity in Water Supplies in England and Wales. S Newstead, M Wakerley. Proceedings of a Workshop on Harmonisation of East-West Radioactive Pollutant Measurement, Standardisation of Techniques, Consideration of Socio-Economic Factors. Budapest, Hungary 1994.
6. Review of Radioactive Waste Management Policy: Final Conclusions. Cm 2919 HMSO (1995).
7. 1990 Recommendations of the International Commission on Radiological Protection. Pergamon Press, Oxford, 210 pp [ICRP Publ. 60] (1991).
8. Dose Limits for Members of the Public. NRPB-GS4. London, HMSO (1986).
9. Board Statement on the 1990 Recommendations of ICRP. Documents of the NRPB, Vol 4, No 1, 1993, London, HMSO (1993).
10. Recommendations on the Introduction of the New SI Units for Use with Radioactivity and Ionizing Radiations. British Committee on Radiation Units and Measurements, National Physical Laboratory, Teddington (1978).
11. Age-dependent Doses to Members of the Public from Intake of Radionuclides: Part 5 Compilation of Ingestion and Inhalation Dose Coefficients. Pergamon Press, Oxford 91 pp [ICRP Publ. 72] (1996).
12. Investigation of External Radiation Exposure Pathways in the Eastern Irish Sea, 1989, Fisheries Research Data Report No. 22. Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft.
13. An Investigation of the Uses made of the Cumbrian Coastal Area by Transient and Indigenous Population Groups. Research Surveys of Great Britain Limited. HMIP Research Report DoE/HMIP/RR/91/057. Department of the Environment (1991).
14. MAFF Private Communication (1993).
15. A Survey of Radioactivity in the Ribble Estuary: I, Activity Concentrations and Estuarine Dynamics; II, Radiological Assessment. HMIP Environment Series Reports (1994).
16. Generalised Habit Data for Radiological Assessments. National Radiological Protection Board, NRPB-M636 (1996).
17. Guidelines for Drinking Water Quality. Vol. 1. Recommendations 2nd Edition. World Health Organisation Geneva (1993).
18. Site Specific Background Dose Rates in Coastal and River Areas. AEA Technology. HMIP Research Report. DOE/HMIP/RR/94/037.

19. Routine Measurement of Gamma Ray Air Kerma Rate in the Environment. HMIP Technical Guidance Note M5, London HMSO (1995).
20. Radiation Exposure of the UK Population – 1993 Review. National Radiological Protection Board. Report No. R263, London HMSO (1994).
21. Radioactive Discharges and Monitoring of the Environment. Annual Report 1996. British Nuclear Fuels plc. Health and Safety Directorate, Risley, Warrington.
22. Simple Models for Prediction of External Radiation Exposure from Aquatic Pathways. G J Hunt. Radiation Protection Dosimetry, Vol. 8, No. 4, pp. 215-224 (1984).
23. A Study of the Radiological Implications of Releases of Radionuclides to Sewer Systems. Electrowatt Engineering (UK) Limited. HMIP Research Report DoE/HMIP/RR/94/002.
24. A Review of the Use of and Disposal of Gaseous Tritium Light Devices. Expected publication 1997.
25. Generalised Derived Limits for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium. Documents of the NRPB, Volume 7, No 1, 1996.

TABLE 1

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Amersham International plc</b>				
<b>Amersham</b>				
Liquid	Alpha	3.00E-04	6.75E-05	23
	Beta > 0.4 MeV	1.00E-01	1.59E-02	16
	Tritium	2.00E-01	2.84E-03	1.4
	Iodine-125	2.00E-01	1.27E-03	0.6
	Caesium-137	5.00E-03	2.67E-05	0.5
	Other radionuclides	3.00E-01	1.28E-01	43
Gaseous	Alpha	2.00E-06	3.50E-07	18
	Other (penetrating)	5.00E-02	1.60E-04	0.3
	Other (non-penetrating)	5.00E-01	2.30E-02	4.6
	Tritium	4.00E+01	6.50E-04	0.0
	Selenium-75	3.00E-02	6.70E-04	2.2
	Iodine-131	5.00E-02	6.90E-03	14
	Radon-222	1.00E+01	1.70E+00	17
	Iodine-125	1.00E-01	2.20E-02	22
<b>Cardiff</b>				
Liquid	Tritium	9.00E+02	5.42E+02	60
	Carbon-14	2.00E+00	1.60E+00	80
	Phosphorus-32/33	1.00E-02	1.33E-04	1.3
	Iodine-125	5.00E-02	1.55E-02	31
	Others	5.00E-04	1.46E-04	29
Gaseous	Soluble tritium	4.00E+02	1.73E+02	43
	Insoluble tritium	1.00E+03	5.22E+02	52
	Carbon-14	6.00E+00	3.84E+00	64
	Phosphorus-32/33	2.00E-04	5.53E-06	2.8
	Iodine-125	5.00E-04	1.20E-04	24
	Other activity	4.00E-02	1.22E-03	3.1
<b>British Nuclear Fuels plc</b>				
<b>Capenhurst</b>				
Rivacre Brook	Uranium	2.00E-02	1.40E-03	7.0
Uranium daughters	2.00E-02	3.00E-03	15	
Non-uranic alpha	3.00E-03	6.80E-05	2.3	
Technetium-99	1.00E-01	3.20E-03	3.2	
Gaseous	Uranium	(c)	5.20E-06	



TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Drigg</b>				
Sea pipeline	Alpha	1.00E-01	2.66E-04	0.3
	Beta (d)	3.00E-01	8.95E-03	3.0
	Tritium	1.20E+02	1.95E+00	1.6
Stream (e)	Alpha	9.00E+04	1.20E+02	0.1
	Beta (d)	1.20E+06	3.80E+03	0.3
	Tritium	6.00E+08	2.50E+05	0.1
<b>Sellafield</b>				
Sea pipelines	Alpha	1.00E+00	2.75E-01	28
	Beta	4.00E+02	1.43E+02	36
	Tritium	3.10E+04	3.01E+03	9.7
	Carbon-14	2.08E+01	1.09E+01	52
	Cobalt-60	1.30E+01	4.29E-01	3.3
	Strontium-90	4.80E+01	1.60E+01	33
	Zirconium-95+	9.00E+00	1.15E+00	13
	Niobium-95			
	Technetium-99	2.00E+02	1.55E+02	77
	Ruthenium-106	6.30E+01	9.02E+00	14
	Iodine-129	2.00E+00	4.13E-01	21
	Caesium-134	6.60E+00	2.71E-01	4.1
	Caesium-137	7.50E+01	1.03E+01	14
	Cerium-144	8.00E+00	7.79E-01	9.7
	Plutonium alpha	7.00E-01	2.09E-01	30
	Plutonium-241	2.70E+01	4.35E+00	16
	Americium-241	3.00E-01	7.37E-02	25
	Uranium (f)	2.04E+03	1.16E+03	57
Factory sewer	Alpha	3.30E-03	3.40E-05	1.0
	Beta	1.35E-02	7.10E-04	5.3
	Tritium	1.32E-01	1.20E-02	9.1
Gaseous (g, h)	Alpha	3.50E-03	1.80E-04	5.1
	Beta	3.58E-01	3.40E-03	0.9
	Tritium	1.45E+03	5.30E+02	37
	Carbon-14	8.84E+00	6.30E-01	7.1
	Sulphur-35	2.10E-01	1.40E-01	67
	Argon-41	3.70E+03	2.60E+03	70
	Cobalt-60	9.20E-04	5.00E-05	5.4
	Krypton-85	5.90E+05	9.40E+04	16
	Strontium-90	9.40E-03	1.20E-04	1.3
	Ruthenium-106	9.60E-02	8.80E-04	0.9
	Antimony-125	5.00E-03	7.60E-04	15
	Iodine-129	7.60E-02	2.50E-02	33
	Iodine-131	5.50E-02	2.30E-03	4.2

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Sellafield (cont)</b>				
	Caesium-137	1.83E-02	8.50E-04	4.6
	Plutonium (alpha)	1.34E-03	6.40E-05	4.8
	Plutonium-241	1.81E-02	5.90E-04	3.3
	Americium-241 and Curium-242	7.50E-04	4.90E-05	6.5
<b>Springfields</b>				
Liquid	Alpha	4.00E+00	1.24E-01	3.1
	Beta	2.40E+02	1.53E+02	64
	Technetium-99	6.00E-01	3.30E-02	5.5
	Thorium-230	2.00E+00	4.80E-02	2.4
	Thorium-232	2.00E-01	1.40E-03	0.7
	Neptunium-237	4.00E-02	2.00E-04	0.5
	Uranium	1.50E-01	6.10E-02	41
Gaseous	Uranium	6.00E-03	2.11E-03	35
<b>Devonport Royal Dockyard Ltd</b>				
Pipeline (i)	Total activity (j)	2.00E-03	4.03E-05	2.0
	Tritium	1.20E-01	7.65E-02	64
	Cobalt-60	1.60E-02	5.16E-05	0.3
<b>Hunting BRAE Ltd Aldermaston</b>				
Pipeline	Alpha	1.50E-04	1.28E-05	8.5
	Tritium	5.00E-02	1.64E-03	3.3
	Plutonium-241	6.00E-04	5.10E-05	8.5
	Other radionuclides	1.50E-04	1.33E-05	8.9
<b>Silchester</b>				
Liquid	Alpha	1.00E-04	6.71E-06	6.7
	Beta	3.00E-04	4.45E-05	15
Gaseous (g)	Alpha	9.00E-07	1.65E-07	18
	Beta (k)	4.60E-06	1.11E-07	2.4
	Tritium	3.40E+02	9.46E+00	2.8
	Krypton-85	4.00E-01	3.00E-03	0.8
<b>Burghfield</b>				
Liquid	Alpha	2.00E-06	3.18E-08	1.6
	Other radionuclides	1.20E-05	6.36E-08	0.5
Gaseous (g)	Alpha	2.00E-08	4.00E-10	2.0
	Tritium	3.50E-01	9.40E-05	0.1
	Krypton-85	1.00E+00	3.80E-02	3.8

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Magnox Electric plc (I) Berkeley Power Station and Technology Centre</b>				
Liquid	Tritium	8.00E+00	3.72E-02	0.5
	Caesium-137	2.00E-01	1.03E-02	5.2
	Other radionuclides	4.00E-01	3.87E-02	9.7
Gaseous (Technology Centre)	Alpha and beta	2.00E-05	3.14E-06	16
Gaseous (Power Station and Technology Centre)	Alpha and beta	2.00E-04	3.76E-06	1.9
	Tritium	2.00E+00	9.59E-03	0.5
	Carbon-14	2.00E-01	2.66E-04	0.1
	Sulphur-35	6.00E-03	n/a	
<b>Bradwell</b>				
Liquid	Tritium	3.00E+01	1.36E+00	4.5
	Caesium-137	7.50E-01	3.93E-01	52
	Other radionuclides	1.00E+00	3.63E-01	36
Gaseous	Beta	1.00E-03	2.23E-04	22
	Tritium	1.50E+00	7.86E-01	52
	Sulphur-35	2.00E-01	7.65E-02	38
	Carbon-14	6.00E-01	3.57E-01	60
	Argon-41	1.00E+03	6.47E+02	65
<b>Dungeness A</b>				
Liquid	Tritium	3.50E+01	1.38E+00	3.9
	Caesium-137	1.20E+00	5.54E-01	46
	Other radionuclides	1.40E+00	2.81E-01	20
Gaseous	Beta	1.00E-03	3.22E-04	32
	Tritium	2.00E+00	1.03E+00	52
	Carbon-14	5.00E+00	2.53E+00	51
	Sulphur-35	4.00E-01	4.96E-02	12
	Argon-41	2.00E+03	9.62E+02	48
<b>Hinkley Point A</b>				
Liquid	Tritium	2.50E+01	7.23E-01	2.9
	Caesium-137	1.50E+00	4.35E-01	29
	Other radionuclides	1.00E+00	1.80E-01	18
Gaseous	Beta	1.00E-03	1.64E-04	16
	Tritium	2.50E+01	3.47E+00	14
	Carbon-14	4.00E+00	1.05E+00	26
	Sulphur-35	2.00E-01	7.75E-02	39
	Argon-41	4.50E+03	2.30E+03	51

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Oldbury</b>				
Liquid	Tritium	2.50E+01	1.86E-01	0.7
	Caesium-137	7.00E-01	5.15E-02	7.4
	Other radionuclides	1.30E+00	3.13E-01	24
Gaseous	Beta	1.00E-03	9.06E-05	9.1
	Tritium	5.00E+00	1.73E+00	35
	Carbon-14	6.00E+00	3.85E+00	64
	Sulphur-35	7.50E-01	2.49E-01	33
	Argon-41	5.00E+02	1.12E+02	22
<b>Sizewell A</b>				
Liquid	Tritium	3.50E+01	1.13E+00	3.2
	Caesium-137	1.00E+00	3.60E-01	36
	Other radionuclides	7.00E-01	2.29E-01	33
Gaseous	Beta	1.00E-03	2.33E-05	2.3
	Tritium	7.00E+00	8.74E-01	13
	Carbon-14	1.50E+00	1.07E-01	7.1
	Sulphur-35	6.00E-01	9.60E-03	1.6
	Argon-41	3.00E+03	2.95E+02	9.8
<b>Trawsfynydd</b>				
Liquid	Tritium	1.20E+01	1.03E-01	0.9
	Strontium-90	8.00E-02	4.40E-03	5.5
	Caesium-137	5.00E-02	6.17E-03	12
	Other radionuclides	7.20E-01	1.01E-02	1.4
Gaseous	Beta	2.00E-03	1.62E-06	0.1
	Tritium	1.00E+01	6.30E-02	0.6
	Carbon-14	5.00E+00	7.02E-04	0.1
	Sulphur-35	4.00E-01	-	0.0
	Argon-41	3.50E+03	-	0.0
<b>Wylfa</b>				
Liquid	Tritium	4.00E+01	9.88E+00	25
	Other radionuclides	1.50E-01	6.10E-02	41
Gaseous	Beta	1.00E-03	8.70E-05	8.7
	Tritium	2.00E+01	6.70E+00	34
	Carbon-14	2.40E+00	1.24E+00	52
	Sulphur-35	5.00E-01	2.00E-01	40
	Argon-41	1.20E+02	4.39E+01	37



TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Nuclear Electric Ltd (m)</b>				
<b>Dungeness B</b>				
Liquid	Tritium	6.50E+02	2.52E+02	39
	Sulphur-35	2.00E+00	3.16E-01	16
	Cobalt-60	3.00E-02	1.66E-03	5.5
	Other radionuclides	2.50E-01	1.67E-02	6.7
Gaseous	Beta particulate	1.00E-03	4.86E-05	4.9
	Tritium	1.50E+01	1.52E+00	10
	Carbon-14	5.00E+00	4.90E-01	9.8
	Sulphur-35	4.50E-01	1.33E-02	3.0
	Argon-41	1.50E+02	2.79E+01	19
	Iodine-131	5.00E-03	4.14E-06	0.1
<b>Hartlepool</b>				
Liquid	Tritium	1.20E+03	3.53E+02	29
	Sulphur-35	3.00E+00	8.99E-01	30
	Cobalt-60	3.00E-02	1.45E-02	48
	Other radionuclides	3.00E-01	5.48E-03	1.8
Gaseous	Beta particulate	1.00E-03	3.49E-05	3.5
	Tritium	6.00E+00	1.56E+00	26
	Carbon-14	5.00E+00	1.51E+00	30
	Sulphur-35	1.60E-01	4.77E-02	30
	Argon-41	6.00E+01	2.39E+01	40
	Iodine-131	5.00E-03	2.75E-04	5.5
<b>Heysham 1</b>				
Liquid	Tritium	1.20E+03	3.41E+02	28
	Sulphur-35	2.80E+00	2.23E-01	8.0
	Cobalt-60	3.00E-02	1.02E-03	3.4
	Other radionuclides	3.00E-01	7.82E-03	2.6
Gaseous	Beta particulate	1.00E-03	4.74E-05	4.7
	Tritium	6.00E+00	9.23E-01	15
	Carbon-14	4.00E+00	1.02E+00	26
	Sulphur-35	1.20E-01	1.37E-02	11
	Argon-41	6.00E+01	1.07E+01	18
	Iodine-131	5.00E-03	1.20E-03	24

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Heysham 2</b>				
Liquid	Tritium	1.20E+03	3.79E+02	32
	Sulphur-35	2.30E+00	3.58E-02	1.6
	Cobalt-60	3.00E-02	6.90E-04	2.3
	Other radionuclides	3.00E-01	1.14E-02	3.8
Gaseous	Beta particulate	1.00E-03	2.20E-05	2.2
	Tritium	1.50E+01	2.14E+00	14
	Carbon-14	3.00E+00	8.49E-01	28
	Sulphur-35	3.00E-01	1.74E-02	5.8
	Argon-41	8.50E+01	1.29E+01	15
	Iodine-131	5.00E-03	2.32E-04	4.6
<b>Hinkley Point B</b>				
Liquid	Tritium	6.20E+02	3.20E+02	52
	Sulphur-35	5.00E+00	7.95E-01	16
	Cobalt-60	3.30E-02	4.00E-04	1.2
	Other radionuclides	2.35E-01	8.64E-03	3.7
Gaseous	Beta particulate	1.00E-03	7.68E-05	7.7
	Tritium	3.00E+01	2.10E+00	7.0
	Carbon-14	8.00E+00	1.93E+00	24
	Sulphur-35	4.00E-01	7.00E-02	18
	Argon-41	3.00E+02	3.32E+01	11
	Iodine-131	5.00E-03	2.09E-05	0.4
<b>Sizewell B</b>				
Liquid	Tritium	4.00E+01	3.76E+01	94
	Other radionuclides	2.00E-01	1.99E-02	10
Gaseous (outlets 1 - 3)	Noble gases	2.95E+02	6.11E+00	2.1
	Halogens	2.70E-03	4.92E-05	1.8
	Beta particulate	1.00E-02	8.71E-06	0.0
	Tritium	7.80E+00	5.79E-01	7.4
	Carbon-14	5.90E-01	5.42E-02	9.2

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>United Kingdom Atomic Energy Authority Harwell</b>				
Pipeline	Alpha	1.00E-03	4.14E-05	4.1
	Beta (d)	2.00E-02	1.82E-03	9.1
	Tritium	4.00E+00	5.20E-02	1.3
	Cobalt-60	7.00E-03	8.57E-05	1.2
	Caesium-137	7.00E-03	3.11E-04	4.4
Lydebank Brook	Alpha	5.00E-04	4.56E-05	9.1
	Beta (d)	2.00E-03	3.00E-04	15
	Tritium	1.00E-01	1.87E-02	19
Gaseous	Alpha	7.00E-06	2.90E-07	4.1
	Beta	4.50E-04	6.30E-06	1.4
	Tritium	1.50E+02	6.90E+00	4.6
<b>Windscale</b>				
Gaseous	Alpha	1.20E-05	4.20E-07	3.5
	Beta	5.00E-03	2.20E-04	4.4
	Tritium	2.30E+00	8.20E-03	0.4
	Krypton-85	1.40E+01	2.40E-02	0.2
	Iodine-131	1.20E-03	6.00E-06	0.5
<b>Winfrith</b>				
Inner pipeline	Alpha	3.00E-01	1.83E-03	0.6
	Tritium	6.50E+02	1.59E+00	0.2
	Cobalt-60	1.00E+01	1.99E-03	0.0
	Zinc-65	6.00E+00	6.80E-04	0.0
	Other radionuclides	8.00E+01	2.40E-02	0.0
Outer pipeline	Alpha	4.00E-03	1.19E-04	3.0
	Tritium	1.00E+00	1.77E-02	1.8
	Other radionuclides	1.00E-02	1.85E-04	1.9
Gaseous	Alpha	2.00E-06	4.08E-10	0.0
	Beta	2.50E-05	9.24E-09	0.0
	Tritium	5.00E+00	6.11E-01	12.2
	Carbon-14	3.00E-01	5.84E-04	0.2
	Krypton-85	1.50E+02	0.00E+00	0.0
<b>URENCO Capenhurst</b>				
Gaseous	Uranium	2.50E-06	1.10E-07	4.4

TABLE 1 (cont)

**PRINCIPAL DISCHARGES OF RADIOACTIVE WASTE FROM NUCLEAR  
ESTABLISHMENTS IN ENGLAND AND WALES IN 1996**

Establishment	Radionuclide	Discharge limit annual equivalent TBq	Discharges during 1996 TBq(a)	%of limit (b)
<b>Vickers Shipbuilding and Engineering Ltd Barrow</b>	Liquid			
	Tritium	2.00E-02	2.09E-03	11
	Manganese-54	2.50E-07	5.51E-09	2.2
	Cobalt-58	7.00E-07	2.22E-09	0.3
	Cobalt-60	7.00E-08	1.29E-08	18
	Tin-113	2.50E-07	5.49E-09	2.2
	Antimony-124	2.00E-06	8.85E-09	0.4
	Other radionuclides	3.50E-06	1.96E-07	5.6
	Gaseous			
	Tritium	3.20E-06	0.00E+00	0.0
	Argon-41	8.00E-02	0.00E+00	0.0

- (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 1 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<sup>-3</sup>.
- (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. All discharges were below the appropriate limit for each location.
- (h) Some limits are related to the operation of the THORP plant and may thus vary from year to year.
- (i) The authorisation includes a limit on concentration of total activity of 4.0E-6 TBq m<sup>-3</sup>. At no time did the concentration exceed the limit.
- (j) Excluding cobalt-60.
- (k) Excluding tritium, plutonium-241, krypton-85 and volatile beta emitters (no releases in this category during the year).
- (l) Nuclear Electric plc changed its name to Magnox Electric plc on 1 April 1996.
- (m) The total discharges quoted represent the total discharges from the approved outlets (liquid and gaseous) for power stations in 1996, but the owner and operator changed as of 1 April 1996 from Nuclear Electric plc to Nuclear Electric Ltd. The new authorisations issued in 1996 did not alter any of the numerical limits.

TABLE 2

**MEAN GAMMA RADIATION DOSE RATES AT 1 METRE  
OVER INTER-TIDAL AREAS OF THE WEST CUMBRIAN COAST**

Location	Ground type	Dose rate, $\mu\text{Gy h}^{-1}$		Occupancy $\text{hr y}^{-1}$	Estimated annual dose in excess of background $\mu\text{Sv y}^{-1}$
		Quarter 2	Quarter 4		
Whitehaven Harbour	Silt	0.14	0.15	470	30
St Bees	Sand	0.10	0.11	300	14
Coulderton	Sand	0.12	0.13	300	19
Nethertown	Sand	0.13	0.13	300	20
Braystones	Sand	0.12	0.13	300	19
Sellafield (Ehen Spit)	Sand	0.12	0.13	300	20
Seascale	Sand	0.11	0.10	300	14
Drigg	Sand	0.10	0.11	470	22
Saltcoats	Silt	0.11	0.13	300	13
Ravenglass	Silt	0.12	0.11	300	11
Newbiggin	Silt	0.14	0.15	315	19
Haverigg	Sand	0.08	0.09	920	28
Askam	Sand	0.10	0.09	960	35
Walney Island	Sand	0.07	0.09	300	10

**Notes**

1. Each result is the mean of three individual measurements.
2. Occupancy data were obtained from studies of each location by MAFF <sup>(1)</sup> and RSGB <sup>(13)</sup>.
3. The dose rates shown include a contribution from background radiation.



TABLE 3

## RADIOACTIVITY IN SEDIMENTS FROM WEST CUMBRIA

Concentrations in sediment samples Bq kg<sup>-1</sup> (dry weight)

Radionuclide	Ehen Spit (Sand) Quarter 1	Newbiggin (Silt) Quarter 1	Newbiggin (Silt) Quarter 2	Newbiggin (Silt) Quarter 3	Newbiggin (Silt) Quarter 4	Walney Island (Sand) Quarter 1
Gross alpha	350	1490	1010	1110	1310	<100
Gross beta	730	3680	2050	2170	2904	<500
Cobalt-60	3.1	15	21	13	13	<1
Strontium-90	<100	210	200	190	220	<100
Niobium-95	<2	<4	32	<6.5	5	<2
Zirconium-95	<1	<8	<13	<0.8	3.3	<1
Ruthenium-106	<2	71	220	85	145	<2
Silver-110m	<0.3	<0.6	<2	<1	<.5	<0.2
Antimony-125	<0.8	10	9.9	5.9	9.3	<0.5
Caesium-134	<0.3	<3	<3	<2	<2	<0.3
Caesium-137	83	510	280	220	310	15
Cerium-144	<2	12	23	8.1	9.8	<1
Europium-154	<5	15	10	7	11	<0.7
Europium-155	<2	5.5	4.9	<5	4.8	<0.6
Plutonium-238	30	110	76	77	110	9.1
Plutonium-239/240	140	590	350	350	470	41
Plutonium-241	3050	13000	5000	4100	9790	<1000
Americium-241	180	840	450	460	550	45

TABLE 4

## RADIOACTIVITY IN SURFACE WATERS FROM WEST CUMBRIA

Location	Radionuclide	Sample concentration Bq kg <sup>-1</sup>			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Ehen Spit issue	Gross beta	3.1	9.6	4.2	6.4
	Tritium	320	600	210	450
	Caesium-137	1.5	0.89	1.1	1.7
	Potassium-40	<10	10	<20	<10
Factory sewer outfall	Gross beta	<0.5	0.5	0.9	<0.5
	Tritium	14	9.1	18	22
	Caesium-137	<0.1	<0.1	<0.5	<0.3
River Calder	Gross beta	<0.5	<0.5	<0.5	<0.5
	Tritium	8	10	16	13
	Caesium-137	<0.6	0.66	<0.1	<0.1
River Calder at bridge	Tritium	6	N.S.	N.S.	N.S.
River Ehen	Tritium	3	N.S.	N.S.	N.S.
River Mite	Tritium	6	N.S.	N.S.	N.S.
River Irt	Tritium	6	N.S.	N.S.	N.S.
River Esk	Tritium	6	N.S.	N.S.	N.S.
Wastwater	Tritium	3	N.S.	N.S.	N.S.
Ennerdale Water	Tritium	3	N.S.	N.S.	N.S.
Devoke Water	Tritium	3	N.S.	N.S.	N.S.
Thirlmere	Tritium	4	N.S.	N.S.	N.S.

## Notes

- Except where specified, for all samples:
  - gross alpha activities were less than 0.1 Bq kg<sup>-1</sup>;
  - gross beta activities were less than 1.0 Bq kg<sup>-1</sup>;
  - no other radionuclides were detected by gamma-ray spectrometry.
- With the exception of Ehen Spit issue, factory sewer outfall and River Calder, samples were collected once per year.
- N.S. - not sampled.

TABLE 5

**RADIOACTIVITY IN SURFACE WATERS  
IN THE VICINITY OF BNFL DRIGG**

Location	Radionuclide	Sample concentration Bq kg <sup>-1</sup>			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Drigg Stream water	Gross alpha	<0.1	<0.1	<0.1	<0.1
	Gross beta	<1	<1	<1	<1
	Tritium	34	150	170	210
	Strontium-90	<1	<1	<1	<1
	Technetium-99	<0.1	<0.1	<0.1	<0.1
	Caesium-137	<0.3	0.6	<0.1	<0.2
Drigg Stream sediment	Gross alpha	330	<100	<100	<100
	Gross beta	1360	<500	600	540
	Cobalt-60	4.5	2.9	3.0	3.8
	Strontium-90	<10	<10	<10	<10
	Niobium-95	<0.9	<4	<0.9	<2
	Zirconium-95	<0.9	<3	<0.8	<1
	Ruthenium-106	<5	<9	<3	<5
	Silver-110m	<3	<2	<0.4	<0.9
	Antimony-125	<2	<3	<1	<2
	Caesium-134	3	<3	<3	<3
	Caesium-137	710	320	360	370
	Cerium-144	<3	<4	<2	<4
	Europium-154	<1	<2	<0.8	<1
	Europium-155	<2	<2	<1	<1
	Plutonium-238	17	5.6	9.9	12
	Plutonium-239/240	72	19	24	34
	Plutonium-241	1400	400	450	680
	Americium-241	46	11	13	21
Railtrack drain water	Gross alpha	<0.1	N.S.	N.S.	N.S.
	Gross beta	<1.0	N.S.	N.S.	N.S.
	Tritium	<10	N.S.	N.S.	N.S.
	Strontium-90	<1.0	N.S.	N.S.	N.S.
	Technetium-99	<0.1	N.S.	N.S.	N.S.
	Caesium-137	<0.14	N.S.	N.S.	N.S.

**Notes**

- All samples:
  - plutonium-238, plutonium-(239+240), plutonium-241, americium-241 and thorium were less than 0.1, 0.1, 1.0, 0.1 and 0.1 Bq kg<sup>-1</sup> respectively;
  - uranium-235 and uranium-238 were less than 0.1 Bq kg<sup>-1</sup>;
  - no radionuclides were detected by gamma-ray spectrometry.
- The Railtrack drain was sampled in the first quarter only of 1996.
- N.S. - not sampled.

TABLE 6

**RADIOACTIVITY IN WATER AND MUD SAMPLES FROM RIVACRE BROOK  
DOWNSTREAM OF BNFL CAPENHURST**

Location	Sample type	Radionuclide	Water concentration, Bq kg <sup>-1</sup> Mud concentration, Bq kg <sup>-1</sup> (dry weight)	
			Quarter 2	Quarter 3
0.7km downstream of BNFL's outfall	Water	Gross alpha	<0.1	<0.1
		Gross beta	5.0	11.0
		Uranium-235	<0.1	<0.8
		Uranium-238	<0.1	<0.1
		Technetium-99	2.3	0.6
		Neptunium-237	<0.1	<0.1
	Mud	Gross alpha	280	310
		Gross beta	2100	2700
		Uranium-235	14	20
		Uranium-238	200	250
		Caesium-134	<1.8	<0.26
		Caesium-137	15	13
		Neptunium-237	35	53
		Technetium-99	1800	2100
1.6km downstream of BNFL's outfall	Water	Gross alpha	<0.1	<0.1
		Gross beta	1.1	5.5
		Uranium-235	<0.1	<0.1
		Uranium-238	<0.1	<0.1
		Technetium-99	1.0	1.0
		Neptunium-237	<0.1	<0.1
	Mud	Gross alpha	290	320
		Gross beta	1730	1250
		Uranium-235	6.8	10
		Uranium-238	210	260
		Caesium-134	<0.7	<0.3
		Caesium-137	5.9	5.6
		Neptunium-237	57	44
		Technetium-99	1210	780

TABLE 6 (cont)

**RADIOACTIVITY IN WATER AND MUD SAMPLES FROM RIVACRE BROOK  
DOWNSTREAM OF BNFL CAPENHURST**

Location	Sample type	Radionuclide	Water concentration, Bq kg <sup>-1</sup> Mud concentration, Bq kg <sup>-1</sup> (dry weight)	
			Quarter 2	Quarter 3
3.1km downstream of BNFL's outfall	Water	Gross alpha	<0.1	<0.1
		Gross beta	1.5	3.4
		Uranium-235	<0.1	<0.1
		Uranium-238	<0.1	<0.1
		Technetium-99	0.6	0.7
		Neptunium-237	<0.1	<0.1
	Mud	Gross alpha	280	<100
		Gross beta	<1000	<1000
		Uranium-235	1.0	2.8
		Uranium-238	210	30
		Caesium-134	<0.2	<0.2
		Caesium-137	<1	1.3
		Neptunium-237	<10	<10
		Technetium-99	220	110
	Water	Gross alpha	<0.1	<0.1
		Gross beta	<0.5	4.1
		Uranium-235	<0.1	<0.1
		Uranium-238	<0.1	<0.1
		Technetium-99	<0.1	1.1
		Neptunium-237	<0.1	<0.1
4.3km downstream of BNFL's outfall	Mud	Gross alpha	<100	<100
		Gross beta	<1000	<1000
		Uranium-235	4.9	3.6
		Uranium-238	97	46
		Caesium-134	<0.3	<0.2
		Caesium-137	7.7	2.4
		Neptunium-237	28	12
		Technetium-99	140	200

**Notes**

- Gamma radiation dose rates, including a contribution from background, measured each quarter at each location did not exceed 0.1  $\mu\text{Gy h}^{-1}$ .



TABLE 7

**RADIOACTIVITY IN WATER AND SEDIMENTS  
IN THE VICINITY OF BNFL SPRINGFIELDS**

Location	Radionuclide	Water concentration, Bq kg <sup>-1</sup>			
		Sediment concentration, Bq kg <sup>-1</sup> (dry weight)			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Bank of Ribble Estuary near pipeline out-fall	Gross alpha	<1000	<1000	<1000	<1000
	Gross beta	134200	150000	190000	25400
	*Cobalt-60	<0.5	<0.5	<2	2.8
	*Caesium-134	<5	<1	<2	<7
	*Caesium-137	110	46	160	560
	*Europium-154	<1	<1	<2	<4
	*Americium-241	<10	<40	<30	322
	*Neptunium-237	<100	<100	<100	<100
	Uranium-235	4	2.8	3.8	<0.5
	Uranium-238	74	61	110	14
	Thorium-230	110	100	230	72
	Thorium-232	15	9.5	12	16
	Thorium-234	218000	148700	351100	39180
	Protactinium-234m	281900	191200	404500	42430
	Protactinium-234	150	180	270	63
Deepdale Brook	Gross alpha	1.2	3.0	3.2	<0.1
	Gross beta	<0.5	4.7	7.3	<0.5
	Uranium-235	<0.1	<0.1	<0.1	<0.1
	Uranium-238	0.86	2.9	3.5	<0.1
	Gross alpha	<1000	<1000	<1000	<1000
	Gross beta	<10000	<10000	<10000	<10000
	Uranium-235	12	2.2	4.2	4.7
	Uranium-238	240	50	80	95
	Thorium-230	85	51	62	68
	Thorium-232	23	9.0	8.4	7.4
	Neptunium-237	<100	<100	<100	<100
	Caesium-134	<0.6	<0.2	<0.3	<2
	Caesium-137	7.9	1.3	1.8	3.5
	Europium-155	<1	<0.6	<0.8	<0.8
	Protactinium-234m	1300	<100	570	270
	Thorium-234	930	48	250	190

TABLE 7 (cont)

**RADIOACTIVITY IN WATER AND SEDIMENTS  
IN THE VICINITY OF BNFL SPRINGFIELDS**

Location	Radionuclide	Water concentration, Bq kg <sup>-1</sup>			
		Sediment concentration, Bq kg <sup>-1</sup> (dry weight)			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Bank of the River Ribble near Savick Brook	*Caesium-134	8.9	<3	<3	<4
	*Caesium-137	750	730	650	640
	*Cobalt-60	4.0	<4	5.1	<7
	Thorium-230	230	200	230	310
	Thorium-232	45	42	27	25
	Thorium-234	184400	746200	637400	423700
	Protactinium-234m	206600	879000	711200	464000
	Uranium-235	4.4	7.4	7.0	5.3
	Uranium-238	85	130	110	100
	*Americium-241	580	1240	1490	1570
Bank of the River Ribble near Penwortham Bridge	*Caesium-134	<0.6	<2	<0.8	<0.7
	*Caesium-137	440	490	290	290
	*Cobalt-60	<3	<4	<2	<3
	Thorium-230	260	250	100	84
	Thorium-232	35	33	11	17
	Thorium-234	29540	168800	57640	27320
	Protactinium-234m	37500	215300	64170	39290
	Uranium-235	2.1	3.2	1.2	1.3
	Uranium-238	40	58	33	26
	*Americium-241	170	610	209	230
Bank of the River Ribble near Broadgate	*Caesium-134	<0.8	<20	<2	1.9
	*Caesium-137	700	750	660	670
	*Cobalt-60	3.0	<6	<6	<7
	Thorium-230	170	190	110	140
	Thorium-232	45	46	29	24
	Thorium-234	40810	284600	238700	89000
	Protactinium-234m	46370	324600	282400	120500
	Uranium-235	2.5	4.1	5.0	1.7
	Uranium-238	48	71	60	38
	*Americium-241	310	630	570	510
Bank of the River Ribble near Lower Penwortham Park	*Caesium-134	<0.9	<2	<1	<0.7
	*Caesium-137	880	530	550	550
	*Cobalt-60	4.1	<5	<3	3.3
	Thorium-230	410	360	400	180
	Thorium-232	43	40	43	23
	Thorium-234	51300	108700	80900	29600
	Protactinium-234m	58800	145900	92400	54800
	Uranium-235	2.4	3.3	4.1	0.9
	Uranium-238	44	56	54	34
	*Americium-241	350	310	350	300

TABLE 7 (cont)

**RADIOACTIVITY IN WATER AND SEDIMENTS  
IN THE VICINITY OF BNFL SPRINGFIELDS**

Location	Radionuclide	Water concentration, Bq kg <sup>-1</sup>			
		Sediment concentration, Bq kg <sup>-1</sup> (dry weight)			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Bank of the River Ribble near Penwortham railway bridge	*Caesium-134	5.8	<2	<2	<2
	*Caesium-137	770	730	700690	690
	*Cobalt-60	4.5	4.9	<6	<6
	Thorium-230	220	200	160	160
	Thorium-232	46	46	36	21
	Thorium-234	44200	225300	92300	84100
	Protactinium-234m	52800	271700	101100	112900
	Uranium-235	2.7	4.0	4.1	0.8
	Uranium-238	47	64	70	37
	*Americium-241	320	470	350	470
Bank of the River Ribble opposite Frenchwood Position 1	*Caesium-134	<5	<3	<2	<1
	*Caesium-137	690	470	520	560
	*Cobalt-60	<2	<3	<3	4.7
	Thorium-230	220	210	240	190
	Thorium-232	48	38	36	34
	Thorium-234	5800	63400	144600	73000
	Protactinium-234m	8400	83400	159100	99400
	Uranium-235	2.7	2.6	2.4	1.3
	Uranium-238	55	57	49	40
	*Americium-241	280	250	400	320
Bank of the River Ribble opposite Frenchwood Position 2	*Caesium-134	<1	<5	<2	<2
	*Caesium-137	570	290	430	530
	*Cobalt-60	3.9	<2	<3	<5
	Thorium-230	200	180	190	130
	Thorium-232	42	36	22	21
	Thorium-234	18400	19100	97800	59100
	Protactinium-234m	21900	24800	126100	80900
	Uranium-235	2.3	2.5	2.1	0.8
	Uranium-238	48	41	31	30
	*Americium-241	240	130	240	340
Lytham Yacht Club	*Caesium-134	<0.6	<8	<0.7	<0.9
	*Caesium-137	540	660	650	600
	*Cobalt-60	<4	3.9	5.0	<4
	Thorium-230	100	86	60	89
	Thorium-232	37	38	22	25
	Thorium-234	10700	49500	24000	15000
	Protactinium-234m	15000	62300	28200	19000
	Uranium-235	1.5	2.3	1.8	<1
	Uranium-238	34	45	29	17
	*Americium-241	210	310	330	280

**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. \*\* Results of these analyses have been corrected for decay to the sampling date in each case.
3. 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 IN THE VICINITY OF BNFL SPRINGFIELDS**

Location	Dose rate, $\mu\text{Gy h}^{-1}$	
	Quarter 2	Quarter 4
Bank of Ribble Estuary near pipeline out-fall	0.13	0.21
Bank of the River Ribble near Savick Brook	0.27	0.39
Bank of the River Ribble near Penwortham Bridge	0.17	0.21
Bank of the River Ribble near Broadgate	0.18	0.22
Bank of the River Ribble near Lower Penwortham Park	0.15	0.18
Bank of the River Ribble near Penwortham Railway Bridge	0.11	0.18

**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.

TABLE 9

**MEAN GAMMA RADIATION DOSE RATES AT 1 METRE  
OVER INTER-TIDAL AREAS IN THE VICINITY OF  
NUCLEAR ELECTRIC POWER STATIONS**

Location	Ground type	Dose rate, $\mu\text{Gy h}^{-1}$	
		Quarter 2	Quarter 4
Sizewell			
Sizewell Beach	Sand	0.07	0.06
Bradwell			
Bradwell Beach	Sand	0.39	0.11
Beach opposite power station on north side of estuary	Silt	0.07	0.06
Dungeness			
Rye Bay	Sand	0.06	0.08
Jury Gap	Pebbles	0.06	0.08
Dungeness south coast	Pebbles	0.05	0.09
Dungeness east coast	Pebbles	0.06	0.08
Greatstone on Sea	Pebbles	0.06	0.07
Littlestone on Sea	Pebbles	0.06	0.08

TABLE 9 (cont)

**MEAN GAMMA RADIATION DOSE RATES AT 1 METRE  
OVER INTER-TIDAL AREAS IN THE VICINITY OF  
NUCLEAR ELECTRIC POWER STATIONS**

Location	Ground type	Dose rate, $\mu\text{Gy h}^{-1}$	
		Quarter 2	Quarter 4
<b>Hinkley Point</b>			
Weston-super-Mare	Sand	0.07	0.07
Burnham on Sea beach	Sand	0.06	0.07
Stearl Flats (wall common)	Silt	0.07	0.10
Stolford	Silt	0.07	0.07
Beach at Kilve	Sand	0.07	0.10
Watchet harbour	Sand	0.09	0.11
Beach at Blue Anchor Bay	Sand	0.08	0.09
Hinkley Point Beach	Pebbles	0.08	0.23
<b>Berkeley</b>			
Beach near Severn House Farm			
Point A	Silt	0.09	0.10
Point B	Silt	0.09	0.12
Point C	Silt	0.09	0.08
Point D	Silt	0.09	0.13
Beach at Newtown	Silt	0.09	0.12
Beach at Purton	Silt	0.09	0.12
Lydney Harbour	Pebbles/rock	0.07	0.08
<b>Oldbury</b>			
Beach at Chapel House	Silt	0.11	0.12
Beach at Aust	Silt	0.09	0.09
Beach at Littleton Wharf	Silt	0.09	0.11
Beach at Pill House	Silt	0.08	0.11
Beach at Beachley	Silt	0.08	0.09
Heysham			
Beach at Middleton Sands	Sand	0.09	0.08
Beach at Half Moon Bay	Sand	0.08	0.07
<b>Hartlepool</b>			
Seaton Carew	Sand	0.06	0.10
<b>Trawsfynydd</b>			
Lake shore at Boat Club	Pebbles	0.09	0.08
<b>Wylfa</b>			
Cemaes Bay	Sand	0.07	0.11

**Notes**

- Each result shown is the mean of three readings obtained using a Mini-Instruments Environmental meter type 6-80.
- The dose rates shown include a contribution from background radiation.



TABLE 10

**RADIOACTIVITY IN SURFACE WATERS IN  
THE VICINITY OF NUCLEAR ELECTRIC POWER STATIONS**

Location	Radionuclide	Sample concentration Bq kg <sup>-1</sup>	
		Quarter 2	Quarter 4
Sizewell			
Nature Reserve	Tritium	2.7	N.S.
The Meare	Tritium	6.8	N.S.
Leisure Park	Tritium	10.0	N.S.
Bradwell			
Public supply near Bradwell	Tritium	4.6	0.7
	Gross beta	5.2	<0.5
Coastal ditch sample point 1	Tritium	Dry	Dry
Coastal ditch sample point 2	Tritium	Dry	Dry
Coastal ditch sample point 3	Tritium	118	Dry
	Gross beta	6.5	
Coastal ditch sample point 4	Tritium	114	16
	Gross beta	7.9	17
	Sulphur-35	4.7	<1
Dungeness			
Standing water at Long Pits	Tritium	4.7	5.5
Pumping station well no. 1	Tritium	4.4	N.S.
Pumping station well no. 2	Tritium	N.S.	4.1
Pumping station well no. 3	Tritium	4.4	N.S.
Reservoir	Tritium	N.S.	4.7
Hinkley Point			
Durleigh Reservoir	Tritium	4.9	4.4
Ashford Reservoir	Tritium	7.2	8.7
Berkeley			
Gloucester and Sharpness Canal	Tritium	5.4	4.7
Oldbury			
Public supply	Tritium	3.2	2.9
Heysham			
Public supply at Lancaster	Tritium	5.1	6.4

TABLE 10 (cont)

**RADIOACTIVITY IN SURFACE WATERS IN  
THE VICINITY OF NUCLEAR ELECTRIC POWER STATIONS**

Location	Radionuclide	Sample concentration Bq kg <sup>-1</sup>	
		Quarter 2	Quarter 4
Hartlepool			
Public supply	Tritium	4.1	3.7
Boreholes at Dalton Piercy	Tritium	2.6	2.7
Trawsfynydd			
Public supply	Tritium	3.6	8.4
Gwylan stream	Tritium	6.9	3.9
Diversion culvert	Tritium	3.9	4.2
Hot lagoon	Tritium	4.8	9.4
Afon Prysor	Tritium	3.8	10.0
Lake Trawsfynydd	Tritium	5.2	4.8
Wylfa			
Public supply	Tritium	3.7	N.S.

**Notes**

1. All samples:
  - (a) except where shown the gross alpha and gross beta activity of all samples was less than 0.1 and 0.5 Bq kg<sup>-1</sup> respectively;
  - (b) except where shown the concentrations of sulphur-35 were less than 1.0 Bq kg<sup>-1</sup>;
  - (c) except where noted in (2) below no radionuclides were detected by gamma-ray spectrometry.
2. Gross beta activity was detected in samples of water from the coastal ditch, Bradwell. Increased concentrations of potassium-40 were also observed in some samples which would, at least in part, account for the gross beta activities observed. Potassium-40 is a naturally occurring radionuclide and the increased levels observed probably result from the agricultural use of artificial fertilisers.
3. N.S. - not sampled. Samples were obtained from Sizewell and Wylfa only once during 1996.

TABLE 11:

**RADIOACTIVITY IN SEDIMENTS FROM THE RIVER THAMES  
IN THE VICINITY OF HARWELL**

Location	Radionuclide	Sample concentration, Bq kg <sup>-1</sup> (dry weight)			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Lydebank Brook	Uranium-234	20	16	11	9.2
	Uranium-238	20	15	11	9.2
	Cobalt-60	<1	<2	<0.3	<0.6
	Caesium-134	<0.6	<2	<0.3	<0.5
	Caesium-137	18	17	10	14
	Plutonium 239/240	1.2	1.0	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
<b>River Thames bank</b>					
Sutton Courtenay	Uranium-234	19	11	10	7.2
	Uranium-238	19	12	11	7.8
	Cobalt-60	5.9	9.9	7.8	12
	Caesium-134	<3	<2	<0.6	<2
	Caesium-137	243	247	315	200
	Plutonium-239/240	2.4	2.5	<0.2	3.4
	Americium-241	<0.2	<0.2	<0.2	<0.2
Appleford	Uranium-234	21	15	12	3.3
	Uranium-238	21	14	13	4.1
	Cobalt-60	<2	<1	<0.8	<0.9
	Caesium-134	<0.7	<2	<0.3	<0.8
	Caesium-137	20	24	25	32
	Plutonium-239/240	0.84	2.7	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2
Day's Lock	Uranium-234	13	13	15	3.6
	Uranium-238	13	13	16	4.0
	Cobalt-60	<1	<0.3	<0.2	<0.6
	Caesium-134	<0.4	<0.3	<0.2	<0.2
	Caesium-137	17	4.2	2.6	2.7
	Plutonium-239/240	0.43	0.22	<0.2	<0.2
	Americium-241	<0.2	<0.2	<0.2	<0.2

**Notes**

- All samples:
  - gross alpha and gross beta activities were less than 100 and 1000 Bq kg<sup>-1</sup> respectively;
  - except for cobalt-60, caesium-134, caesium-137 and americium-241, no radionuclides were detected by gamma-ray spectrometry.
- Mean gamma radiation dose rates in air, including a contribution from background, at 1m over sediments on the bank of the River Thames, measured in the second and fourth quarters, at Appleford, Sutton Courtenay and Day's Lock, did not exceed 0.10 µGy h<sup>-1</sup>.

TABLE 12

**RADIOACTIVITY IN SURFACE WATERS OF THE RIVER THAMES  
IN THE VICINITY OF HARWELL**

Location	Radionuclide	Sample concentration, Bq kg <sup>-1</sup>			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Lydebank Brook	Tritium	6.6	5.2	5.0	4.8
River Thames above discharge point	Tritium	3.5	4.6	7.6	8.7
River Thames below discharge point	Tritium	5.7	11	11	9.7
Day's Lock	Tritium	7.4	7.4	15	4.0

**Notes**

1. All samples:

- (a) gross alpha and gross beta concentrations were less than 0.1 and 1.0 Bq l<sup>-1</sup> respectively;  
 (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  
IN THE VICINITY OF WINFRITH**

Location	Ground type	Dose rate, $\mu\text{Gy h}^{-1}$
		Quarter 2
Kimmeridge Bay	Silt	0.08
Poole Harbour	Silt	0.06
Weymouth Bay	Sand/shingle	0.06
Beach between Radcliffe Point and Black Head	Shingle/rock	0.06
Ringstead Bay	Pebbles/rock	0.06
Durdle Door	Sand/shingle	0.07
St Oswald's Bay	Sand/shingle	0.06
Lulworth Cove	Shingle	0.06
Arish Mell	Sand/shingle	0.05
Swanage Bay	Sand	0.06

**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.

TABLE 14

**RADIOACTIVITY IN SURFACE WATER AND ASSOCIATED SEDIMENTS  
IN THE VICINITY OF UKAEA WINFRITH.**

Location	Sample type	Radionuclide	Sample concentration	
			Water, Bq kg <sup>-1</sup>	Sediment, Bq kg <sup>-1</sup> (dry weight)
			Quarter 2	Quarter 4
Local Stream A north of site	Water	Gross beta	<1	<1
		Tritium	9.6	19
	Sediment	Cobalt-60	<0.6	<1
		Caesium-134	<0.2	<0.2
		Caesium-137	8.8	7.9
River Frome at Wool	Water	Gross beta	<1	<1
		Tritium	8.3	8.8
River Frome at Winfrith	Water	Gross beta	<1	8.8
		Tritium	<1	10
	Sediment	Cobalt-60	<0.5	<0.7
		Caesium-134	<0.6	<0.5
		Caesium-137	1.5	<0.4
Local Stream B east of site	Water	Gross beta	<1	<1
		Tritium	13	11
	Sediment	Cobalt-60	<0.2	<0.8
		Caesium-134	<0.2	<0.6
		Caesium-137	<0.7	1.2

**Notes**

1. All water samples:
  - a) gross alpha activities were below 0.1 Bq kg<sup>-1</sup>;
  - b) no radionuclides were detected by gamma-ray spectrometry.
2. All sediment samples:
  - a) gross alpha and gross beta activities were below 100 and 1000 Bq kg<sup>-1</sup> respectively;
  - b) no other radionuclides were detected by gamma-ray spectrometry.
3. Sediment from the River Frome at Wool was not sampled during 1996.



TABLE 15

**RADIOACTIVITY IN SEWAGE AT MAPLE LODGE SEWAGE  
TREATMENT PLANT**

Sample type	Radionuclide	Sample concentration, Bq kg <sup>-1</sup>			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Raw effluent	Gross alpha	0.14	<0.1	0.11	<0.1
	Gross beta	1.7	0.7	0.77	0.6
	Tritium	<1.0	4.2	7.7	<3.0
	Carbon-14	<0.1	<0.1	<0.1	<0.4
	Iodine-125	8.9	<0.05	<0.7	<1.0
	Potassium-40	ND	ND	ND	ND
Final effluent	Gross alpha	<0.1	<0.1	<0.1	<0.1
	Gross beta	1.4	<0.9	0.58	<0.5
	Tritium	<1.0	3.9	6.4	<3.0
	Carbon-14	<0.1	<0.1	<0.1	<0.4
	Iodine-125	<0.05	<0.05	<0.8	<1.5
Digested sludge	Gross alpha	5.5	3.3	5.1	2.2
	Gross beta	12.1	10.4	9.5	10.1
	Tritium	6.6	5.1	6.3	<3.0
	Carbon-14	<0.1	<0.1	<0.1	3.0
	Iodine-125	0.6	<0.05	<0.5	<0.2
	Cobalt -57	3.1	2.6	<1.0	1.5
	Cobalt -58	1.1	<1.0	<1.0	<1.0
	Zinc-65	2.8	2.1	<1.0	2.8
	Europium-155	ND	ND	ND	ND
	Potassium-40	ND	ND	ND	ND
Total solids (g l <sup>-1</sup> )		24.2	24.2	23.0	25.4

**Note**

1. ND - not detected.

TABLE 16

**RADIOACTIVITY IN SURFACE WATERS AND ASSOCIATED SEDIMENTS  
IN THE VICINITY OF AMERSHAM INTERNATIONAL (AMERSHAM)**

Location	Sample type	Radionuclide	Sample concentration			
			Water, Bq kg <sup>-1</sup>		Sediment, Bq kg <sup>-1</sup> (dry weight)	
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
River Colne at Maple Cross	Water	Gross beta	1.2	1.2	<0.5	<0.5
		Tritium	3.2	12	9.7	9.5
	Sediment	Cobalt-57	4.6	<3	5.4	4.1
		Caesium-134	<0.3	<0.6	<0.5	<0.7
		Caesium-137	1.6	2.3	2.6	8.8

**Notes**

1. *Water samples:*  
 (a) gross alpha activities were less than 0.1 Bq l<sup>-1</sup>;  
 (b) except where shown, no radionuclides were detected by gamma-ray spectrometry.
2. *Sediment Samples:*  
 (a) gross alpha and gross beta activities were less than 100 and 1000 Bq kg<sup>-1</sup> respectively;  
 (b) except for cobalt-57, caesium-134 and caesium-137 as specified, no radionuclides were detected by gamma-ray spectrometry.

TABLE 17

**RADIOACTIVITY IN SURFACE WATERS IN THE  
VICINITY OF AMERSHAM INTERNATIONAL (CARDIFF)**

Location	Radionuclide	Sample concentration, Bq kg <sup>-1</sup>			
		Quarter 1	Quarter 2	Quarter 3	Quarter 4
Storm-water outfall	Tritium		7.2	460	83
	Total beta	Dry	<0.5	<0.5	<0.5
River Taff	Tritium	6.2	7.6	11	10
	Total beta	<0.5	<0.5	<0.5	<0.5
Glamorganshire Canal	Tritium	42	43	65	39
	Total beta	<0.5	<0.5	<0.5	<0.5

**Notes**

1. *All samples:*  
 (a) gross alpha activities were less than 0.1 Bq l<sup>-1</sup>;  
 (b) no radionuclides were detected by gamma-ray spectrometry.

TABLE 18

**RADIOACTIVITY IN WATER AND ASSOCIATED SEDIMENTS IN THE VICINITY  
OF ATOMIC WEAPONS ESTABLISHMENT (ALDERMASTON)**

Location	Sample type	Radionuclide	Sample concentration			
			Water, Bq kg <sup>-1</sup>		Sediment, Bq kg <sup>-1</sup> (dry weight)	
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
River Thames at Pangbourne	Water	Gross beta	<0.5	<0.5	<0.5	<0.5
		Tritium	7.0	14	11	7.2
	Sediment	Caesium-134	<2	<08	<0.4	<0.2
		Caesium-137	27	19	33	18
		Uranium-234	12	8.9	6.0	10
		Uranium-238	12	9.2	6.5	11
		Plutonium-239/240	0.66	4.5	1.9	4.8
River Thames at Mapledurham	Water	Gross beta	<0.5	<0.5	<0.5	<0.5
		Tritium	4.6	15	5.2	19
	Sediment	Caesium-134	<0.3	<0.8	<0.3	<0.3
		Caesium-137	24	26	16	40
		Uranium-234	13	13	11	12
		Uranium-238	13	14	12	11
		Plutonium-239/240	0.61	0.52	1.6	<0.2
River Kennet at Reading	Water	Tritium	<0.5	<0.5	<0.5	<0.5
		Gross beta	4.1	8.1	7.2	8.3
	Sediment	Caesium-134	<0.8	<0.7	<0.3	<0.3
		Caesium-137	8.5	6.2	1.2	1.8
		Uranium-234	28	15	10	5.8
		Uranium-238	28	15	11	6.2
		Plutonium-239/240	0.39	0.52	1.3	<0.2
Stream at Aldermaston village	Water	Gross beta	<0.5	<0.5	<0.5	<0.5
		Tritium	29	96	30	26
	Sediment	Caesium-134	<0.4	<0.5	<0.5	<0.3
		Caesium-137	5.9	5.2	3.9	6.1
		Uranium-234	17	16	12	11
		Uranium-238	17	16	14	12
		Plutonium-239/240	2.5	2.0	7.0	4.1
Stream at Spring Lane	Water	Gross beta	<0.5	<0.5	<0.5	<0.5
		Tritium	12	16	9.7	13
	Sediment	Caesium-134	<0.3	<0.8	<0.5	<0.4
		Caesium-137	3.0	3.7	2.1	2.4
		Uranium-234	16	14	15	12
		Uranium-238	16	14	13	11
		Plutonium-239/240	0.68	0.43	0.70	<0.2

**Notes**

1. All water samples:
  - (a) gross alpha activities were less than 0.1 Bq kg<sup>-1</sup>;
  - (b) no radionuclides were detected by gamma-ray spectrometry.
2. All sediment samples:
  - (a) gross alpha and gross beta activities were less than 100 and 1000 Bq kg<sup>-1</sup> respectively;
  - (b) except for caesium-134 and caesium-137, no radionuclides were detected by gamma-ray spectrometry.

TABLE 19

**TRITIUM CONCENTRATIONS IN SURFACE WATER  
IN THE VICINITY OF SURELITE'S SITE**

Location	Distance from site (km)	Sample concentration Bq kg <sup>-1</sup>
Stream at Weldon	1	12.8
Stream at Weldon Lodge, Weldon	2	8.2
Harper's Brook at Brigstock	5	6.1
River Welland at Rockingham	6	3.8
Harper's Brook on A6014	7	5.2
Eyebrook Water	10	6.0
Rutland Water	16	2.7
Pitsford Reservoir	24	3.5

**Notes**

1. All samples:

- (a) gross alpha and gross beta activities were below 0.1 and 1.0 Bq kg<sup>-1</sup> respectively;
- (b) no radionuclides were detected by gamma-ray spectrometry;
- (c) sampling period: quarter 1.

TABLE 20

**RADIOACTIVITY IN LEACHATES, GROUND AND SURFACE WATERS  
IN THE VICINITY OF LANDFILL SITES**

Location	Sample source	Radionuclide	Activity concentration Bq kg <sup>-1</sup>			
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
<b>Cambridgeshire</b>						
Milton landfill	Site borehole A	Tritium	270	N.S.	260	N.S.
Cambridge		Gross beta	23	N.S.	19	N.S.
	Site drainage	Tritium	16	N.S.	Dry	N.S.
	Groundwater borehole	Tritium	3.0	N.S.	9.2	N.S.
	Phase 2 borehole L9	Tritium	24	N.S.	38	N.S.
		Gross beta	0.5	N.S.	4.0	N.S.
	Phase 2 borehole L12	Tritium	Dry	N.S.	100	N.S.
		Gross beta	Dry	N.S.	8.2	N.S.
<b>Cardiff</b>						
Lamby Way tip	Borehole 1A	Tritium	200	N.S.	190	N.S.
		Gross beta	3.6	N.S.	5.3	N.S.
<b>Cheshire</b>						
Witton tip	Site borehole WM6G	Tritium	580	N.S.	580	N.S.
Northwich		Gross beta	4.2	N.S.	5.9	N.S.
	Site borehole WM20G	Tritium	6.2	N.S.	6.5	N.S.
		Gross beta	1.2	N.S.	<0.5	N.S.
	Site borehole WM5G	Tritium	22	N.S.	21	N.S.
		Gross beta	5.5	N.S.	6.4	N.S.
<b>Cleveland</b>						
ICI Ltd	Local stream, upstream	Tritium	12	N.S.	19	N.S.
		Gross beta	11	N.S.	6.8	N.S.
Cowpen Bewley tip	Local stream, downstream	Tritium	1210	N.S.	1220	N.S.
		Gross beta	4.0	N.S.	9.4	N.S.
<b>Cumbria</b>						
Vickers waste ponds Walney Island	Pond water	Tritium	5.4	N.S.	N.S.	N.S.
<b>Derbyshire</b>						
Rolls-Royce Hilts Quarry	Fritchley Brook	Tritium	4.1	N.S.	N.S.	N.S.
<b>Durham</b>						
High Urpeth tip	Local water	Tritium	7.3	N.S.	N.S.	N.S.
<b>Gloucestershire</b>						
Crooks Marsh	Leachate	Tritium	13	N.S.	Dry	N.S.
Farm Avonmouth		Gross beta	1.4	N.S.		N.S.

TABLE 20 (cont)

**RADIOACTIVITY IN LEACHATES, GROUND AND SURFACE WATERS  
IN THE VICINITY OF LANDFILL SITES**

Location	Sample source	Radionuclide	Activity concentration Bq kg <sup>-1</sup>			
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
Greater London						
Murex Ltd	Local stream A	Tritium	2.9	N.S.	N.S.	N.S.
	Local stream B	Tritium	3.5	N.S.	N.S.	N.S.
Greater Manchester						
Magnesium Elektron Swinton	Local water	Tritium	3.2	N.S.	N.S.	N.S.
Gwynedd						
Cilgwyn Quarry Caernarfon	Leachate	Tritium	N.S.	160	N.S.	230
		Gross beta	N.S.	1.0	N.S.	1.0
	Leachate 2nd Pit	Tritium	N.S.	Dry	N.S.	5.2
		Gross beta	N.S.		N.S.	1.0
Hertfordshire						
Braziers landfill	Site borehole 1	Tritium	4.8	N.S.	22	N.S.
	Site borehole 5	Tritium	3.8	N.S.	4.1	N.S.
	Site borehole 9	Tritium	5.1	N.S.	5.4	N.S.
Cole Green landfill	Culverted stream	Tritium	3.6	N.S.	53	N.S.
	Site borehole	Tritium	64	N.S.	82	N.S.
		Gross beta	5.2	N.S.	9.8	N.S.
Lancashire						
Clifton Marsh, Preston	Site borehole 6	Tritium	18	N.S.	21	N.S.
		Gross beta	0.8	N.S.	1.3	N.S.
	Site borehole 9	Tritium	12		9.6	
	Site borehole 19	Tritium	8.7	N.S.	14	N.S.
		Gross beta	2.1	N.S.	1.1	N.
	Site borehole 40	Tritium	5.4	N.S.	9.8	N.S.
		Gross beta	0.8	N.S.	1.1	N.S.
	Site borehole 59	Tritium	37	N.S.	34	N.S.
Ulmes Walton	River Lostock upstream	Gross beta	1.8	N.S.	<0.5	N.S.
		Tritium	4.2	N.S.	N.S.	N.S.
	River Lostock downstream	Tritium	4.4	N.S.	N.S.	N.S.
Whittle Hill Quarry	River Lostock	Tritium	6.1	N.S.	5.4	N.S.
Birkacre mine shaft	Local water	Tritium	4.1	N.S.	6.6	N.S.
	River Yarrow	Tritium	4.9	N.S.	7.5	N.S.
Lincolnshire						
Millennium	Local water	Tritium	2.2	N.S.	4.5	N.S.
Inorganic Chemicals						
Stallingborough		Gross beta	1.5	N.S.	3.0	N.S.
Site tip						



TABLE 20 (cont)

**RADIOACTIVITY IN LEACHATES, GROUND AND SURFACE WATERS  
IN THE VICINITY OF LANDFILL SITES**

Location	Sample source	Radionuclide	Activity concentration Bq kg <sup>-1</sup>			
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
Merseyside						
Sefton Meadows tip	Site borehole 25	Tritium	3.0	N.S.	N.S.	N.S.
Arpley landfill		Tritium	12	N.S.	20	N.S.
		Gross beta	<0.5	N.S.	0.7	N.S.
Norfolk						
Strumpshaw landfill	Site leachate borehole 3	Tritium	N.S.	4.1	N.S.	4.9
	Site leachate borehole 2	Tritium	N.S.	3.8	N.S.	3.6
	Strumpshaw Reservoir	Tritium	N.S.	4.7	N.S.	N.S.
	Strumpshaw abstraction	Tritium	N.S.	3.6	N.S.	N.S.
Nottinghamshire						
School of Agriculture Sutton Bonington	Local stream	Tritium	3.2	N.S.	N.S.	N.S.
Oxfordshire						
Stanford in the Vale	Local water	Tritium	4.7	N.S.	9.2	N.S.
	Site borehole 15	Tritium	10	N.S.	11	N.S.
South Yorkshire						
Bighton tip	Local water	Tritium	11	N.S.	N.S.	N.S.
Sheffield	Site borehole	Tritium	17	N.S.	N.S.	N.S.
		Gross beta	1.9	N.S.	N.S.	N.S.
Sussex						
Beddingham Quarry	Leachate - site 1	Tritium	N.S.	430	N.S.	300
		Gross beta	N.S.	8.6	N.S.	7.5
	Stream - site 2	Tritium	N.S.	Dry	N.S.	Dry
	Borehole - site 3	Tritium	N.S.	27	N.S.	27
Tyne and Wear						
Folly Quarry/Ryton Tip, Gateshead	Local water	Tritium	8.3	N.S.	N.S.	N.S.
Kibblesworth Colliery	Local water	Tritium	3.9	N.S.	N.S.	N.S.

TABLE 20 (cont)

**RADIOACTIVITY IN LEACHATES, GROUND AND SURFACE WATERS  
IN THE VICINITY OF LANDFILL SITES**

Location	Sample source	Radionuclide	Activity concentration Bq kg <sup>-1</sup>			
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
West Yorkshire						
Gelderd Road tip	Local water	Tritium	4.3	N.S.	9.5	N.S.
Leeds		Gross beta	0.7	N.S.	<0.5	N.S.
Greaseworks tip	Local water	Tritium	84	N.S.	130	N.S.
Morley		Gross beta	2.8	N.S.	2.8	N.S.
Wilson Road tip	Local water	Tritium	3.2	N.S.	42	N.S.
Bradford		Gross beta	<0.5	N.S.	1.9	N.S.
Dean House Farm	Local water	Tritium	22	N.S.	23	N.S.
tip, Bradford		Gross beta	2.2	N.S.	2.3	N.S.

**Notes**

1. All samples:

- (a) except where shown all gross alpha and gross beta activities were less than 0.1 and 1.0 Bq kg<sup>-1</sup> respectively;
- (b) except where shown no radionuclides were detected by gamma-ray spectrometry;
- (c) uranium, thorium, carbon-14 and iodine-125 measured in leachate samples were all less than 0.1 Bq kg<sup>-1</sup>.

2. N.S. - not sampled.

TABLE 21

## RADIOACTIVITY IN AIR AND RAINWATER

Location	Sample type	Radionuclide	Sample concentration air $\mu\text{Bq kg}^{-1}$ rainwater $\text{Bq kg}^{-1}$			
			Quarter 1	Quarter 2	Quarter 3	Quarter 4
Chilton	Air	Caesium-137	0.73	0.48	<0.2	0.13
		Beryllium-7	2600	4100	2500	2500
	Rainwater	Caesium-137	<0.021	<0.023	<0.057	<0.019
		Beryllium-7	1.4	2.1	2.8	1.0
Aberporth	Air	Caesium-137	<0.3	<0.3	<0.4	<0.3
		Beryllium-7	2400	2700	2200	1900
	Rainwater	Caesium-137	<0.031	<0.026	<0.041	<0.024
		Beryllium-7	1.5	1.0	<1.0	1.6
		Tritium	0.7	<2	2.3	<2
Conlig	Air	Caesium-137	0.94	0.93	<0.8	0.46
		Beryllium-7	2500	2200	2700	2200
	Rainwater	Caesium-137	<0.014	<0.012	<0.029	<0.014
		Beryllium-7	1.3	1.5	<0.5	1.3
Dishforth	Air	Caesium-137	0.72	0.49	<0.3	0.35
		Beryllium-7	2600	2500	2500	2500
	Rainwater	Caesium-137	<0.044	<0.03	<0.026	<0.032
		Beryllium-7	2.6	2.1	1.3	1.5
Eskdalemuir	Air	Caesium-137	1.2	0.85	<0.8	0.42
		Beryllium-7	2900	2600	3300	1800
	Rainwater	Caesium-137	<0.010	<0.007	<0.019	<0.007
		Beryllium-7	1.1	1.5	1.2	1.2
		Tritium	3.2	4.2	<2	4.3
Lerwick	Air	Caesium-137	0.62	0.81	<0.4	0.42
		Beryllium-7	3500	2400	3200	2300
	Rainwater	Caesium-137	<0.021	0.038	<0.022	<0.012
		Beryllium-7	2.5	3.0	1.9	1.5
Orfordness	Air	Caesium-137	1.3	0.53	<0.5	0.8
		Beryllium-7	2700	3400	3800	4400
	Rainwater	Caesium-137	<0.044	<0.120	<0.042	<0.023
		Beryllium-7	<1.0	2.8	<4	1.8
		Tritium	2.0	<2.0	<2	3.1
Aldergrove	Rainwater	Caesium-137	<0.011	<0.018	<0.020	<0.012
		Beryllium-7	1.2	1.0	1.7	0.8
Snowdon	Rainwater	Caesium-137	N.S	N.S	<0.028	<0.017
		Beryllium-7	N.S	N.S	1.4	1.2

## Notes

1) N.S. Not sampled.

TABLE 22

## PUBLIC DRINKING WATER SOURCES

Calendar quarter	Gross alpha <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	H-3 Bq l <sup>-1</sup>	K-40 <sup>a</sup> mBq l <sup>-1</sup>	Sr-90 mBq l <sup>-1</sup>	I-125 mBq l <sup>-1</sup>	Cs-134 mBq l <sup>-1</sup>	Cs-137 mBq l <sup>-1</sup>	Po-210 mBq l <sup>-1</sup>	Ra-226 mBq l <sup>-1</sup>	U-234 mBq l <sup>-1</sup>	U-235 mBq l <sup>-1</sup>	U-238 mBq l <sup>-1</sup>	K mg l <sup>-1</sup>	Ca mg l <sup>-1</sup>	Sr mg l <sup>-1</sup>
<b>Elan Valley Reservoir, Powys, Wales</b>																	
Q1	< 0.02	< 0.05	< 0.05	1.23	< 10	10.7	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.3	2.1	< 0.1
Q2	< 0.02	< 0.05	< 0.05	1.41	< 10	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	< 0.1	70	0.25
Q3	< 0.02	< 0.05	< 0.05	1.35	< 10	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	< 0.1	1.3	< 0.1
Q4	< 0.02	< 0.05	< 0.05	4.63	31	3.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	18	< 0.1
<b>River Severn, Tewkesbury, Gloucs</b>																	
Q1	0.060	0.199	0.197	1.40	130	< 1	< 2	< 1	< 1	< 10	< 10	20	< 10	13	4.2	57	0.24
Q2	0.044	< 0.05	< 0.05	1.77	133	3.8	< 2	< 1	< 1	< 10	< 10	22	< 10	10	4.4	57	0.25
Q3	0.032	0.324	0.279	1.62	200	< 1	< 2	< 1	< 1	< 10	< 10	22	< 10	13	6.6	66	0.3
Q4	0.046	0.198	0.171	1.26	124	1.8	< 2	< 1	< 1	< 10	< 10	16	< 10	< 10	4.1	100	0.3
<b>Meerbrook Sough, Groundwater, Derbyshire</b>																	
Q1	0.181	0.099	0.099	1.56	31	< 1	< 2	< 1	< 1	< 10	< 10	39	< 10	19	1	130	0.63
Q2	0.071	0.180	0.177	1.62	94	< 1	NS	< 1	< 1	< 10	< 10	52	< 10	25	3.1	20	< 0.1
Q3	0.115	0.117	0.104	1.68	27	< 1	< 2	< 1	< 1	< 10	< 10	29	< 10	15	0.9	88	0.6
Q4	0.130	0.125	0.113	1.55	33	< 1	< 2	< 1	< 1	< 10	< 10	50	< 10	25	1.1	88	0.5
<b>River Tees, County Durham</b>																	
Q1	0.030	0.108	0.113	1.69	62	7.8	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	88	0.34
Q2	< 0.02	0.090	0.082	1.88	36	14.8	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.2	45	0.15
Q3	0.020	0.095	0.084	1.69	30	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	22	0.2
Q4	0.025	0.090	0.088	1.71	42	6.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.4	100	0.4
<b>Kielder Reservoir, Northumbria</b>																	
Q1	< 0.02	0.063	0.067	6.93	16	8.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.5	9.8	< 0.1
Q2	< 0.02	0.064	0.057	6.95	15	7.9	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.5	9.1	< 0.1
Q3	< 0.02	0.069	0.076	6.26	18	4.6	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.6	9.1	< 0.1
Q4	< 0.02	< 0.05	< 0.05	6.24	20	6.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.7	16	0.1
<b>Tunstall Reservoir, County Durham</b>																	
Q1	< 0.02	0.074	0.075	1.78	31	9.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	10	< 0.1
Q2	0.024	< 0.05	< 0.05	1.93	36	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.2	10	< 0.1
Q3	< 0.02	0.088	0.076	1.66	30	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	12	< 0.1
Q4	< 0.02	0.074	0.063	1.74	36	5.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.2	17	< 0.1
<b>Haweswater Reservoir, Cumbria</b>																	
Q1	NS	NS	NS	1.46	NS	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Q3	< 0.02	0.093	0.083	1.78	30	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	36	0.2
Q4	< 0.02	0.094	0.083	1.79	45	7.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.5	40	0.1
<b>River Lune, Halton, Lancashire</b>																	
Q1	NS	NS	NS	1.70	NS	9.4	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Q3	NS	NS	NS	1.52	NS	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q4	< 0.02	< 0.05	< 0.05	2.52	12	2.6	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.4	7.4	< 0.1
<b>Arnfield Water Treatment Works, Derbyshire</b>																	
Q1	< 0.02	0.066	0.070	2.06	25	6.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	22	< 0.1
Q2	< 0.02	< 0.05	< 0.05	1.87	26	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	6.9	< 0.1
Q3	< 0.02	0.062	0.055	1.72	24	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	6.3	< 0.1
Q4	0.039	0.057	0.053	1.84	28	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.9	62	1

TABLE 22 (cont)

## PUBLIC DRINKING WATER SOURCES

Calendar quarter	Gross alpha <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	H-3 Bq l <sup>-1</sup>	K-40 <sup>a</sup> mBq l <sup>-1</sup>	Sr-90 mBq l <sup>-1</sup>	I-125 mBq l <sup>-1</sup>	Cs-134 mBq l <sup>-1</sup>	Cs-137 mBq l <sup>-1</sup>	Po-210 mBq l <sup>-1</sup>	Ra-226 mBq l <sup>-1</sup>	U-234 mBq l <sup>-1</sup>	U-235 mBq l <sup>-1</sup>	U-238 mBq l <sup>-1</sup>	K mg l <sup>-1</sup>	Ca mg l <sup>-1</sup>	Sr mg l <sup>-1</sup>
<b>Ennerdale Lake, Cumbria</b>																	
Q1	NS	NS	NS	2.70	NS	12.6	< 2	< 1	1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q2	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Q3	NS	NS	NS	2.41	NS	4.4	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q4	< 0.02	< 0.05	< 0.05	2.81	12	6.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.4	6.8	< 0.1
<b>Corn Close, groundwater, Lancashire</b>																	
Q1	< 0.02	0.052	0.053	1.91	25	4.8	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	92	1.6
Q2	< 0.02	0.079	0.072	1.91	54	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.8	32	0.2
Q3	0.027	0.152	0.131	1.50	97	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.2	34	0.4
Q4	< 0.02	0.087	0.074	2.04	36	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.2	30	0.1
<b>Denge, shallow groundwater, Folkestone, Kent</b>																	
Q1	< 0.02	0.254	0.255	2.75	174	9.8	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5.6	50	0.3
Q2	< 0.02	0.151	0.159	2.64	185	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	6.1	120	0.6
Q3	< 0.02	0.314	0.271	2.19	218	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	7.2	60	0.4
Q4	< 0.02	0.155	0.134	2.63	182	3.6	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	6	89	0.4
<b>Kent, Deep Groundwater</b>																	
Q1	< 0.02	0.269	0.255	< 1	31	2.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	110	0.2
Q2	< 0.02	0.082	0.073	< 1	64	3.5	NS	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.1	0.6	< 0.1
Q3	< 0.02	0.140	0.129	< 1	30	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	110	0.2
Q4	< 0.02	0.057	0.051	< 1	19	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.6	64	0.2
<b>River Dee, Cheshire</b>																	
Q1	0.095	0.199	0.201	1.51	130	10.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.2	34	0.1
Q2	0.153	< 0.05	< 0.05	1.40	148	10.7	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4.9	33	0.1
Q3	< 0.02	0.250	0.255	1.23	172	5.3	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	5.7	26	0.2
Q4	< 0.02	0.170	0.146	1.43	97	4.7	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.2	24	< 0.1
<b>Llwyn-on Reservoir, Mid-Glamorgan</b>																	
Q1	0.061	0.087	0.091	1.05	16	10.0	< 2	< 1	< 1	10.3	< 10	< 10	< 10	< 10	0.5	10	< 0.1
Q2	0.038	0.067	0.058	20.69	18	8.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.6	19	< 0.1
Q3	NS	NS	NS	2.40	NS	3.9	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	NS	NS	NS
Q4	< 0.11	< 0.097	< 0.084	2.66	12	7.4	< 4	< 2	< 2	< 10	< 10	< 10	< 10	< 10	0.4	14	< 0.1
<b>Cwmystadrlllyn Treatment Works, Gwynedd, Wales</b>																	
Q1	< 0.02	0.064	0.064	2.96	9	16.9	< 2	< 1	1.3	12.3	< 10	< 10	< 10	< 10	0.3	70	0.1
Q2	NS	NS	NS	1.28	NS	11.8	NS	< 1	< 1	11.9	< 10	< 10	< 10	< 10	NS	NS	NS
Q3	0.034	0.126	0.113	< 1	< 10	9.5	< 2	< 1	< 1	12.8	< 10	< 10	< 10	< 10	< 0.1	1.3	< 0.1
Q4	0.021	0.103	0.093	1.41	12	26.7	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.4	42	0.1
<b>Ashford Reservoir, Bridgwater, Somerset</b>																	
Q1	0.061	0.137	0.144	1.57	71	5.1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.3	68	0.1
Q2	0.079	0.100	0.091	1.50	51	5.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.7	81	0.2
Q3	0.030	0.120	0.102	1.51	61	2.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	54	0.1
Q4	0.041	0.124	0.111	1.60	79	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.6	200	0.6
<b>Chew Valley Lake Reservoir, Avon</b>																	
Q1	0.024	0.184	0.175	1.54	118	6.4	< 2	< 1	< 1	< 10	< 10	15	< 10	12	3.8	79	1.7
Q2	< 0.02	< 0.05	< 0.05	1.56	112	7.3	NS	< 1	< 1	< 10	< 10	< 10	< 10	< 10	3.7	68	1.8
Q3	< 0.02	0.192	0.176	1.48	121	3.4	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	4	56	1.9
Q4	0.023	0.193	0.177	1.57	115	< 1	< 2	< 1	< 1	< 10	< 10	11	< 10	< 10	3.8	130	1.9

TABLE 22 (cont)

## PUBLIC DRINKING WATER SOURCES

Calendar quarter	Gross alpha' Bq l <sup>-1</sup>	Gross beta' Bq l <sup>-1</sup>	Gross beta' Bq l <sup>-1</sup>	H-3 Bq l <sup>-1</sup>	K-40' mBq l <sup>-1</sup>	Sr-90 mBq l <sup>-1</sup>	I-125 mBq l <sup>-1</sup>	Cs-134 mBq l <sup>-1</sup>	Cs-137 mBq l <sup>-1</sup>	Po-210 mBq l <sup>-1</sup>	Ra-226 mBq l <sup>-1</sup>	U-234 mBq l <sup>-1</sup>	U-235 mBq l <sup>-1</sup>	U-238 mBq l <sup>-1</sup>	K mg l <sup>-1</sup>	Ca mg l <sup>-1</sup>	Sr mg l <sup>-1</sup>
<b>River Avon, Christchurch, Hampshire</b>																	
Q1	0.024	0.117	0.119	1.43	65	5.2	<2	<1	<1	<10	<10	<10	<10	<10	2.1	100	0.3
Q2	0.055	0.177	0.174	1.36	109	7.4	NS	<1	<1	<10	<10	<10	<10	<10	3.6	190	0.7
Q3	0.140	0.162	0.146	1.20	73	<1	<2	<1	<1	<10	<10	<10	<10	<10	2.4	96	0.3
Q4	<0.02	0.107	0.092	1.29	82	<1	<2	<1	<1	<10	<10	<10	<10	<10	2.7	110	0.3
<b>River Fowey, Cornwall</b>																	
Q1	0.330	0.862	1.029	<1	62	4.2	<2	<1	<1	<10	<10	<10	<10	<10	2	8.8	<0.1
Q2	0.056	0.078	0.066	<1	45	6.9	<2	<1	<1	<10	<10	<10	<10	<10	1.5	7.8	<0.1
Q3	<0.02	0.084	0.072	<1	61	3.8	<2	<1	<1	<10	<10	<10	<10	<10	2	5.5	<0.1
Q4	0.067	0.117	0.099	<1	82	4.1	<2	<1	<1	<10	<10	<10	<10	<10	2.7	22	<0.1
<b>River Exe, Devon</b>																	
Q1	<0.02	0.098	0.100	<1	62	5.0	<2	<1	<1	<10	<10	<10	<10	<10	2	20	<0.1
Q2	0.032	0.262	0.240	1.11	97	5.0	<2	<1	<1	<10	<10	<10	<10	<10	3.2	37	0.2
Q3	<0.02	0.119	0.101	<1	76	2.5	<2	<1	<1	<10	<10	<10	<10	<10	2.5	22	<0.1
Q4	<0.02	0.105	0.096	1.11	51	2.2	<2	<1	<1	<10	<10	<10	<10	<10	1.7	17	<0.1
<b>Grafham Reservoir, Cambridgeshire</b>																	
Q1	0.034	0.395	0.396	2.59	270	6.0	<2	<1	<1	<10	<10	12	<10	<10	8.7	120	0.5
Q2	<0.02	<0.05	<0.05	1.41	257	2.8	<2	<1	<1	<10	<10	15	<10	13	8.5	120	0.5
Q3	<0.02	0.419	0.375	2.61	297	3.8	<2	<1	<1	<10	<10	10	<10	<10	9.8	130	0.6
Q4	<0.02	0.525	0.494	2.57	302	4.1	<2	<1	<1	<10	<10	<10	<10	<10	10	220	0.7
<b>River Wissey, Stoke-Ferry, Norfolk</b>																	
Q1	<0.02	0.156	0.166	1.48	90	4.7	<2	<1	<1	<10	<10	13	<10	11	2.9	200	0.6
Q2	<0.02	<0.05	<0.05	1.36	73	2.1	20	<1	<1	<10	<10	11	<10	<10	2.4	110	0.3
Q3	<0.02	0.120	0.113	1.57	76	<1	<2	<1	<1	<10	<10	<10	<10	<10	2.5	110	0.3
Q4	<0.02	0.151	0.141	1.40	103	3.4	<2	<1	<1	<10	<10	12	<10	10	3.4	180	0.4
<b>Littlecoates, Grimsby, groundwater, S. Humberside</b>																	
Q1	<0.02	0.157	0.159	1.32	105	4.3	<2	<1	<1	<10	<10	<10	<10	<10	3.4	110	0.5
Q2	<0.02	<0.05	<0.05	1.10	97	<1	<2	<1	<1	<10	<10	<10	<10	<10	3.2	100	0.5
Q3	0.071	0.166	0.141	1.43	88	<1	<2	<1	<1	<10	<10	<10	<10	<10	2.9	110	0.5
Q4	0.043	0.151	0.129	1.38	88	<1	<2	<1	<1	<10	<10	<10	<10	<10	2.9	180	0.5
<b>River Thames, Oxford, Oxfordshire</b>																	
Q1	<0.02	0.177	0.176	2.23	121	7.0	<2	<1	<1	<10	<10	<10	<10	<10	3.9	110	0.3
Q2	0.074	0.176	0.181	2.23	130	1.1	<2	<1	<1	<10	<10	11	<10	<10	4.3	100	0.3
Q3	<0.02	0.305	0.280	2.53	206	<1	<2	<1	<1	<10	<10	<10	<10	<10	6.8	110	0.4
Q4	0.052	0.322	0.272	2.15	194	<1	<2	<1	<1	<10	<10	11	<10	<10	6.4	180	0.6
<b>River Thames, Walton, Surrey</b>																	
Q1	0.041	0.147	0.155	2.30	164	10.3	<2	<1	<1	<10	<10	11	<10	<10	5.3	110	0.4
Q2	<0.02	0.247	0.210	2.75	103	4.4	NS	<1	<1	<10	<10	<10	<10	<10	3.4	81	0.3
Q3	<0.02	0.385	0.329	2.50	263	<1	<2	<1	<1	<10	<10	<10	<10	<10	8.7	98	0.4
Q4	<0.04	0.314	0.270	1.93	189	2.7	<2	<1	<1	<10	<10	<10	<10	<10	6.1	67	NS
<b>Bourne End, groundwater, Buckinghamshire</b>																	
Q1	<0.02	0.101	0.108	2.01	31	4.5	<2	<1	<1	<10	<10	<10	<10	<10	1	110	0.3
Q2	<0.02	<0.05	<0.05	1.74	27	<1	<2	<1	<1	<10	<10	<10	<10	<10	0.9	170	0.5
Q3	<0.02	0.05	<0.05	1.90	30	<1	<2	<1	<1	<10	<10	<10	<10	<10	1	120	0.4
Q4	<0.02	<0.05	<0.05	1.71	36	<1	<2	<1	<1	<10	<10	<10	<10	<10	1.2	150	1.3



TABLE 22 (cont)

## PUBLIC DRINKING WATER SOURCES

Calendar quarter	Gross alpha <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	Gross beta <sup>a</sup> Bq l <sup>-1</sup>	H-3 Bq l <sup>-1</sup>	K-40 <sup>a</sup> mBq l <sup>-1</sup>	Sr-90 mBq l <sup>-1</sup>	I-125 mBq l <sup>-1</sup>	Cs-134 mBq l <sup>-1</sup>	Cs-137 mBq l <sup>-1</sup>	Po-210 mBq l <sup>-1</sup>	Ra-226 mBq l <sup>-1</sup>	U-234 mBq l <sup>-1</sup>	U-235 mBq l <sup>-1</sup>	U-238 mBq l <sup>-1</sup>	K mg l <sup>-1</sup>	Ca mg l <sup>-1</sup>	Sr mg l <sup>-1</sup>
<b>River Lee, Chingford, Waltham Forest, London</b>																	
Q1	< 0.02	0.380	0.362	22.70	267	10.3	< 2	< 1	< 1	< 10	< 10	11	< 10	< 10	8.6	120	0.4
Q2	< 0.02	0.426	0.414	3.41	278	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	9.2	270	0.5
Q3	0.118	0.507	0.433	2.94	393	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	13	110	0.5
Q4	< 0.02	0.639	0.541	3.50	363	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	12	110	0.5
<b>River Thames, Chertsey, Surrey</b>																	
Q1	0.036	0.114	0.116	2.56	164	9.5	< 2	< 1	< 1	< 10	< 10	< 10	< 10	10	5.3	150	0.4
Q2	< 0.02	< 0.05	< 0.05	2.47	171	1.3	< 2	< 1	< 1	< 10	< 10	11	< 10	< 10	5.7	110	0.4
Q3	0.033	0.325	0.275	2.30	239	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	7.9	110	0.5
Q4	< 0.02	0.326	0.307	2.37	248	< 1	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	8.2	160	0.7
<b>Eccup Reservoir, Leeds, Yorkshire</b>																	
Q1	0.060	0.199	0.209	1.78	99	13.4	< 2	< 1	< 1	< 10	< 10	13	< 10	< 10	3.2	64	0.3
Q2	< 0.02	< 0.05	< 0.05	1.71	27	5.2	< 2	< 1	< 1	< 10	< 10	12	< 10	< 10	0.7	120	0.5
Q3	0.024	0.196	0.166	1.72	97	7.4	< 2	< 1	< 1	< 10	< 10	11	< 10	< 10	3.2	46	0.4
Q4	< 0.02	0.124	0.106	1.63	73	9.2	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.4	30	0.2
<b>Chellow Heights, Bradford, Yorkshire</b>																	
Q1	< 0.02	0.073	0.075	1.77	31	11.3	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1	46	11
Q2	0.137	0.178	0.187	1.54	88	7.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.9	55	0.3
Q3	< 0.02	0.072	0.068	1.79	24	6.7	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	0.8	32	0.4
Q4	< 0.02	0.072	0.061	1.37	33	5.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	1.1	49	0.1
<b>Roadford Reservoir, Dowrgrann, St Austell, Cornwall</b>																	
Q1	< 0.02	0.092	0.100	< 1	74	13.9	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.4	11	0.2
Q2	< 0.02	0.089	0.085	< 1	61	8.6	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2	93	0.3
Q3	< 0.02	0.087	0.074	< 1	67	5.0	< 2	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.2	11	< 0.1
Q4	< 0.04	0.227	0.193	< 1	62	4.7	NS	< 1	< 1	< 10	< 10	< 10	< 10	< 10	2.0	12	NS

## Notes:

1. (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<sup>-1</sup> stable potassium (0.0118% potassium-40 natural abundance).

NS No sample

## APPENDIX 1

### ANALYTICAL METHODS DISCHARGE MONITORING

#### A1.1 Gross alpha

##### 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.

##### 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 Gross beta

Source preparation is as in the procedures above.

##### Aqueous samples

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

##### 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 Gross 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 media) 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, 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 media 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 phenomena 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-diethylcarbamyolphosphonate) 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/hydroiodic 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 the plutonium solution prior to electroplating 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 supernatant 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 media 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 supernatant produced (A) is reserved for strontium-89/90 (and calcium-45 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 supernatant 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-ethylhexyl)) 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

**(i) 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.

**(ii) 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.

**(iii) 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 media to utilise the Cherenkov phenomena). 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**

### **ANALYTICAL METHODS**

#### **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 50ml 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.

## **APPENDIX 3**

### **ANALYTICAL METHODS**

#### **ENVIRONMENTAL MONITORING**

##### **A3.1 Total or gross 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 electrodeposited 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.

##### **A3.2 Total or gross 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.

##### **A3.3 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.

##### **A3.4 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 is dependent 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-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.

##### **A3.5 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.

##### **A3.6 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 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 electrochemical 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) prior to 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

### ANALYTICAL METHODS

#### RADIOACTIVITY IN AIR AND RAINWATER

##### A4.1 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.

##### A4.2 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 were 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.

###### Rainwaters

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 carrier is precipitated. Yttrium carrier is added, the yttrium-90 activity is adjusted for decay from the time of its separation from the strontium-

<sup>90</sup> 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

### ANALYTICAL METHODS

#### DRINKING WATER SOURCES

##### A5.1 Gross 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.

##### A5.2 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.

##### A5.3 Potassium-40

The potassium-40 activity concentrations are calculated from the stable potassium concentrations using a potassium-40 specific activity of 31 mBq mg<sup>-1</sup> stable potassium.

##### A5.4 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.

##### A5.5 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.

##### A5.6 Caesium-137

Following concentration by evaporation and adjustment to pH 2, caesium is concentrated onto ammonium molybdophosphate (AMP) in a batchwise manner. 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.

##### A5.7 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.

##### A5.8 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.

#### **A5.9 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.

#### **A5.10 Stable calcium, strontium and potassium**

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

#### **A5.11 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.

## MANAGEMENT AND CONTACTS:

The Environment Agency delivers a service to its customers, with the emphasis on authority and accountability at the most local level possible. It aims to be cost-effective and efficient and to offer the best service and value for money.

Head Office is responsible for overall policy and relationships with national bodies including Government.

Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD  
Tel: 01454 624 400 Fax: 01454 624 409

### ENVIRONMENT AGENCY REGIONAL OFFICES

#### ANGLIAN

Kingfisher House  
Goldhay Way  
Orton Goldhay  
Peterborough PE2 5ZR  
Tel: 01733 371 811  
Fax: 01733 231 840

#### SOUTHERN

Guildbourne House  
Chatsworth Road  
Worthing  
West Sussex BN11 1LD  
Tel: 01903 832 000  
Fax: 01903 821 832

#### MIDLANDS

Sapphire East  
550 Streetsbrook Road  
Solihull B91 1QT  
Tel: 0121 711 2324  
Fax: 0121 711 5824

#### SOUTH WEST

Manley House  
Kestrel Way  
Exeter EX2 7LQ  
Tel: 01392 444 000  
Fax: 01392 444 238

#### NORTH EAST

Rivers House  
21 Park Square South  
Leeds LS1 2QG  
Tel: 0113 244 0191  
Fax: 0113 246 1889

#### THAMES

Kings Meadow House  
Kings Meadow Road  
Reading RG1 8DQ  
Tel: 0118 953 5000  
Fax: 0118 950 0388

#### NORTH WEST

Richard Fairclough House  
Knutsford Road  
Warrington WA4 1HG  
Tel: 01925 653 999  
Fax: 01925 415 961

#### WELSH

Rivers House/Plas-yr-Afon  
St Mellons Business Park  
St Mellons  
Cardiff CF3 0LT  
Tel: 01222 770 088  
Fax: 01222 798 555



For general enquiries please call your local Environment Agency office. If you are unsure who to contact, or which is your local office, please call our general enquiry line.

#### ENVIRONMENT AGENCY GENERAL ENQUIRY LINE

**0645 333 111**

The 24-hour emergency hotline number for reporting all environmental incidents relating to air, land and water.

#### ENVIRONMENT AGENCY EMERGENCY HOTLINE

**0800 80 70 60**



**ENVIRONMENT  
AGENCY**