Department of Energy and Climate Change

MONITORING OF RADIOACTIVITY IN AIR AND RAINWATER IN THE UK

ANNUAL RESULTS REPORT 2009

Contract Title: **Environment Agency Management of RAS Research and Monitoring on behalf of DECC**

Contractor's Reference: HPA/MR/4/6602

Period covered by report: 2009

Author/Affiliations etc: L Mitchell

Abstract (100-200 words as desired):

Analysis of samples of atmospheric particulate material and rainwater collected from seven sites in the United Kingdom has continued during 2009. The results presented in this report show that there has been no measurable increase in radioactivity measured in air and rain in 2009. These results are comparable to those reported for 2008. The trend of slowly declining levels of anthropogenic radioactivity in the environment has been generally maintained.

Executive Summary

This report presents the results obtained from the analysis of samples of atmospheric particulate material and rainwater collected from 7 sites around the United Kingdom during 2009.

Samples were analysed for beryllium-7, caesium-137 and (for some sites) a number of other analytes (gross beta activity, tritium, strontium-90, plutonium-239/240 and americium-241).

Where comparison of the 2009 results with previous years has been performed, this has been done by calculating the 10 year running mean and setting the significance level at the mean plus 2 standard deviations. Setting a significance level allows any uncertainties against the measured value to be accounted for and allows identification of elevated radioactivity levels in the presence of declining background.

Results contained in this report show that there has been no significant increase in anthropogenic radioactivity measured in air and rain during 2009. Specific comments on individual 2009 results can be found in the discussion section of this report. Measurements are comparable with those taken in 2008, continuing the trend of slowly declining levels of anthropogenic radioactivity in the environment.

Monitoring of Radioactivity in Air and Rainwater in the UK
Annual Results Report 2009

Contents

1. Introduction

A programme for monitoring of radioactivity in air and rainwater was established in the United Kingdom (UK) in the 1950's and is currently managed by the Environment Agency (EA) on behalf of Defra (Department for the Environment, Food and Rural Affairs).
The contract to carry out this work was awarded by competitive tender to the Health Protection Agency (HPA) in November 2008..The previous contracts were held by AMEC, Winfrith Environmental Level Laboratory (1999-2008) and AEA-T (and predecessor organisations) who undertook the contract from 1954 to1998. HPA commenced sampling and analysis in January 2009.

Samples of airborne particulates and rainwater are collected at 7 sites in the UK located at Aberporth (Ceredigion, Wales), Chilton (Oxfordshire, England), Conlig (Co. Down, N. Ireland), Dishforth (N. Yorkshire, England), Eskdalemuir (Dumfries, Scotland) and Lerwick (Shetland Islands, Scotland). The site locations and sampling programme can be found in Figure 1 and Table 1 respectively. The air and rainwater samples are securely packaged by site staff and returned to HPA Glasgow laboratories for analysis of beryllium-7 (Be-7) caesium-137 (Cs-137) and tritium (H-3) as well as a few other analytes at specific locations.

This report presents the analytical results of samples collected during calendar year 2009. A synopsis of the sampling schedules and analysis methods is given in section 2 and discussed in section 4 of this report. This section also provides a comparison of 2009 data with that from previous years.

In recent years there had been a general decline in the measured levels of anthropogenic radioactivity monitored by this programme. Previous measurements clearly show the influence of atmospheric testing of nuclear weapons and later the incident at the civil nuclear reactor Chernobyl Unit 4, which took place on 26th April 1986. This resulted in a significant release of radioactivity to the atmosphere. Above ground weapons testing officially ceased on 16th October 1980 when a nuclear explosion was carried out at the Lop Nor test site in China.

2 Sampling and Analysis

Airborne particulate material and rainwater samples are collected from 7 sites around the UK (Table 1, figure 1) and returned to HPA laboratories in Glasgow for preparation and analysis. Methods are outlined below.

All test methods are accredited by UKAS to the ISO 17025 standard.

2.1 Airborne Particulate Sampling

Atmospheric particulate sampling uses centrifugal fans and motors to pull air through melt-blown Polypropylene air filter material. The filter material has been tested and retains over 99.5% of particulates of 0.423µm aerodynamic diameter and above, under test conditions. Air samplers are housed in wooden cases; the air intake duct is positioned in a vertical position approximately 1metre above the ground to avoid fouling. Air filters are run continuously, excluding a few minutes down-time during the filter change procedure. Filters are changed weekly at 6 of the locations, with the Conlig filter being changed dependent on a defined pressure drop. The mass of air sampled at each site varies depending on the specific performance parameters of the filter motor unit. Normally for each site this is approximately 3000 to 4500 kg/day except at Chilton where 15000 kg/day are sampled.

Air sampling is subject to occasional stoppages for a number of reasons ranging from local interruptions to electricity supply to mechanical failure. Reported results account for these interruptions.

Air filters are generally bulked and analysed quarterly, with the exception of the Chilton filter which is bulked and analysed on a monthly basis. The quarterly Chilton result can be inferred from the monthly results and compared with those from other locations.

2.2 Rainwater sampling

Rainwater samples are collected using polythene funnels which drain into polythene collection bottles ranging in size from 2.5 l (tritium collection), 5 l (quarterly gamma spec.) to 25 l (monthly Aberporth and Chilton gamma spec). A suitable carrier solution is added to the sample bottle directly before deployment in the field to reduce loss by adsorption on to the walls of the sample bottle. The measured samples include all material deposited by wet and dry deposition.

Rainwater samples are collected continuously at all sites and bulked quarterly at HPA labs. In addition, separate monthly samples are taken at Aberporth and Chilton sites, and an annual bulk sample is also taken at Aberporth. Sample collection bottles are deployed at Aberporth, Eskdalemuir and Orfordness for analysis of tritium.

2.3 Radiochemical Analysis

A summary of the sample preparation and analytical methods used is given below.

Individual air filters are bulked and ashed in a muffle furnace before leaching with concentrated mineral acids to extract the radioactivity into solution.

Rainwater samples are filtered prior to evaporation which concentrates the radionuclides. Particulates from the filtered rainwater undergo a leach using concentrated mineral acids to extract the radionuclides into solution which is combined with the evaporated water sample.

Gamma ray emitting radionuclides such as Cs-137 and Be-7 are measured in both air and rainwater samples by placing the prepared sample into a suitable geometry before assessing the activity by a high resolution gamma spectrometry.

Strontium-90 (Sr-90) is determined in a sample by oxalate precipitation followed by purification using a crown-ether resin and then counting of the yttrium-90 daughter products after a suitable period of in-growth.

Gross alpha and gross beta measurements are carried out by evaporating a known volume of the sample on to a stainless steel planchet before assessing the activity with a gas-flow proportional counter.

Plutonium-239/240 and Americium-241 are all determined by separation from the sample using various selective ion exchange resins to remove interferants. The purified fractions of the sample are then electro-deposited on to a stainless steel disc and counted by alpha spectrometry.

2.4 Changes and Additions to the Programme

A pre-generated calendar of sample change dates is sent to each site for the start of each year. On occasions these dates change due to a variety of reasons. In addition air filter units can suffer from mechanical failures (drive belt breakage, wear and tear of bearings etc), electrical failures (power cuts etc) and planned interruptions (general site maintenance, filter unit maintenance etc). Where disruptions to the planned programme occur, the changes are reflected in the reported results for each site. Comments for each site are provided below for 2009.

Aberporth

- Scheduled power outage to site leading to loss of collection for 8 hours between 12/9/09 and 13/9/09. A further planned outage occurred on 26/9/09 for 1.4 hrs.
- Air filter unit re-sited during week commencing 9/11/09. 4 hours of sampling time lost
- 20 minutes collection time lost on 21/12/09 to allow maintenance work on motor.

Chilton

- Power outage of 10 hours during week commencing 29/6/09
- Scheduled power outage of 21 hours on 8/7/09

Conlig

- Stoppage from 10:00 8/1/09 to 08:00 10/1/09. No reason found.
- Failure of air sampler due to severe mechanical damage. No sample available for quarter 3. The unit was completely replaced and re-commissioned on 8/10/09.
- Unit failures in weeks commencing 8/8/09 and 24/11/09. No reason was found. Total loss of sampling time was 93.75 hrs.

Dishforth

- Q2 rainwater sample not collected until 13/7/09 due to staff oversight
- Power outage of about 17 hours on 19/7/09
- Power outage of about 2 hours on 30/8/09
- Power outage of about 10 hours on 31/8/09
- Power outage of 9.2 hrs on 18/10/09

Eskdalemuir

- Stoppage 03:00 27/2/09 to 09:00 27/2/09. No reason found
- Drive belt failure on 24/5/09. Loss of collection for 495 minutes
- Power failure on 25/6/09. Loss of collection for 550 minutes
- Drive belt failure on 18/9/09. Los of collection for 12.5 hours

- Drive belt failure on 27/9/09. Los of collection for 12 hours
- Power outage of 12 hours on 24/9/09
- Power outage of 12 hours on 26/9/09

Lerwick

- Drive belt failure on 30/7/09 or 31/7/09. Loss of collection for about 9 hrs
- Electrical maintenance work during week commencing 19/10/09. Loss of collection for 2 hours.
-

Orfordness

- Dive belt failure. Assumed stoppage from 12:00 15/3/09 to 13:00 16/3/09
- Rainwater collection bottle left for extended period of time (2/1/09 to 5/5/09) due to staff oversight.
- Drive belt failure between 3/5/09 and 5/5/09.
- Quarterly rainwater sample collected from 6/5/09 to 6/7/09 due to staff oversight.

3 Calculation and Presentation of Results

Sampling of air and rainwater is carried out by site operators (currently MET Office, VT Communications and Northern Ireland Environment Agency staff) and includes a number of factors with associated uncertainties e.g. atmospheric temperature and pressure. These uncertainties have not been considered in this report.

The analytical uncertainties quoted in this report contain an estimate of all sources of uncertainty except those caused by sub-sampling in the analytical process. The uncertainties are calculated at the 95% confidence level.

Limits of detection are calculated following the procedure described by T J Summerling and S C Darby (NRPB R-113) [1] as agreed with the Environment Agency Programme Manager. In addition HPA undertook a comparison of the calculation of decision thresholds and detection levels for radioactive counting experiments between the methods described in ISO 11929-7 [2] and NRPB R-113. For cases where the decision threshold is based on counting statistics of a measured background, it has been demonstrated that the two methods are identical. A document summarising HPA's analysis of the 2 methods has been passed to the Environment Agency Programme Manager [3].

Reported results have been decay corrected to the mid-point of the sampling period and any missed sampling time is accounted for.

For consistency results are presented in a similar format to that produced by the previous contractor.

Statistical data presented in this report have been derived from a database of results produced from 1987 to date. Trending of results is carried out on data collected over a 10 year period (current year plus previous 9 year's results) to produce a 10 year running mean. This is compared to the current year's data and a significance level set at the 10 year running mean plus 2 standard deviations.

All Limits of Detection quoted depend on the collection of an adequate sample size. Air collection disruptions and low rainfall will both reduce the sample size available and thus increase the analytical detection limit.

4 Results and Discussion

4.1 Cs-137 concentrations in air and rainwater

The Cs-137 found in both air particulate and rainwater samples derives from anthropogenic sources including discharges from nuclear installations, fallout from the Chernobyl incident and nuclear weapons testing.

Table 2 shows the Cs-137 results from monthly rainwater and bulked air filter samples at Chilton and monthly rainwater samples at Aberporth. There are no results available from Chilton air filters for April – June 2009 or Q2 Aberporth air filter due to a fire in the laboratory furnace during sample preparation leading to destruction of the samples. All rainwater samples at both Chilton and Aberporth were below the analytical limit of detection, as were the Chilton air particulate concentrations for the latter half of the year. Positive levels of Cs-137 were detected in the first quarter, but these are very close to the analytical detection limit and since the analytical detection limit is lower than achieved last year it is not possible to say whether these results are different.

The monthly airborne particulate results are shown graphically in Figure 2. Figure 3 illustrates the monthly measurements from 1987 until the end of 2009, along with the 10 year running mean. This graph indicates the continued plateau in the airborne concentrations of Cs-137 mentioned in previous annual reports, with results being around or below the limit of detection.

Further statistical analysis of the past 10 years data (2000-2009) are presented in Table 2. All air and rain results from Chilton and all rainwater results from Aberporth are below the significance level.

The results from analysis of airborne particulates for Cs-137 at all the collection sites are shown in Table 3 and illustrated in Figure 4. Most results are below the analytical limit of detection except Chilton Q1 (which, as noted above, gave positive results). Further no results were available from Conlig as mentioned in section 2.4 above. Both Chilton and Aberporth Q2 air filter sample results are unavailable due to the furnace fire mentioned in section 4.1 above.

Tables 4 and 5 display the rainwater concentration and deposition of Cs-137 in quarterly samples. With one exception (Eskdalemuir Q3) all results are below the analytical limit of detection. All concentration values are below the significance level based on the 10 year mean for each station.

4.2 Be-7 concentrations in air and rainwater

Beyllium-7 is a naturally occurring gamma-emitting radionuclide which is produced during cosmic ray interactions with nitrogen and oxygen in the upper atmosphere. It has a relatively short half-life of 53.2 days and is measured and reported to ensure a consistency in monitoring across the programme; it can also provide a context against which the anthropogenic radioactivity can be compared.

The Be-7 results from Chilton monthly air filter and rainwater samples and the monthly rainwater from Aberporth are shown in Table 6.

Chilton Be-7 results in air range between 0.000910 ± 0.000095 (December) to 0.00262 ± 0.00027 (March) Bq kg^{-1}. These are all below the significance level although some of the results are slightly elevated above the 10-year mean. This pattern of results is consistent with previous data, illustrated in Figure 5. There are no reportable results for samples collected in April, May and June as these were damaged during the analysis process.

Chilton Be-7 in 2009 rain ranges between 0.31 ± 0.17 and 2.41 ± 0.59 Bq l^{-1} for June, this elevated June result of 2.41 ± 0.59 Bq l^{-1} is more than double the 10-year mean and above the significance value. At present, there is no explanation for this anomalous result although analytical data have been verified. Figure 6 illustrates Be-7 concentrations in air since 1990 and shows 2009 results are consistent with previous years. Although the high result in June was inconsistent with the data for the rest of the year, such levels have been seen regularly and even exceeded over the whole collection period.

Aberporth results for beryllium-7 in rain also contain one result (February) which slightly exceeds the significance level. However, this may be due to the low rainfall that month or other atmospheric factors.

Quarterly Be-7 measurements in air at all sites are shown in Table 7. As explained above (see Sections 2.4 and 4.1) some results are unavailable. Excluding Orfordness, all Q1 results are above the annual significance levels, as are Q2 results at Eskdalemuir and Orfordness and Q3 results at Chilton, and Orfordness. All Q4 results are below significance values. There is currently no explanation for these results but the high Q1 results from across all sites may indicate some atmospheric process generally affecting the UK causing more efficient mixing of tropospheric air (where Be-7 is produced) with stratospheric air (where the samplers are situated).

The corresponding quarterly Be-7 results in rainwater are shown in Table 8. A similar pattern to the airborne particulate pattern is observed, with many stations exceeding the significance level in Q1 and Q2 but less in Q3 and Q4. The situation is less clear with the rainfall data as the levels are also influenced by seasonal variations in rainfall. Table 9 shows the calculated Be-7 deposition results for all sites. It should be noted that periods of low rainfall are known to be associated with elevated levels of Be-7 in rain.

4.3 Other gamma emitting radionuclides

During the analysis of all samples for gamma emitting radionuclides, any artificial nuclides above the detection limit are quantified. No samples have produced results above the detection limit during 2009. Table 10 shows the annual results for Be-7 and Cs-137 in Chilton rainwater. No other artificial gamma emitting radionuclides were detected.

4.4 Sr-90 concentration in Chilton rainwater

The annual sample for analysis of strontium-90 activity at Chilton was made by bulking the monthly rainwater samples collected during 2009. Results are shown in Table 11.

Strontium-90 was measured below the analytical detection limits. The result is also markedly less than both the 10-year mean and the significance levels, continuing the downward trend year on year. Strontium in the atmosphere is mainly from anthropogenic sources.

4.5 Gross alpha and gross beta in Chilton rainwater

The annual sample for analysis of gross alpha and beta particle activity at Chilton was made by bulking the monthly rainwater samples collected during 2009. Samples were counted using a low background, gas flow proportional counter. These results are presented in Table 12.

Both gross alpha and gross beta radioactivity concentrations were below the analytical detection limits. Results are also markedly less than the significance levels for each measurement.

It should be noted that the World Health Organisation guideline value for drinking water is < 0.5 Bq l^{-1} and < 1.0 Bq l^{-1} for gross alpha and gross beta respectively. 2009 results are significantly below this level.

4.6 Pu-239/240 and Am-241 in Aberporth air and rainwater

The 2009 results for plutonium-239/240 and americium-241 in air particulate and rainwater samples are shown in Table 13.

No Pu-239/240 or Am-241 was quantified in the samples collected during 2009, all returning results less than the analytical detection level. All results are below the significance levels for each radionuclide measured.

4.7 Tritium in rainwater

Quarterly concentrations of tritium in rainwater are shown in Table 14. During 2009 no results were detected above the significance level.

Tritium in the environment can be from natural or anthropogenic sources. Small quantities are produced by cosmic ray reactions with gases in the upper atmosphere, which are then deposited by rain.

5 Conclusion

Samples of rainwater and airborne particulates have been collected during 2009 for seven sites around the UK. There were some disruptions to the sampling programme due to mechanical and electrical failures of air samplers and some variable collection periods for rainwater samples. Overall these were of a minor nature allowing a large dataset to be collected for 2009.

Samples were analysed for beryllium-7, caesium-137 and (for some sites) a number of other analytes (gross beta activity, tritium, strontium-90, plutonium-239/240 and americium-241).

Beryllium-7 results were similar to historic values and again no results exceeded the significance level

For Cs-137 low positive results for Q1 were observed at Chilton, but all other air and all rainwater results were below the analytical limit of detection. Results were comparable to the 10-year means and no results exceeded the significance level.

Comparison of the 2009 results with those from previous years has been done where possible by calculating the 10 year running mean and setting a significance level at the mean plus 2 standard deviations. This helps to account for results which are close to the analytical detection limits, where uncertainties are large compared to the result. The significance level allows identification of any comparatively high levels of radioactivity in the presence of declining background levels.

The results show that there has been no significant increase in the measured levels of anthropogenic radioactivity in air particulate and rainwater samples taken during 2009.
The results are comparable to the previous 10 year's data and show a continuing decline of anthropogenic radioactivity in the environment.

6 References

1. Statistical Aspects of the Interpretation of Counting Experiments Designed to Detect Low Levels of Radioactivity, T J Summerling and S C Darby, NRPB R-113

2. International Standards Organisation. Determination of the detection limits and decision threshold for ionizing radiation measurements — Part 7: Fundamentals and general applications. ISO/FDIS11929-7.

3. Davidson M, A comparison of two methods for calculating limits of detection for measurements of radioactivity- HPA internal document (November 2008).

4. AA Dale/DEFRA, Monitoring of Radioactivity in Air and Rainwater in the UK, Annual Results Report 2008, DEFRA/RWP/09.001 (July 2009)

5. AA Dale/DEFRA, Monitoring of Radioactivity in Air and Rainwater in the UK, Annual Results Report 2007, DEFRA/RWP/08.001 (July 2008)

Table 1 Sampling Programme

Airborne Particulates

Station	Latitude	Longitude	Height above ground	Sampling Frequency
Lerwick, Shetland	N60^{o}:08':20"	W1^{o}:11':01"	approx. 1m	weekly
Eskdalemuir, Dumfries	N55^{o}:18':43"	W3^{o}:12':22"	approx. 1m	weekly
Conlig, Co Down	N54^{o}:37':50"	W5^{o}:40':56"	approx. 1m	weekly*
Dishforth, N Yorks	N54^{o}:08':05"	W1^{o}:24':52"	approx. 1m	weekly
Orfordness, Suffolk	N52^{o}:06':18"	W1^{o}:35':03"	approx. 1m	weekly
Aberporth, Ceredigion	N52^{o}:08':23"	W4^{o}:34':11"	approx. 1m	weekly
Chilton, Oxon	N51^{o}:34':23"	W1^{o}:18':34"	approx. 1m	weekly

* The air filter at Conlig is monitored twice-weekly and changed if airflow falls by 30% of its original value.

Rainwater

Station	Latitude	Longitude	approx. mean annual rainfall (mm)	Sampling Frequency
Lerwick, Shetland	N60^{o}:08':20"	W1^{o}:11':01"	1260	quarterly
Eskdalemuir, Dumfries	N55^{o}:18':43"	W3^{o}:12':22"	1840	quarterly
Conlig, Co Down	N54^{o}:37':50"	W5^{o}:40':56"	935	quarterly
Dishforth, N Yorks	N54^{o}:08':05"	W1^{o}:24':52"	655	quarterly
Orfordness, Suffolk	N52^{o}:06':18"	W1^{o}:35':03"	600	quarterly
Aberporth, Ceredigion	N52^{o}:08':23"	W4^{o}:34':11"	930	quarterly & monthly
Chilton, Oxon	N51^{o}:34':23"	W1^{o}:18':34"	745	quarterly & monthly

Table 2 Monthly Cs-137 concentrations at Chilton and Aberporth

Sampling Period 2009	Chilton			Aberporth	
	Cs-137 in air (Bq kg^{-1})	Rainfall (mm)	Cs-137 in rain (Bq l^{-1})	Rainfall (mm)	Cs-137 in rain (Bq l^{-1})
Jan	0.00000029 ± 0.00000025	49.9	< 0.01	119.1	< 0.0026
Feb	0.00000048 ± 0.00000030	48.1	< 0.0079	23.1	< 0.019
Mar	0.00000040 ± 0.00000020	24.0	< 0.013	34.6	< 0.0014
Apr	No result	34.4	< 0.012	58.3	< 0.0046
May	No result	52.3	< 0.0095	75.2	< 0.0075
Jun	No result	24.5	< 0.016	61.8	< 0.0068
Jul	< 0.00000027	101.6	< 0.0067	155	< 0.0033
Aug	< 0.00000022	50.6	< 0.0065	59.2	< 0.0060
Sep	< 0.00000027	9.1	< 0.019	21	< 0.014
Oct	< 0.00000026	32.0	< 0.0065	83	< 0.016
Nov	< 0.00000048	152.1	< 0.0083	199.2	< 0.0050
Dec	< 0.00000038	83.9	< 0.0087	136	< 0.0048
Annual mean	0.00000033	-	< 0.010	-	0.0076
10 year mean	0.00000041	-	0.013	-	0.011
Significance Level	0.00000073	-	0.036	-	0.037

Note: 'less than' values are taken to be the reported result for the calculation of annual and 10 year mean values. Significance values are based on the mean plus 2 standard deviations.
No uncertainty is reported where there is a mix of positive and 'less than' results.
For Chilton Cs-137 in rain the April 2007 result has been excluded from running mean due to an unavoidably high limit of detection

Table 3 Quarterly concentration of Cs-137 in air at all sites

Sample station	Cs-137 in air (Bq kg^{-1})				10 year mean (Bq kg^{-1})	Significance level (Bq kg^{-1})
	Q1	**Q2**	**Q3**	**Q4**		
AB	< 0.00000060	No result	< 0.00000010	< 0.00000057	0.00000059	0.00000110
CH	0.00000117 ± 0.00000044	No result	< 0.00000076	< 0.00000107	0.00000055	0.00000102
CO	0.00000045	0.00000045	No result	< 0.00000100	0.00000066	0.00000118
DI	< 0.00000046	< 0.00000072	< 0.00000066	< 0.00000080	0.00000063	0.00000106
ES	< 0.00000030	< 0.00000056	< 0.00000070	< 0.00000048	0.00000055	0.00000096
LE	< 0.00000048	< 0.00000022	< 0.00000089	< 0.00000067	0.00000063	0.00000126
OR	< 0.00000091	< 0.00000057	< 0.00000065	< 0.00000061	0.00000061	0.00000107

Table 4 Quarterly concentration of Cs-137 in rainwater at all sites

Sample station	Cs-137 in rainwater (Bq l^{-1})				10 year mean (Bq l^{-1})	Significance level (Bq l^{-1})
	Q1	**Q2**	**Q3**	**Q4**		
AB	< 0.017	< 0.019	< 0.014	< 0.014	0.041	0.105
CH	< 0.061	< 0.018	< 0.017	< 0.0099	0.040	0.099
CO	< 0.014	< 0.014	< 0.018	< 0.019	0.029	0.068
DI	< 0.020	< 0.014	< 0.014	< 0.020	0.041	0.098
ES	< 0.0160	< 0.0071	<0.0066	< 0.0078	0.014	0.031
LE	< 0.016	< 0.012	< 0.016	< 0.020	0.026	0.056
OR	< 0.021	< 0.017	< 0.020	< 0.021	0.054	0.118

Table 5 Quarterly Cs-137 deposition by rainwater at all sites

Sample Station	**Q1**		**Q2**		**Q3**		**Q4**	
	Rainfall (mm)	Cs-137 (Bq m^{-2})	Rainfall (mm)	Cs-137 (Bq m^{-2})	Rainfall (mm)	Cs-137 (Bq m^{-2})	Rainfall (mm)	Cs-137 (Bq m^{-2})
AB	172.0	< 2.9	192	< 3.6	235.2	< 3.3	413	< 5.8
CH	122.0	< 7.4	111.2	< 2.0	161.3	< 2.7	268	< 2.7
CO	162.3	< 2.3	206.2	< 2.9	154.3	< 2.8	439.4	< 8.3
DI	96.2	< 1.9	176.8	< 2.5	164	< 2.3	267.4	< 5.3
ES	454.4	< 7.3	314	< 2.2	737.2	< 4.9	741.8	< 5.8
LE	385	< 6.2	153.6	< 1.8	251	< 4.0	462	< 9.2
OR	157.2	< 3.3	80	< 1.4	61	< 1.22	224.6	< 4.7

Table 6 Monthly Be-7 concentrations at Chilton and Aberporth

Sampling Period 2009	Chilton			Aberporth	
	Be-7 in air (Bq kg^{-1})	Rainfall (mm)	Be-7 rain (Bq l^{-1})	Rainfall (mm)	Be-7 in rain (Bq l^{-1})
Jan	0.00188 ± 0.00020	49.9	0.58 ± 0.21	119.1	0.177 ± 0.050
Feb	0.00148 ± 0.00015	48.1	1.17 ± 0.24	23.1	3.00 ± 0.51
Mar	0.00262 ± 0.00027	24.0	0.34 ± 0.18	34.6	0.60 ± 0.24
Apr	Not available	34.4	0.31 ± 0.17	58.3	0.510 ± 0.091
May	Not available	52.3	0.60 ± 0.43	75.2	1.44 ± 0.30
Jun	Not available	24.5	2.41 ± 0.59	61.8	1.66 ± 0.36
Jul	0.00188 ± 0.00019	101.6	0.46 ± 0.21	155	1.15 ± 0.20
Aug	0.00156 ± 0.00016	50.6	0.97 ± 0.25	59.2	1.60 ± 0.40
Sep	0.00207 ± 0.00021	9.1	0.59 ±0.37	21	2.17 ± 0.42
Oct	0.00180 ± 0.00019	32	0.31 ± 0.18	83	0.88 ± 0.45
Nov	0.00110 ± 0.00012	152.1	0.30 ± 0.20	199.2	1.12 ± 0.45
Dec	0.000910 ± 0.000095	83.9	0.95 ± 0.22	136	0.88 ± 0.16
Annual mean	0.00170 ± 0.00061	-	0.749 ± 0.085	-	1.27 ± 0.091
10 year mean	0.00165	-	0.99	-	1.33
Significance Level	0.00267	-	1.98	-	2.63

Table 7 Quarterly concentrations of Be-7 in airborne particulates

Sample station	Be-7 in air (Bq kg^{-1})				Annual mean (Bq kg^{-1})	Annual Significance level (Bq kg^{-1})
	Q1	**Q2**	**Q3**	**Q4**		
AB	0.00260 ± 0.00027	No result	0.00183 ± 0.00020	0.00116 ± 0.00013	0.00186 ± 0.00012	0.00198
CH	0.00598 ± 0.00037	No result	0.00553 ± 0.00033	0.00381 ± 0.00025	0.00511 ± 0.00185	0.00529
CO	0.0026 ± 0.00027	0.00195 ± 0.00021	No result	0.00153 ± 0.00017	0.00203 ± 0.00013	0.00215
DI	0.00169 ± 0.00018	0.00138 ± 0.00016	0.00137 ± 0.00015	0.000997 ± 0.000012	0.00136 ± 0.00071	0.00143
ES	0.00196 ± 0.00021	0.00170 ± 0.00019	0.00126 ± 0.00014	0.000797 ± 0.000087	0.00142 ± 0.00080	0.00150
LE	0.00196 ± 0.00021	0.00180 ± 0.00019	0.00180 ± 0.00020	0.00141 ± 0.00015	0.00174 ± 0.00094	0.00184
OR	0.00184 ± 0.00021	0.00221 ± 0.00024	0.00237 ± 0.00025	0.00175 ± 0.00019	0.00204 ± 0.00112	0.00215

Table 8 Quarterly concentrations of Be-7 in rainwater

Sample station	Be-7 in rain (Bq l^{-1})				Annual mean (Bq l^{-1})	Annual Significance level (Bq l^{-1})
	Q1	**Q2**	**Q3**	**Q4**		
AB	1.87 ± 0.40	1.8 ± 1.1	0.65 ± 0.35	0.84 ± 0.37	1.29 ± 0.32	1.61
CH	< 1.7	2.01 ± 0.80	1.05 ± 0.39	1.33 ± 0.31	1.52 ± 0.24	1.76
CO	0.73 ± 0.23	1.14 ± 0.53	1.04 ± 0.42	1.63 ± 0.47	1.14 ± 0.21	1.35
DI	1.70 ± 0.48	1.40 ± 0.56	0.78 ± 0.29	0.94 ± 0.44	1.21 ± 0.23	1.43
ES	1.37 ± 0.38	0.43 ± 0.26	1.18 ± 0.26	0.79 ± 0.25	0.94 ± 0.15	1.09
LE	1.57 ± 0.41	1.49 ±0.55	1.03 ± 0.27	1.11 ± 0.25	1.30 ± 0.19	1.49
OR	1.49 ± 0.43	3.9 ± 1.0	1.85 ± 0.45	2.23 ± 0.53	2.37 ± 0.32	2.69

Table 9 Quarterly Be-7 deposition by rainwater at all sites

Sample Station	**Q1**		**Q2**		**Q3**		**Q4**	
	Rainfall (mm)	Be-7 (Bq m^{-2})	Rainfall (mm)	Be-7 (Bq m^{-2})	Rainfall (mm)	Be-7 (Bq m^{-2})	Rainfall (mm)	Be-7 (Bq m^{-2})
AB	172	322 ± 69	192	346 ± 211	235.2	153 ± 82	413	347 ± 153
CH	122	< 207	111.2	224 ± 89	161.3	169 ± 63	268	356 ± 83
CO	162.3	118 ± 37	206.2	235 ± 109	154.3	160 ± 65	439.4	716 ± 207
DI	96.2	164 ± 46	176.8	248 ± 99	164	128 ± 48	267.4	251 ± 118
ES	454.4	623 ± 173	314	135 ± 82	737.2	870 ± 192	741.8	586 ± 185
LE	385	604 ± 158	153.6	229 ± 84	251	259 ± 68	462	513 ± 116
OR	157.2	234 ± 68	80	312 ± 80	61	113 ± 27	224.6	501 ± 119

Table 10 Annual concentrations of gamma emitting radionuclides in Chilton rainwater

Sample station	Radionuclide activity (Bq l^{-1})	
	Be-7	**Cs-137**
Chilton	2.84 ± 0.55	< 0.0016
10-year mean	2.35	< 0.0018
Significance level (+2σ)	3.5	< 0.0033

Table 11 Annual concentration and deposition of Sr-90 in Chilton rainwater

Sample station	Sr-90 in rain (Bq l^{-1})	10 year mean (Bq l^{-1})	Significance level (Bq l^{-1})	Rainfall (mm)	Sr-90 deposition (Bq m^{-2})
Chilton	< 0.00048	0.0018 ± 0.0011	0.0065	662.5	< 0.32

Table 12 Annual concentration of gross alpha and gross beta in Chilton rainwater

Sample station	Gross alpha (Bq l^{-1})	Gross beta (Bq l^{-1})
Chilton	< 0.018	< 0.13
10 year mean	0.043	0.117
Significance level (+2σ)	0.076	0.21

Table 13 Annual concentrations of Pu-239+240 and Am-241 in Aberporth air particulates and rainwater

Sample station	Air		Rain		
	Pu 239+240 (Bq kg^{-1})	Am-241 (Bq kg^{-1})	Rainfall (mm)	Pu 239+240 (Bq l^{-1})	Am-241 (Bq l^{-1})
Aberporth	< 0.0000000010	< 0.0000000030	1025.6	< 0.000020	< 0.000020
10 year mean	0.00000000066 ± 0.00000000030	< 0.0000000023	_	0.000023 ± 0.000014	0.000040 ± 0.000028
Significance level (+2σ)	0.0000000014	0.0000000091		0.000066	0.000123

Table 14 Quarterly tritium concentrations in rainwater

Sample station	Q1 H-3 (Bq l^{-1})	Q2 H-3 (Bq l^{-1})	Q3 H-3 (Bq l^{-1})	Q4 H-3 (Bq l^{-1})	10 year mean (Bq l^{-1})	Significance level (+2σ) (Bq l^{-1})
Aberporth	< 0.98	< 1.2	< 1.3	< 1.3	1.3	2.7
Eskdalemuir	< 0.98	< 1.2	1.7 ± 1.2	< 1.2	1.9	5.2
Orfordness	1.09 ± 0.88	1.2 ± 1.1	< 1.3	< 1.2	1.4	3.0

Figure 1 Sampling Station Locations

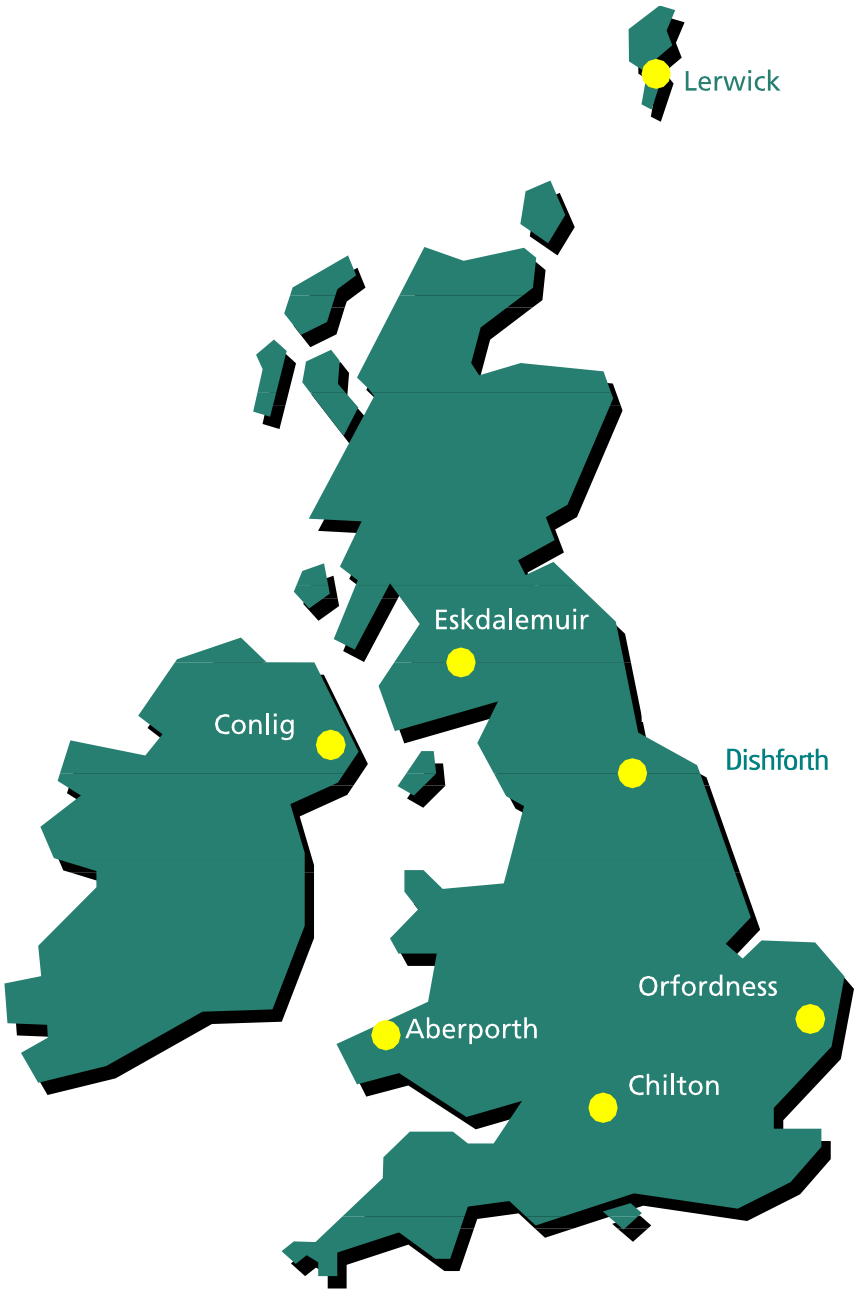
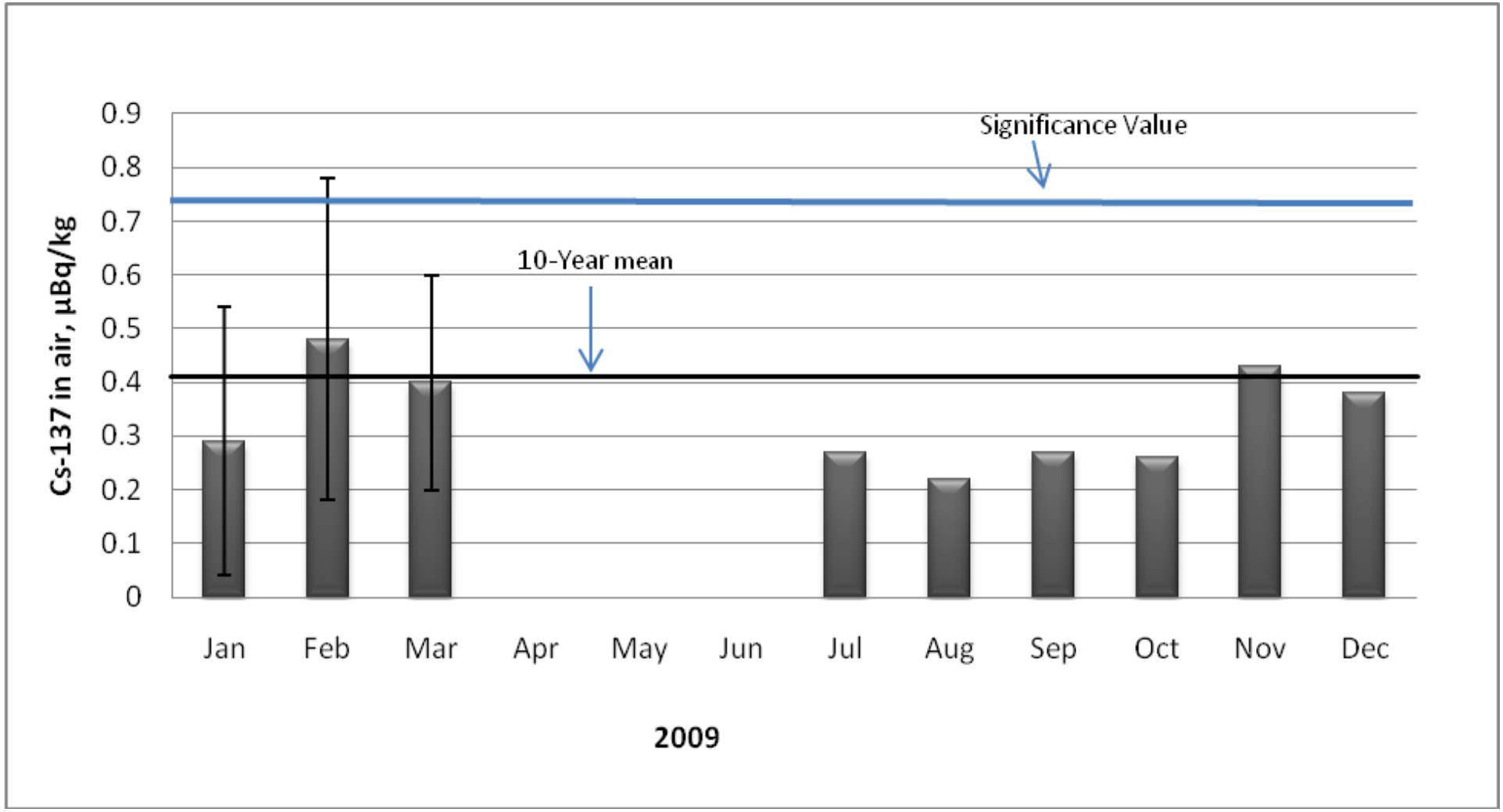


Figure 2 Monthly Cs-137 concentrations in air at Chilton



Results above are shown with uncertainty bars where available, results without uncertainty bars are below the limit of detection

Figure 3 Cs-137 concentrations in air at Chilton. Monthly measurements from 1987 until end 2009

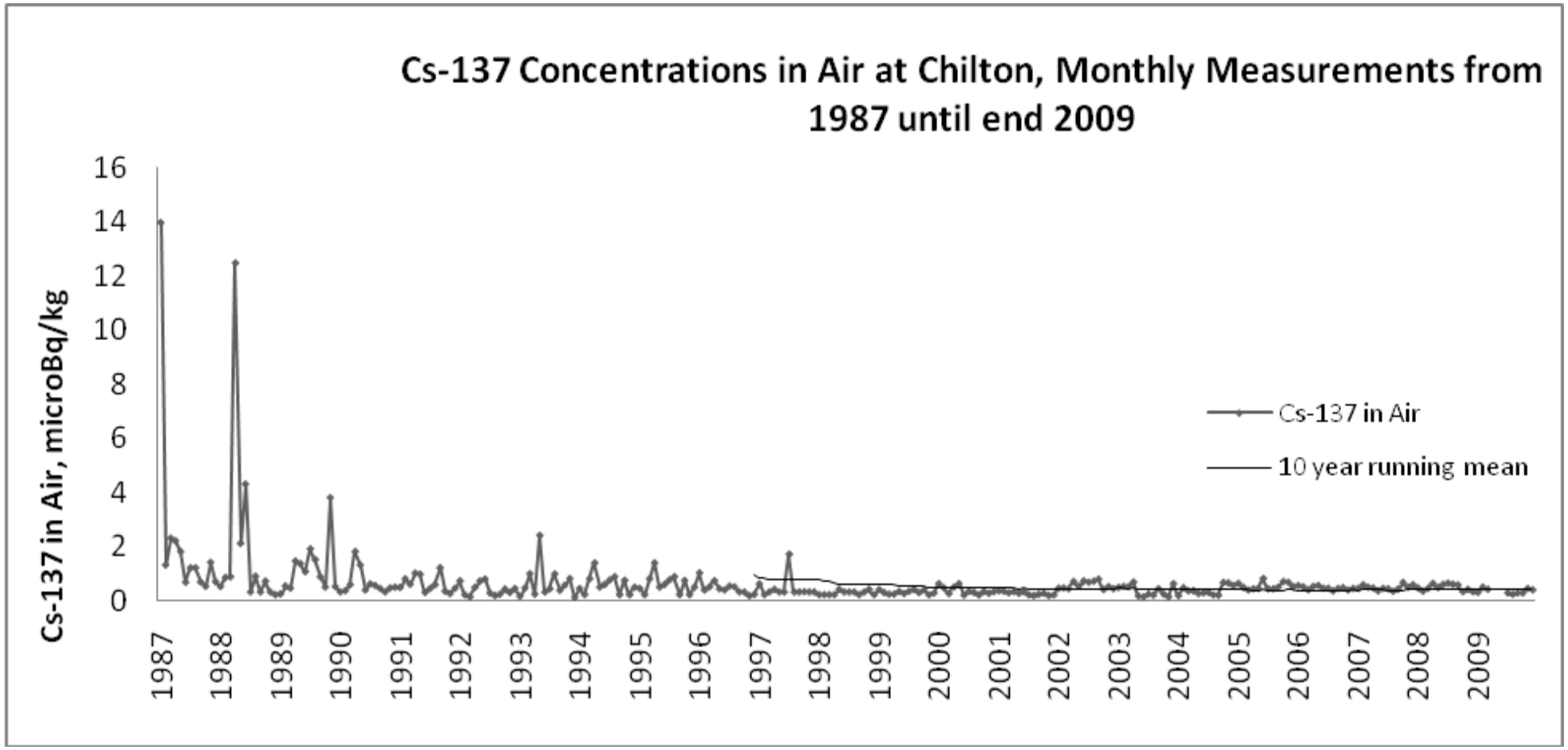


Figure 4 Quarterly Cs-137 concentrations in air at all stations for 2009

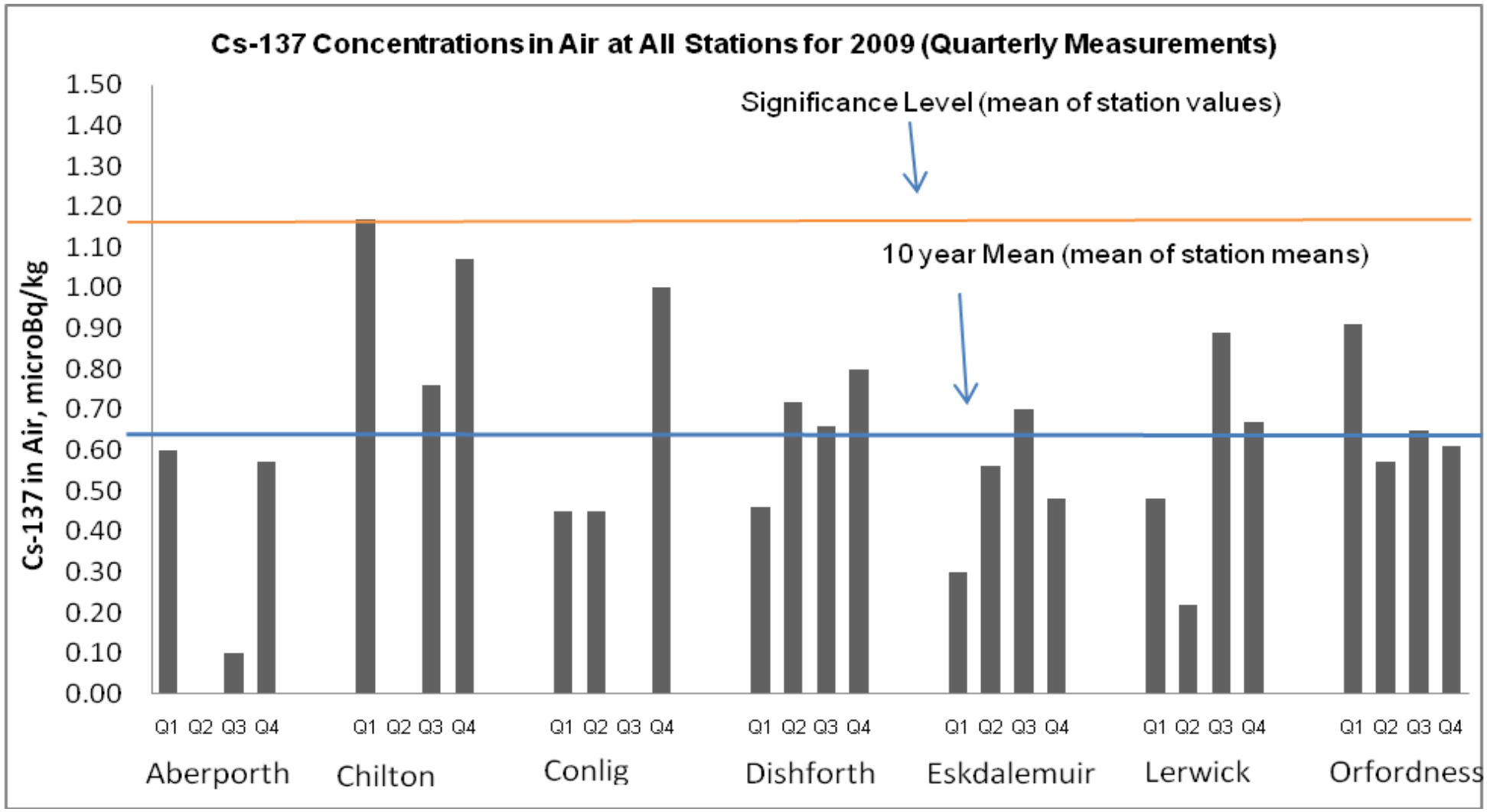


Figure 5 Be-7 Concentrations in Air at Chilton

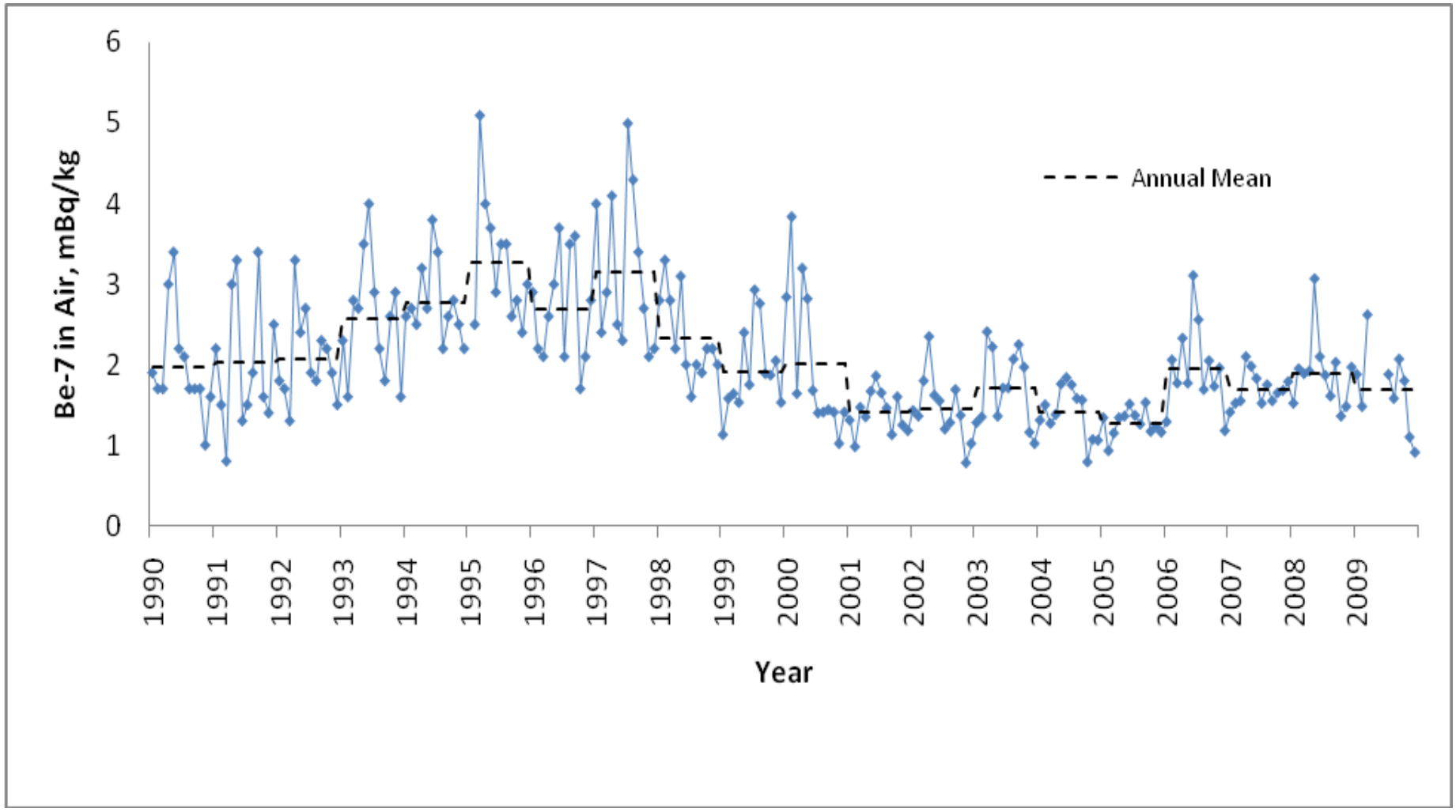


Figure 6 Be-7 Concentrations in Rain at Chilton

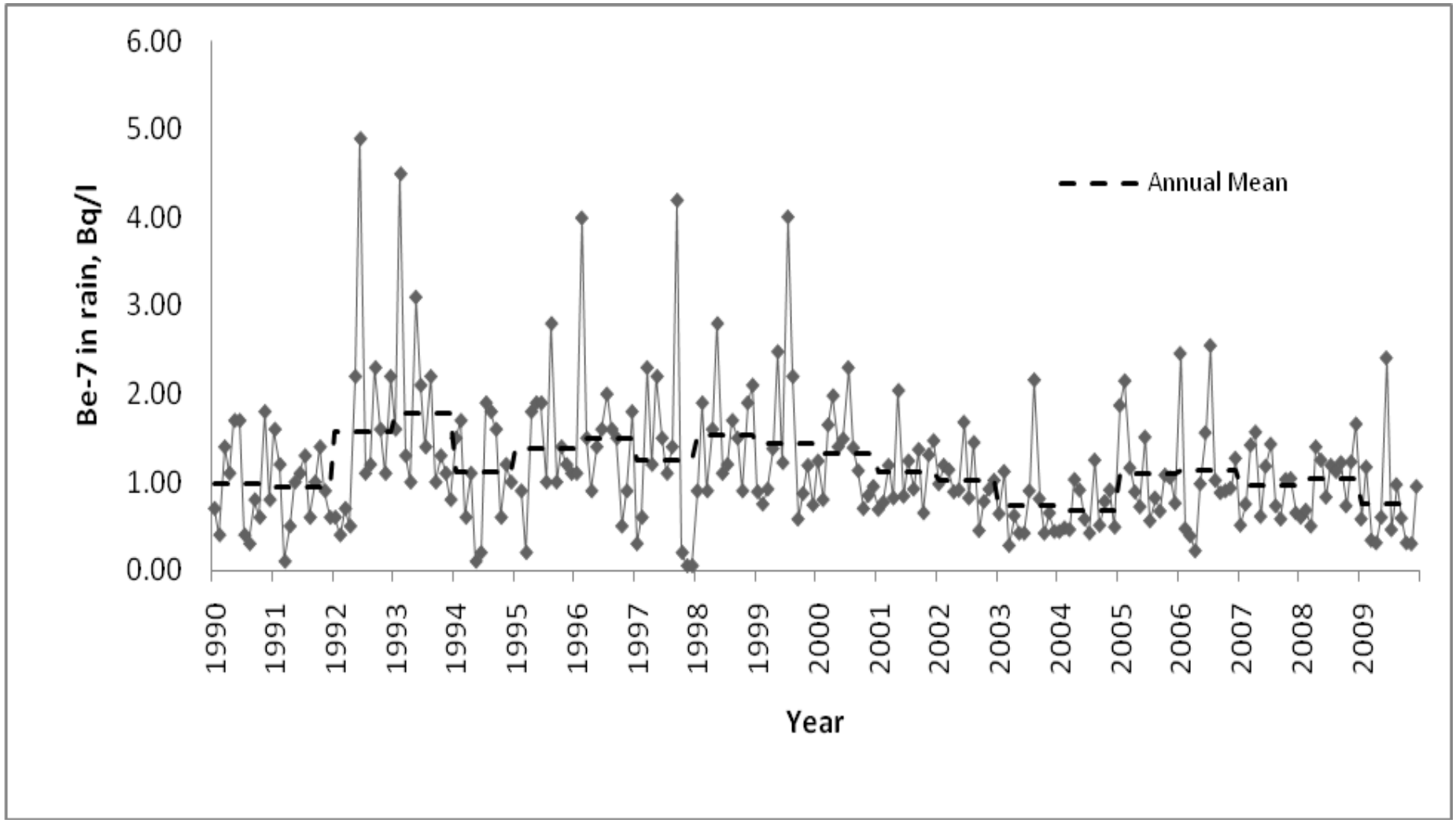


Figure 7 Annual concentration of gross beta activity in rainwater at Chilton