ENVIRONMENTAL RADIOACTIVITY AROUND STEEL WORKS

An Evaluation of the Significance of Lead -210 and Polonium-210 in Environmental Samples Collected in 1996/97 from around Steel Works Operated by British Steel at Redcar, Scunthorpe, Llanwern and Port Talbot

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SUMMARY

Reported levels of ^{210}Pb and ^{210}Po in samples of soil and vegetation taken during 1996 and 1997 from around Steel Works at Redcar, Scunthorpe, Llanwern and Port Talbot have been compared with background levels derived from data reported earlier for other areas of England and Wales. The derived background data for urban/industrial and rural/semi-rural locations proved to be essentially identical. For soils, the background levels derived were 26±14 Bq kg^{-1} for ^{210}Pb and 24±16 Bq kg^{-1} for ^{210}Po. For grass/herbage, the values were 22±14 Bq kg^{-1} for ^{210}Pb and 14±16 Bq kg^{-1} for ^{210}Po. The similarity between the levels of ^{210}Pb and ^{210}Po in the soil background data suggested that the ^{210}Po was fully supported by radioactive decay of ^{210}Pb. The same was true for many of the grass/herbage background samples but in the majority, the levels of ^{210}Pb clearly exceeded those of ^{210}Po.

Within the natural variabilities and analytical uncertainties, the reported levels of ^{210}Pb in soil at Redcar (25±4 Bq kg^{-1}), Scunthorpe (23±12 Bq kg^{-1}) and Llanwern (<30 Bq kg^{-1}) were well within the spread of the derived background level. The value of 'less than 10 Bq kg^{-1}' for ^{210}Pb in soil at Port Talbot was unusually low.

Similarly, the reported levels of ^{210}Po in soil at Redcar (33±11 Bq kg^{-1}) and Port Talbot (15±8 Bq kg^{-1}) were within the range of the derived background level. The ^{210}Po levels in soil at Scunthorpe (8±2 Bq kg^{-1}) and Llanwern (<10 Bq kg^{-1}) were within the derived background range but probably lower than the ^{210}Pb.

The level of 57±29 Bq kg^{-1} reported for ^{210}Pb in grass/herbage at Llanwern was relatively high but not outside the range of the derived background. At Port Talbot, the ^{210}Pb value of 26±5 Bq kg^{-1} was well within the derived background range. The figure of 'less than 10 Bq kg^{-1}' for ^{210}Pb in grass/herbage at Scunthorpe did not exceed the derived background level. There were no data reported for ^{210}Pb in grass/herbage at Redcar, but in a sample of mixed vegetation which included grass, the ^{210}Pb was reported as <65 Bq kg^{-1}.

The levels of ^{210}Po in the grass/herbage from Scunthorpe, Llanwern and Port Talbot were all well within the range of the derived background level. There were no data reported for Redcar.

The levels of ^{210}Pb in all grass/herbage samples, and in other samples of vegetation from around the Steel Works, always exceeded the levels of ^{210}Po. This, coupled with the observation that the ^{210}Pb levels were typical of background level, was indicative of naturally-occurring ^{222}Rn in the atmosphere being the major source. Had resuspended soil been responsible, the levels of ^{210}Pb and ^{210}Po would have been essentially equal. Enhanced root-uptake of ^{210}Pb is an unlikely explanation for ^{210}Pb levels exceeding ^{210}Po levels.

The available data show that the levels of both ^{210}Pb and ^{210}Po in soil and in/on grass/herbage in the environs of the Steel Works at Redcar, Scunthorpe, Llanwern and Port Talbot were probably no different from those elsewhere in England and Wales, nor indeed in some other parts of Europe and the United States.

CONTENTS

EVALUATION OF THE SIGNIFICANCE OF REPORTED LEVELS OF ^{210}Pb AND ^{210}Po IN ENVIRONMENTAL SAMPLES FROM AROUND STEEL WORKS AT REDCAR, SCUNTHORPE, LLANWERN AND PORT TALBOT OPERATED BY BRITISH STEEL

1.0 Introduction

1.1 The Environment Agency (the 'Agency') is investigating possible atmospheric emissions of natural radionuclides from sinter plants operated by British Steel at their Works at Redcar and Scunthorpe in England, and Llanwern and Port Talbot in South Wales. The geographical locations of the Works are shown at Figure 1. In 1996, the Agency's National Centre for Regulatory Monitoring (NCRM)[1] arranged for environmental samples to be taken from around the Works and analysed (by the Laboratory of the Government Chemist (LGC) and ICI Tracerco) for ^{210}Pb and ^{210}Po. The samples included 'surface soil', grass, weeds, leaves, road dust and pond water. Soil samples from Redcar and Scunthorpe were also analysed for ^{238}U and daughters and ^{232}Th. The sampling points around the Works at Redcar, Scunthorpe, Llanwern and Port Talbot are shown in Figures 2-5 respectively.

1.2 As an indicator of the levels of ^{210}Pb and ^{210}Po in soil and grass/herbage remote from Steel Works in England and Wales, data from the Ministry of Agriculture, Fisheries and Food (MAFF) and the Agency have been processed and 'background levels' derived. The background data were collated in two categories according to whether they came from urban/industrial areas or rural/semi-rural areas. Some literature values for ^{210}Pb and ^{210}Po in soils overseas were also found (and are quoted in Appendix 1) but they were not used in derivation of background levels.

1.3 The reported levels of ^{210}Pb and ^{210}Po in the soil and in the grass/herbage samples from around the Steel Works have been compared with the derived background levels.

1.4 Measurements of ^{210}Pb and ^{210}Po in samples of other than soil and grass/herbage collected in the environs of the Works, and measurements of members of the ^{238}U natural decay series and ^{232}Th, in soil are also discussed.

2.0 Source and Behaviour of ^{210}Pb and ^{210}Po in the Biosphere

2.1 Irrespective of man's activities, soil and vegetation will always be associated with ^{210}Pb and ^{210}Po since the primordial natural source of these radionuclides is ^{238}U in the Earth's crust.

2.2 In the ^{238}U natural decay series, all the members from ^{238}U down to ^{226}Ra inclusive are solids but the daughter of ^{226}Ra is ^{222}Rn, a radioactive noble gas which is sufficiently long-lived ($t_{1/2}$ 3.82 days) and chemically unreactive for significant amounts to leave the ground and escape into the Earth's atmosphere. In the ambient air, the ^{222}Rn decays to ^{210}Pb (via three short-lived radionuclides) which then decays

[1] Now the Agency's National Centre for Compliance Assessment (NCCA).

via ^{210}Bi ($t_{1/2}$ 5 days) to ^{210}Po. Since the half-life of ^{210}Pb is 22 years, and that of the ^{210}Po is only 138 days, equilibrium in a closed system would be established in about two years. However, the ambient air in this case is not an enclosed system and various processes (essentially dry and wet deposition) return the nuclides to the ground long before the $^{210}Pb \rightarrow {}^{210}Po$ equilibrium can be established. For this reason, the downward flux of ^{210}Pb always exceeds that of ^{210}Po. If these were the only processes transporting ^{210}Pb to the ground, the levels of ^{210}Pb found on surfaces (of say crops) exposed for short periods (say up to a few months) would always greatly exceed those of ^{210}Po. However, the deposition of airborne soil onto crops can be an important source of ^{210}Pb and ^{210}Po but, since in soils the two nuclides are normally in equilibrium, equal amounts of both would be deposited.

2.3 Root-uptake is another factor which might influence levels of ^{210}Pb and ^{210}Po in vegetation but this pathway is normally very much less important than deposition from the atmosphere.

3.0 Derivation of Background Levels of ^{210}Pb and ^{210}Po in Soil and in Grass/Herbage in England/Wales

3.1 Table 1 shows the data for ^{210}Pb and ^{210}Po in soil and grass/herbage from urban/industrial areas and Table 2 shows the data for rural/semi-rural areas.

3.2 Since the urban/industrial backgrounds did not differ from the rural/semi-rural backgrounds for either radionuclide, the two pairs of data were used to derive overall mean background values for each radionuclide and these are detailed in Table 3.

4.0 ^{210}Pb and ^{210}Po in Soil and in Grass/Herbage Samples from around the Steel Works at Redcar, Scunthorpe, Llanwern and Port Talbot

4.1 All samples taken in the environs of the Steel Works at Scunthorpe, Llanwern and Port Talbot were analysed by the LGC (1996/7) and the Redcar samples were analysed by ICI Tracerco (1996).

4.2 All individual measurements of ^{210}Pb and ^{210}Po in soil and grass/herbage from the environs of the four Steel Works are shown in Table 4. Where replicate measurements were reported, the derived means (in bold) were based on the series of measurements regardless of the uncertainties associated with the counting of radioactive disintegrations.

5.0 ^{210}Pb and ^{210}Po in Soils and Grass/Herbage From around the Steel Works Compared with Background Levels

5.1 The mean levels of ^{210}Pb and ^{210}Po in samples of soil and grass/herbage from around the Steel Works, together with mean values derived for the background sites in England and Wales, are detailed in Table 5. For interest, levels of ^{210}Pb and ^{210}Po in some soils overseas are shown in Appendix 1.

6.0 ^{210}Pb and ^{210}Po in Miscellaneous Vegetation from around the Steel Works

6.1 Results of measurements on samples of miscellaneous vegetation from around the Steel Works are detailed in Table 6.

7.0 Some Uncertainties and Natural Variabilities Associated with the Measurement of ^{210}Pb and ^{210}Po in Environmental Media

7.1 In order to obtain reliable results, sampling and analysis for ^{210}Pb and ^{210}Po must be carried out with due diligence. Some points calling for special attention are as follows:

- In order to minimise uncertainties associated with measurement of unsupported ^{210}Po, samples should be analysed soon after collection in order to minimise losses through radioactive decay ($t_{½}$ 138 days). (Unsupported ^{210}Po is of particular interest around some high temperature processing plant).

- ^{210}Po is tenaciously held by certain environmental media (soils in particular) (Berger et al., 1965) and it is essential to know extraction yields in the first stage of the radiochemical analysis.

- Determinations of ^{210}Pb and ^{210}Po in vegetation are difficult since root-uptake of these elements is exceedingly small and surface contamination rather than systemic contamination normally dominates. Contamination is seasonal (growth dilution occurs in spring) and atmospheric precipitation and soil resuspension can vary greatly from day to day; according to Mattson (1970), the concentration of ^{210}Po in the lower atmosphere shows seasonal fluctuations by up to a factor of ten. The radon-generating power of clay minerals apparently varies with moisture content (Tso et al. 1964).

- Any soil adhering to samples of vegetation will produce a positive bias in the results and adversely affect the precision. Moreover, the ratio of ^{210}Pb/^{210}Po in soil will be different from that in material deposited from the atmosphere from the decay of ^{222}Rn.

- ^{210}Po in natural waters is mostly attached to suspended particulate and bottom sediment; the amount in the water depends on the particulate loading (Matsumaga et al., 1995).

7.2 Quoted uncertainties in radiochemical measurements often refer only to the counting of radioactive disintegrations, but others such as those associated with chemical yield can be at least as great.

8.0 ^{238}U and Daughters and ^{232}Th in Soils at Redcar and Scunthorpe

8.1 The reported levels of ^{238}U and its daughters and ^{232}Th in three soil samples from Redcar and two from Scunthorpe are detailed in Table 7.

9.0 Discussion of Results

SOIL

9.1 When deriving background levels for ^{210}Pb in surface soil in England/ Wales, no apparent difference was found between the ^{210}Pb levels at the urban/industrial sites (25±8 Bq kg^{-1}) and those at the rural/semi-rural sites (26±12 Bq kg^{-1}) and an overall mean background level of 26±14 Bq kg^{-1} was derived. The same applied to ^{210}Po, where the levels were 22±10 Bq kg^{-1} (urban/industrial areas), 26±12 Bq kg^{-1} (rural/semi-rural areas) and the overall mean background derived was 24±16 Bq kg^{-1}.

9.2 The similarity of the reported levels derived for ^{210}Pb and ^{210}Po in soil indicates that the ^{210}Po was fully supported by radioactive decay of the ^{210}Pb.

9.3 Reference to Appendix 1 shows that the ^{210}Pb level (26±14 Bq kg^{-1}) and the ^{210}Po level (24±16 Bq kg^{-1}) in background soil in England/Wales compare with figures of 14±5 Bq kg^{-1} and 16±4 Bq kg^{-1} respectively for Luneberg Heath in Germany (Bunzl & Kracke, 1984).and 17±1Bq kg^{-1} and 18±1Bq kg^{-1} for the means of two soils in Poland (Pietrzak-Flis & Skowrorisk-Smolak, 1995). In Southern France, 10 Bq kg^{-1} of ^{210}Pb for a sandy soil and 13 Bq kg^{-1} for a loamy soil were reported by Marenco and Fontan (1972). From the data of Tso et al. (1964) for soils in some tobacco fields in the Southern USA, a mean ^{210}Po level of 17±6 Bq kg^{-1} was derived and in tobacco fields in Wisconsin, USA, Berger et al. (1965) found ^{210}Po levels of 71±5 Bq $kg^{-1}$for loamy soils, 76±4 Bq kg^{-1} for silt loams and 219±10 Bq kg^{-1} for 'muck'(i.e. highly organic) soils. The soils in Wisconsin were treated annually with phosphate fertilizer which normally contains members of the ^{238}U decay series. Where data were available for both ^{210}Pb and ^{210}Po (i.e. Luneberg Heath and Poland) the ^{210}Po was shown to be fully supported by radioactive decay of the ^{210}Pb .

9.4 Data from the Steel Works (Table 5) show that the levels of ^{210}Pb in soil samples from Redcar (25±4 Bq kg^{-1}), Scunthorpe (23±12Bq kg^{-1}), Llanwern (<30 Bq kg^{-1}) and Port Talbot (<10 Bq kg^{-1}) were not excessive in relation to the derived background for England and Wales. At Scunthorpe, Sample 1 (23±12 Bq kg^{-1}) was taken where maximum deposition was expected and Sample 2 (14±9 Bq kg^{-1}) from a point considered to be remote from, and unaffected by the Works (i.e. an analytical control or reference) (see Table 4). Although the level of ^{210}Pb in Sample 2 (the control) was possibly less than that in Sample 1, both were well within the derived background level.

9.5 Similarly, Table 4 shows that levels of ^{210}Po in soils from Redcar (33±11 Bq kg^{-1}), Scunthorpe (8±2 Bq kg^{-1}), Llanwern (<10 Bq kg^{-1}) and Port Talbot (15±8 Bq kg^{-1}) all fell within the derived background range.

9.6 At Redcar, the ^{210}Pb and ^{210}Po in soil were probably in secular equilibrium but the data from Scunthorpe and Llanwern were not sufficiently precise for any conclusion to be drawn in this respect except that there was no evidence for the presence of unsupported ^{210}Po.

9.7 The ^{210}Pb value of <10 Bq kg^{-1} (for all 8 samples) at Port Talbot is difficult to reconcile with figures for ^{210}Po ranging from <5 to 29±8 Bq kg^{-1} (Table 4); the mean ^{210}Po value was 15±8 Bq kg^{-1} (which was in-line with the <10 Bq kg^{-1} for ^{210}Pb) but the spread of results may indicate non-uniform deposition and deposition of unsupported ^{210}Po in places.

9.8 The background levels derived for ^{210}Pb and ^{210}Po in soils in England/Wales, the mean levels found in soil samples from around each of the Steel Works, and reported levels for some soils overseas are all displayed in Figure 6.

9.9 Except in recent geological sediments, ^{226}Ra ($t_{1/2}$ 1600 years) is in secular equilibrium with the parent ^{238}U ($t_{1/2}$ 4.5x 10^9 years). However, it is difficult to equate levels of ^{238}U with levels of daughters beyond ^{226}Ra since (a) the ^{222}Rn tends to leave its parent, enter interstitial air spaces in the soil and emanate from the ground surface into the Earth's atmosphere (b) not all the ^{222}Rn enters the interstices (some remains trapped inside solid particles), (c) the rate at which the ^{222}Rn leaves the ground varies according to climatic conditions and ground moisture and (d) the concentration of ^{222}Rn reduces in interstitial air closer to the ground surface.

9.10 The ^{210}Pb and ^{210}Po generated in the earth's atmosphere (from decay of ^{222}Rn) eventually returns to the Earth's surface, but since the atmospheric life-time of the ^{210}Pb is only 4-45 days (Bennett & Sandalls, 1991), there is insufficient time for the ^{210}Po to grow-in to anywhere near equilibrium and the downward flux of ^{210}Pb always exceeds that of ^{210}Po. The net result is that none of the ^{222}Rn which leaves the ground ever returns, all the ^{210}Pb which would have been formed in the ground (had the ^{222}Rn not departed) does return, and after a lapse of time, ^{210}Po attains equilibrium with the ^{210}Pb deposited on the ground. The situation is complicated further since the ^{222}Rn and its daughters are sufficiently long-lived in the atmosphere for deposition of ^{210}Pb and ^{210}Po to occur at places far removed from where exhalation took place. Clearly, it is difficult to equate soil levels of ^{238}U, or even levels of ^{226}Ra, with those of ^{210}Pb and ^{210}Po except that normally the ^{238}U levels will marginally exceed those of ^{210}Pb and ^{210}Po but these differences are too small to show up in normal radiometric analysis. Uncontaminated soil should therefore appear to contain identical activity concentrations of ^{238}U, ^{234}Th, ^{234}Pa, ^{234}U, ^{230}Th, ^{226}Ra, ^{210}Pb and ^{210}Po and, for those nuclides measured at Redcar (i.e. all except ^{234}Pa), this is indeed what was reported in 1996 (see Table 7). However, this was not the case at Scunthorpe where in Sample 1 the ^{234}Th and the ^{226}Ra exceeded the ^{238}U by about an order of magnitude and the level of ^{234}Th in Sample 2 was very much lower than in Sample 1. No explanation is offered for these apparent inconsistencies.

9.11 The reported levels of ^{238}U in the three samples of soil from Redcar were 43±5, 43±8 and 39±5 Bq kg^{-1} and these compare with uranium levels of 13-40 Bq kg^{-1} reported for much of Northern England by Jenkins et al. (1989).

9.12 At Scunthorpe, the ^{238}U levels (10±3 Bq kg^{-1} in the sample and 6±1 Bq kg^{-1} in the control) were lower than the levels at Redcar or those reported for Northern England by Jenkins et al. (1989).

9.13 ^{232}Th levels were also measured in the three soil samples from Redcar, but since ^{210}Pb and ^{210}Po are not members of the ^{232}Th natural decay series, the ^{232}Th levels have no influence on the these two radionuclides. However, in 327 samples of surface soil in the USA, Myrick et al. (1983) found a mean activity ratio of 1.2 for ^{226}Ra/^{232}Th which compares with ratios of 1.2, 1.3, and <2.3 for the Redcar samples. No useful conclusions were drawn from the ^{226}Ra/^{232}Th ratio in the two soil samples from Scunthorpe.

GRASS/HERBAGE AND MISCELLANEOUS VEGETATION

9.14 In about 60% of the background grass/herbage samples, the levels of ^{210}Pb clearly exceeded those of ^{210}Po as would be expected if the radionuclides originated from decay of ^{222}Rn in the Earth's atmosphere. However, levels of ^{210}Pb and ^{210}Po in the remainder were about equal, possibly resulting from a significant time lapse between sampling and analysis thereby allowing some in-growth of ^{210}Po and/or perhaps a small amount of soil was attached to the vegetation.

9.15 The levels of ^{210}Pb in grass/herbage from Scunthorpe (<10 Bq kg^{-1}) and Port Talbot (26±5 Bq kg^{-1}) were well within the range of the England/Wales derived background level of 22±14 Bq kg^{-1}.

9.16 The level of 57±29 Bq kg^{-1} for ^{210}Pb in grass/herbage at Llanwern was relatively high but within the range of the derived background.

9.17 The mean levels of ^{210}Po in grass/herbage at Scunthorpe, Llanwern and Port Talbot were within the derived background level of 14±16 Bq kg^{-1}. There were no grass/herbage data for Redcar.

9.18 The levels of ^{210}Pb in herbage from Llanwern, Port Talbot and possibly Redcar and Scunthorpe were higher than the respective levels of ^{210}Po, corresponding with natural deposition following radioactive decay of ^{222}Rn in the atmosphere. Had particles of soil been attached to the vegetation analysed, the levels of the two nuclides would have been expected to have been much closer.

9.19 Placing into perspective the levels of ^{210}Pb and ^{210}Po in the samples of miscellaneous vegetation is difficult since no appropriate backgrounds or reference levels were available for comparison. Moreover, since deposition from the atmosphere is essentially the only source of ^{210}Pb and ^{210}Po on the aerial parts of vegetation, only like species should be compared since the ratio of mass-to-surface area of vegetation influences surface contamination levels expressed as 'activity per unit mass'. Notwithstanding this point, the reported levels of ^{210}Pb on/in mixed vegetation, tree leaves, unspecified leaves and a thistle head were all in line with the background level derived for grass/herbage and, as with the grass/herbage from around the Steel Works, the ^{210}Pb values were much higher than the corresponding ^{210}Po levels indicating the natural situation with no evidence for deposition of unsupported ^{210}Po.

9.20 The background levels derived for England/Wales for ^{210}Pb and ^{210}Po in/on grass/herbage, together with the mean levels found in grass/herbage and in miscellaneous vegetation around each of the Works, are summarised and displayed in Figure 7.

10.0 Conclusions

10.1 The levels of ^{210}Pb in soil around the Steel Works at Redcar, Scunthorpe and Llanwern were probably no different from those elsewhere in England and Wales. At Port Talbot, the levels were consistently lower than the derived background.

10.2 The levels of ^{210}Po in soil around all four Steel Works were consistent with the derived background for England/Wales.

10.3 The ^{210}Po in soil around the Works at Redcar was probably fully supported by radioactive decay of ^{210}Pb, just as it was in the background samples in England /Wales, Germany and Poland. The same may have been true for ^{210}Po in the single sample from Scunthorpe. At Llanwern, there was no indication of ^{210}Po levels exceeding those of ^{210}Pb. At Port Talbot, the levels of ^{210}Po varied over a wide range with the ^{210}Po sometimes exceeding the ^{210}Pb and sometimes vice versa. The possibility of deposition of unsupported ^{210}Po onto soil at Port Talbot cannot be ruled out.

10.4 At Llanwern and Port Talbot, the levels of ^{210}Pb associated with grass/herbage were in-line with the derived background for grass/herbage in England/Wales. The level of 'less than 10 Bq kg^{-1}' for ^{210}Pb at Scunthorpe indicated that levels were not excessive relative to the derived background level.

10.5 In contrast to the soil data for Port Talbot, the ^{210}Pb exceeded (often by a factor of 5-10) the ^{210}Po in/on all samples of grass/herbage and miscellaneous vegetation from around all the Works. Therefore, although the possibility of aerial deposition of unsupported ^{210}Po onto soil at Port Talbot cannot be ruled out, the grass/herbage data indicate that this is a remote possibility.

10.6 A Redcar, where ^{238}U and its daughters down to and including ^{226}Ra were measured in soil, the levels were much as expected from surveys in Britain and the results for the individual radionuclides were internally consistent. The ratio of $^{226}Ra/^{232}Th$ at Redcar was typical of that found in a comprehensive study of soils in the USA and there is no reason to expect this to be different in the UK.

10.7 Overall, it was concluded that although the monitoring data were insufficient for unequivocal conclusions to be drawn, the levels of ^{210}Pb and ^{210}Po around the Steel Works at Redcar, Scunthorpe, Llanwern and Port Talbot were probably no different from those elsewhere in England and Wales or indeed in parts of Germany, France, Poland, India, Florida, Tennessee, North Carolina and South Carolina.

11.0 Acknowledgement

The photocopies of parts of O.S. maps at Figures 2-5 inclusive were made by the licensed agent Carbon Colour Co., Observatory Street, Oxford.

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TABLE 1 ^{210}Pb and ^{210}Po in Soil and Grass/Herbage Samples from some Urban/Industrial Areas in England and Wales (MAFF 1996)

Soil		Grass/Herbage		Source of Sample
^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	
(Bq kg^{-1})		(Bq kg^{-1})		
31±3	30±1	17±3	11±3	Nr. Power station, Eggborough, 1995
22±2	22±1	15±2	7.5±1	Nr. Oil refinery, Ellesmere,1995
33±4	33±1	21±2	7.8±1	Nr. Oil refinery, Milford Haven, 1995
41±3	38±1	23±4	6.3±1	Nr. Albright & Wilson, Cumbria, 1994
37±3	36±1	13±2	5.3±1	Nr. Power station, Aberthaw, 1994
24±4	22±1	11±1	15±1	Nr. Power station, Eggborough, 1994
23	9	6	1.3	Mixed industry, Newton Bewley, 1993
23	9	12	12	Mixed industry, Billingham, 1993
23	24	28	13	Nr.Smelter, Avonmouth, 1991/2
12	10	24	32	Nr. Britag Fertilizer, Hmb'side, 1991/2
18	16	40	43	Nr. Capper Pass, Humberside, 1991/2
18	15	26	30	Nr. Power station, Drax 1991/2
20	20	45	29	Nr.Oil refinery & Smelter, Kent, 1991/2
Mean	**Mean**	**Mean**	**Mean**	
25±8	**22±10**	**22±11**	**16±13**	

TABLE 2 ^{210}Pb and ^{210}Po in Samples of Soil and Grass/Herbage from some Rural and Semi-Rural Areas of England and Wales (MAFF 1996)

Soil		Grass/Herbage		Source of Sample
^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	
(Bq kg^{-1})		(Bq kg^{-1})		
nd	nd	19±1	8.1±0.5	Single sample, Marloes, Dyfed, 1995
36±0.5	40±14	15±1	5.5± 0.2	Harrogate, Yorks., 1994
39	38	15	20	Single sample, Oulton Broad, Suffolk, 1993
14	18	25	6	Single sample, Salisbury, Wilts., 1993
23	14	21	10	Single sample, Andover, Hants., 1991/2
16	14	38	33	Single sample, New Haw, Surrey,1991/2
39	38	15	2	Oulton Broad, Suffolk, 1991/2
14	18	25	6	Salisbury, Wilts., 1991/2
Mean	**Mean**	**Mean**	**Mean**	
26±12	**26±12**	**22±8**	**11±10**	

'nd'represents 'no data'

TABLE 3 Derived Mean Background Levels for ^{210}Pb and ^{210}Po in Soil and Grass /Herbage in England and Wales

Soil		Grass/Herbage	
^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
26±14	**24±16**	**22±14**	**14±16**

TABLE 4 ^{210}Pb and ^{210}Po in Samples of Soil and Grass/Herbage taken in the Environs of the Steel Works, 1996/7

Redcar

Soil Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1*	NZ 563238	28±8	37±12
2**	NZ 563238	27±8	42±14
3**	NZ 570235	20±9	21±7
	Means:	**25±4**	**33±11**

*Surface scrapings
** 2-5 cm depth

Scunthorpe

Soil Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1	SE 933086	23±12	8±2
2 (Control)	SE 868094	14±9	<5

Grass Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1	SE 933086	<10	<5
2(Control)	SE 868094	<10	<5

Llanwern

Soil Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1*	ST 376876	30± 9	<5
2*	ST 378878	<20	10 ±2
3*	ST 375875	<20	3 ±1
4*	ST 373876	<20	7 ±2
5*	ST 372880	39 ±20	<5
	Means:	**<30**	**<10**

*Topmost 1 cm of soil, May 1997.

Grass Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1	ST 384876	92±37	12±5
2	ST 383878	41±8	9±4
3	ST 378874	85±14	<5
4	ST 380868	39+11	<5
5	ST 383867	29+6	7±3
	Means:	**57±29**	**8±3**

continued...

Port Talbot

Soil Ref. No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1	SS 783888	<10	14±5
2	SS 783888	<10	<5
3	SS 782888	<10	12±3
4	SS 783887	<10	20±4
5	SS 783889	<10	<5
6	SS 784890	<10	14±3
7	SS 786890	<10	21±7
8	SS 787890	<10	29±8
	Means:	**<10**	**15±8**

Herbage Ref. No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
1	SS 786890	26±5	7 ±1
2	SS 787890	26±4	5 ±1
	Means:	**26± 5**	**6±1**

TABLE 5 Summaries of ^{210}Pb and ^{210}Po in Soil and Grass/Herbage Samples from England/Wales Background Sites and from the Environs of the Steel Works

Source of Sample	Soil		Grass/Herbage		Source of Data
	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	
	(Bq kg^{-1})		(Bq kg^{-1})		
Background England/Wales	26±14	24±16	22±14	14±16	Table 3
Redcar	25±4	33±11	nd	nd	Table 4
Scunthorpe	23±12	8±2	<10	<5	Table 4
Llanwern	<30	<10	57±29	8±3	Table 4
Port Talbot	<10	15±8	26±5	6±1	Table 4

'nd' represents 'no data'

TABLE 6 ^{210}Pb and ^{210}Po in Samples of Miscellaneous Vegetation from around the Steel Works

Redcar

Material and Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
Mixed vegetation 1	NZ 563328	<65	<10
Tree leaves 1	NZ 575239	<49	<5

continued...

Scunthorpe

Material and Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
Leaves 1	SE 933086	13±3	6±2
Leaves 2 (Control)	SE 868094	18±6	<5

Llanwern

Material and Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
Weeds 1	ST 380870	21±5	<5
Tree leaves 1	ST 386870	77±19	<5

Port Talbot

Material and Sample No.	Sampling Point (O.S. Grid Ref.)	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})
Thistle head 1	SS 783889	22±11	<5

TABLE 7 Members of the ^{238}U Natural Decay Series and ^{232}Th in Soil Samples from Redcar and Scunthorpe

Redcar (measurements by ICI Tracerco, 1996)

Sample	Concentration of Radionuclide in Soil (Bq kg^{-1})									
	^{238}U	^{234}Th	^{234}U	^{230}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{210}Pb	^{210}Po	^{232}Th
Soil 1*	43±5	49±6	33± 7	16±2	33±12	33±3	32±2	28± 8	37±12	27±2
Soil 2°	43±8	39±6	40±10	36±6	42±11	22±2	22±2	27±8	42±14	32±5
Soil 3•	39±5	41±6	36±5	43±3	<70	23±2	22±2	20±9	21±7	30±5

* surface scrapings at O.S. Grid Ref. NZ 563238
° 2-5 cm depth at O.S. Grid Ref. NZ 563238
• 2-5 cm depth at O.S. Grid Ref. NZ 570235

Scunthorpe (gamma spectrometric measurements by LGC, 1996)

Sample	Concentration of Radionuclide in Soil (Bq kg^{-1})									
	^{238}U	^{234}Th	^{234}U	^{230}Th	^{226}Ra	^{214}Pb	^{214}Bi	^{210}Pb	^{210}Po	^{232}Th
Soil 1	10±3	90±20	nd	nd	95±40	20±5	25±5	23±12	8±2	<20
Soil 2	6 ±1	<25	nd	nd	<40	20±10	<15	14±9	<5	<20

Soil 1 taken at O.S. Grid Ref. SE 933086
Soil 2 (control) taken at O.S. Grid Ref. SE 869094
'nd' represents 'no data'

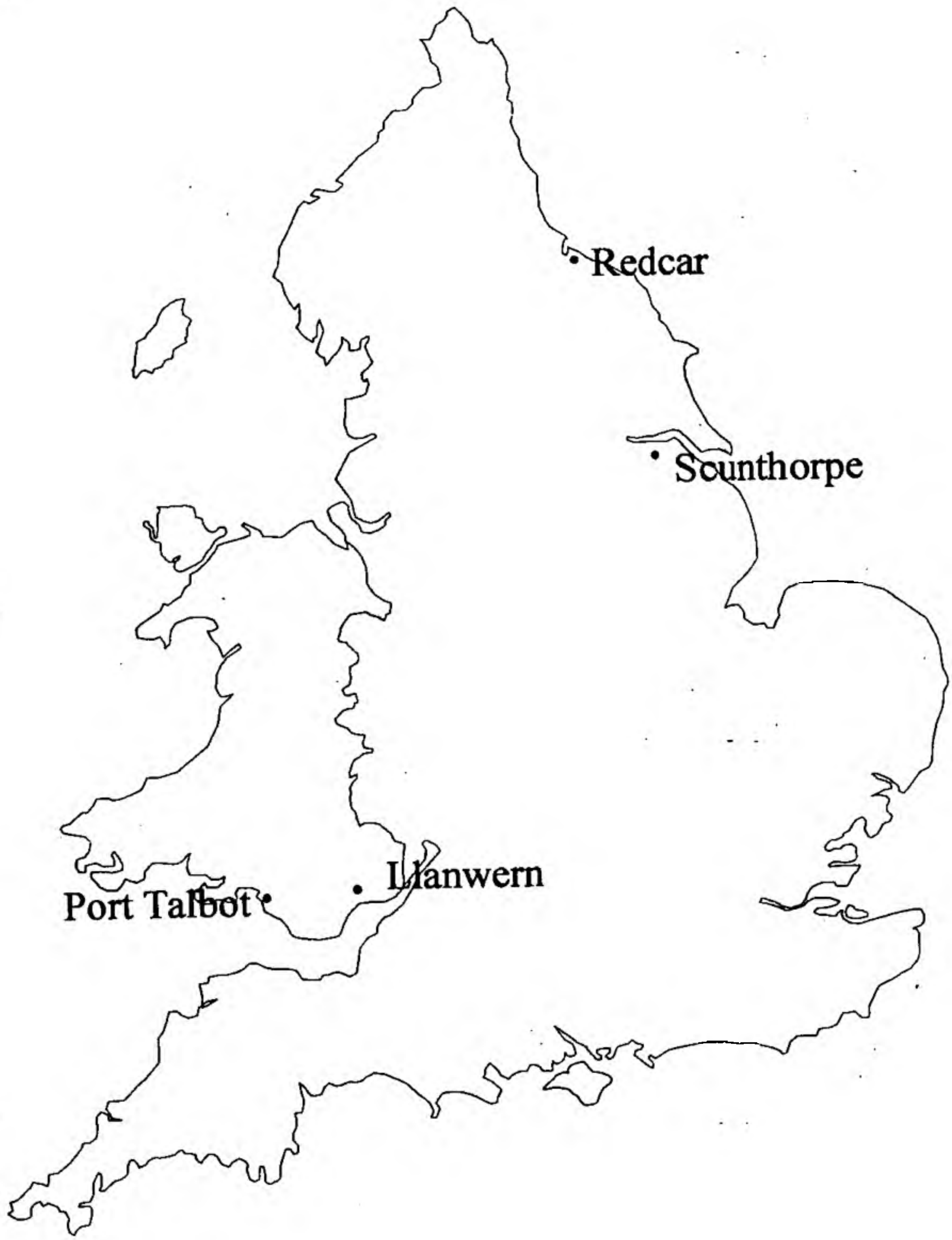


FIGURE 1 LOCATIONS OF THE STEEL WORKS

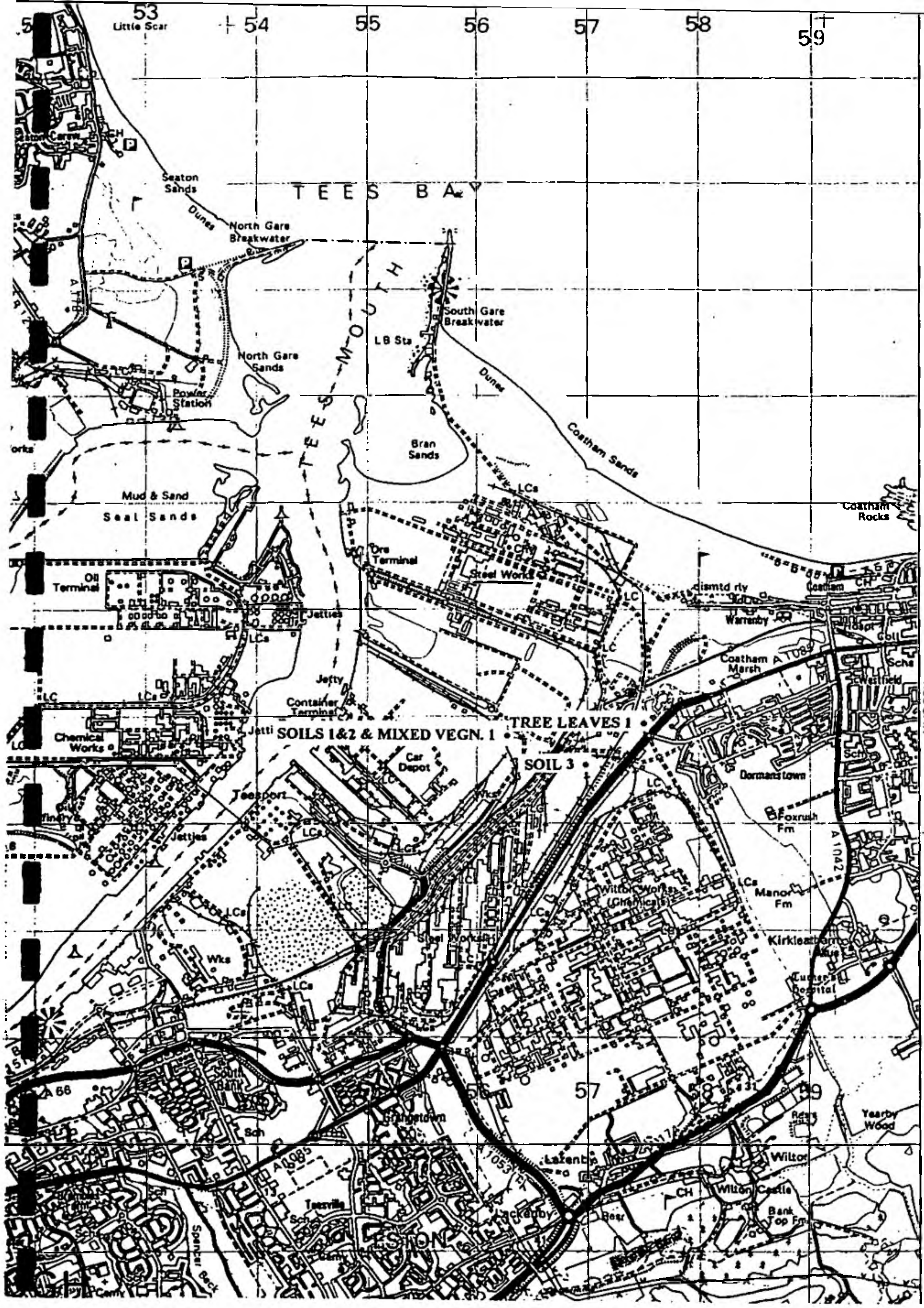


FIGURE 2 SAMPLING POINTS AROUND REDCAR STEEL WORKS Scale: 2cm to 1km
(From Ordnance Survey Landranger Sheet 93)

FIGURE 3 SAMPLING POINTS AROUND SCUNTHORPE STEEL WORKS

Scale 2cm to 1km (From Ordnance Survey Landranger Sheet 112)

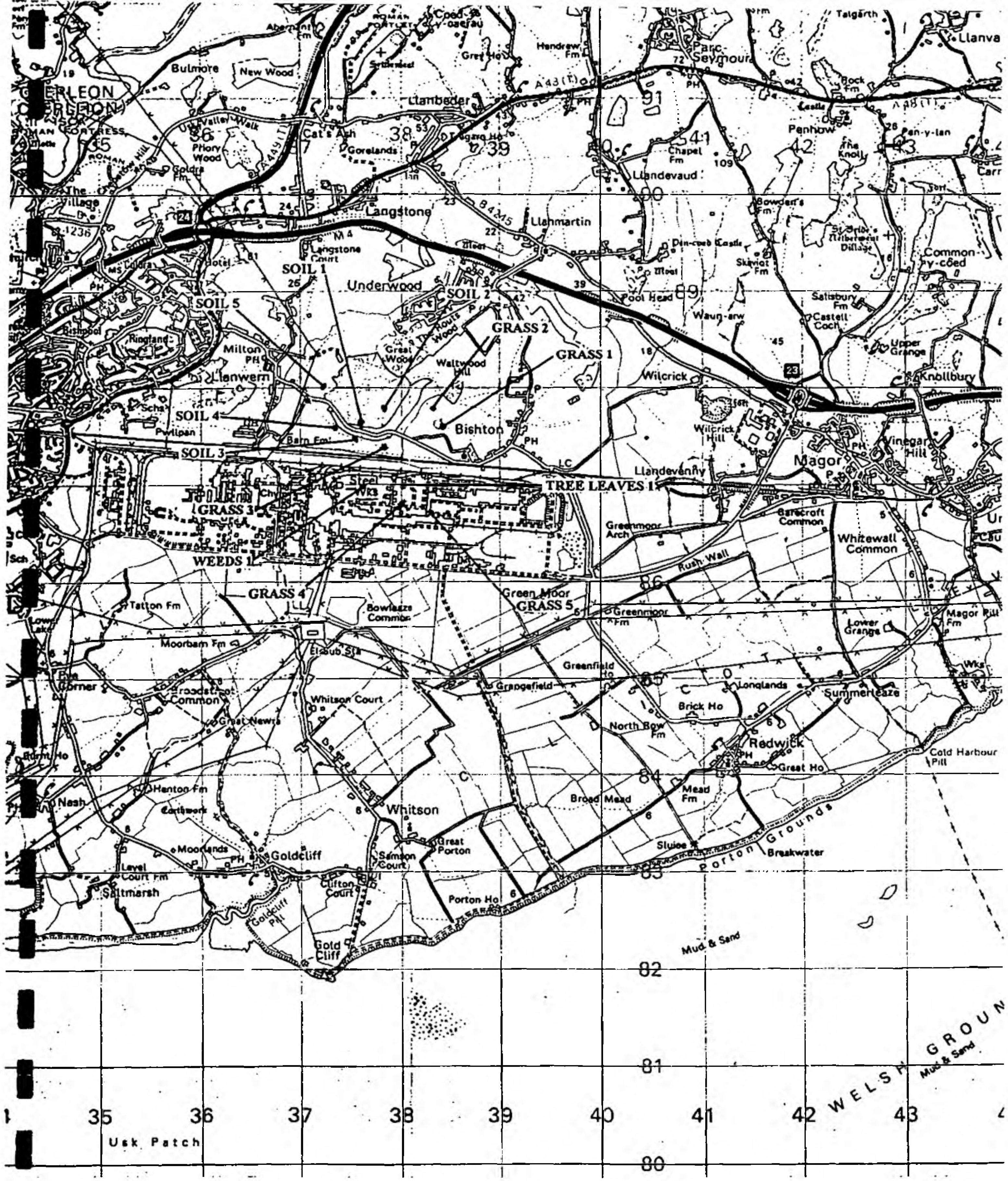


FIGURE 4 SAMPLING POINTS AROUND LLANWERN STEEL WORKS Scale 2cm to1km

(From Ordnance Survey Landranger Sheet 171)

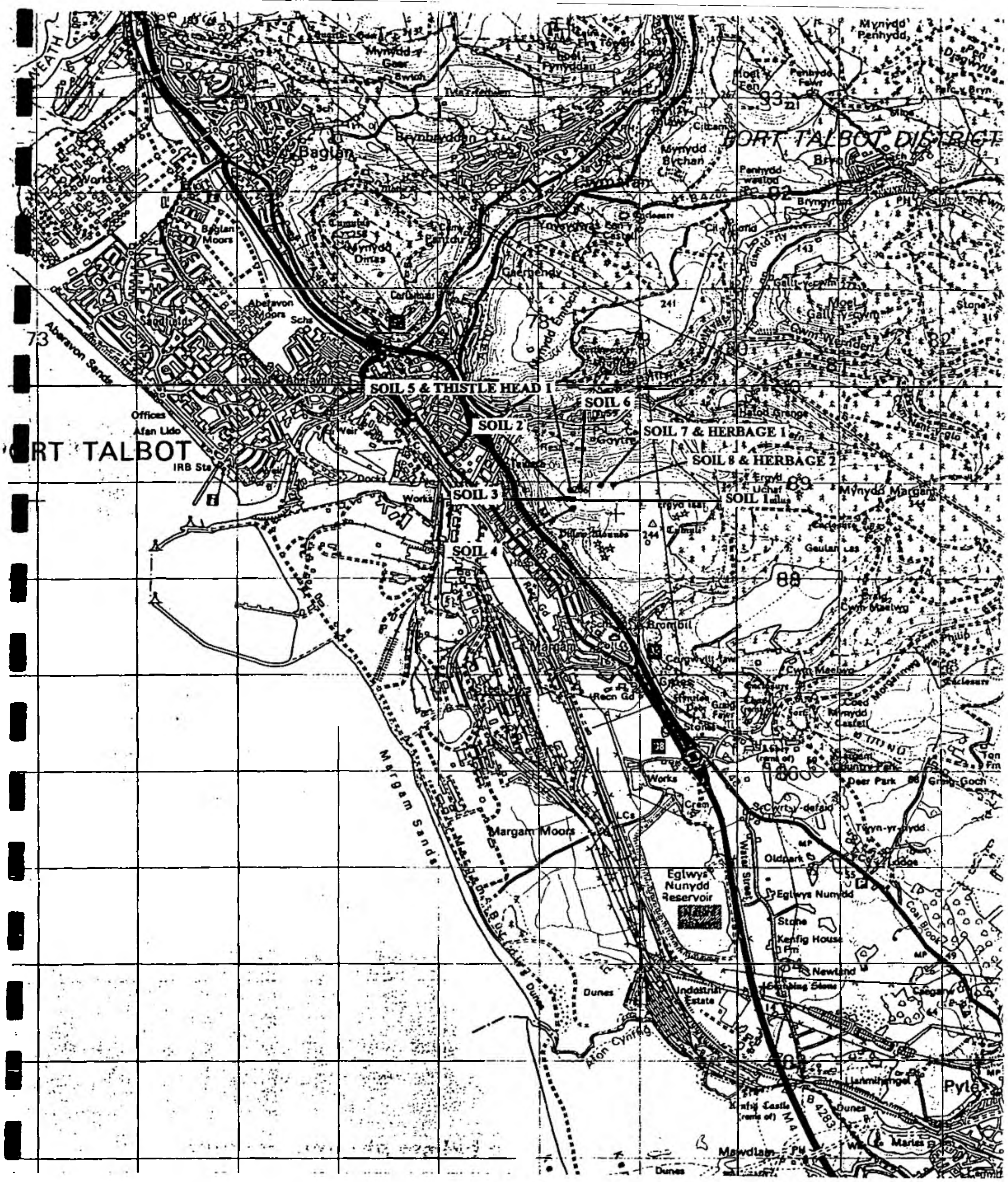
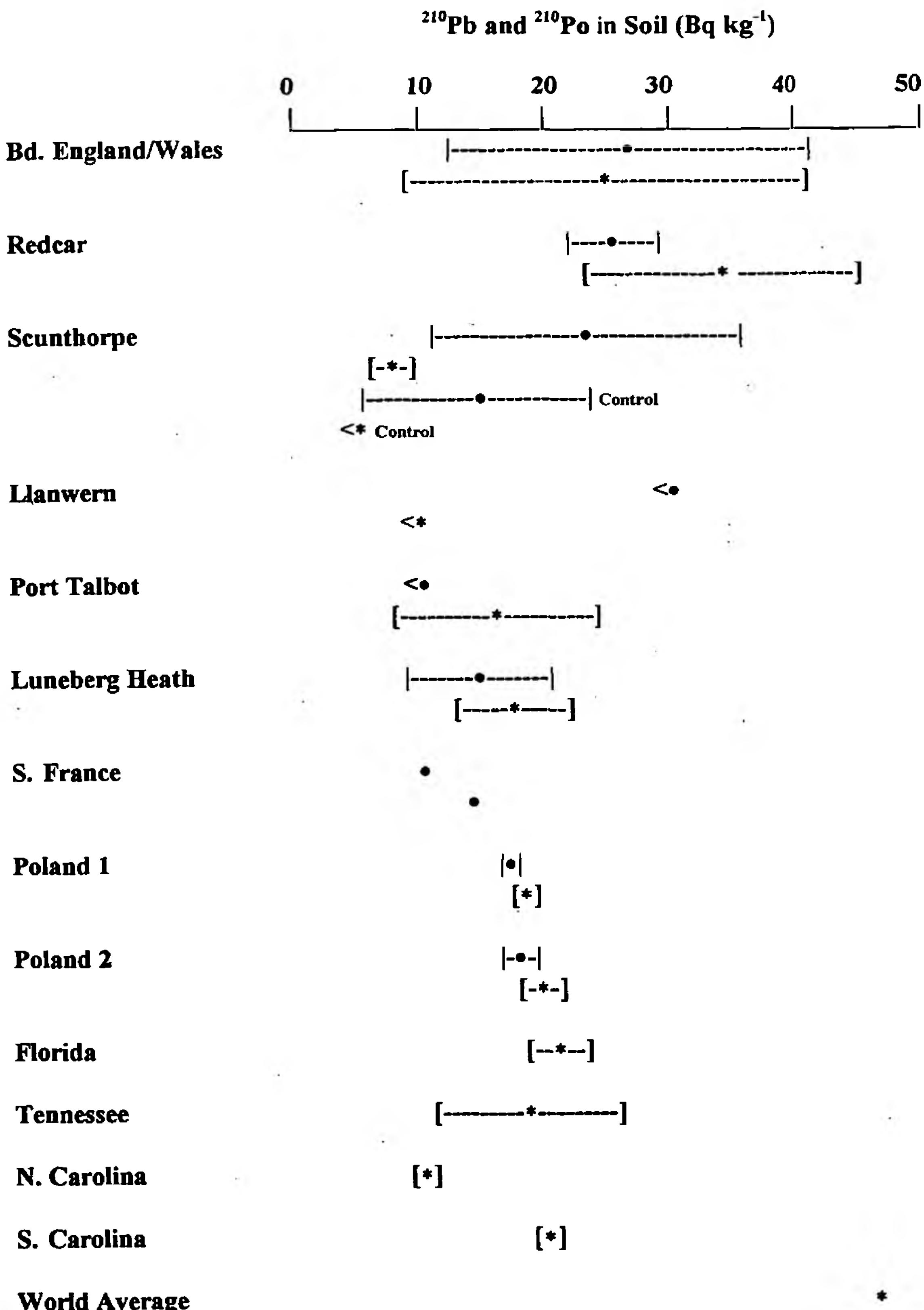


FIGURE 5 SAMPLING POINTS AROUND PORT TALBOT STEEL WORKS

Scale: 2cm to 1km (From Ordnance Survey Landranger Sheet 170)



|--•--| represents mean and s.d for ^{210}Pb. <• represents 'less than' for ^{210}Pb

[--*--] represents mean and s.d. for ^{210}Po <* represents 'less than' for ^{210}Po

FIGURE 6 LEVELS OF ^{210}Pb AND ^{210}Po IN SOILS

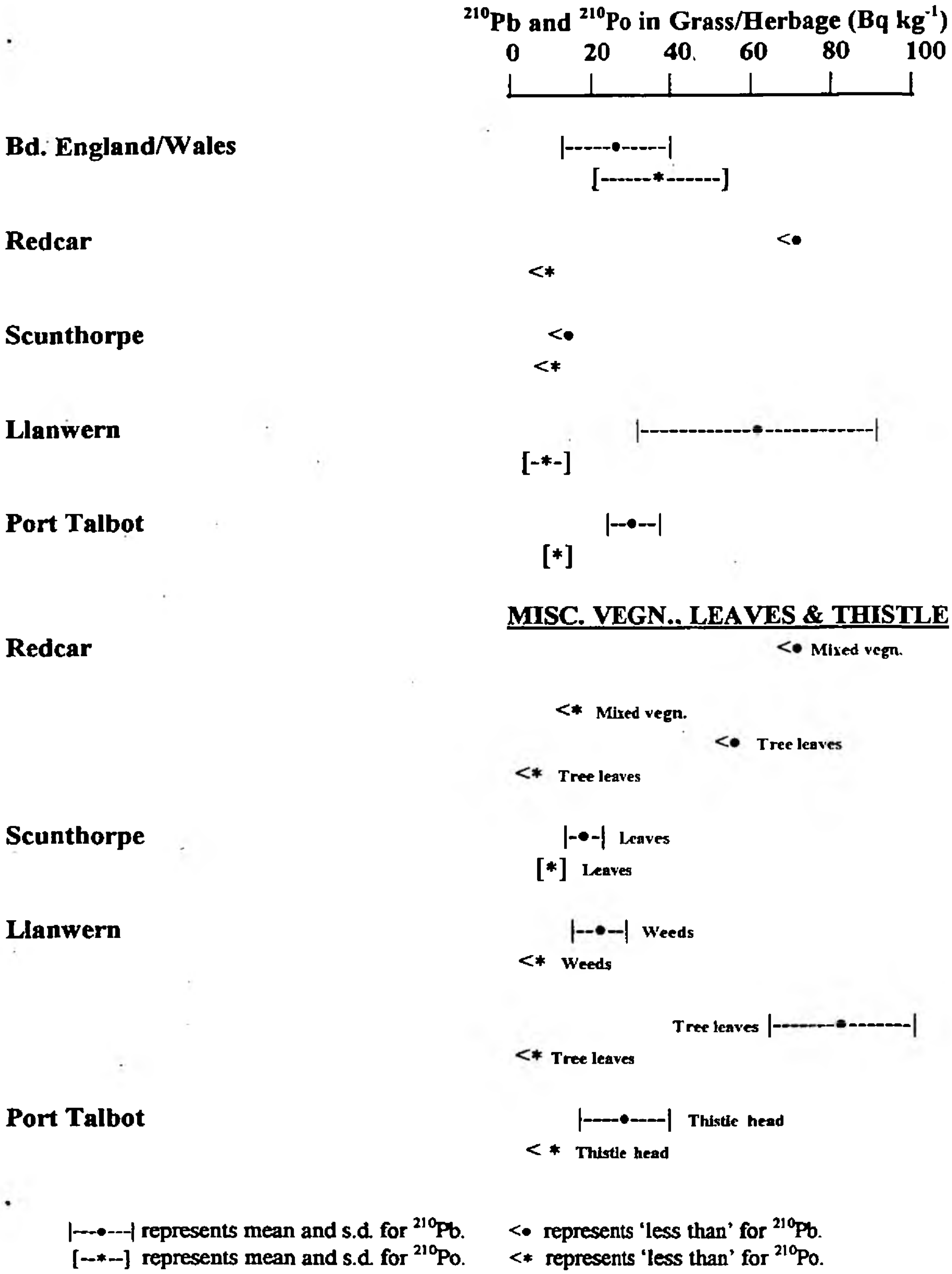


FIGURE 7 LEVELS OF ^{210}Pb AND ^{210}Po IN GRASS/HERBAGE AND IN MISCELLANEOUS VEGETATION

APPENDIX 1: ^{210}Pb AND ^{210}Po IN SOILS OVERSEAS

Place	Soil Type	^{210}Pb (Bq kg^{-1})	^{210}Po (Bq kg^{-1})	Reference
Luneberg Heath, Germany	ns	14±5	16±4	Bunzl & Kracke (1984)
S.France	Sandy	10	nd	Marenco & Fontan (1972)
	Loamy	13	nd	
Poland	Sandy	16±0.4	17±0.6	Pietrzak-Flis & Skowroriska-Smolak (1995)
		17±0.8	18±0.2	
S. India	ns	6-43	11-20	Narayama (1995)
Florida, USA	ns	nd	20±2	Tso et al.(1964)
	ns	nd	14±1	
	ns	nd	17±2	
Tennessee, USA	Silt loam	nd	37±4	Tso et al. (1964)
	Sandy loam	nd	11±4	
		nd	14±0.11	
		nd	15±0.4	
	Loamy sand	nd	14±0.11	
N. Carolina, USA	ns	nd	9.6±0.2	Tso et al.(1964)
S.Carolina	ns	nd	20±0.7	Tso et al.(1964)
Wisconsin tobacco fields*, USA	ns	nd	132±6	Berger et al. (1964)
			108±6	
			105±6	
			94±6	
			94±6	
			90±6	
			84±5	
			84±5	
			79±6	
			65±5	
	2 loamy	nd	71±5	
	13 silt loams	nd	76±4	
	5 muck**	nd	219±10	
World average		nd	44.4	Parfenov (1974)

'ns' represents 'not specified' 'nd' represents 'no data'

* treated annually with phosphate fertilizer.

** organic soil rich in humus

APPENDIX 2: GLOSSARY OF TERMS

Aerial Deposition. Deposition from the atmosphere to the ground.

Becquerel (Bq). The unit of measurement of **radioactivity.** 1 Bq is one disintegration per second.

Natural Radioactivity. Natural Radioactivity is due to the disintegration of naturally occurring **radionuclides**, most which may be arranged in three radioactive series. They are the Uranium Series (which includes ^{226}Ra, ^{222}Rn, ^{210}Pb and ^{210}Po), the Thorium Series and the Actinium Series.

Nuclide. Any given atomic species characterised by: (1) the number of protons, Z, in the nucleus, (2) the number of neutrons, N, in the nucleus and, in the case of an isomer, (3) the energy state of the nucleus.

Radioactive Equilibrium. A state ultimately reached when a **radionuclide** with a relatively long half-life (i.e. the parent) decays to a radionuclide with a shorter half-life (i.e. the daughter). At equilibrium, the number of disintegrations per unit time is the same for both the parent and the daughter. For practical purposes, radioactive equilibrium is assumed to be established when about 4-5 half-lives of the daughter have elapsed (after four half-lives, the number of radioactive disintegratios per unit time from the daughter will be equal to 94% of those from the parent, after five half-lives 97%, and so on.)

Radioactive Half-life ($t_{1/2}$). The time taken for the activity of a **radionuclide** to decay to half of its original value.

Radioactivity. The property of spontaneous disintegration possessed by certain unstable types of atomic nuclei. The disintegration is accompanied by the emission of either alpha or beta particles and/or gamma rays. The rate at which **radionuclides** disintegrate (or decay) is unaffected by any chemical changes, any normal changes of temperature and pressure, or by the effects of electric or magnetic fields. The unit of measurement of radioactivity is the **Becquerel**.

Radionuclide. A radioactive **nuclide**.

Unsupported Radionuclide. At **radioactive equilibrium**, the activity of the daughter remains essentially constant because as it decays it is replaced by decay of the parent. But, when a **radionuclide** is isolated from its parent it is said to be unsupported' and will decay with its own characteristic half-life. For example, in a closed system, given time, ^{210}Pb and ^{210}Po will attain equilibrium and the rate of decay of the ^{210}Po will appear to be the same as that of the ^{210}Pb. However, if the accumulated ^{210}Po were to be separated from the ^{210}Pb, it would then be unsupported and would decay with its own characteristic **half-life** of 138 days.