INSTITUTE OF TERRESTRIAL ECOLOGY

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Vegetation and Soil Survey in Cumbria to Validate the Aerial Survey of 1988

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CONTENTS

SUMMARY

A ground survey of radiocaesium activity concentrations in vegetation and soils was conducted in 3 areas (each 3 x 5 km) in the south western corner of the restricted area of west Cumbria. The areas all appeared to have unexpected $^{137}Cs:^{134}Cs$ ratios in the Scottish Universities Research and Reactor Centre aerial survey.

In the study areas the aerial survey appears to have overestimated the total radiocaesium deposit by a factor of approximately 2. However, extrapolation of these results to the larger area surveyed during the aerial survey would be unjustified; the general pattern of radiocaesium deposition recorded by the full aerial survey was broadly similar to that found by other authors. The presence of areas of peat associated with low ^{40}K measurements appears adversely to affect ^{134}Cs measurements determined by the aerial survey, causing comparatively low estimates of ^{134}Cs deposition.

In the areas studied aged radiocaesium, primarily from nuclear weapons fallout and the Windscale accident, accounted for 30-50% of the ^{137}Cs deposit. The uptake by vegetation of aged and Chernobyl radiocaesium deposited onto soil was measured, as ultimately it is radiocaesium levels in vegetation which determine activity levels in sheep rather than total deposition. The transfer of Chernobyl radiocaesium from the top 4cm of soil 4 years after the accident is now similar to that of the aged radiocaesium, which will mostly have been present in the environment for more than 20 years. This suggests that future reductions in radiocaesium levels in vegetation and therefore sheep will be slow, but cannot be quantified on the currently available data. However, physical decay, particularly in the short term, of ^{134}Cs, will inevitably result in small yearly reductions of the total radiocaesium deposit.

The total aged radiocaesium deposit was less available for plant uptake than that from Chernobyl. This is because a greater proportion of the earlier deposit has migrated down the soil profile.

The problems of identifying "hot spots", areas within the restricted areas with comparatively high radiocaesium activities in vegetation and hence sheep, are discussed. Additionally preliminary studies are presented which show the potential importance of fungal hyphae in retaining radiocaesium in the rooting zone of the affected upland soils.

PART 1 RADIOCAESIUM DEPOSITION AND PLANT UPTAKE STUDIES

1. INTRODUCTION

A helicopter survey of radiocaesium deposition in Cumbria was conducted in July-August 1988 by the Scottish Universities Research and Reactor Centre (SURRC) (Sanderson & Scott, 1989a;1989b). The survey appeared to show areas with $^{137}Cs:^{134}Cs$ ratios in the south west of the restricted area which departed from those which might be expected. Prior to the Chernobyl accident this area was contaminated by radiocaesium from both nuclear weapons fallout and the Windscale accident of 1957.

These anomalies were investigated by conducting a ground survey. The uptake of aged and Chernobyl radiocaesium by vegetation were also measured, as ultimately it is the availability of radiocaesium for plant uptake and consequent radiocaesium levels of vegetation, rather than the total deposit in the soil, which determines the radiocaesium concentrations in sheep.

2. RADIOCAESIUM DEPOSITION

2.1 Interpretation of SURRC data set

Further interpretation of the SURRC data set (Sanderson & Scott, 1989b) was conducted to locate suitable sampling areas. After consultation with SURRC staff it was decided to concentrate on areas showing ^{137}Cs >30 kBq m^{-2} or ^{134}Cs >15 kBq m^{-2} or ^{40}K <50 kBq m^{-2} (Figures 1-3). This identified three types of anomalous areas:

i) high ^{137}Cs deposition compared with ^{134}Cs deposition;
ii) high ^{134}Cs deposition compared with ^{137}Cs deposition, including some ^{137}Cs:^{134}Cs ratios less than 1.0;
iii) low (sometimes negative) ^{134}Cs deposition associated with low ^{40}K.

These inconsistencies are evident if the overlays (Figure 1a and and 3a) are compared with Figure 2.

2.2 Sampling strategy

Sampling was conducted in 1 example of each of the 3 types of anomalous areas outlined above. The 3 areas sampled, "Black Combe", "Corney Fell" and "Thwaites", were each 3 x 5 km (Figure 4). Black Combe is a type (i) area with high ^{137}Cs in comparison with ^{134}Cs (Figure 5a), Corney Fell is a type (ii) area of high ^{134}Cs compared with ^{137}Cs (Figure 5b) and Thwaites is a type (iii) area with low ^{40}K and low ^{134}Cs (Figure 5c). They contained 62, 56 and 61 aerial survey measurements respectively. All three areas are predominantly unimproved grassland, although they all contain some enclosed pastures or woodland, and Black Combe has extensive areas of heather (*Calluna vulgaris*).

A total of 108 ground survey samples were collected in February/March 1990. Six 1 km^2 squares (based on the Ordinance Survey National Grid) were chosen at random from each 15 km^2 area. Within each of these six squares, six random sampling points were identified. Therefore, a total of 36 sites were sampled in each of the three areas.

Particular care was taken to ensure that sample location was noted accurately; height above sea level was estimated from the Ordinance Survey 1:25000 series maps for the area. Samples of soil, complete with surface vegetation, were collected down to bedrock or to 40cm if the soil was particularly deep. Soil depth was noted and bulk density of the complete soil profile estimated, by weighing a known volume of fresh soil after drying to a constant weight at 80°C.

2.3 Radioanalyses

Samples were oven dried at 80°C and milled, complete with surface vegetation, for gamma-analyses. Stones (>2 mm) were removed and weighed. Milled samples were placed in 750mL Marinelli containers and counted on hyperpure Ge detectors for between 10 000 and 80 000 seconds. Counting error was <5% for both radiocaesium isotopes.

2.4 Selection of Chernobyl ^{137}Cs:^{134}Cs ratio for use in calculations

Calculations of pre-Chernobyl ^{137}Cs levels are obviously dependent on the assumed ^{137}Cs:^{134}Cs ratio for the Chernobyl deposit. Literature values for this ratio vary. Table 1 lists radiocaesium ratios for Chernobyl fallout recorded in May 1986 for the northern UK and Ireland. From these data a value for the ^{134}Cs:^{137}Cs ratio of Chernobyl fallout in Cumbria of 1.9 was considered appropriate. However, considering the variations within these data we considered it desirable to also use a minimum ratio of 1.5 and a maximum of 2.1 to calculate the potential range of aged radiocaesium in samples. All ^{134}Cs was assumed to have originated from Chernobyl in these calculations. For 61 sites in Cumbria, ranging from an altitude of 0 to 500m Horrill & Thompson (pers comm.) found no correlation between the radiocaesium ratio of vegetation samples shortly following the Chernobyl accident and altitude. Therefore calculations of the aged and Chernobyl radiocaesium presented in this report should be valid over the range of altitudes from which samples were taken (ie 60-600m).

Table 1. ^{137}Cs:^{134}Cs ratios recorded in air, rainwater and vegetation from the north of the UK and Ireland in samples taken in May 1986.

Sample type	n	^{137}Cs:^{134}Cs			Reference
		mean	SE	Range	
AIR*	39	1.89	0.035	1.25-2.78	DOE 1986
	NA	2.00			Cunningham *et al* 1987
	2	1.89		1.64-2.17	Cambray *et al* 1987
RAINWATER*	24	1.79	0.064	1.10-2.38	DOE 1986
	8	2.04	0.125	1.79-2.08	Colgan pers comm.
	5	1.89	0.071	1.82-2.13	Cambray *et al* 1987
VEGETATION	84	1.82	0.033	1.03-2.04	DOE 1986
	80	1.96	0.012	1.85-2.38	Horrill *et al* 1987
	12	2.00	0.040	1.79-2.13	Howard *et al* 1989

*Air and rainwater data are for samples collected before 7-05-86.

NA Not available

2.5 Results

For statistical comparison with the ground survey data, 36 of the SURRC measurements for each area were chosen at random. Where negative values appear in the SURRC data set a value of 1000 Bq m^{-2} was used; this is half the limit of detection quoted for the aerial survey (Sanderson & Scott, 1989). Comparisons were made using t-tests under the SAS software package. A comparison of the ground and aerial measurements is presented in Table 2. Both data sets have been decay corrected to May 1986.

Levels of ^{137}Cs deposition as determined by the ground survey were significantly lower than aerial measurements in all three areas ($p<0.01$). For ^{134}Cs deposition the ground survey found significantly lower values than the aerial survey for the Black Combe and Corney Fell areas ($p<0.001$). For Thwaites both surveys showed similar ^{134}Cs deposition levels, but, there are particular problems associated with the aerial survey's measurement of ^{134}Cs at this site (see section 4.1).

For the relatively small areas sampled during the ground survey there was no correlation between radiocaesium deposition and altitude of the sampling site.

Potassium-40 values from the ground survey were considerably lower than those determined by the aerial survey (Table 3). There will be significant quantities of ^{40}K in bedrocks (Kathren, 1984), which would have been detected by the aerial survey, but not by soil sampling. Because of the short count times used for radiocaesium analyses, the low gamma-yield of ^{40}K and the relative inefficiency of Ge detectors at 1460 keV the counting errors are sometimes >10% for ^{40}K measurements from the ground survey. However, the ground survey supports the observation from the aerial survey that the Thwaites area has depleted levels of ^{40}K.

The relative amounts of ^{137}Cs originating from Chernobyl and from previous sources as determined from the ^{137}Cs:^{134}Cs ratios obtained during the ground survey are shown in Table 4. Caesium-137 from the Chernobyl accident accounts for 50-70 % of the total ^{137}Cs deposit in these areas.

Table 2. A comparison of radiocaesium deposition (Bq m^{-2} mean±SE) in 3 areas of south-west Cumbria as determined by the SURRC aerial survey and ITE's ground survey.

Radiocaesium	Survey Method		Area	
		Black Combe	Corney Fell	Thwaites
^{134}Cs	Aerial	12300±700	18600±1740	3400±400
	Ground	5300±380	4800±380	3900±250
Aerial:Ground		2.32	3.88	0.87
^{137}Cs	Aerial	34300±1180	18800±570	21500±535
	Ground	19900±1340	15100±1160	11800±830
Aerial:Ground		1.72	1.25	1.82
^{137}Cs:^{134}Cs*	Aerial	2.78±0.186	1.01±0.099	6.23±0.740
	Ground	3.73±0.367	3.18±0.351	3.00±0.288

NB Results from both studies have been decay corrected to May 1986.

* The ^{137}Cs:^{134}Cs ratio shown is calculated from the mean values of ^{137}Cs and ^{134}Cs deposition as calculated by each survey. It should be noted that because of the non-uniform distribution of the data, particularily that of the aerial survey, the mean radiocaesium ratio is considerably different if calculated from individual values. Ratios of: 3.03±0.153 (Black Combe), 2.97±1.143 (Corney Fell) and 12.3±2.87 (Thwaites) are obtained from the aerial survey if calculated in this manner. Whilst values of: 5.41±1.697 (Black Combe), 3.25±0.125 (Corney Fell) and 3.01±0.084 (Thwaites) are obtained from the ground survey.

Table 3. A comparison of ^{40}K levels in the study areas as determined by the aerial and ground surveys.

Survey Method	Area Black Combe	 Corney Fell	 Thwaites
	(Bq m^{-2} mean±SE)		
Aerial	217000±11000	141000±13200	80000±7100
Ground	73000±9900	30000±5300	11000±1900

Table 4. ^{137}Cs deposition levels in the three study areas in February/March 1990 showing ^{137}Cs attributable to the Chernobyl accident and previous releases.

Radiocaesium		Area Black Combe	 Corney Fell	 Thwaites
		(Bq m^{-2} mean±SE)		
Total ^{137}Cs		18300±1230	13900±1060	10800±750
"Chernobyl" ^{137}Cs	A	7900±570	7000±560	5800±380
	B	**9300±670**	**8300±670**	**6900±450**
	C	11300±810	10100±810	8300±550
Aged $^{137}Cs^{+}$	A	10500±800	6900±630	5100±450
	B	**9000±740**	**5600±570**	**4000±400**
	C	*	3800±520	*
% ^{137}Cs due to aged deposit	A	55±2.1	49±1.6	45±1.4
	B	**48±2.5**	**39±2.0**	**35±1.7**
	C	*	26±2.3	*

$^{+}$Aged radiocaesium levels were calculated using an initial ^{137}Cs:^{134}Cs ratio for Chernobyl fallout of 1.5 (A), **1.9 (B)** and 2.1 (C).

*Some negative values were obtained for Black Combe and Thwaites when a ^{137}Cs:^{134}Cs ratio of 2.1 is used.

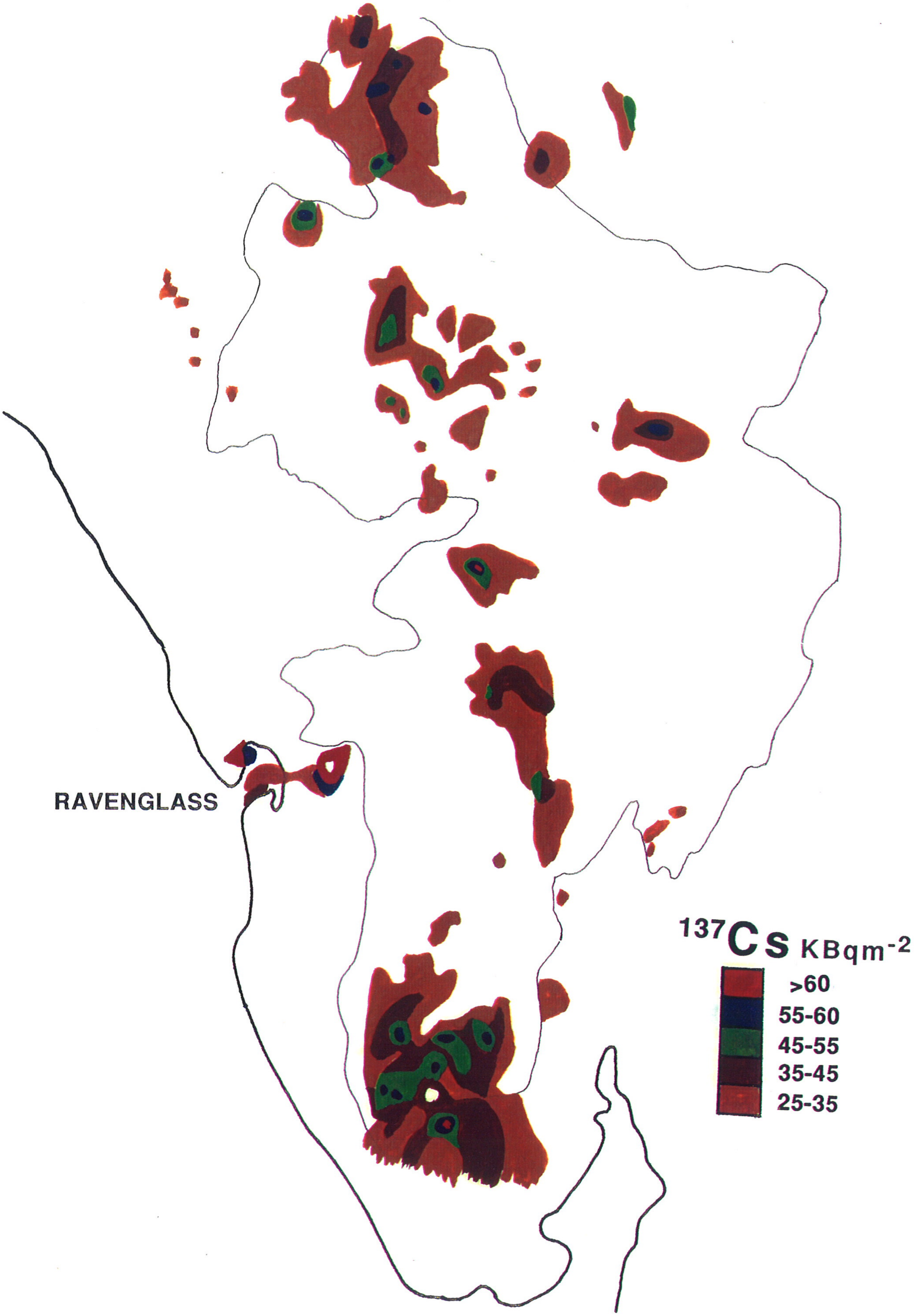


Figure 1. Areas of high ^{137}Cs deposition as determined by the aerial survey

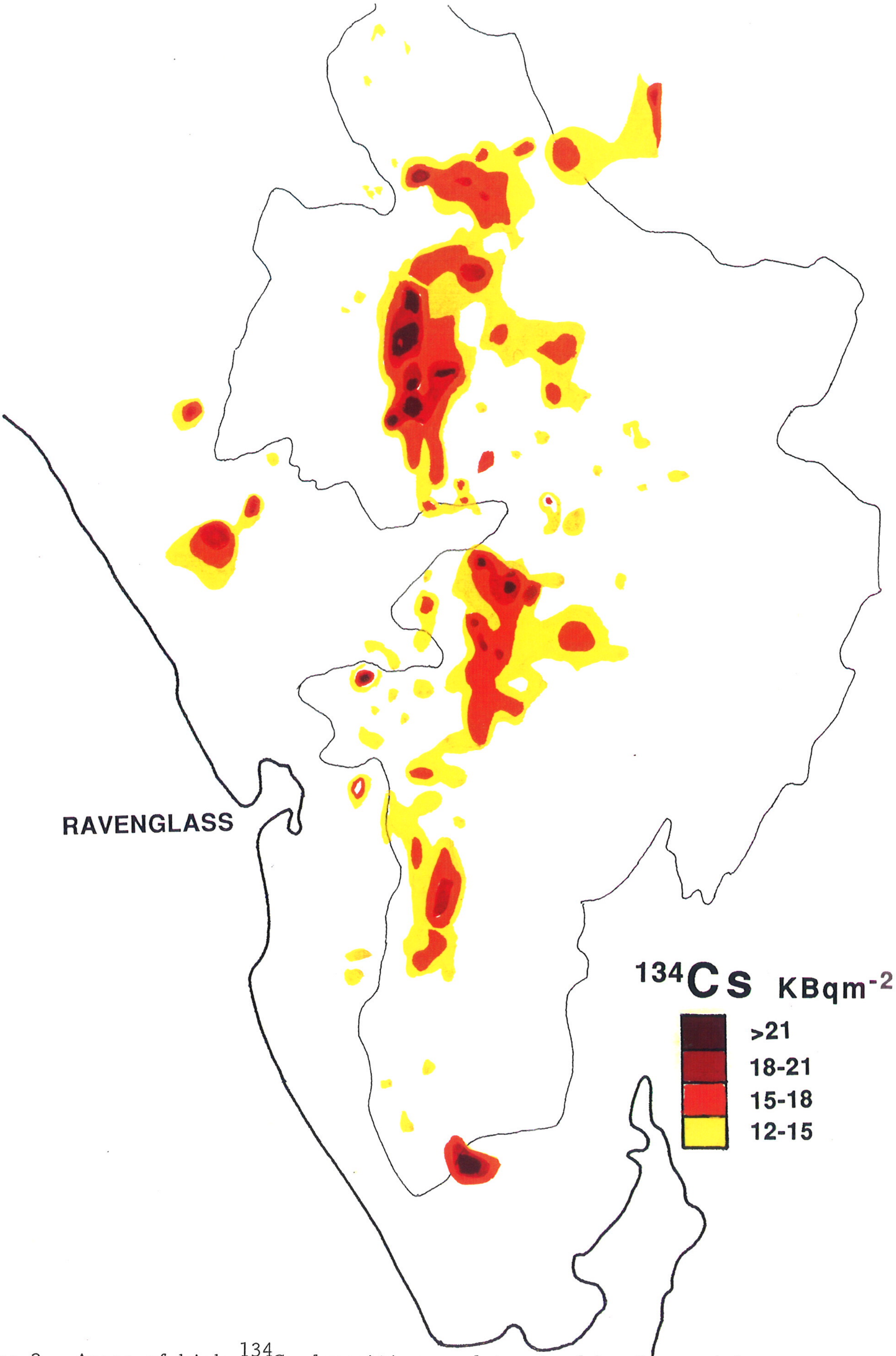


Figure 2. Areas of high ^{134}Cs deposition as determined by the aerial survey

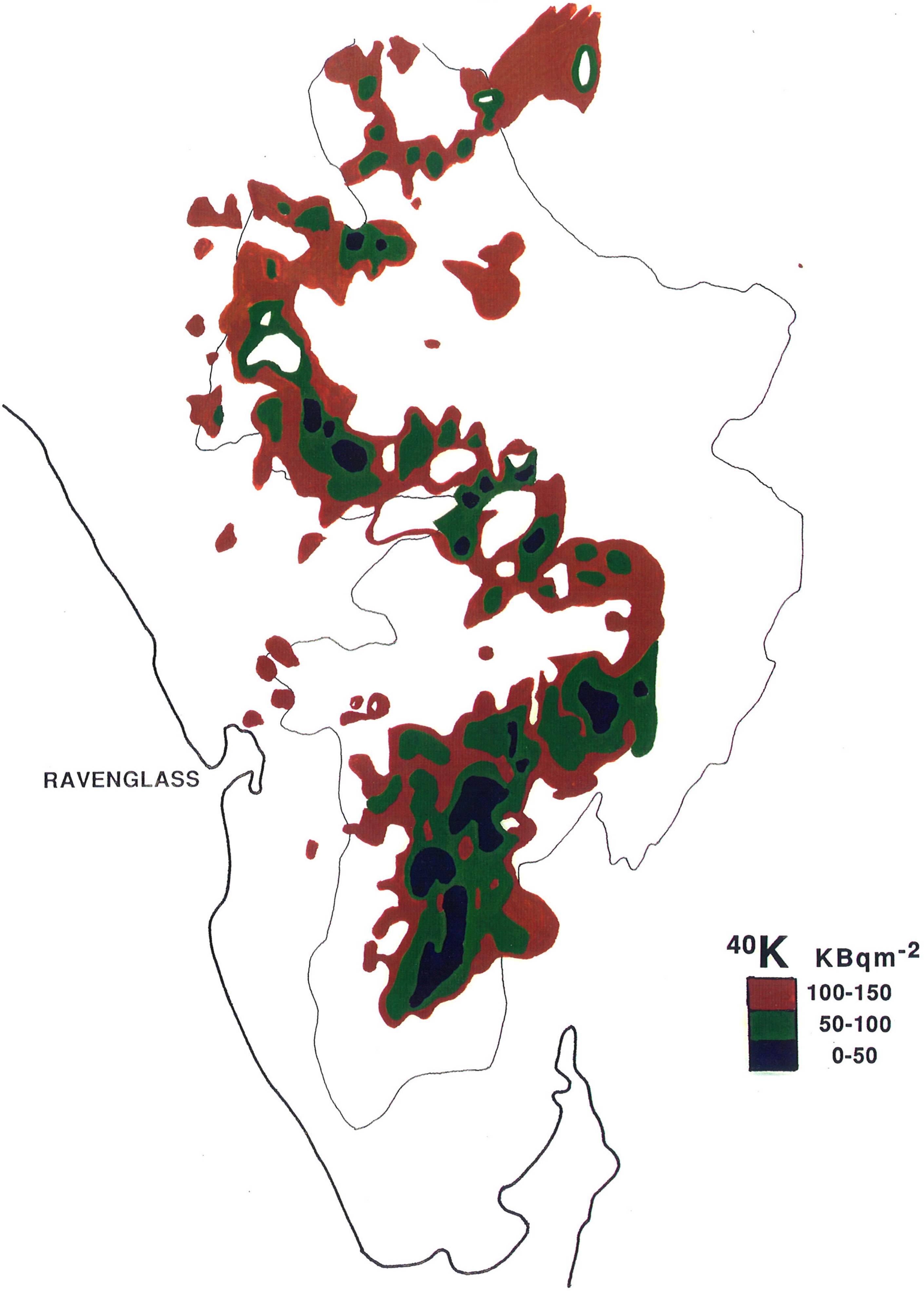


Figure 3. Areas of low ^{40}K as determined by the aerial survey

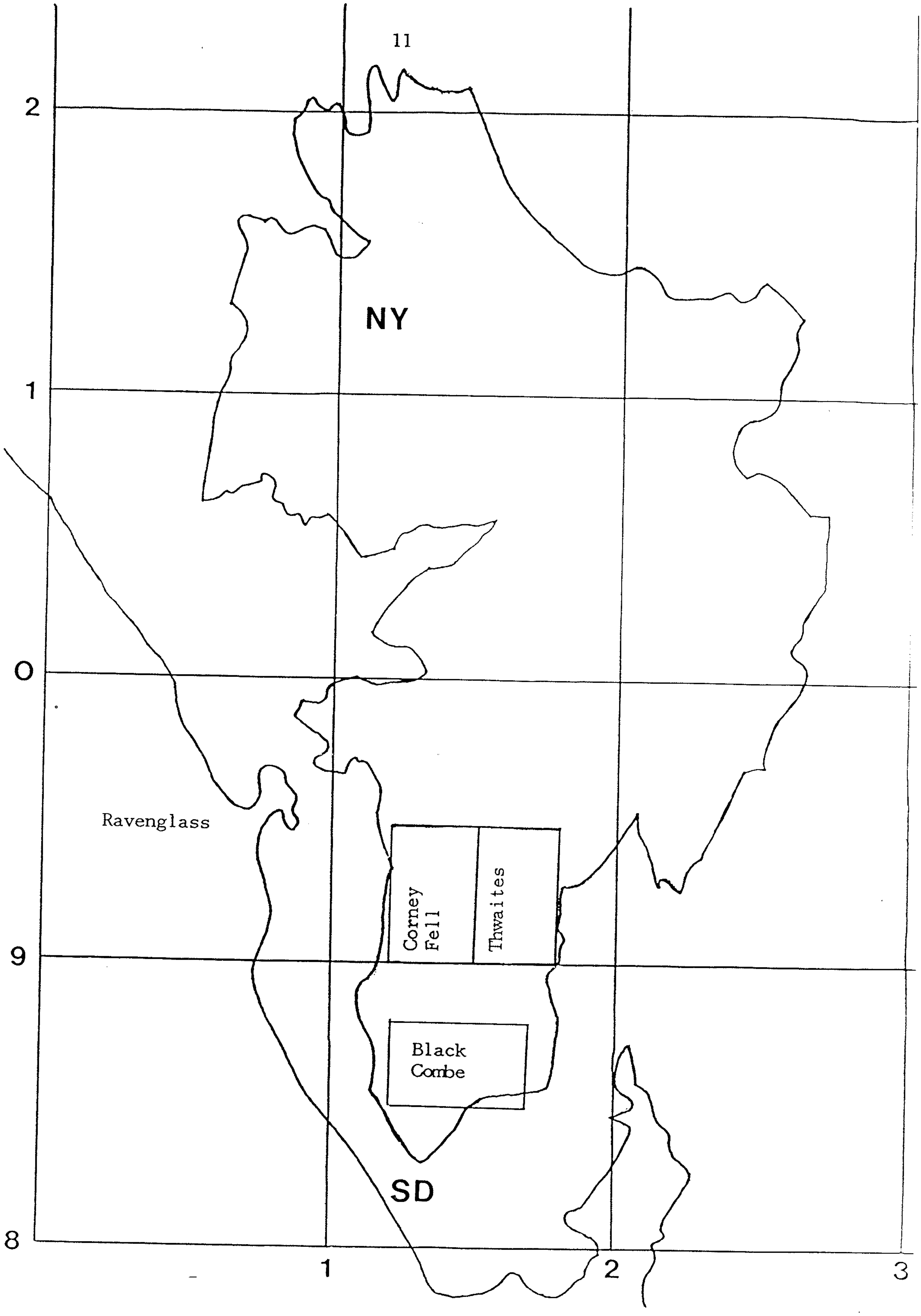
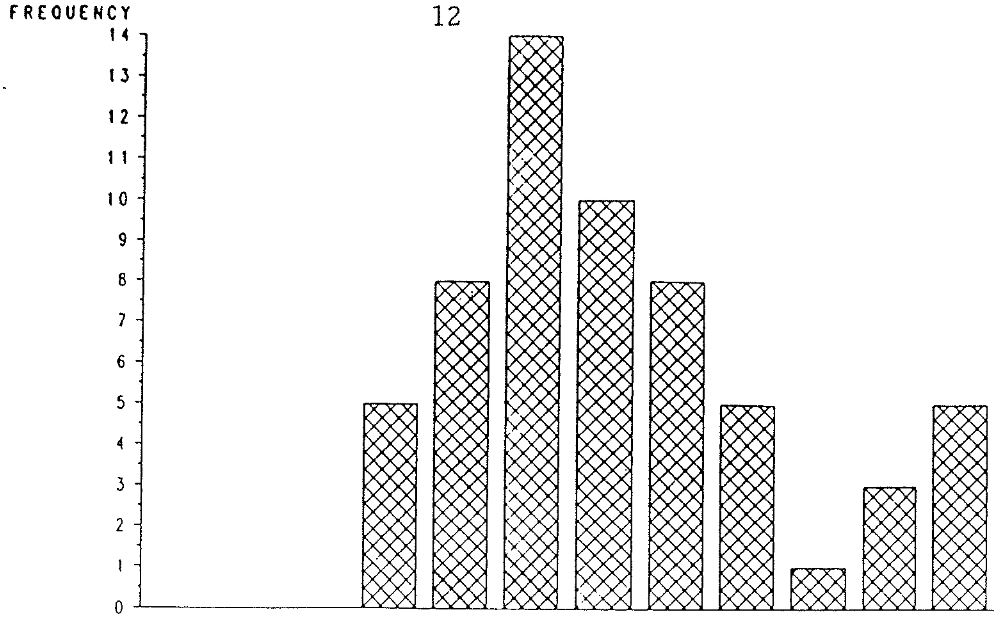
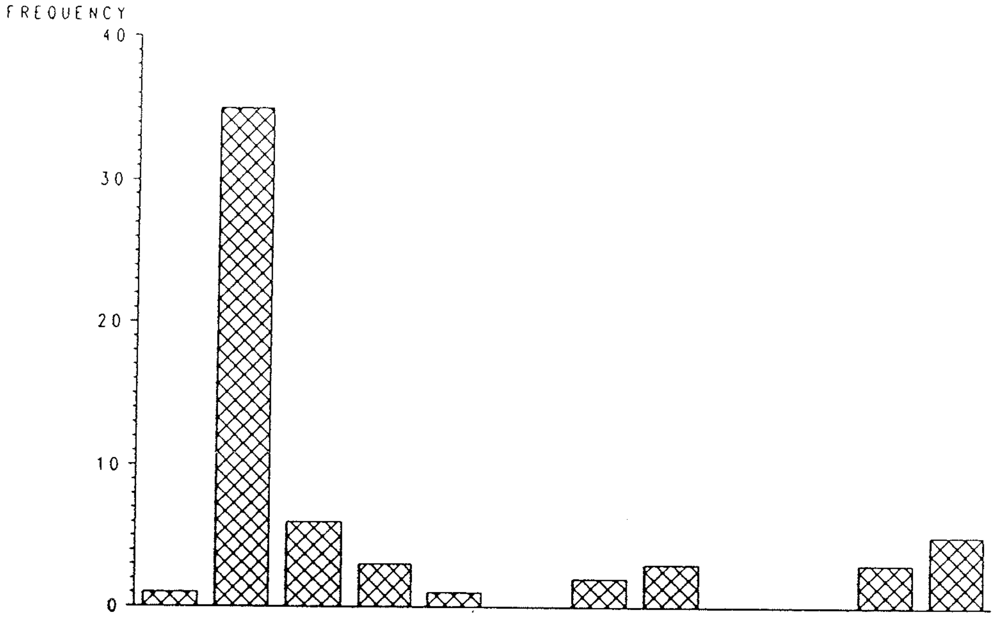


Figure 4 Location of the three sampling areas

(a) Black Combe



(b) Corney Fell



(c) Thwaites

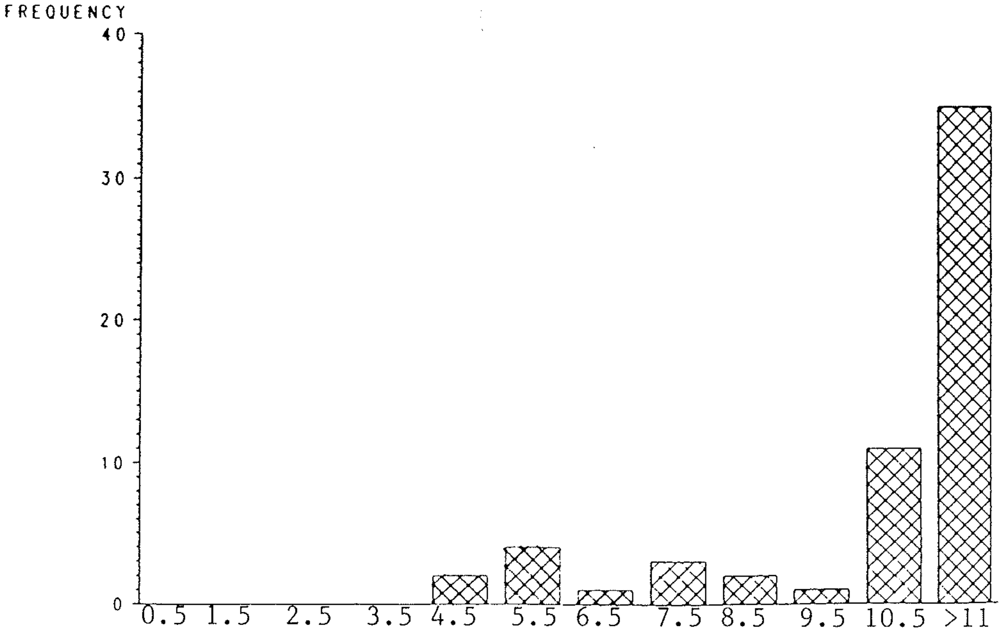


Figure 5. Frequency distribution of the ^{137}Cs:^{134}Cs ratio for the three sampling areas as determined by the aerial survey (where negative values occur in SURRC data set a value of zero was used)

3 PLANT UPTAKE STUDIES

3.1 Field studies

To compare the plant uptake of Chernobyl with aged radiocaesium, samples of vegetation and soil were collected from 30 randomly selected sites in each of two areas in November/December 1989. The study areas both had humic ranker soils (very shallow, acid peaty soils (Livens & Loveland, 1988)) and were located in or close to the "Black Combe" (Figure 6) and "Corney Fell" (Figure 7) sites described in section 2.2. All samples were collected from unenclosed fell land.

"Grassy" vegetation (in addition to grasses this may have included sedges and rushes (eg Carex, Trichophorum and Eriophorum spp.)) was clipped from an area of $1m^2$. Samples of underlying soil were taken down to a depth of 40cm or bedrock. The 0-4cm layer was separated from the rest of the profile. Additional samples were collected for determination of pH from all sites.

Because of the time of year that sampling had to be conducted, there was insufficient vegetation to sample at 18 of the 30 Black Combe sites.

3.2 Greenhouse study

Results from the field study may be different to those which might have been expected if vegetation had been actively growing. To overcome this 5 soil monoliths (36x27x17 cm) were taken from each area and vegetation growth was promoted in greenhouse conditions.

The monoliths were placed in a heated greenhouse and standing vegetation removed. The monoliths were watered regularily and vegetation was allowed to grow over the next 12 weeks. All vegetation was then harvested and "grassy" vegetation only was retained for analysis. Soil blocks were weighed wet and divided into 0-4cm and below 4cm layers.

3.3 Sample analyses

Soil and vegetation samples were weighed wet and then dried at 80°C and reweighed to determine % moisture. They were then ground and placed in 150 mL plastic containers or 750mL Marinellis for gamma-analyses. Count times ranged from 40 000 to 170 000 seconds depending upon the activity present.

Bulk density was measured for both soil layers by drying and weighing a known volume of soil. Organic matter content was determined, as percentage loss on ignition, by ashing 1g of dry sample at 550°C for 2 hours. The pH of the fresh soils was determined in distilled water (soil:water ratio of 1:2).

Statistical comparisons and relationships were performed using the SAS software package (Cody & Smith, 1987).

3.4 Results

3.4.1 Field Studies

The maximum radiocaesium activity concentration in vegetation sampled during the survey was 100 Bq kg^{-1} DW ^{134}Cs and 700 Bq kg^{-1} DW ^{137}Cs on Black Combe and 150 Bq kg^{-1} DW ^{134}Cs and 1070 Bq kg^{-1} DW ^{137}Cs on Corney Fell. Activity concentrations of total and aged radiocaesium in vegetation and soil are compared in Table 5. At both sites the ratio of ^{137}Cs:^{134}Cs in vegetation was not significantly different from that in the 0-4cm soil layer.

Table 5. A comparison of the activity concentration (Bq kg^{-1} DW) of 'total' radiocaesium with aged radiocaesium determined by assuming a ^{137}Cs:^{134}Cs ratio for Chernobyl fallout of 1.5 (A), **1.9 (B)** and 2.1 (C).

		Radiocaesium Activity Concentration (Mean±SE and range)		
		Vegetation	0-4cm Soil	Lower Soil
Black Combe*				
Total ^{137}Cs	X±SE	370±45	1180±103	140±36
	Range	147-696	669-1896	35-432
^{134}Cs	X±SE	50±8	130±15	-
	Range	4-96	65-245	$<2-35^{+\#}$
^{134}Cs:^{137}Cs	X±SE	15.6±5.54	9.7±0.84	77.2±16.81
	Range	6.5-62.5	6.7-16.2	12.3-235.6
Aged ^{137}Cs				
A	X±SE	160±19	570±62	120±25
	Range	53-245	222-887	31-268
B	**X±SE**	**110±20**	**420±62**	**110±23**
	Range	**30-227**	**118-770**	**30-250**
C	X±SE	80±22	340±64	110±22
	Range	3-224	41-707	30-245
Corney Fell				
Total ^{137}Cs	X±SE	320±44	1020±63	170±23
	Range	44-1071	258-1775	10-498
^{134}Cs	X±SE	50±7	130±9	-
	Range	3-154	35-260	$<2-48^{+@}$
^{134}Cs:^{137}Cs	X±SE	10.3±2.24	7.9±0.26	60.6±13.42
	Range	6.0-64.7	6.0-11.7	6.6-273.3
Aged ^{137}Cs				
A	X±SE	110±14	390±32	124±15
	Range	16-347	94-1061	6-338
B	**X±SE**	**60±9**	**245±29**	**110±14**
	Range	**3-178**	**23-893**	**5-308**
C	X±SE	**	**	110±13
	Range	-15-175	-104-802	5-292

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* n=12

\+ Where ^{134}Cs was below detection limits a value of half the detection limit was used to determine ^{137}Cs:^{134}Cs ratios and hence aged radiocaesium ($^{\#}$ n=22 below detection limits; @ n=12 below detection limits).

** mean not calculated as some negative values obtained.

The total radiocaesium burden (decay corrected to May 1986) in the sites sampled was 6200±390 Bq m^{-2} ^{134}Cs + 30800±2450 Bq m^{-2} ^{137}Cs for Black Combe and 5500±500 Bq m^{-2} ^{134}Cs + 19700±1940 Bq m^{-2} ^{137}Cs for Corney Fell. These values are similar to deposition values for the overall area, as described in section 2.5, of Corney Fell. However, at Black Combe the area of ranker soil appears to have received a significantly higher deposition of ^{137}Cs, but not ^{134}Cs, compared with the surrounding area (section 2.5), and must therefore have received comparatively high levels of aged ^{137}Cs.

In both areas the distribution of Chernobyl and aged radiocaesium in the soil profile was significantly different ($p<0.001$) (Figure 8). Considerably more of the Chernobyl fallout is still in the top 4cm of the soil compared with the older deposit, over 50% of which is now in the lower layer. If only the 12 sites at Black Combe, where vegetation was sampled, are considered 0.2 % of the Chernobyl radiocaesium burden and 0.05 % of the aged radiocaesium burden occurs in vegetation compared with 0.09 % and 0.02 % respectively, if all 30 sites are used as in Figure 8.

Plant uptake of radiocaesium was estimated by calculating a transfer ratio (TR) where:-

$$TR = \frac{\text{Activity Concentration in Vegetation (Bq kg}^{-1}\text{ DW)}}{\text{Activity Concentration in 0-4 cm Soil (Bq kg}^{-1}\text{ DW)}} \qquad (1)$$

for both Chernobyl (^{134}Cs) and aged radiocaesium (Table 6). Since some values of aged radiocaesium were negative when the higher value for the Chernobyl ratio of 2.1 was used, this ratio was not used in the calculation of plant:soil transfer ratios. There was no significant difference in the transfer ratios of Chernobyl or aged radiocaesium, showing that the plant uptake of both sources of radiocaesium were similar at the time of sampling.

Table 6. Plant:Soil transfer ratios of Chernobyl and aged radiocaesium, from 2 areas with ranker soils (mean±SE) assuming an initial Chernobyl fallout ratio for ^{137}Cs:^{134}Cs of 1.5 (A) and **1.9 (B)**.

Area	n	Transfer Ratio Chernobyl ^{134}Cs	Aged ^{137}Cs A	 **B**
Black Combe	12	0.41±0.090	0.35±0.075	**0.42±0.151**
Corney Fell	30	0.38±0.069	0.33±0.049	**0.37±0.071**

Relationships between the uptake of radiocaesium and the following soil characteristics were investigated: % moisture, bulk density, pH, loss on ignition and ^{40}K concentration. However no significant relationships were found.

Additionally the transfer of radiocaesium has been expressed as the ratio of the activity concentration in vegetation and the total activity in a m^2 of soil (Table 7). This indicates a greater availability of the total Chernobyl radiocaesium deposit compared with the total from previous sources ($p<0.01$). However the difference is due to the greater proportion of aged radiocaesium which has migrated further down the soil profile, below the major rooting zone of many vegetation species.

Table 7. The transfer of radiocaesium expressed as the ratio of the activity concentration in vegetation to the total activity in a m^2 of soil (mean±SE) assuming an initial Chernobyl fallout ratio of ^{137}Cs:^{134}Cs of 1.5 (A) and **1.9 (B)**.

Area	n	Transfer Ratio (on an area basis) Chernobyl ^{134}Cs	Aged ^{137}Cs A	 B
Black Combe	12	0.03±0.006	0.009±0.0015	**0.007±0.0013**
Corney Fell	30	0.05±0.009	0.016±0.0019	**0.013±0.0038**

3.4.2 Greenhouse Study

Vegetation collected from the soil monoliths had considerably higher radiocaesium activity concentrations than that collected during the field study. The mean ^{134}Cs and ^{137}Cs activity concentrations of vegetation from the Black Combe soil blocks was 200±34 and 1610±271 respectively, whilst for vegetation from the Corney Fell soil blocks it was 160±35 and 1310±272 respectively. Plant:soil transfer ratios (on a weight basis, as defined by equation (1)) were therefore higher than those found during the field study (Table 8). Although the transfer of Chernobyl radiocaesium appears to be higher than for aged radiocaesium for the Black Combe samples, there was no significant difference between the uptake of the different sources of radiocaesium at either site.

Table 8. Plant:Soil transfer ratios of Chernobyl and aged radiocaesium for vegetation collected from the greenhouse study (mean±SE) assuming an initial Chernobyl fallout ratio of ^{137}Cs:^{134}Cs of 1.5 (A) and **1.9 (B).**

Area	n	Transfer Ratio		
		Chernobyl ^{134}Cs	Aged ^{137}Cs	
			A	**B**
Black Combe	5	3.91±1.920	1.71±0.481	**1.43±0.346**
Corney Fell	5	1.49±0.337	1.30±0.234	**1.24±0.216**

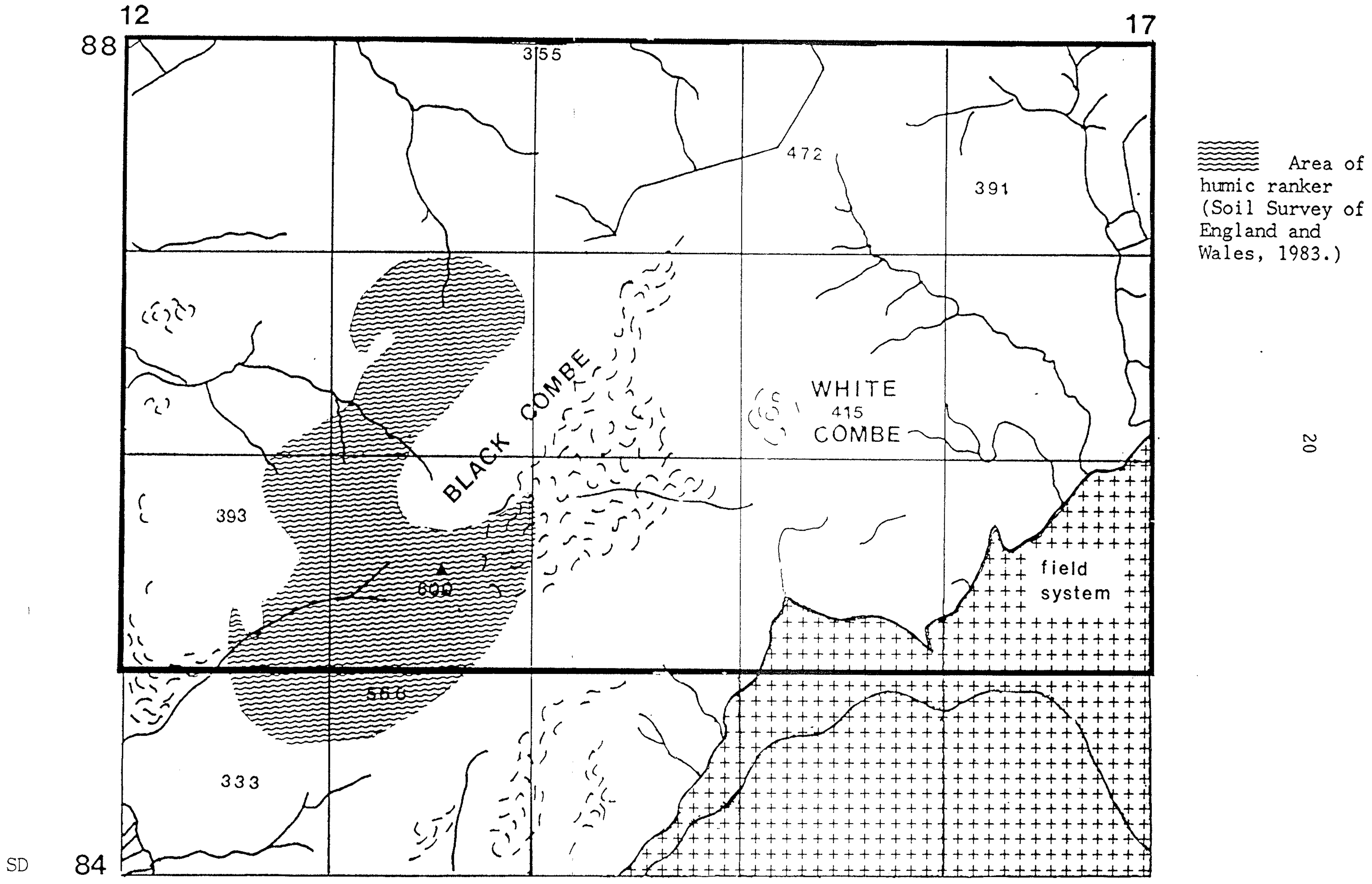

Figure 6 Area of humic ranker soil used for plant uptake studies at Black Combe. (Area within emboldened box is the 15 km^2 area used in the deposition study)

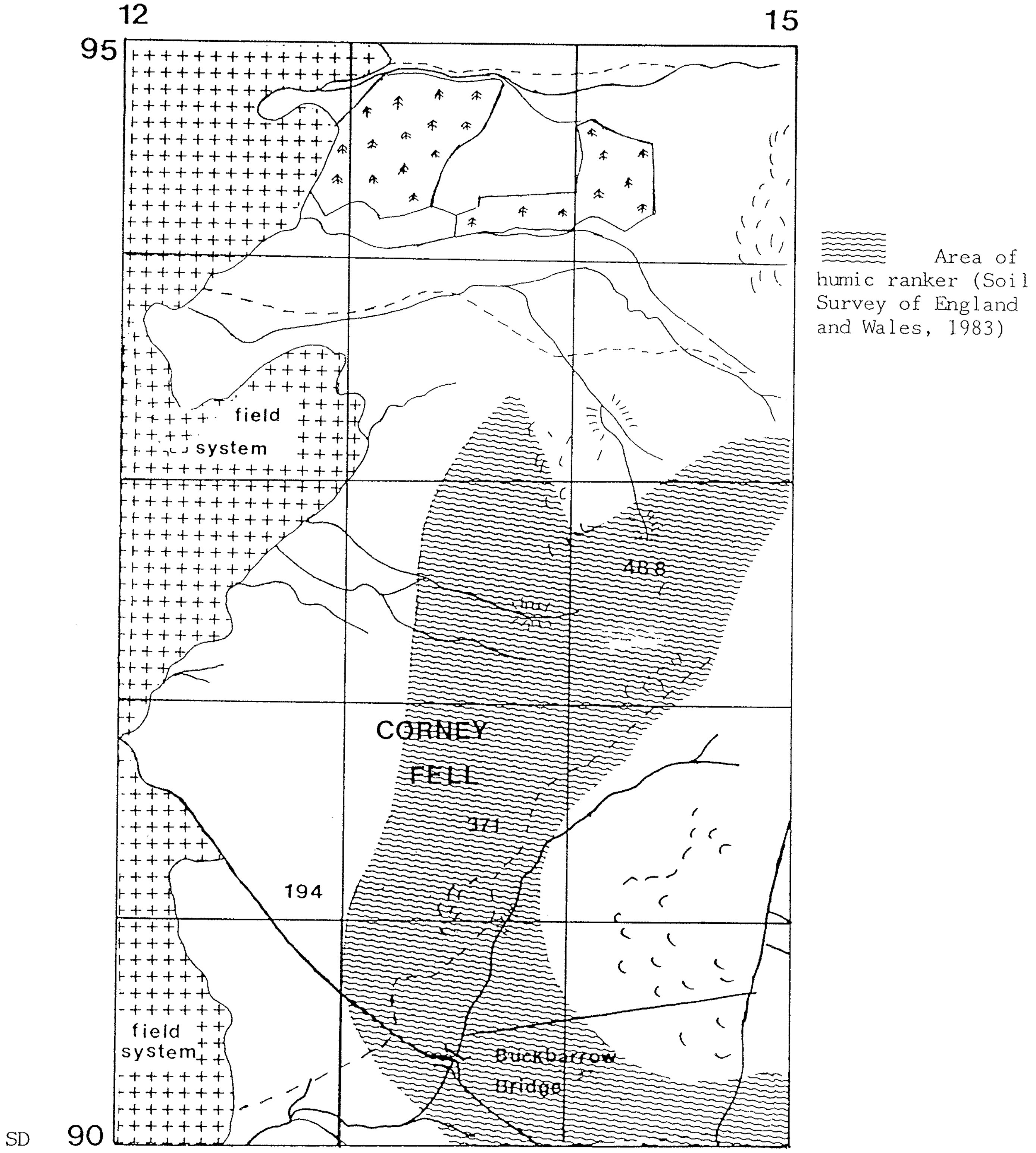

Figure 7 Area of humic ranker soil used for plant uptake study at Corney Fell. (The whole 15 km^2 area shown is that used in the deposition study.)

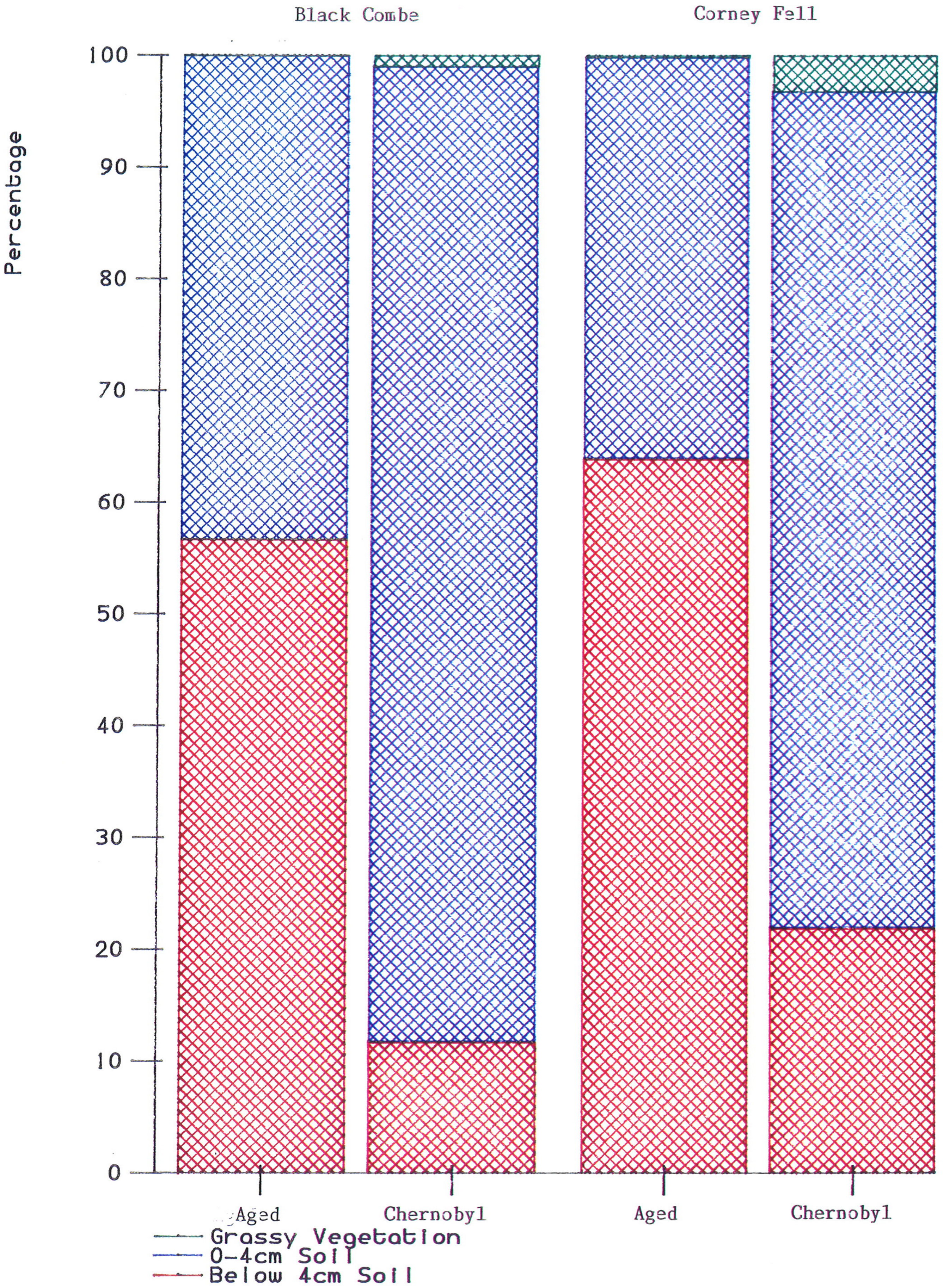

Figure 8 Distribution of aged (calculated using a Chernobyl ^{137}Cs:^{134}Cs ratio of 1·9) and Chernobyl radiocaesium

4 DISCUSSION

4.1 Radiocaesium deposition

In the 3 study areas it appears that the aerial survey may have overestimated total radiocaesium deposition by a factor of about 2. However, the differences are not consistent in the 3 sample areas. At Corney Fell the aerial survey appears to overestimate ^{134}Cs by a factor of nearly 4 whilst the ^{137}Cs estimate is only 25% higher. Conversely at Thwaites the 2 surveys agree for ^{134}Cs, but the ^{137}Cs deposition from the ground survey is less than half that estimated by aerial measurements. Although the ITE survey was conducted over 1.5 years after the aerial survey it is unlikely that there had been any significant loss of radiocaesium from the soils of the study areas.

The purpose of this study was to determine whether aerial survey results showing unexpected radiocaesium ratios in part of the restricted area could be confirmed. It was not to comment on the accuracy of the aerial survey across the whole of the area surveyed by SURRC. Extrapolation of the results of this study to the larger area surveyed by SURRC is unjustified.

Aerial surveys are designed to give rapid estimates of deposition to ground immediately following a nuclear incident, allowing problem areas to be identified quickly. In these circumstances a factor of 2 difference between aerial and ground measurements seems acceptable; deposition is unlikely to be underestimated. The ITE surveys of deposition levels onto vegetation in mainland Britain conducted following the Chernobyl accident took 2 months to collect and analyse samples, and report fully on the results (Allen, 1986). The sampling involved many of the staff members from all 6 ITE stations and was thus very labour intensive. In comparison aerial survey techniques were used successfully in Sweden after the Chernobyl accident and the results were presented to the public within 2 weeks of the accident (Sanderson

& Scott, 1989a). Furthermore the radiocaesium deposition pattern recorded by the aerial survey in west Cumbria was broadly similar to that found by other authors. The areas of high ^{137}Cs attributable to sources before Chernobyl in the south (ie the "Black Combe" area) and north (close to Ennerdale) of the restricted area detected by the aerial survey agree with measurements made in 1978 (Cawse, 1980). The observation that Chernobyl deposition was highest down the centre of the surveyed region is similar to that found by Horrill et al (1987). The latter study also found high deposition in coastal areas outside the region surveyed by SURRC. The elevated radiocaesium levels around the Esk estuary due to marine discharges from the Sellafield plant are well known (eg. Horrill, 1984).

A source of error in the aerial measurements may have occurred because of the number of different radiocaesium sources, contributing to the total radiocaesium deposit in west Cumbria. This has resulted in different distributions in the soil profile of ^{134}Cs and ^{137}Cs. Considerably more ^{137}Cs is located deeper down the soil profile. The system was calibrated for sites in the Solway Firth, Scotland, (Sanderson & Scott, 1989a) using an intergrated deposition to a depth of at least 30cm. The calibration assumes a similar distribution of radiocaesium in Cumbrian soils as in those of the Solway Firth. However, unlike the Solway region the Cumbrian sites received considerable ^{137}Cs deposition from the Windscale accident which has moved further down the soil profile than that from Chernobyl fallout (see Baxter et al (1987) for radiocaesium levels in soils of the Solway region).

Additionally the aerial survey does not take soil type into account. Soil type will obviously affect factors such as bulk density, soil moisture, soil depth and ^{40}K concentrations, all of which may affect aerial survey measurements. The main soil types in the restricted area of west Cumbria are humic rankers, podzols and, to a lesser extent, peats and brown earths (Soil Survey of England and Wales, 1983). The possible coincidence of anomalous aerial survey measurements with certain soil types was investigated by comparing soil maps with radiocaesium and ^{40}K distribution. It appears that areas of low ^{40}K as determined by the aerial survey are associated with or occur close to areas of peat (compare overlay Figure 3a with Figure 9). This is, perhaps, not surprising given that unmanaged peat soils may typically have 10 to 20 times lower potassium concentrations than mineral soils (Brady, 1984). Furthermore areas of low ^{40}K coincide with areas of very low ^{134}Cs deposition (Figures 2 & 2a) in the aerial survey data. SURRC have suggested a potential reason for the low ^{134}Cs values may be due an error in the stripping routine when ^{40}K values are low (Sanderson, pers comm.). No other associations of certain soil types and anomalous aerial survey measurements were evident. Most of the restricted area's soils (ie podzols, humic rankers and peats) are highly organic and are unlikely to be the same as the soils at the sites in the Solway Firth used to standardize the aerial survey.

Deposition levels of aged radiocaesium as determined by the ground survey (Table 4) are of the order that would be expected from weapons fallout and the 1957 Windscale accident for this region. Caesium-137 deposition from the 1957 accident can be calculated from the ^{131}I deposition data presented by Booker (1958) and Chamberlain (1959) assuming a $^{137}Cs:^{131}I$ ratio of 0.02

(Chamberlain, 1959; Booker, 1962). This indicates that deposition of ^{137}Cs in the study areas exceeded 3700 Bq m^{-2}, with much of the area receiving greater than 7400 Bq m^{-2}. For a site just to the east of our "Corney Fell" sampling area Booker (1962) reports a ^{137}Cs deposit of nearly 6000 Bq m^{-2} in 1961. Parts of Black Combe may have received up to 16000 Bq m^{-2}. By early 1990 ^{137}Cs levels from the Windscale accident would have more than halved due to the physical decay of ^{137}Cs alone. However, in 1978 a ^{137}Cs deposit of over 14 000 Bq m^{-2} was found at a marginal grassland site on the lower southern slopes of White Combe (within our "Black Combe" sampling area (Figure 6)) (Cawse, 1980). This was largely attributed to the Windscale accident since there was no concurrent accumulation of plutonium as would have been expected from weapons fallout. The deposition of radiocaesium from the Windscale accident on Black Combe may explain the higher aged ^{137}Cs burden and higher ^{137}Cs:^{134}Cs ratio in the ranker soil in comparison with the deposit as estimated for the larger 15 km^2 "Black Combe" area. The ranker soil sampling area is at at the top of the mountain which appeared to receive higher deposition from the Windscale accident (Booker 1958).

In 1977 Cambray and Eakins (1980) found a ^{137}Cs burden (down to 15cm) of 9700 Bq m^{-2} for a site on Corney Fell. They suggested approximately half of this was due to weapons fallout (estimated from annual rainfall) and half due to the 1957 accident (based on unpublished measurements by Booker). By 1986 the ^{137}Cs in UK soils resulting from weapons testing would have been approximately 3200 Bq m^{-2} per 1000 mm of annual rainfall (Cambray, et al 1987). Therefore, if we use the value of 1520 mm y^{-1} given by Cambray and Eakins (1980) for Corney Fell we could expect in the order of 4000-5000 Bq m^{-2} of ^{137}Cs due to weapons fallout for sites sampled during the ground survey.

Since relatively large aged ^{137}Cs deposits were therefore to be expected in the study areas, it would appear that the use of a Chernobyl ^{137}Cs:^{134}Cs ratio of 2.1 (C in the tables) is too high; since it frequently gives negative values for aged deposits.

Table 9 summarizes data available on radiocaesium burdens in the study area following the Chernobyl accident. They are all within that expected from the ground survey results, although direct comparisons are difficult due to the small areas sampled by other authors and the differing soil depths taken.

Table 9. Reported radiocaesium burdens for the study areas following the Chernobyl accident^{+}.

Area	Radiocaesium deposition (Bq m^{-2}) ^{134}Cs	^{137}Cs	Soil Depth (cm)	Reference
Corney	8000-15000	19000-48000	14	Jackson _et al_, 1987
Corney	4800-10800	17400-23500	5*	Coughtrey _et al_, 1989a
Corney	8000-10000	20000-25000	5	Sandalls _et al_, 1989
Black Combe	4700	21000	10	Coughtrey, 1989
Black Combe	6900	35000	7.5	Coughtrey, 1989

$^{+}$ All measurements taken in 1986, except Sandalls _et al_ sampled in 1987.
* Depth below root mat

4.2 Availability of radiocaesium for plant uptake

Values for the soil to plant transfer of radiocaesium derived from either the field or greenhouse studies should not be taken as absolute values. Seasonal trends have been reported for the radiocaesium uptake by vegetation in west Cumbria, suggesting that values during the winter may be lower than at other times of the year (Sandalls et al, 1989). Equally bringing soil blocks into greenhouses and cropping vegetation to allow new growth increases radiocaesium uptake, and hence transfer ratios, and changes species composition (Coughtrey et al, 1989b). However, this should not effect the comparisons of the behaviour of Chernobyl and aged radiocaesium uptake. In the present study, although transfer ratios determined in the greenhouse study were of the order of 4 times higher than those determined by field sampling the conclusion that the availability of aged and Chernobyl radiocaesium from the top 4 cm soil layer is now similar, remained valid. Although many studies have been conducted by various organizations in upland west Cumbria since 1986, direct comparisons of plant transfer data with the results from the current study are difficult since the depth to which soil samples are taken and results presented are not standardized.

Both the field and greenhouse studies suggest that the plant uptake of Chernobyl and aged radiocaesium is now similar in the sample areas. Transfer ratios calculated from samples taken nearer to the time of Chernobyl deposition showed initially higher uptake of Chernobyl radiocaesium compared with the aged sources. For instance, Sandalls et al (1989) found a two to four fold greater uptake (from top 5cm of soil) of Chernobyl compared with aged radiocaesium for 2 peat ranker sites in the Corney region in 1987. Similarily Jackson et al (1987) have presented data for a Corney fell site which showed a lower uptake of aged radiocaesium in comparison with Chernobyl fallout for 4 sampling dates from June 1986 - Feb 1987.

The current finding that the transfer of aged and Chernobyl radiocaesium to vegetation is now similar has obvious implications for the future rate of decline in the radiocaesium activity of the vegetation and hence sheep within the restricted area of west Cumbria. If after 4 years Chernobyl radiocaesium is as available for plant uptake as aged radiocaesium which may have been present in the environment for over 20 years, it suggests that henceforth any reductions in activity concentrations of vegetation and hence sheep meat will be slow.

The similarity in transfer from soil to vegetation of aged and Chernobyl radiocaesium agrees with other recent observations from west Cumbria. For instance Jackson (1990) recently observed that the radiocaesium isotopic ratio of vegetation from a site close to Black Combe was now less dominated by Chernobyl fallout. Changes in the $^{134}Cs:^{137}Cs$ ratio in the NH_4^+ extractable fraction of podzol soil samples from a site a few kilometres north of the study area also suggest a change in the availability of Chernobyl radiocaesium such that it is becoming more like the aged deposit (Howard et al, in press).

Slow reductions in the radiocaesium activity of animal products from unimproved areas have also been predicted in Norwegian alpine ecosystems (Hove & Strand, 1989). By comparing weapons testing fallout radiocaesium data from the 1950's - 1970's with weapons fallout radiocaesium present in animal products after 1986 they have predicted ecological half-lives for lamb meat and goat whey cheese in the order of 20 years. They also stated that physical decay of radiocaesium will be the major factor in the reduction of activity concentrations in uncultivated areas of Norway.

The transfer of the total aged radiocaesium deposit to vegetation was lower than that of Chernobyl radiocaesium, reflecting the greater proportion of aged radiocaesium that has migrated to below the plant rooting zone. Movement of the Chernobyl deposit down the soil profile and hence out of the rooting zone of many vegetation species will therefore result in reductions of Chernobyl radiocaesium levels in vegetation with time. However, it is unclear what processes govern the rate of downwards radiocaesium migration in the organic soils of west Cumbria, although it is obviously slow since a significant proportion of the aged radiocaesium deposit is still within the top 4 cm soil layer (Figure 8).

4.2.1 Recommendations

It is recommended that further comparisons of Chernobyl and pre-Chernobyl radiocaesium transfers in other parts of the restricted areas are made to investigate whether the transfer from the two sources is simalar elsewhere. It would be possible to resample sites visited in 1986 and 1987 (Beresford et al 1987b; Beresford et al 1987c) so that the behaviour of pre-Chernobyl and Chernobyl radiocaesium could be compared throughout west Cumbria 1 month, 1 year and >4 years after deposition.

4.3 Identification of "Hot Spots"

It is of obvious interest to the regulatory bodies to identify possible indicative characteristics of areas which could give rise to vegetation, and hence sheep, with high radiocaesium activities. However, the vegetation uptake data in this report are too limited to do this. The study was designed to compare the uptake of Chernobyl and aged radiocaesium, it was therefore restricted to one soil and dominant vegetation type. Other studies at ITE have suggested that wet areas are likely to have vegetation with a higher radiocaesium activity (unreported data). However alternative methods of identifying problem areas may be possible.

Total deposition data, such as that provided by aerial surveys gives only a very limited indication of likely radiocaesium activity levels in vegetation and hence sheep (Jeffers et al, 1989). It could be combined with data on various soil characteristics (Livens and Loveland, 1988) to identify areas where vegetation activities are likely to be high. This would be most useful in the immediate aftermath of fallout from a nuclear incident. However, it is unlikely to have adequate resolution to be currently of assistance in identifying 'hot spots' within the restricted areas. Even if it were possible to identify 'hot spots' in this way it would be uncertain if the areas identified were those causing high levels in sheep.

We suggest that if the identification of such areas is desirable then it should be conducted on an individual farm basis at possible problem farms. Grazing areas which cause high levels in sheep could be identified by using sheep which are consistently the most active as indicators. This has been possible on the farm studied in detail by ITE, where certain areas which consistently gave the more radioactive sheep were identified by observing the grazing behaviour of marked ewes (Beresford et al, 1987a).

However, even if areas which are causing comparatively high radiocaesium levels in sheep can be identified there may be secondary effects of implementing a policy such as restricting grazing (by fencing) to the area which should be considered. Apart from the practical problems of fencing these areas such a policy would cause increased grazing in other areas with potential associated effects on animal production and the ecology of the area.

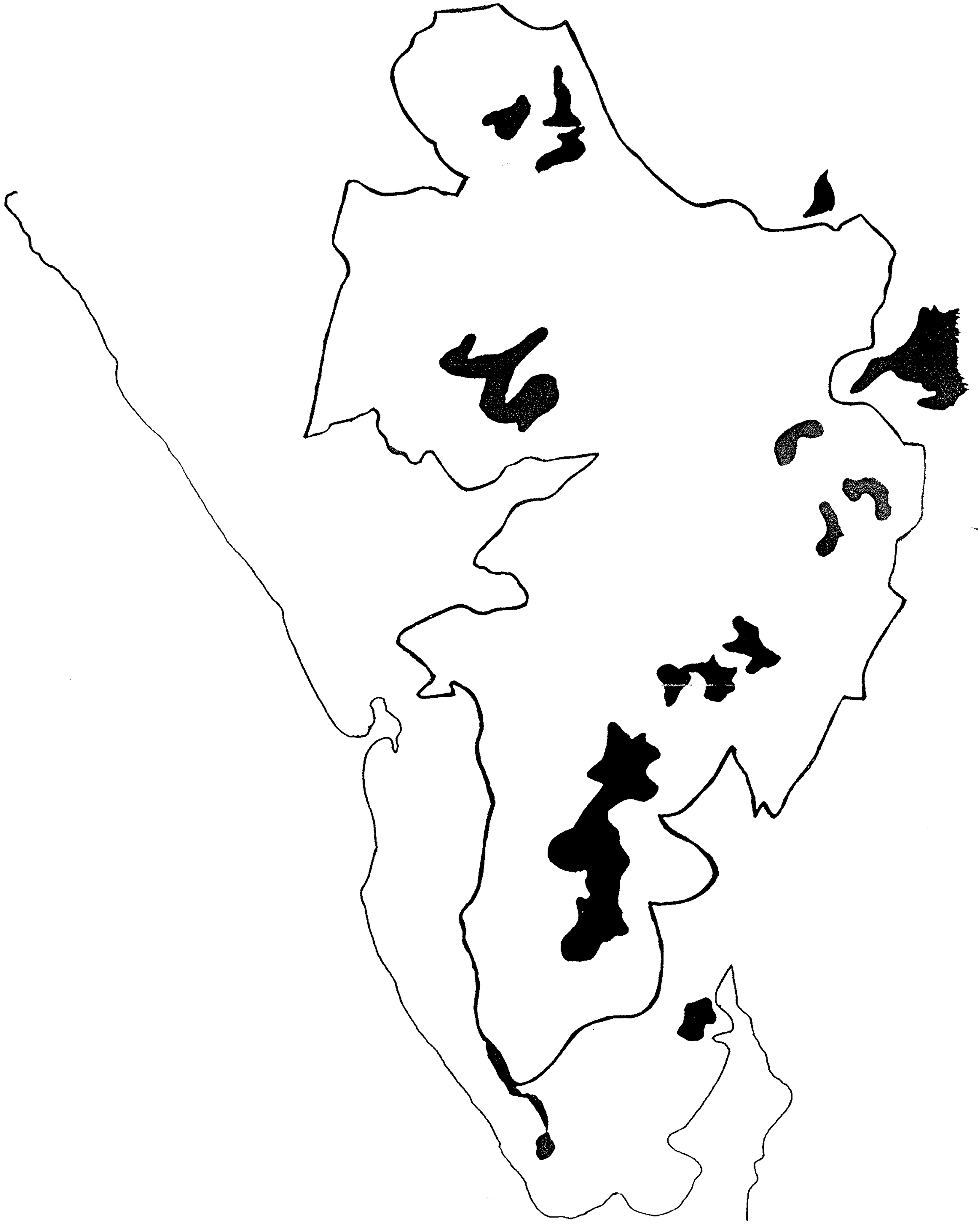

Figure 9. Areas of Peat in Western Cumbria
(Soil Survey of England and Wales, 1983)

6 REFERENCES

ALLEN S.E., 1986. Radiation: A guide to a contaminated countryside. *The Guardian*. July 25, 17.

BAXTER, M.S., COOK, G.T. & McDONALD, P., 1987. *An Assessment of Artificial Radionuclide Transfer from Sellafield to South West Scotland*. Report to Department of the Environment. DOE Report No. DOE/RW/89/127. Scottish Universities Research and Reactor Centre: East Kilbride.

BERESFORD, N.A., LIVENS, F.R. & HOWARD, B.J., 1987a. *Radioecology of 137Cs and 134Cs in upland sheep pasture systems following the Chernobyl accident.* Progress report to Ministry of Agriculture Fisheries and Foods. ITE Project 1113. Institute of Terrestrial Ecology: Grange-over-Sands.

BERESFORD, N.A., ADAMSON, J.K. & HOWARD, B.J., 1987b. *A comparison of 1986 and 1987 caesium activities of vegetation in west Cumbria*. Final report to Ministry of Agriculture Fisheries and Foods ITE Project 1113. Institute of Terrestrial Ecology: Grange-over-Sands.

BERESFORD, N.A., HOWSON, G. & ADAMSON, J.K., 1987c. *A comparison of 1986 and 1987 caesium activities of vegetation in the restricted area of north Wales*. Final report to Ministry of Agriculture Fisheries and Foods. ITE Project 1113. Institute of Terrestrial Ecology: Grange-over-Sands.

BRADY, N.C., 1984. *The Nature and Properties of Soils*. Macmillan Publishing Company: New York.

BOOKER, D.V., 1958. *Physical Measurements of Activity in Samples from Windscale*. AERE HP/R 2607. UKAEA: Harwell.

BOOKER, D.V., 1962. Caesium-137 in Soil in the Windscale Area. AERE-R-4020. UKAEA: Harwell.

CAMBRAY, R.S. & EAKIN, J.D., 1980. Studies of Environmental Radioactivity in Cumbria Part 1 Concentrations of Plutonium and Caesium-137 in Environmental Samples from West Cumbria and a Possible Maritime Effect. AERE-R 9807. AERE: Harwell.

CAMBRAY, R.S., CAWSE, P.A., GARLAND, J.A., GIBSON, J.A.B., JOHNSON, P., LEWIS, G.N.J., NEWTON, D., SALMON, L. & WADE, B.O., 1987. Observations on Radioactivity from the Chernobyl Accident. AERE R 12462. AERE: Harwell.

CAWSE, P.A., 1980. Studies of Environmental Radioactivity in Cumbria Part 4 Caesium-137 and Plutonium in Soils of Cumbria and the Isle of Man. AERE-R 9851. AERE: Harwell.

CHAMBERLAIN, A.C., 1959, Deposition of iodine-131 in Northern England in October 1957. Quart. J. R. Met. Soc. **89**, 350-361.

CODY, R.P. & SMITH, J.K., 1987. Applied Statistics and the SAS Programming Language. North-Holland: New York.

COLGAN, P.A., pers comm., Nuclear Energy Board, Dublin, Ireland.

COUGHTREY, P.J., 1989. A review of levels and distribution of caesium in upland environments prior to the Chernobyl accident. Report to Ministry of Agriculture Fisheries and Food. ANS Report No. 2131-1. Associated Nuclear Fuels: Epsom.

COUGHTREY, P.J., KIRTON, J.A. & MITCHELL, N.G., 1989a. Caesium Transfer and cycling in upland pastures. Sci. Tot. Environ., **85**, 149-158.

COUGHTREY, P.J., KIRTON, J.A., MITCHELL, N.G. & MORRIS, C.M. 1989b. Transfer of radioactive caesium from soil to vegetation and comparison with potassium in upland grasslands. Environ. Pollut., 62, 281-315.

CUNNINGHAM, J.D., MacNEILL, G. & POLLARD, D., 1987. Chernobyl its effect on Ireland. Nuclear Energy Board: Dublin. 60pp.

DEPARTMENT OF THE ENVIRONMENT, 1986. Levels of radioactivity in the UK from the accident at Chernobyl USSR, on 26 April 1986. A compliation of results of environmental measurements in the UK. July 1986. HMSO:London.

HORRILL, A.D., LIVENS, F.R. & BERESFORD, N.A., 1987. Post Chernobyl Sudies. Final Report to Ministry of Agriculture Fisheries and Food. ITE Project 1085. Institute of Terrestrial Ecology: Grange-over-Sands.

HORRILL, A. D., LOWE, V. P. W., & HOWSON, G. 1989. Chernobyl fallout in Great Britain. Final Report. 90pp. TFS Project T07006e1. Department of the Environment.

HORRILL, A.D. & THOMPSON, A.J., Personal communication. Institute of Terrestrial Ecology, Merlewood Research Station, Grange-over-Sands, Cumbria UK.

HOVE, K. & STRAND, P., 1989. Predictions of the duration of the Chernobyl-radiocaesium problem in non-cultivated areas based on a reassessment of the behaviour of fallout from the nuclear bomb tests. In Extended Synopses: International Symposium on Environmental Contamination Following a Major Nuclear Accident. (IAEA-SM-306), 80-82, IAEA: Vienna.

HOWARD, B.J., MAYES, R.W., BERESFORD, N.A. & LAMB, C.S., 1989. Transfer of radiocaesium from different environmental sources to ewes and suckling lambs. Health Phys., 57, 579-586.

HOWARD, B.J., BERESFORD, N.A. & LIVENS, F.R., in press, An overview of radiocaesium in the semi-natural ecosystem of an upland sheep farm. In Proc: Workshop The Transfer of Radionuclides in Natural and Semi-Natural Environments. 11th-15th Sept. 1989 Udine.

JACKSON, D., JONES, S.R., FULKER, M.J. & COVERDALE, N.G.M., 1987. Environmental monitoring in the vicinity of Sellafield following deposition of radioactivity from the Chernobyl accident. J. Soc. Radiol. Prot., 7, 75-87.

JACKSON, D., 1990. The availability of Chernobyl caesium to vegetation in west Cumbria. Presented at: Scope-Radpath meeting. Lancaster University. 26th-30th March 1990.

JEFFERS, J., NORTH, P. & BELL, E., 1989. Radiological Monitoring of Cumbrian Grassland: Comparison of aerial data with ground data on control sites. University of Kent: Canterbury.

KATHREN, R.L., 1984. Radioactivity in the Environment: Sources, Distribution, and Surveillance. Harwood Academic Publishers: Chur.

LIVENS, F.R. & LOVELAND, P.J., 1988. The influence of soil properties on the environmental mobility of caesium in cumbria. Soil Use and Management, 4, 69-75.

SANDALLS, F.J., EGGLETON, A.E.J. & GAUDERN, S.L., 1989, Uptake of Radiocaesium by Upland Herbaceous Vegetation in Relation to Soil Type. AERE R 13389. AERE: Harwell.

SANDERSON, D.C.W. & SCOTT, E.M., 1989a. Aerial Radiometric Survey in West Cumbria 1988. Final Report to Ministry of Agriculture Fisheries and Foods. Project N611. Scottish Universities Research and Reactor Centre: East Kilbride.

SANDERSON, D.C.W. & SCOTT, E.M., 1989b. Aerial Radiometric Survey in West Cumbria 1988. Technical Annex. Report to Ministry of Agriculture Fisheries and Foods. Project N611. Scottish Universities Research and Reactor Centre: East Kilbride.

SANDERSON, D.C.W., Personal Communication. Scottish Universities Research and Reactor Centre, East Kilbride.

SOIL SURVEY OF ENGLAND AND WALES, 1983. Sheet 1 Northern England. Rothamstead Experimental Station: Harpenden.

ADDENDUM: THE ROLE OF FUNGI IN IMMOBILIZATION OF RADIOCAESIUM IN UPLAND SOILS.

1 INTRODUCTION

High radiocaesium activity concentrations have been reported in the fruiting bodies of a number of fungal species since the Chernobyl accident (Haselwandter, 1987; Elstner et al., 1987; Haselwandter et al., 1988; Byrne, 1988; Dighton & Horrill, 1988; Oolbekkink & Kuyper, 1989). Deviations from the $^{137}Cs:^{134}Cs$ ratio attributable to Chernobyl fallout suggests that there is considerable aged accumulation in these fungal structures (Dighton & Horrill, 1989; Byrne, 1988). By implication, therefore, it would appear that fungi may be conservative in their ability to accumulate and retain caesium. As fungal structures in soil are long lived and movement of nutrient elements occur within the thallus, they may form a major pool of radiocaesium in soil.

The importance of fungi in the decomposer community increases during succession from grassland to forest or from agricultural soils to open moorland (Cromack, 1981; Dickinson & Pugh, 1974; Swift et al., 1979, Heal & Dighton, 1986). The fungal community, which has the potential to accumulate radiocaesium, therefore becomes more important in upland soils where most deposition of Chernobyl fallout occurred.

In forest and woodland floor communities, the dominant fungal populations are able to immobilize nutrients and, because of the shortage of mineral nutrients relative to available carbon, translocate the nutrients within their hyphal biomass from regions of thallus which are dying and lysing to actively growing hyphal zones (Dighton & Boddy, 1989). In this way the mycelium is conservative and little nutrient is mineralized on death of the older parts of the thallus. Such spatiotemporal redistribution of nutrient elements within the fungus is important in terms of temporary immobilization of nutrients in the ecosystem. Fungal turnover rates and degree of conservation of any element will regulate the availability of the element to other components of the ecosystem.

Assuming that Cs behaves in a similar manner to other Group 1 elements, such as potassium, it may also be conserved and retained in the fungal biomass of the soil, particularly in soils of high organic matter content. This will prevent loss from the soil by leaching processes and, where slow mineralization from fungal tissue occurs, will result in prolonging the retention of radiocaesium in the upper soil horizons.

The study presented here investigates the relative abilities of a range of fungal species to take up and retain radiocaesium from solution. The winter fungal biomass of two upland sites was determined and the predicted accumulation of radiocaesium in the fungal component of the ecosystem calculated.

2 MATERIALS AND METHODS

2.1 Fungal biomass assessment

Five replicate soil samples were taken from the Black Combe and Corney Fell ranker soil sites, described above. From the top 5 cm horizon of each soil sample 10 g fresh weight of soil was homogenized for 10 sec in 100 ml distilled water using an MSE Atomix homogenizer at half speed. The suspension was made up to 1 l, thoroughly mixed and allowed to settle for 10 sec before 10 ml was pipetted into 90 ml of water. 1 ml of this final suspension was then filtered through a 13 mm diameter, 1.2 μm Millipore filter and washed with 15 ml of sterile water containing 3 drops of Loeffler methylene-blue solution. Five filters were made from each soil sample. Filters were mounted on microscope slides in immersion oil. Hyphal length was estimated using Olson's grid intersection method by counting the number of intersections between fungal hyphae and a 12x12 grid mounted in a 12.5x eyepiece and using a 40x objective. Ten fields of view per filter were counted and the length of hyphae per filter was calculated.

Using the bulk density of the top 5 cm soil horizon (0.4 g cm^3, Black Combe and 0.2 g cm^3, Corney Fell), the mean hyphal length for each sampling area was calculated on a per m^2 basis of the 0-5 cm depth horizon. Using a mean hyphal diameter of 3 μm (determined as a mean of 50 diameter measurements) and an average dry weight density value of 0.27 g cm^{-3} fresh weight of hyphae (Lodge, 1987), the fungal biomass (dry weight) per m^2 was calculated using the equation:

$$\text{Biomass} = \pi\ (\text{hyphal diameter}/2)^2 \times \text{hyphal length} \times 0.27$$

2.2 Caesium uptake by six grassland fungal species

Six fungal species were selected which were representative of those often found in upland grassland areas. Five replicate cultures of each fungal species were inoculated, under sterile conditions, onto 6.5 cm diameter nylon mesh circles of known weight in Petri dishes containing 20 ml Hagem's nutrient solution and 2 mM MES (2[N-morholino]ethanesulphonic acid) adjusted to pH 6.0 with potassium hydroxide.

After incubation at 22°C for 14 days, the mesh circles were placed on top of stiff mesh discs inside the barrel of a cut down 50 ml syringe fitted with a 2 way tap (Figure 10). Six syringes were mounted on a shaker. One replicate of each of the six fungal species was treated as follows in each of 5 runs.

To the fungi in the syringes, 10 ml of sterile, pH 6.0 buffered Hagem's solution containing 5 μM CsCl was added and shaken gently for 10 mins. The solution was drained and the system flushed with a similar solution containing 1000 Bq ml^{-1} (200 Bq $nmol^{-1}$) ^{137}Cs. 10 ml of the same tracer solution was then added and the whole shaken for 15 min before the solution was drained into a scintillation vial. Three further washes with unlabelled solution followed, each being collected in a scintillation vial. Finally, the mesh discs with the fungal hyphae were placed in a fifth vial. All vials were counted in a Canberra Packard Autogamma counter. ^{137}Cs uptake by the fungi was calculated from the specific activity of the tracer solution and the counts in the solutions and the fungi.

3 RESULTS AND DISCUSSION

The influx of ^{137}Cs into the six fungal species selected to represent commonly occurring species in these types of habitat is given in Table 2.1. Uptake figures show a range from 44 to 236 nmol Cs g^{-1} dry weight h^{-1}, depending on species.

Values of hyphal length per gram DW of soil from Black Combe and Corney Fell are given in Table 2.2. It must be borne in mind that at the time of year that the soil samples were taken, the fungal biomass would have been of up to an order of magnitude lower than spring and autumn peaks.

From the Cs influx data from the six fungal species studied, an average value of 134 nmol Cs g^{-1} h^{-1} was calculated. Assuming that this estimate of uptake capacity is a reasonable representation of the uptake capacities of fungi in soil, then a crude estimate may be made of the accumulation potential in fungi in the field (Table 2.3). This was calculated from the product of hyphal biomass m^{-2} and average influx. This can only be illustrative and not quantitative, since there is no data on the influx capacities for fungi exposed to environmental concentrations of Cs. However, from data on stable Cs concentrations in grassland soils (Oughton, 1989) and a dissociation constant of $2x10^4$, one can estimate that in 1 m^2 of soil to a depth of 5 cm, there is approximately 280 u mol ^{133}Cs. At this concentration, our figures for uptake suggest that all of the Cs in the soil could be accumulated in fungal tissue.

Influx studies have also been carried out on 20 ectomycorrhizal and saprotrophic fungi (mainly Basidiomycotina) associated with forest soils. Here uptake values ranged from 85 to 276 nmol Cs g^{-1} dry weight h^{-1} (Dighton, Clint & Rees, submitted). Hyphal biomass in the soils from which these fungi were extracted is very much greater than grazed upland pasture. Thus the fungi could form a greater reservoir of radiocaesium in these soils.

Many of these fungi produce fruitbodies which are eaten by man or grazing animals (reindeer, goats etc.) (Eckl, Hofmann & Turk, 1986; Byrne, 1988). The increase in occurrence of these fungi in soil managed for agroforestry could be important in retention of radiocaesium in a pool which could readily become available to crop plants.

Due to the paucity of essential nutrient elements and high carbon:nutrient ratios in recalcitrant upland organic matter, many fungi become conservative in terms of nutrient retention. Nutrients are moved within the thallus, usually from older to younger tissues and, particularly in the case of wood decomposition, transport of nitrogen from soil into wood is necessary to reduce the C:N ratio, making it favourable for colonization (Dighton & Boddy, 1989). Along with other major nutrients, Cs may well be accumulated and redistributed within the fungal thallus, thus making it temporarily unavailable to other components in the ecosystem (eg. plants). The rate of release of Cs into the soil inorganic pool will depend on the turnover time of the fungi and the degree of internal translocation of the element within the thallus (retention).

Thus, because of the high fungal biomass in upland organic soils, the accumulation of radiocaesium in fungi could form a significant fraction of the radiocaesium pool in soil. The degree of retention by, redistribution within and rates of release of Cs from fungal structures has not been studied in any detail. However, as these organisms are key agents in regulating nutrient fluxes in organic upland soils, the following recommendations for further research are those which would enable us to quantify the importance of fungi in radiocaesium availability to plants.

4 RECOMMENDATIONS

It is obvious that the determination of immobilization is only very approximate, but it does indicate the potential importance of fungal component in soil in the accumulation and possible immobilization of radiocaesium. A large number of assumptions and some unknowns have been used in the calculation, particularly relating to the behaviour of Cs in fungal hyphae. In order to establish a more accurate understanding of the importance of fungal immobilization in soil the following questions need to be addressed by further detailed research:

(i) What proportion of the fungal biomass is physiologically active in Cs uptake?

(ii) Do hyphae growing in nutrient deficient media (soil) have a greater or lesser propensity for Cs uptake than those growing on nutrient rich artificial media used in these experiments (a hunger response)? Dose response curves have yet to be established for any fungi.

(iii) What is the duration of the immobilization phase in fungi, following accumulation? What is the degree of efflux from fungal hyphae in leachate water? Is Cs tightly bound in cellular components or is there significant efflux from cytoplasm and vascuolar compartments? Preliminary evidence from other studies of ours suggests that over 40% of the Cs accumulated is not released by successive washings.

(iv) What is the fate of Cs in the fungal cell and the fungal thallus? We do not know if Cs is bound to cell walls or is free in the cytoplasm or vacuole. Apart from affecting the potential rate of efflux from living tissue by percolating water, the location of Cs in the cell may affect the rate of mineralization from dead and lysing tissue. If the fungi are conservative, then Cs could be mobilized within the thallus and translocated from dead, lysing hyphae into actively growing hyphal tips. As the boundaries of individual fungal thalli are difficult to define, this spatial redistribution of Cs could be important in terms of availability to plants (Dighton & Boddy, 1989). Alternatively if Cs is not mobile in the fungal hyphae, then there will be pulses of mineralization at sites of hyphal degradation. At present there is no information on these processes and no quantitive data on uptake, efflux, internal translocation or other losses of Cs from fungal hyphae or on the factors regulating these processes.

Table 2.1 Cs uptake by 6 grassland fungi (n mol g^{-1} dry wt h^{-1}) at pH 6.0 from 5 μm CsCl solution.

Fungal spp.	Replicates					Mean±SE
	1	2	3	4	5	
Tricoderma viride	163.2	52.2	15.5	124.4	ND	88.9±33.5
Phoma sp.	181.5	182.1	194.9	188.6	367.5	222.9±36.2
Cladosporium sp.	109.3	263.7	141.7	185.8	119.5	164.0±28.1
Mortierella sp.	39.0	103.0	46.2	10.1	35.4	46.7±15.3
Epicoccum nigrum	283.1	336.3	61.5	302.7	194.9	235.7±49.3
Fusarium sp.	63.4	35.6	23.9	ND	54.8	44.4±8.9

Table 2.2 Mean hyphal length (m) g^{-1} dry soil for 2 sites.

Sites	Replicates					Mean±SE
	1	2	3	4	5	
Black Combe	152.38	120.54	197.88	129.66	141.01	148.30±13.48
Corney Fell	156.57	202.62	67.55	82.88	52.19	112.36±28.76

Table 2.3 Determinations of fungal hyphal content of Black Combe and Corney Fell soils (top 5 cm) and potential ^{137}Cs accumulation.

	Black Combe	Corney Fell
Bulk density	0.42	0.24
Mean hyphal length (m g^{-1} dry wt)	148.29	112.36
Mean hyphal length (m m^{-2} to 5 cm depth)	3.15×10^{6}	1.37×10^{6}
Hyphal biomass (g dry ^{wt} m-2)	6.00	2.62
Potential ^{137}Cs immobilization in fungal hyphae (μ mol Cs m^{-2} h^{-1})	804	351

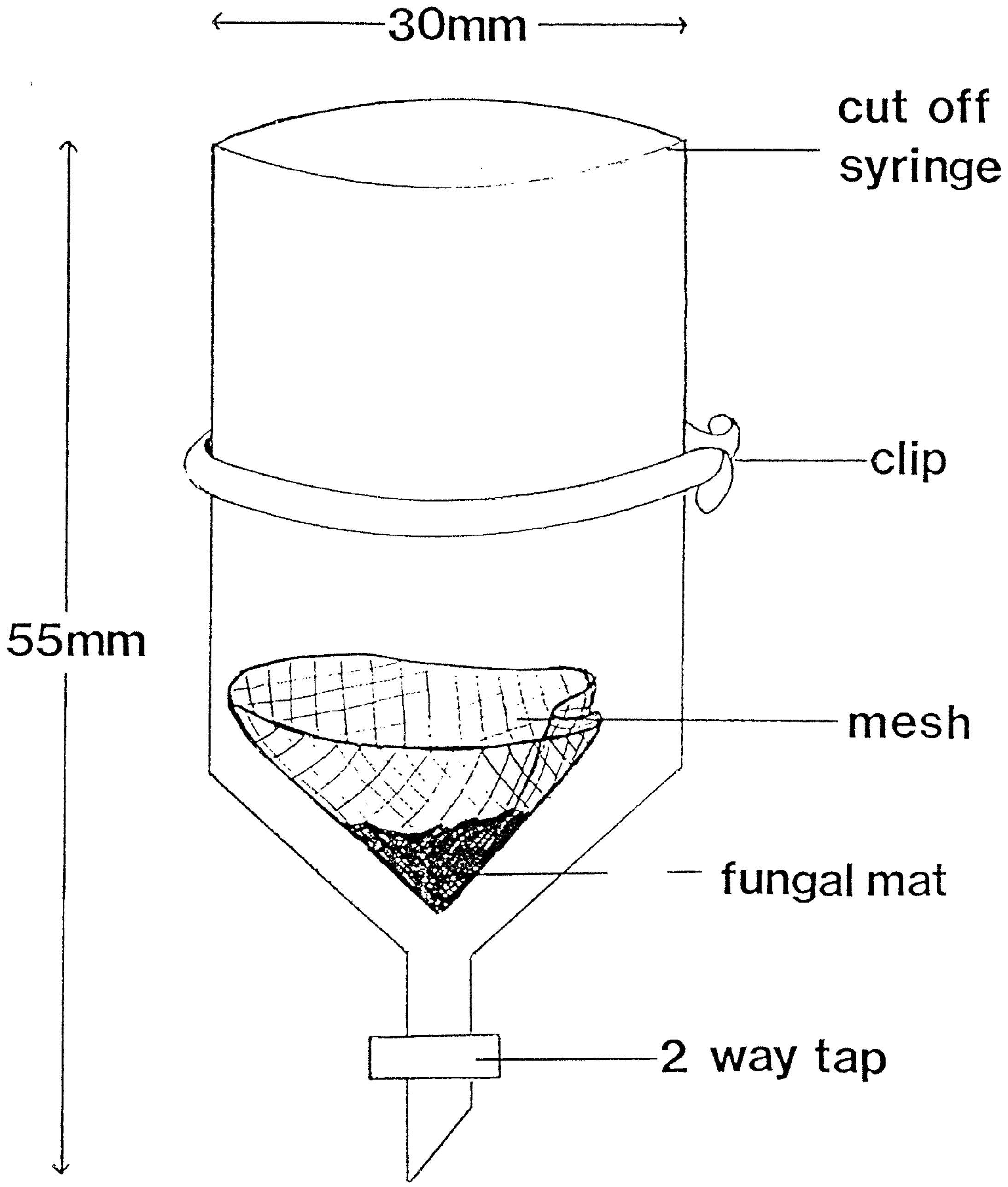

Figure 10 Apparatus used for fungal influx studies

5 REFERENCES

BYRNE, A., R. 1988. Radioactivity in fungi in Slovenia, Yugoslavia, following the Chernobyl accident. J. Environ. Radioact. **6**; 177-183.

CROMACK, J. 1981. Below-ground processes in forest succession. In: D. A. West, H. H. Shugart & D. B. Botkin eds. Forest Succession: Concepts and Applications. pp 361-373, Springer Verlag, New York, USA.

DICKINSON, C. H. & PUGH, G. J. F. 1974. Biology of Plant Litter Decomposition. Academic Press: London.

DIGHTON, J & HORRILL, A. D. 1988. Radiocaesium accumulation in the mycorrhizal fungi Lactarius rufus and Inocybe longicystis, in upland Britain, following the Chernobyl accident. Trans. Br. mycol. Soc., **91**, 335-337.

DIGHTON, J. & BODDY, L. 1989. Role of fungi in nitrogen, phosphorus and sulphur cycling in temperate forest ecosytems. In: L. Boddy, R. Marchant & D. J. Read eds. Nitrogen, Phosphorus and Sulphur Utilization by Fungi. 268-298. Cambridge University Press: UK.

DIGHTON, J., CLINT, G. & REES, S. Submitted, Influx of radiocaesium into fungal hypae in a range of basidiomycetes. New Phytologist.

ELSTNER, E. F., FINK, R., HOLL, W., LENGFELDER, E. & ZIEGLER, H. 1987. Natural and Chernobyl-caused radioactivity in mushrooms, mosses and soil samples of defined biotops in S.W. Bavaria., Oecologia, 73, 553-558.

HASELWANDTER, K. 1987. Accumulation of the radioactive nuclide 137Cs in fruitbodies of basidiomycetes. Hlth. Phys., 34, 713-715.

HASELWANDTER, K., BERRECK, M. & BRUNNER, P. 1988. Fungi as bioindicators of radiocaesium contamination: pre- and post-Chernobyl activities. Trans. Br. mycol. Soc., 90, 171-174.

HEAL, O. W. & DIGHTON, J. 1986. Nutrient cycling and decomposition in natural terrestrial ecosystems. In: M. J. Mitchell & J. P. Nakas eds. Microfloral and Faunal Interactions in Natural and Agro-Ecosystems. 14-73. Martinus Nijhoff/ Dr. W. Junk, Dordrecht, The Netherlands.

OOLBEKKINK, G.T. & KUYPER, T. W. 1989. Radioactive caesium from Chernobyl in fungi. The Mycologist, 3, 3-6.

SWIFT, J. M., HEAL, O. W. & ANDERSON, J. M. 1979. Decomposition in Terrestrial Ecosytems. Blackwell, Oxford, UK.

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