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INSTITUTE OF TERRESTRIAL ECOLOGY
(NATURAL ENVIRONMENT RESEARCH COUNCIL)

DOE/NERC CONTRACT DGR/481/175
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Report to the Department of the Environment

RADIONUCLIDES IN TERRESTRIAL ECOSYSTEMS

Section 3

INCORPORATION OF RADIONUCLIDES BY SHEEP GRAZING ON AN ESTUARINE SALTMARSH

B J HOWARD

Merlewood Research Station
Grange-over-Sands
Cumbria

October 1983

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C O N T E N T S

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3.1 Introduction

Since the development of atomic weapons and nuclear power stations much effort has been devoted to assessing radiation doses to man from routine or accidental releases of radionuclides. An important component of this work has involved studies of the levels of radionuclides present in animal products such as beef, milk, pork and lamb. The routine monitoring of milk, for instance, provides a sensitive biological indicator of fluctuations in environmental levels of radionuclides. However, more detailed investigations of the dynamics of radionuclide movement from feedstuffs to animals are required if models are to be used to predict radiation doses arising from releases of radioactivity into the environment.

Currently accepted values for gastrointestinal absorption, retention and excretion of radionuclides are mainly based on laboratory studies. However, recent data have suggested that gastrointestinal absorption may vary when some radionuclides are presented as organic complexes, or in environmentally contaminated feed (Harrison 1982). Furthermore, absorption is often more efficient in the very young (ICRP 1972). Field studies of radionuclide transfer from vegetation to herbivores are therefore necessary to obtain realistic transfer coefficients which can be applied to specific sites. Such studies have shown that pasture characteristics are important parameters in determining the amount of radionuclide ingested by grazing animals (Garner 1971, Van den Hoek *et al.* 1969).

The principal source of radionuclides in the environment in the United Kingdom is the Sellafield reprocessing plant in West Cumbria (BNFL 1981). Some radionuclides are emitted from a stack, but most of the low-level waste is discharged via a twin pipeline which extends out 2.1 km into the Irish Sea. Some of the radionuclides are carried to the Ravenglass estuary, approximately 7 km south from Sellafield, in association with sedimentary material. During tidal inundation, saltmarshes of the estuary are covered by water carrying diluted radioactive effluent and a suspension of contaminated particulates some of which is deposited as the tide recedes. As a consequence the level of radionuclides on these saltmarshes is considerably higher than on any other grazed pasture in the United Kingdom. These enhanced levels in the environment therefore provide an opportunity to investigate the transfer or radionuclides to grazing animals in realistic field conditions.

In a study of cattle grazing pasture contaminated by the tide in this estuary, Summerling (1981) found a relatively low transfer coefficient of ^{137}Cs from pasture to muscle. He attributed this to the binding of caesium to fine grain silt particles, which decreased ^{137}Cs absorption in the gut.

In this study, the transfer of radionuclides from saltmarsh vegetation to sheep in the pasture has been measured. To investigate the transfer of radionuclides to sheep, measurement of the radionuclide content of sheep tissues and estimation of the daily intake of radionuclides by sheep were necessary. The latter is difficult since sheep which graze saltmarshes frequently graze other areas, which are not inundated, with very different levels of radionuclides. Hence regular sampling of vegetation from all grazed areas had to be combined with frequent observations of grazing behaviour so that realistic estimates of daily radionuclide intake could be made.

3.2 Sheep management in West Cumbria

The majority of sheep stock in West Cumbria are either in fell flocks or lowland flocks.

a. Fell flocks

Fell flocks are mostly self maintaining by breeding their own replacements. The most popular breeds are Swaledale and Herdwick and crosses between these two breeds. Cheviots, Rough Fell, Dalesbred and Scottish Blackface sheep are in the minority.

Fell flocks are maintained on the open fell for most of the year. The ewes are brought off the hills for management purposes, mainly because of the shortage of enclosed land in relation to the size of the flocks. In the spring the ewes are brought from the hills a few weeks before lambing starts in April when they may receive some supplementary feeding in the enclosures around the farm. After lambing most return to the open fell with their lamb. During the summer, the flock is brought in for clipping and dipping to prevent parasites. In the autumn, the ewes and lambs are brought in for weaning the lambs and for the selection of draft ewes which, due to their age, are not likely to survive another year of hill conditions. Draft ewes are sold locally to lowland farmers or for slaughter, depending on their condition and breeding potential for lowland conditions. Wether lambs (castrated males) are sold locally, as stores, to be fattened on better land, but some may be in a good enough condition to be sold as fat lambs. The ewe lambs, suitable as breeding stock, usually leave the farm to be wintered on better land from October till early April. Local lowland farms (often with saltmarshes) or farmers from as far away as Lincoln acquire these wintering hogs. The ewes return to the open fell till they are gathered for mating. Fell ewes normally are put to the ram in the farm enclosures from November, and to the hills before the end of the year.

b. Lowland flocks

The management of lowland flocks is quite different. Unlike the fell flocks, few are self maintained by breeding their own replacements, but depend on introducing purchased ewes from auction. The purchased draft hill ewes are put to either the Suffolk ram to breed lambs for market or they are put to the Leicester ram to produce Mule lambs (in the latter case the ewe is the Swaledale, Figure 3.1). Female Mule lambs are kept or sold as potential breeding stock, whereas male Mule lambs are sold as fat lambs, or as stores to be fattened. Mule ewe lambs are purchased at Lazonby or at other local auctions in Cumbria as replacements for the lowland flocks (this is common in the Duddon estuary). Occasionally not all the Mule lambs are retained, but after producing lambs as hogs, some may be sold in the autumn as shearlings.

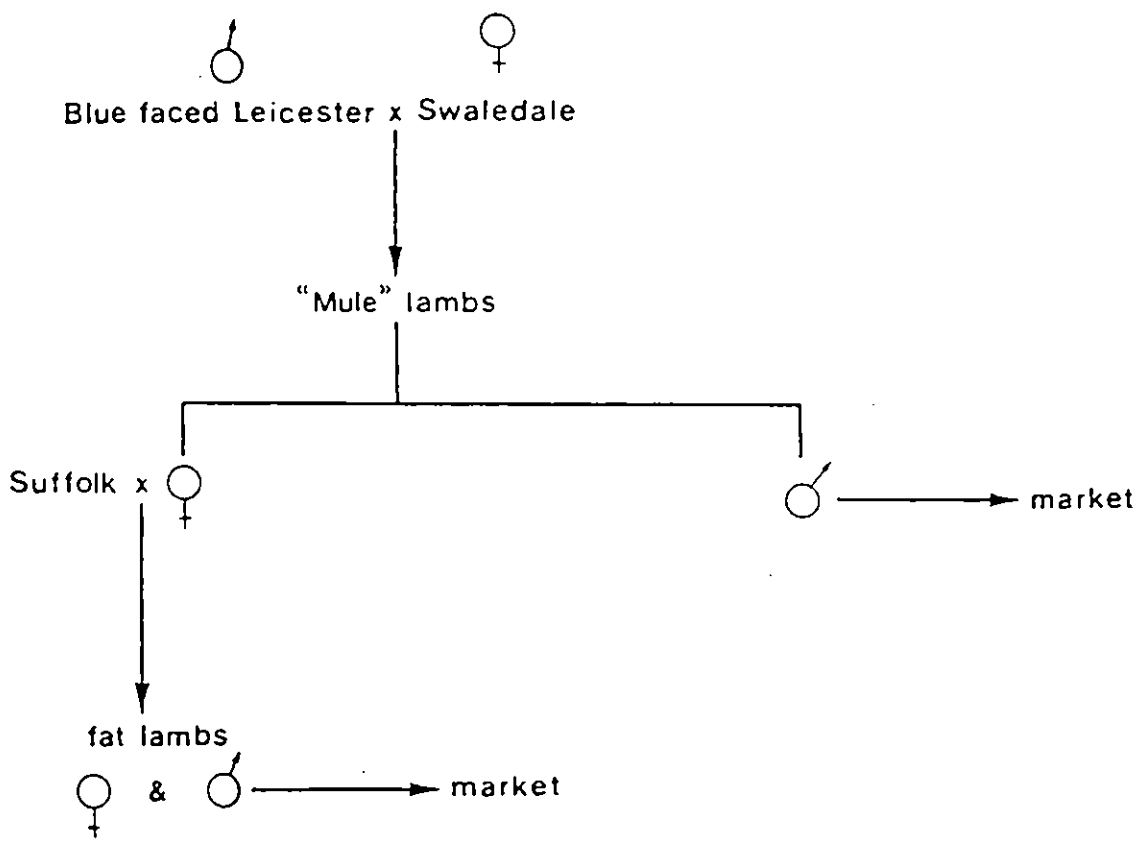

Figure 3.1 The breeding relationships of the different breeds of sheep raised in the Ravenglass and Duddon estuaries.

The Mule ewe is an ideal mother, and when mated with the early maturing Suffolk ram accounts for most of the early fat lambs, especially as some Mule flocks start lambing shortly after New Year. A few other cross bred ewes from the hill ewe and the lowland ram are to be found in the area. Several flocks are maintained on the saltmarshes.

3.2.1 Grazing practices on the Ravenglass and Duddon estuaries

There are 2 relatively small estuaries within 30 km of the Sellafield reprocessing plant, the Ravenglass estuary and the Duddon estuary. On both of these, sheep graze the saltmarshes where radionuclides are deposited on the vegetation and it is in these areas that the results of this study are most relevant. The sheep are allowed to graze the saltmarshes freely for most of the year; they are brought off during high tides and for dipping and clipping and again for a few weeks prior to lambing, when they are fed concentrates and sometimes turnips.

In the Ravenglass estuary there are approximately 260 ewes, producing 400 lambs, with access to grazings on the saltmarshes. In autumn roughly 300 hogs are bought in for fattening and 300 hogs overwinter on the coast and then return to their hill farms. In the Duddon estuary the extensive marshes are often communally grazed (especially those to the north of the river) by over 2 000 ewes, producing approximately 3 000 lambs. About 300 hogs are bought in autumn for overwintering and fattening.

3.3 Sheep farming on the study area

3.3.1 Saltmarsh grazing

The Ravenglass estuary is fed by 3 rivers, the Irt, the Mite and the Esk, which meet just west of Ravenglass village. The Irt and Esk rivers are separated from the Irish sea by extensive sand dunes, behind which saltmarsh has developed (Figure 3.2). The most extensive areas of saltmarsh occur on either side of the river Irt. The saltmarsh on the seaward, western side of the river, is grazed by the sheep which were investigated in this study, whilst the saltmarsh on the eastern edge is grazed by cattle. The river Mite is bordered by small, scattered areas of saltmarsh which are grazed by sheep and cattle. Most of the saltmarshes on the river Esk are to the east of the railway, these include both grazed and ungrazed saltmarsh.

Saltmarshes as grazing pastures have many advantages, they provide a fluke-free, worm-free, self-fertilizing and self-weeding pasture with low fencing and husbandry costs. Their main disadvantages lie in the occasional loss of stock, especially heavily-pregnant ewes, through drowning. Stocking rates on saltmarshes are generally high and live weight gains among lambs compare favourably with inland pastures (Gray 1972).

3.3.2 Grazing practices on the Drigg study site

The Drigg marshes and dunes are grazed virtually all the year round by 200-250 Swaledale ewes and a self maintained herd of Galloway cattle.

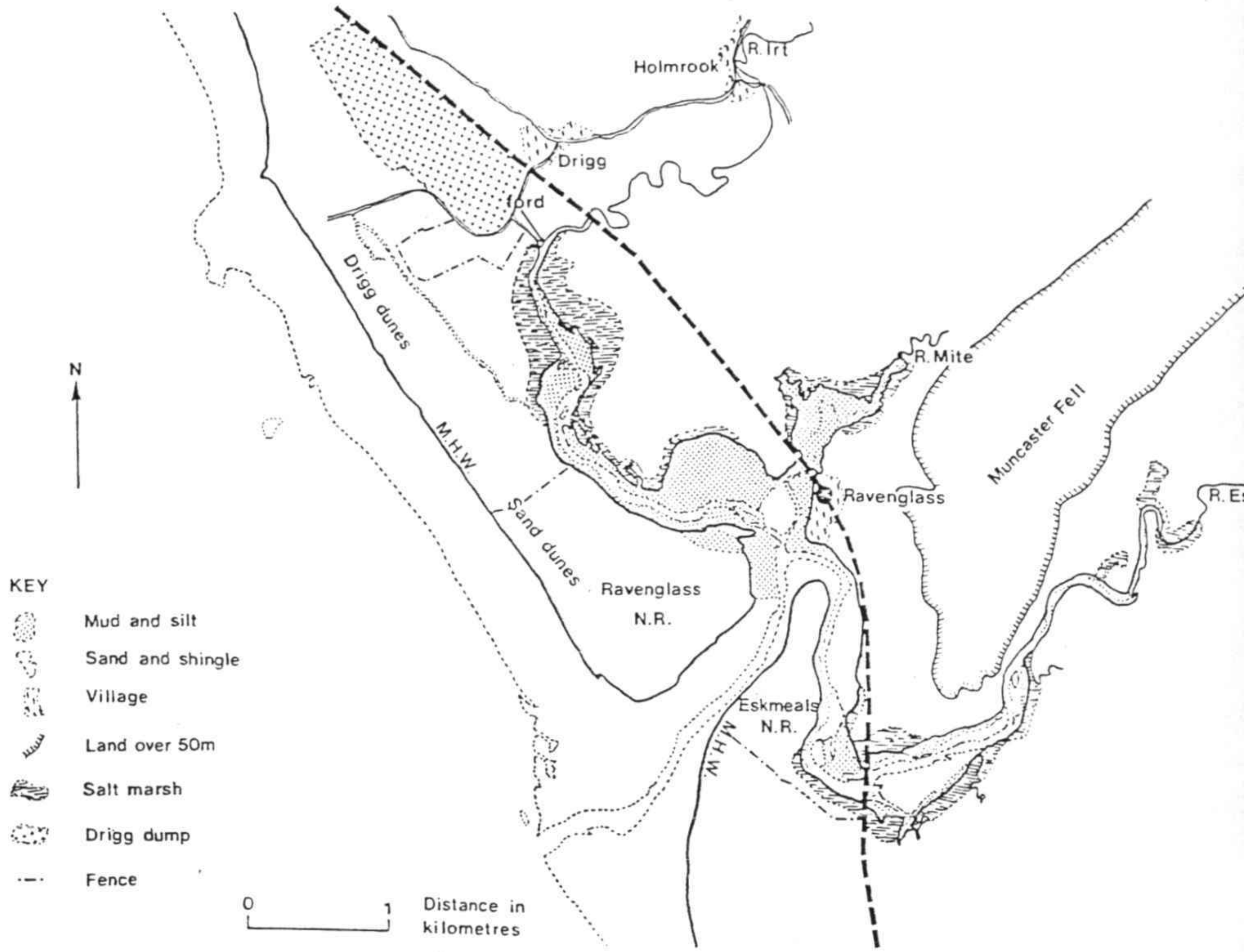

Figure 3.2 Ravenglass estuary showing the distribution of mud flats, saltmarshes and the Drigg study site.

Replacement draft ewes are bought in October from Yorkshire. These 4 year old draft ewes are kept on coastal pasture often for 3-4 years producing 3-4 crops of Mule lambs from each ewe, before being sold as cast ewes at local markets.

Sheep tend to break up into separate flocks, grazing a particular section of the area. The sheep which graze the saltmarsh spend much of their time on the marsh during the warmer months, resting there or on the adjacent hummocks and therefore graze relatively little on the dunes. The different flocks tend to become mixed during the winter when the home range of each becomes extended (Plates 3.1 and 3.2).

The sheep are left grazing freely on the land for most of the year, and are removed only for the following procedures:

a. Lambing

Lambing occurs from early April. The ewes are removed from the marsh/dune area at the end of March and kept in fields near the farmhouse for lambing. Roughly one ewe in two has twin lambs. The lambs are fed nuts and concentrates to supplement the ewes milk until both ewes and lambs are returned to the pasture in mid-May (Plate 3.2).

b. Tupping

The ewes are brought into the fields near the farmhouse at the end of October for one month. The Swaledale ewes are crossed with blue-faced Leicester tups to produce Mule lambs.

c. Clipping

The ewes are clipped in June, but are only removed from the marsh/dune system for one day.

d. Dipping

The sheep are removed from the marsh/dune area for 1-2 days for dipping to prevent ticks, blowfly and mites.

The ewes and lambs graze freely on the open pasture from May to September. In September the lambs are gathered up and are sold at market, according to sex. Male or Wether lambs are sold for fattening at Cockermouth. Occasionally the lambs are fattened on the farm and sold in the spring. Female or Gimmer lambs are sold at Lazonby market for breeding. Old Swaledale ewes are cast when their teeth have deteriorated and they are unfit for further breeding; these are sold at Cockermouth market.

About 250 Herdwick hogs from Eskdale and Wasdale are overwintered in the area from the end of October (Plate 3.1). They graze throughout the whole area, including the dunes, and some animals feed occasionally on the saltmarsh. All these animals are removed in early April and returned to fell pastures.

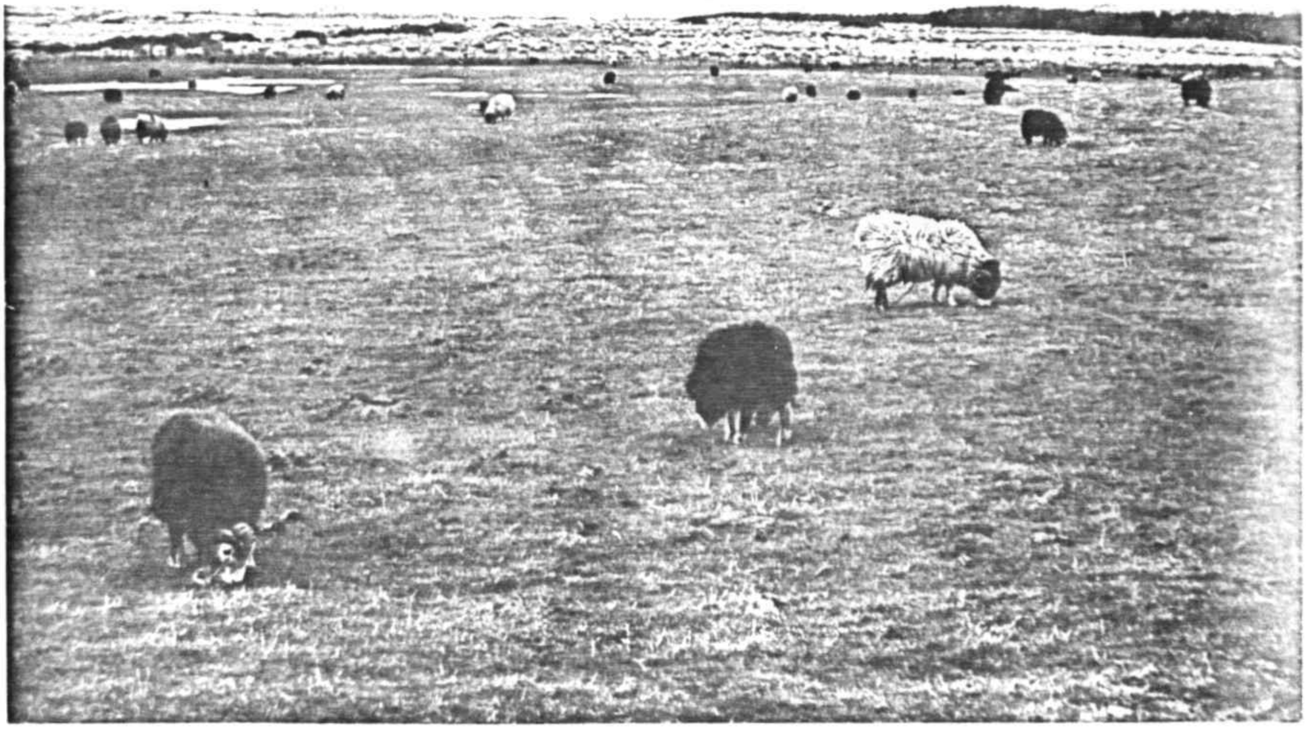

Plate 3.1 Herdwick hogs and Swaledale ewes grazing the saltmarsh in winter.

Plate 3.2 Swaledale ewes with mule lambs grazing the saltmarsh in summer.

The sheep grazing regime at Drigg had a number of practical advantages for studying the uptake of radionuclides from saltmarshes by sheep.

a. The sheep were able to graze freely on the saltmarsh all year.

b. The farmer was interested in the project and has a reputation for intelligent co-operation.

c. The area could be split into distinct zones for vegetation sampling.

d. The levels of radionuclides on the saltmarsh were sufficiently high to allow some replication of samples.

e. The study area adjoined a nature reserve which was managed by a warden who lived on site from March to September. The warden was very helpful, undertaking intermittent observations on the sheep and contacting ITE when unexpected sheep deaths occurred.

3.4 Field observations of grazing behaviour

3.4.1 Introduction

The sheep grazing the saltmarshes at Drigg were also able to graze on the larger area extending beyond the saltmarsh. It was therefore necessary to make frequent observations of the distribution of the sheep so that the proportion of time spent on the different areas could be estimated.

3.4.2 Materials and methods

Both the farmer and the reserve wardens observed that the sheep which grazed the saltmarsh did not graze the pastures to the north of the Drigg road. Only the land to the south therefore was considered in this study.

Preliminary measurements of the radionuclide levels of vegetation from the study area showed that the radionuclide content varied considerably, with the highest levels at the river edge of the marsh (see Horrill, this report). The area was sub-divided into 6 areas (Figure 3.3) according to levels of activity, vegetation types and sheep grazing ranges, so that separate estimates of the radionuclide intake of the sheep from each area could be made.

The saltmarsh itself was sub-divided into 2 areas, (1 and 2) according to the frequency of tidal inundation. Area 1 was immersed more frequently and was more heavily laden with silt. It was most easily distinguished from area 2 in spring when the *Armeria maritima* on area 1 flowered, highlighting the border between the two areas (Plate 3.3). The heathland beyond the marsh was also sub-divided into 2 areas (3 and 4) because it was observed in preliminary studies that sheep rarely ventured onto area 4, which was poorly drained. Areas 5 and 6 were unimproved pasture; much of area 5 consists of sand dunes.

Detailed observations were made of the amount of time that the sheep spent in each area throughout a year. Six recordings were made each month, from vantage points which allowed observation of the distribution of the sheep without disturbing them. The saltmarsh sheep were marked

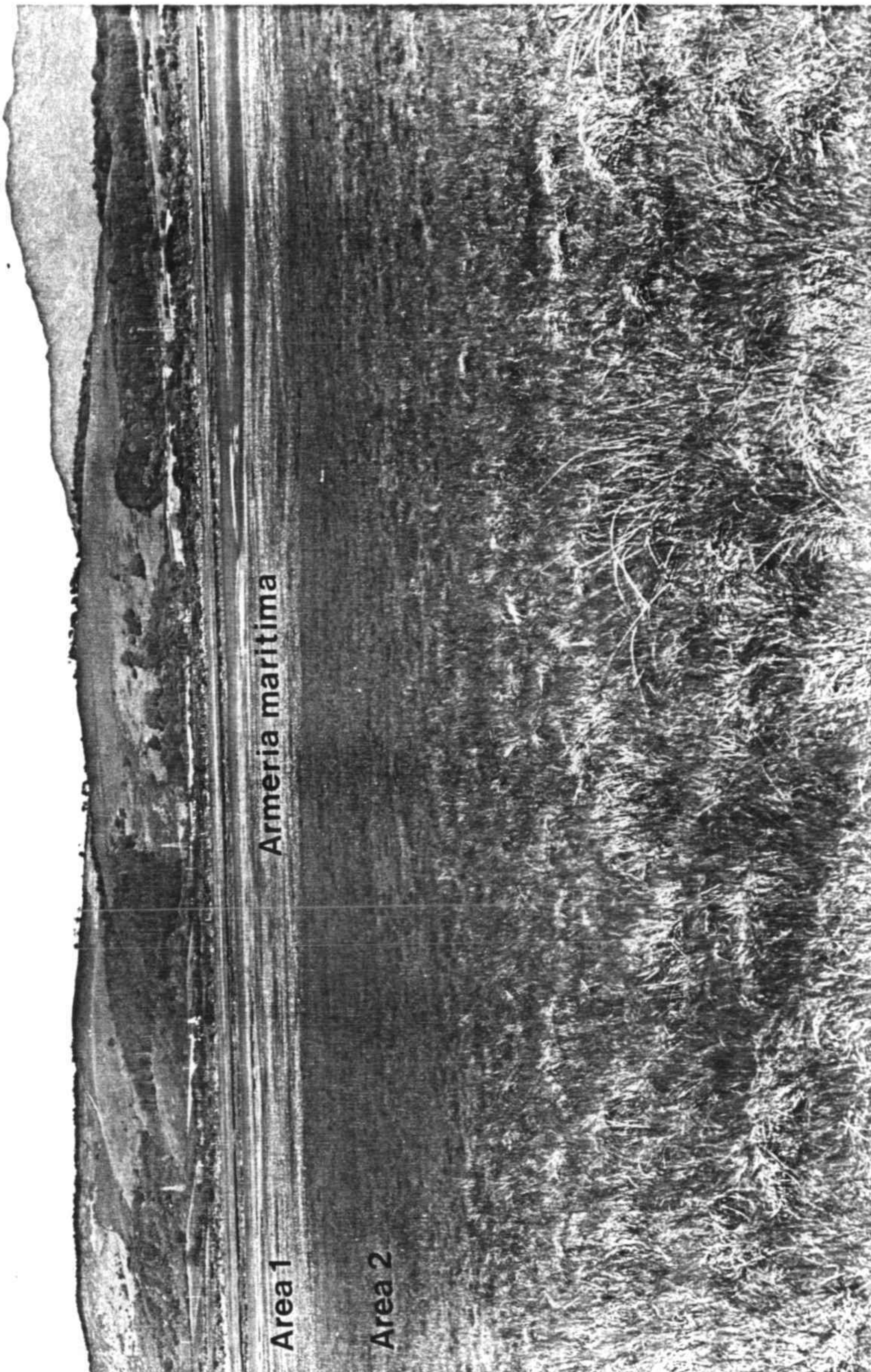

Plate 3.3 Area 1 could easily be distinguished from Area 2 in spring when <u>Armeria</u> <u>maritima</u> was flowering.

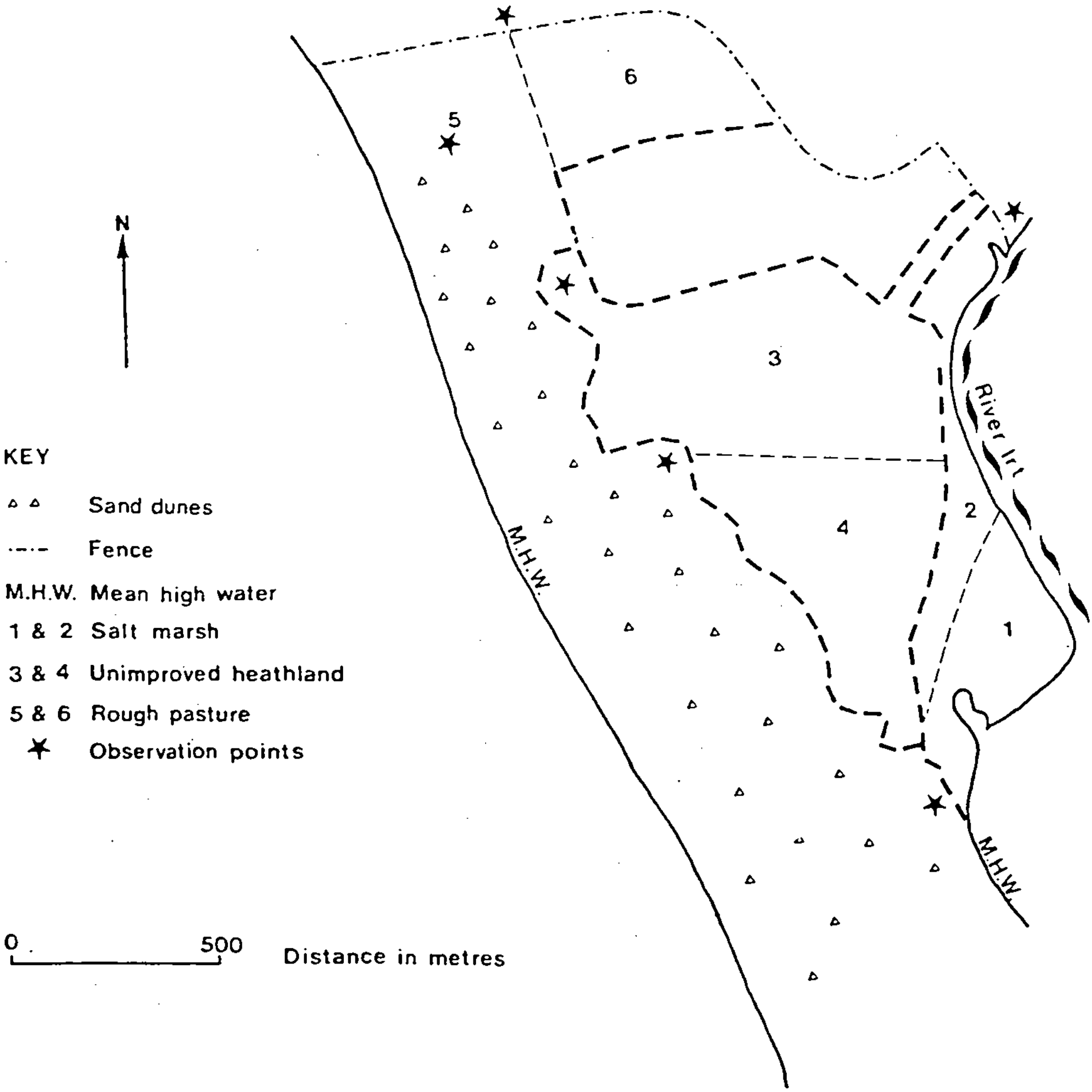

Figure 3.3 Plan of the Drigg study site with the subdivisions in areas 1-6 and the observation points used to observe the sheep.

to distinguish them from other sheep with grazing ranges based on areas 3-6. Most observations were conducted between 10 00 and 14 00 hours G.M.T. Sheep often have a marked periodicity to their grazing behaviour, suggesting that short periods of observation may not be representative of a full day's grazing (Spedding 1965). The diurnal rhythm of the sheep and response to tidal inundation was therefore studied for a limited period in both the summer and winter. Hourly observations of the distribution of the sheep were recorded.

A vegetation survey of areas 1-4 was carried out to give an indication of which vegetation species were being grazed. This enabled a representative sampling regime to be devised for the relatively large areas 3 and 4.

3.4.3 Results

There were 35 ewes which grazed the saltmarsh; these sheep had 45 lambs in the spring. There were therefore a total of 210 observations of ewes each month and 270 of lambs (when present).

If the saltmarsh sheep could not be found on areas 1-4 they were assumed to be grazing in the extensive sand dunes adjacent to area 5, where they were probably hidden from view. When the sheep were gathered and kept near the farm they were also assumed to be grazing vegetation with a radionuclide content similar to area 5 as radionuclide measurements of this pasture were similar to those of area 5. For example, the ^{137}Cs concentration in vegetation from areas 5 and at the farm in May were 1.67 pCi g^{-1} dry wt and 1.60 pCi g^{-1} dry wt respectively. Saltmarsh sheep were not observed on area 6.

The average monthly observations of sheep grazing in each area have been expressed as a percentage of the total grazing in each month (Figure 3.4). There was a considerable difference in the grazing behaviour of the ewes in the summer and winter months. Over 75% of grazing in June, July and August took place on the saltmarsh as opposed to less than 25% in December and January. Although the ewes occasionally grazed the saltmarshes in the colder months when vegetation growth was reduced they had to extend their grazing over a much wider area, and spent much of their time on the heathland and sand dunes in areas 3-5. Consequently, over the study year only 43% of the total grazing occurred on the saltmarsh. As lambs were present in only the warmer months, (from May to September) the proportion of their total grazing time spent on the marsh was greater (55%) than that of the ewes.

Hourly observation, from dawn to dusk, of the grazing behaviour of the saltmarsh sub-flock in summer and winter highlighted differences in individual grazing habits. A one-way analysis of variance of the data showed that during the observation periods the sheep spent significantly more time on areas 3 and 5 in the winter, and areas 2 and 3 in the summer (Appendix 1). In order to test whether the 10 00-14 00 hours G.M.T. regular observation period was atypical of the whole day t-tests were carried out to compare the observations inside and outside the observation period. There was no significant difference in grazing behaviour between the 4-hour period and the whole day; it was therefore acceptable to restrict observations to the period 10 00-14 00 hours G.M.T. It must be stressed, however, that behaviour

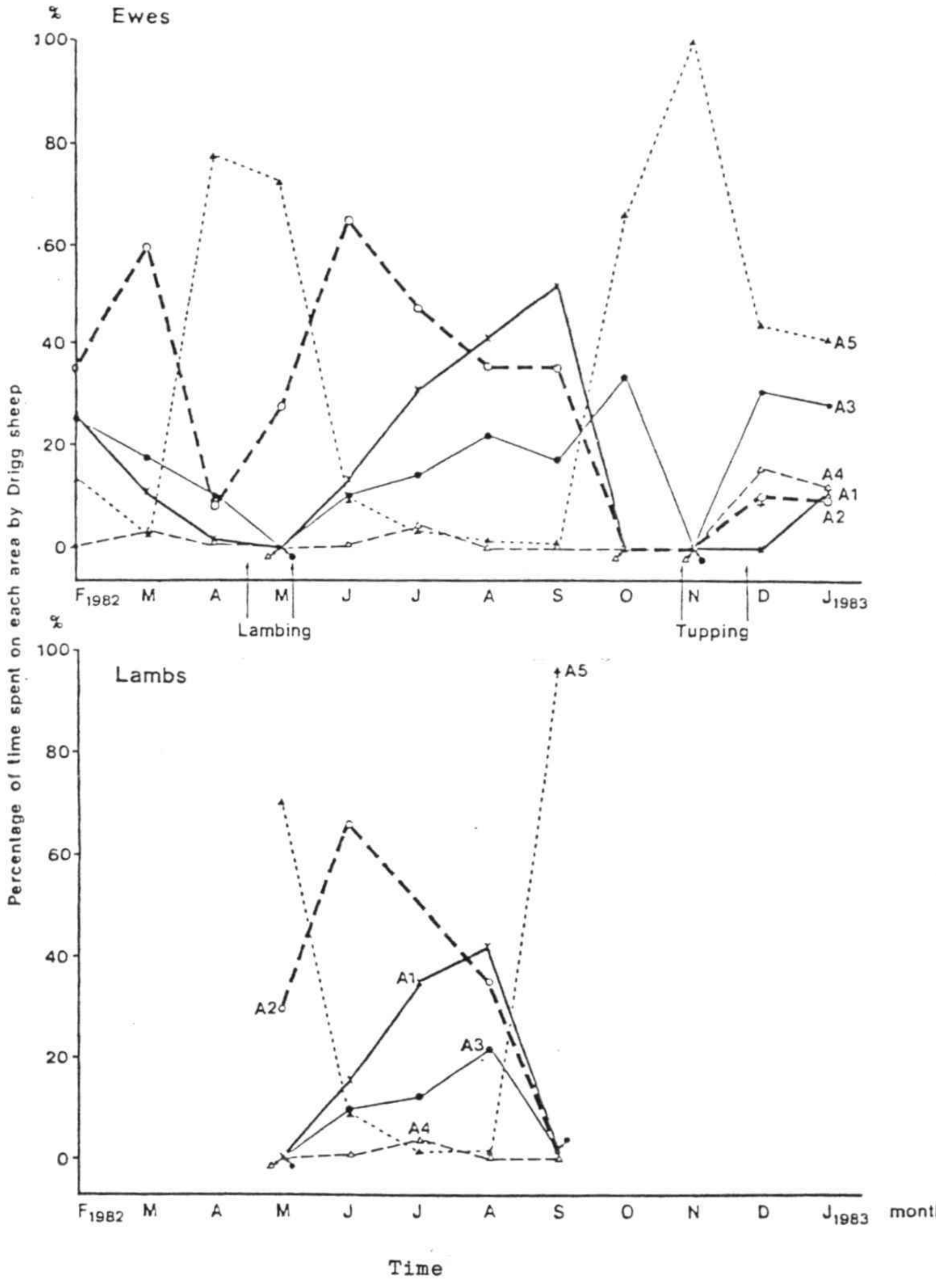

Figure 3.4 The proportion of time that the Drigg sheep spent on the different areas on the Drigg study site.

of the sheep under other weather conditions might have been very different; on 18th January 1983, when there had been hail, snow and strong winds, the majority of the ewes sheltered in area 5.

Hughes & Reid (1952) found that lowland sheep spent an average of 9 hours grazing, of which 95-100% was in daylight in summer, but in winter only 60% occurred during the daylight. The winter observations are therefore likely to be less accurate estimations of grazing behaviour.

Tidal inundation of the marsh affected grazing only while the vegetation was underwater. The sheep moved off the saltmarsh during tidal inundation, but returned to graze recently inundated areas as soon as the vegetation was exposed.

From initial observations of the behaviour of the sheep on the heathland (areas 3 and 4) there was a suggestion that the animals grazed some areas more frequently than others. Because the heathland was extensive, identification of the favoured grazing areas was necessary and a suitable sampling regime for vegetation had to be devised. The vegetation survey of areas 1-4 found that various communities of plants were present (Figure 3.5). The dominant species in each zone are listed in Table 3.1; together with the percentage of the total area that each zone occupied. Some of the species present in areas 3 and 4 were typical of acidic conditions, eg *Calluna vulgaris*, *Erica tetralix*, *Juncus squarrosus*, *Nardus stricta*, *Potentilla erecta* and *Sphagnum* spp. On the poorly drained land in the south-west of the area and around the underground spring, species typical of wet conditions, such as *Caltha palustris*, *Lychnis flos-cuculi* and *Equisetum* spp. were present. The sheep were rarely observed in these wet regions, spending less than 15% of their time on these areas. The saltmarsh comprised only 18% of the total area surveyed (Table 3.2) but the sheep spent 43% of their time on it.

The Herdwick hogs, overwintering at Drigg, were widely dispersed throughout the area, with about 100 on the study site. A few sheep grazed the saltmarsh and since they were not marked it was not possible to state whether or not the same individuals were grazing on the saltmarsh during each observation period.

3.4.4 Discussion

In order to calculate transfer coefficients the daily intake of radionuclides must be calculated. It was therefore necessary to calculate the average number of days each month that the sheep were grazing each area (Tables 3.3, 3.4). The data were used in conjunction with the measured levels of radionuclides on the vegetation in each area (Section 3.5) to calculate the average daily intake of radionuclides by the sheep each month (see Section 3.5).

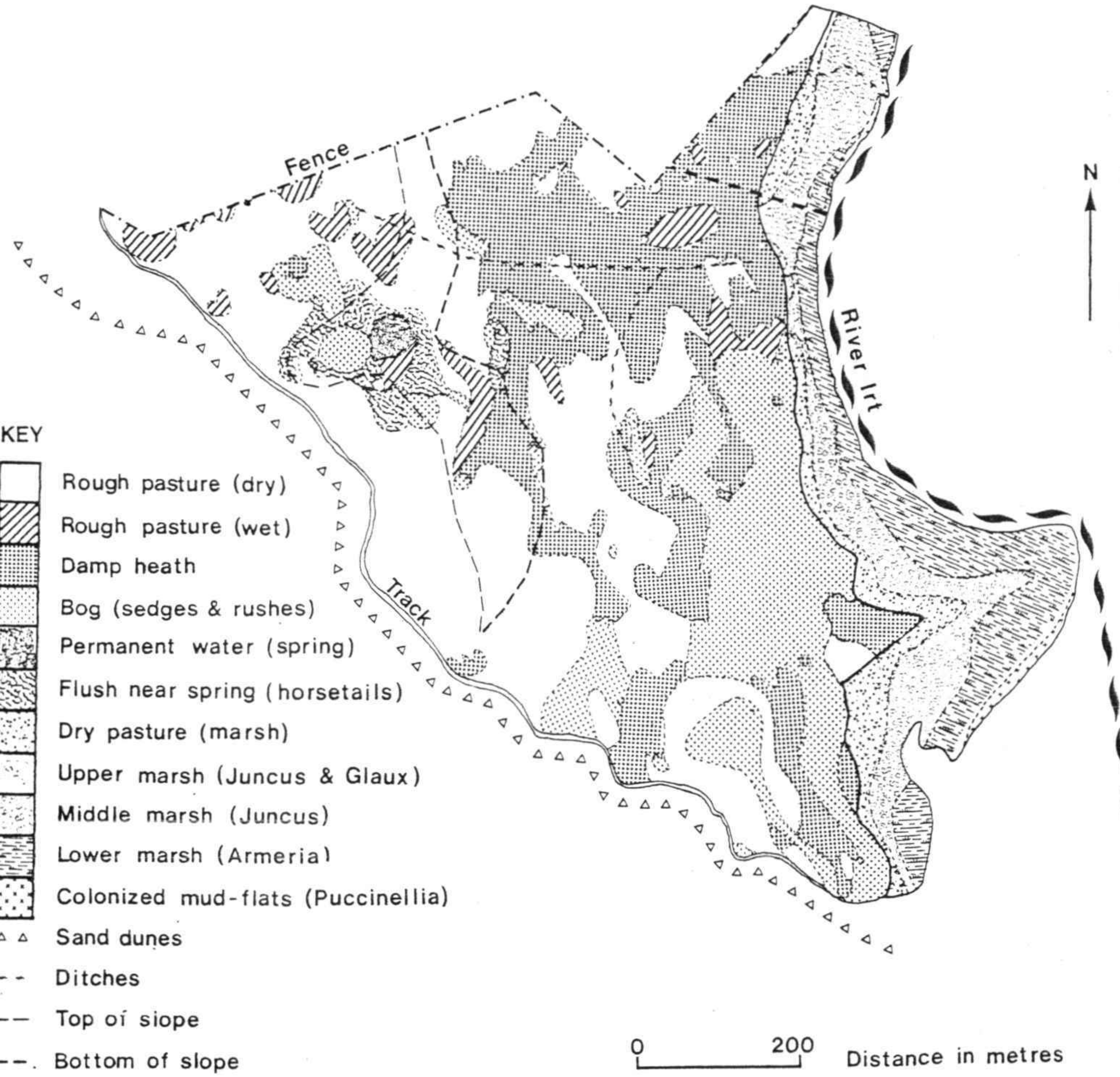

Figure 3.5 The plant communities present on areas 1-4 of the Drigg study site.

Table 3.1 The main vegetation species present in each vegetation zone on the Drigg study areas 1-4.

Rough pasture (dry)

*Achillea ptarmica
Agrostis stolonifera
Ammophila arenaria
*Anthoxanthum odoratum
Carex arenaria
Carex nigra
Erica cinerea
*Festuca rubra
Galium cruciata
Hieraceum pilosella
Holcus lanatus
Juncus articulatus
Juncus effusus
Lichen - Cladonia spp
Lotus corniculatus
Luzula pilosa
Plantago lanceolata
Potentilla erecta
Ranunculus flammula
Rumex acetosella
Stellaria media
Thymus drucei
*Trifolium repens
Ulex europeaus

Rough pasture (wet)

Agrostis stolonifera
Eriocaulon septangulare
Galium spp
Holcus lanatus
*Juncus articulatus
*Juncus effusus
Potentilla anserina
*Ranunculus flammula

Damp heath

Agrostis canina
Agrostis stolonifera
Anthoxanthum odoratum
*Calluna vulgaris
Carex nigra
*Erica tetralix
Festuca ovina
*Galium saxatile
Juncus squarrosus
Luzula pilosa
*Nardus stricta
*Potentilla erecta

Bog (sedges & rushes)

Agrostis stolonifera
Anthoxanthum odoratum
*Caltha palustris
*Cirsium palustre
Epilobium spp
Equisetum spp
*Galium palustre
Juncus articulatus
Juncus effusus
Polytrichum communi
Ranunculus flammula
*Sphagnum spp

Table 3.1 continued

Flush around spring

Agrostis stolonifera	**Equisetum* spp
Anthoxanthum odoratum	*Holcus lanatus*
**Cardamine pretensis*	*Ranunculus flammula*
Cirsium palustre	**Sphagnum* spp

Permanent water (spring)

**Caltha palustris*	**Equisetum* spp
Eriophorum angustifolium	**Lychnis flos-cuculi*

Dry pasture (marsh)

**Agrostis stolonifera*	*Potentilla erecta*
**Holcus lanatus*	**Molinia caerulea*
Trifolium repens	

Upper marsh

**Juncus geradii*	*Puccinellia maritima*
**Glaux maritima*	

Middle marsh

**Juncus geradii*	*Armeria maritima*
**Puccinellia maritima*	*Glaux maritima*

Lower marsh

**Armeria maritima*	**Puccinellia maritima*
**Salicornia* spp	*Glaux maritima*

Colonized mud-flat

**Puccinellia maritima*	**Algae* spp
**Salicornia* spp	

* Indicator species in each zone.

Table 3.2 Percentage of each vegetation zone in the total area 1-4.

Vegetation zone	% of total area
1. Heathland (areas 3 and 4)	
Rough pasture (dry)	34
Rough pasture (wet)	4
Damp heath	23
Bog (sedges & rushes)	18
Permanent water (spring)	0.5
Flush near spring	<2
Total	81.5
2. Saltmarsh (areas 1 and 2)	
Dry pasture (marsh)	3
Upper marsh *(Juncus & Glaux)*	2.5
Middle marsh *(Juncus)*	5
Lower marsh *(Armeria)*	7.5
Colonized mud flat *(Puccinellia)*	<0.5
Total	18.5

Table 3.3 Estimated number of days that the EWES spent grazing each area in each month.

(Mean ± SD from 6 observations $month^{-1}$)

Month	Area				
	A1	A2	A3	A4	A5
1982					
February	7.21± 9.05	9.87± 7.70	7.07± 5.17	0.13± 0.33	3.73± 4.43
March	4.87± 3.58	18.60± 6.19	5.46± 3.33	1.03± 2.13	1.03± 2.53
April	1.00± 1.00	2.43± 2.13	3.00± 3.59	0.29± 0.70	23.29± 6.51
May	0 ± 0	8.56± 7.03	0 ± 0	0 ± 0	22.44± 7.03
June	4.0 ± 5.08	19.57± 6.97	3.14± 2.80	0.14± 0.35	3.14± 3.46
July	9.6 ± 4.80	14.61± 5.00	4.43± 4.62	1.33± 2.84	1.03± 2.53
August	12.7 ± 6.35	11.07± 3.83	6.79±10019	0 ± 0	0.44± 1.08
September	14.0 ±12.32	10.57±11.60	5.14±12.18	0 ± 0	0.29± 0.44
October	0 ± 0	0 ± 0	10.48± 4.73	0 ± 0	20.52± 4.73
November	0 ± 0	0 ± 0	0 ± 0	0 ± 0	30.0 ± 0
December	0 ± 0	3.10± 3.71	8.12±12.03	4.73± 5.30	13.58±13.75
1983					
January	3.25± 3.00	2.95± 2.95	8.71± 2.77	3.40± 2.88	12.7 ±4.97

Table 3.4 Estimated number of days that the LAMBS spent grazing each area in each month

(Mean ± SD from 6 observations $month^{-1}$)

Month	Area				
	A1	A2	A3	A4	A5
May	0 ± 0	9.19± 7.44	0 ± 0	0 ± 0	21.81± 7.44
June	4.56± 5.41	19.89± 6.93	2.78± 2.61	0.11± 0.27	2.67± 3.01
July	10.79± 5.35	15.16± 4.57	3.67± 3.89	1.03± 2.21	0.34± 0.84
August	13.09± 6.69	10.91± 3.88	6.66±10.30	0 ± 0	0.34± 0.84
September	0.56± 0.89	0.33± 0.82	0.44± 0.81	0 ± 0	28.67± 1.03

3.5 Radionuclide levels in the vegetation and faeces

3.5.1 Introduction

An objective of this study was to obtain realistic measurements of the radionuclide content of the vegetation grazed by the sheep. Although the most reliable method for estimating vegetation intake is fistulation this technique was beyond the scope of this study. Estimates of the weight of vegetation consumed each day were taken from feeding trials or from the literature.

3.5.2 Materials and methods

Vegetation and faecal samples from the study area were taken monthly from areas 1, 2 and 3 and quarterly from areas 4, 5 and 6. Fresh faeces were collected 2 days after the vegetation. A sampling regime was devised which mimiked the grazing behaviour of the sheep. Each area was sampled by traversing along a series of north/south walks each 20 m apart, starting at a random point on a specified baseline. Sheep are highly selective feeders and will discriminate in favour of fresh, green herbage, leaving old, dead vegetation. Vegetation samples were therefore collected only where there was evidence of recent grazing, such as the presence of droppings, sheep tracks or nibbled vegetation (Plates 3.4-3.7). Samples were taken from 2 m either side of the transect lines at each point where there was evidence of grazing. Vegetation was clipped with scissors: care was taken to avoid collecting dead vegetation or vegetation contaminated with silt or soil. Three replicates were successively accumulated from each area, the bags for each of the replicates were filled in rotation.

Spelling?

Due to the relatively large size of area 3, it was impractical to sample the whole area. From the vegetation survey and sheep observations, the main areas where grazing occurred were identified and sampling was concentrated in these areas.

Samples collected each month were dried at 105°C, ground in a Tema mill and placed in plastic containers for gamma counting. The containers (55 x 60 mm, volume 150 ml) were wrapped in clingfilm prior to counting on the Ge(Li) detectors. A counting scheme was devised which enabled an estimate of variability of the monthly measurements to be made within the restricted counting time available. The replicates from the saltmarsh were counted for 25 000 seconds each and subsequently mixed together, the resulting sample was counted for a longer period of 80 000 seconds. Due to the relatively low radionuclide content of the vegetation from areas 3-6, similar samples were counted for 60 000 and 120 000 seconds respectively. With this counting regime it was possible to get an estimate of variability from the 3 replicates, which was applied to the result obtained from the more accurate, longer count. A coefficient of variation was calculated from the 3 replicates and was used to estimate a standard deviation for each long count, using the formula

$$SD = \frac{X}{CV}$$

where CV = coefficient of variation
X = mean value

Plate 3.4 Grazed vegetation on the saltmarsh.

Plate 3.5 Only fresh sheep droppings which had not been contaminated with silt or soil were collected.

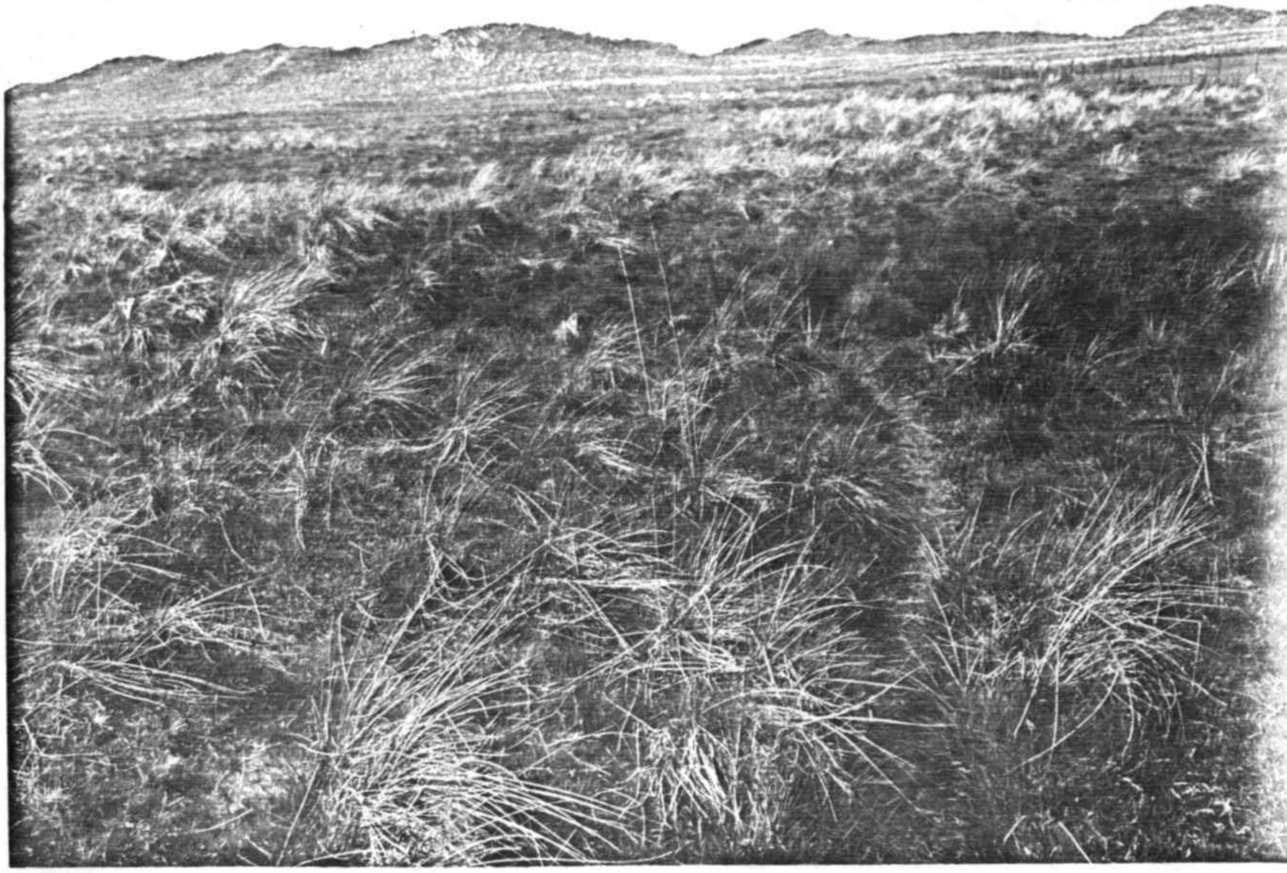

Plate 3.6 A sheep track on Area 3 leading down to the saltmarsh.

Plate 3.7 A grazed tussock of grass alongside a sheep track on Area 3.

To test whether it was acceptable to estimate the variability in this way, 3 replicates of one sample were counted for both 25 000 and 80 000 seconds. The mean and standard deviation calculated from each were 30.9 ± 5.72 pCi g^{-1} and 30.57 ± 5.59 pCi g^{-1} dry wt.

In some cases the low levels of certain radionuclides present meant that quantification was possible only on the long count, therefore it was impossible to estimate variability.

$^{239/240}Pu$, ^{238}Pu and ^{241}Am analyses were carried out on the mixed samples. ^{241}Am was also separated chemically for alpha counting if it was not detected quantitatively by the 59.5 KeV gamma emission. All results have been expressed on a dry wt basis.

It has been suggested that much of the radionuclide content of saltmarsh vegetation is due to the surface deposit of silt. In order to give an indication of the soil/silt contamination of the vegetation, the concentration of titanium of the samples was measured using the method of Sherman & Kanehiro in Black (1965).

Control samples of vegetation and silt were also taken from a saltmarsh on the Humber estuary (National Grid Reference TA/235190).

3.5.3 Results

a. Vegetation

There was a considerable difference in the radionuclide content of the saltmarsh vegetation in different months of the year. Peak concentration of radionuclides were found on the vegetation in the late winter/early spring after which the level of all of the radionuclides dropped markedly (Figures 3.6, 3.7). The fall in concentration was considerable; for example the concentration of ^{106}Ru fell from over 200 pCi g^{-1} dry wt in February to less than 20 pCi g^{-1} dry wt in July. The variation in radionuclide content of the vegetation on areas 3-6 was less marked and there was no obvious seasonal pattern (Figures 3.8, 3.9).

The most abundant radionuclides on the saltmarsh were ^{106}Ru, ^{137}Cs and ^{95}Nb, which together with ^{95}Zr, ^{134}Cs, $^{239/240}Pu$ and ^{241}Am formed the main radionuclide content of the vegetation. ^{144}Ce, ^{154}Eu, ^{60}Co and ^{238}Pu and occasionally ^{103}Ru, ^{155}Eu and ^{125}Sb were also present, especially on area 1. The concentration of ^{40}K and ^{7}Be have been included for comparison in the full set of results listed in Appendices 2-7.

The levels of ^{40}K and ^{7}Be on the Humber estuary saltmarsh were similar to those at Drigg (Table 3.5). In contrast the level of ^{137}Cs was at least 2 orders of magnitude lower than at Drigg. The concentration of ^{137}Cs on the vegetation was lower in late summer suggesting that, as at Drigg, there is a seasonal pattern of radionuclide deposition.

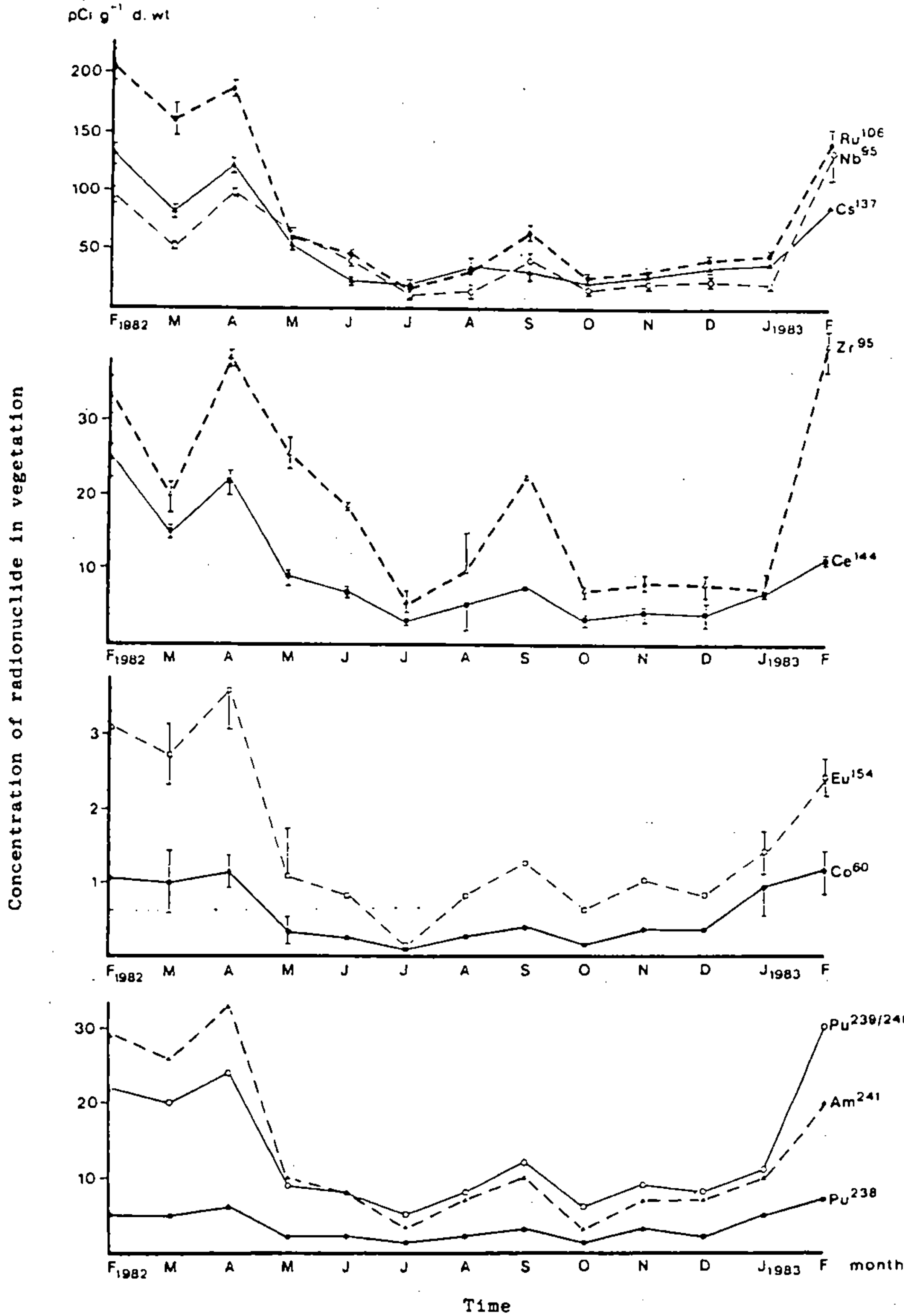

Figure 3.6 Variation in the concentration of various radionuclides in vegetation from area 1 with time.

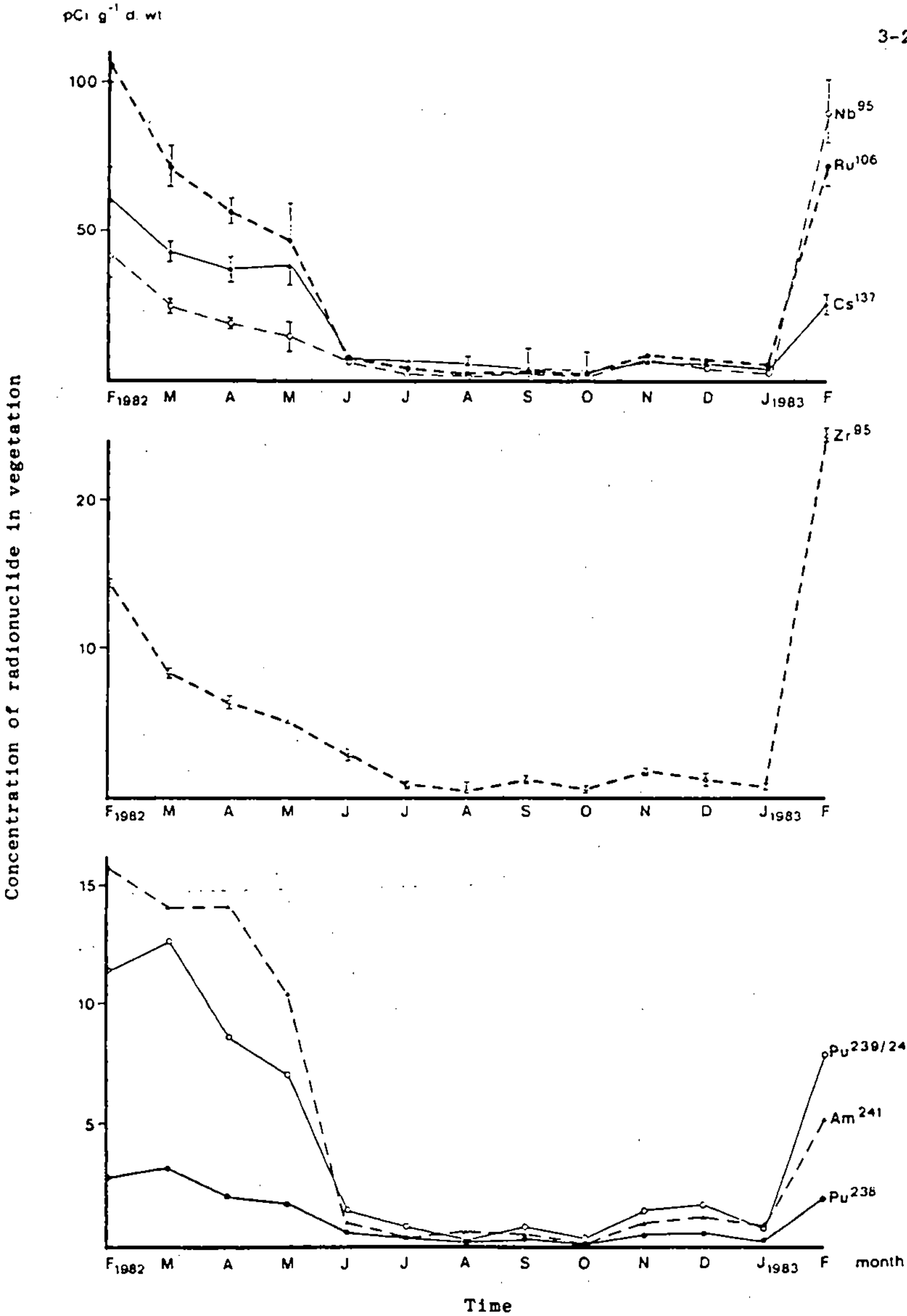

Figure 3.7 Variation in the concentration of various radionuclides in vegetation from area 2 with time.

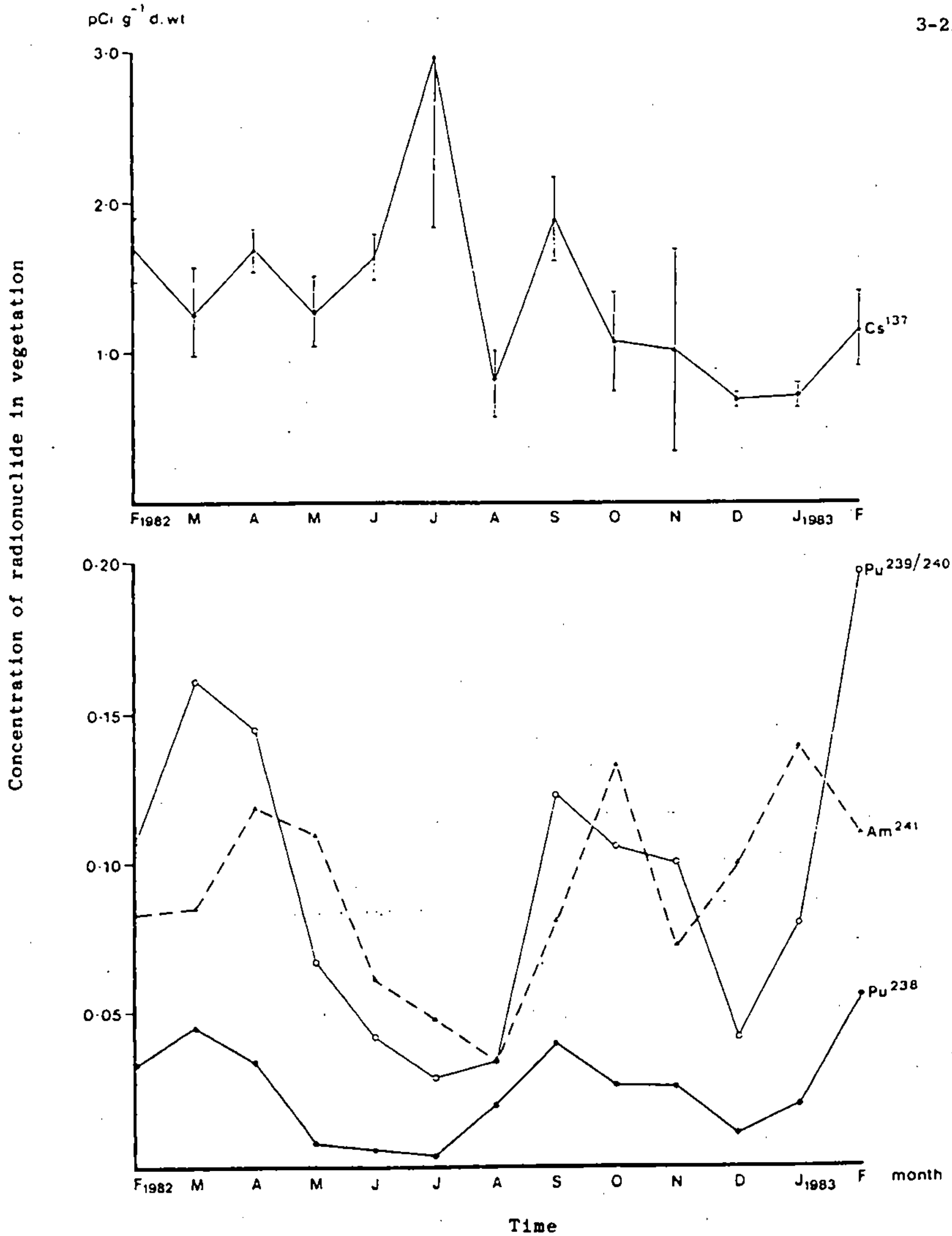

Figure 3.8 Variation in the concentrations of various radionuclides in vegetation from area 3 with time.

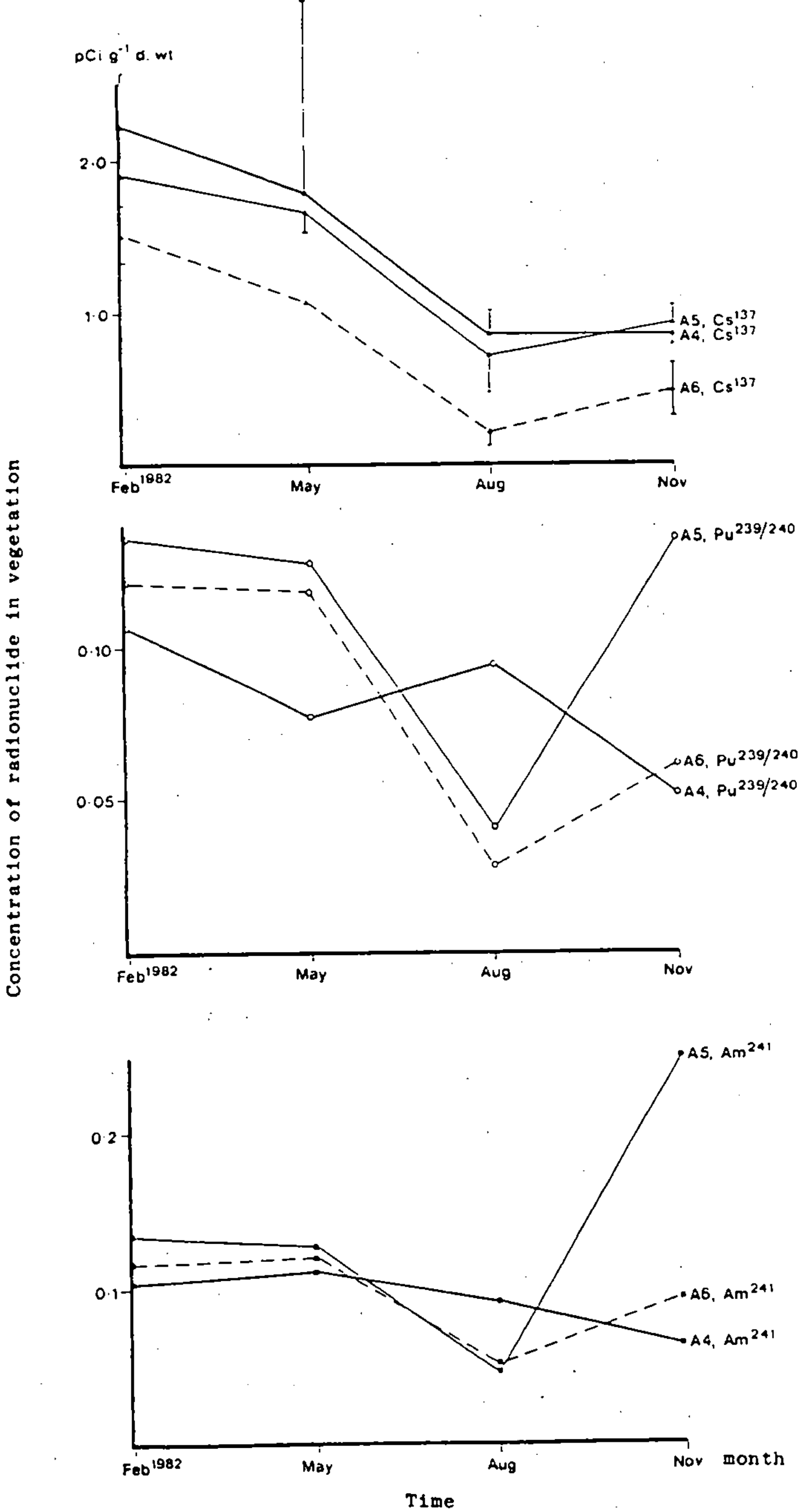

Figure 3.9 Variation in the concentration of radionuclides in vegetation from areas 4-6 with time.

Table 3.5 Radionuclide levels in vegetation and silt from a saltmarsh on the Humber estuary. (pCi g^{-1} dry wt)

Time	Sample		Radionuclide			
			^{137}Cs	^{40}K	^{7}Be	^{125}Sb
May 1982	VEGETATION	1	0.852	13.5	<1.32	0.130
		2	0.601	13.7	<1.17	0.170
		3	0.430	13.6	<1.54	<0.290
	SILT		0.732	5.18	<0.18	<0.030
Sept 1982	VEGETATION	1	0.027	5.38	1.80	<0.031
		2	<0.013	3.94	1.68	<0.033
		3	0.008	4.94	2.08	<0.030
	SILT		0.291	14.4	<0.15	<0.015
Jan 1983	VEGETATION	1	0.835	6.63	1.97	<0.068
		2	0.343	3.54	2.30	<0.058
		3	0.519	3.80	2.40	<0.071
	SILT		0.513	14.3	<0.19	<0.019

The concentration of all radionuclides (except ^{40}K) and the titanium content of the vegetation on the saltmarsh were correlated ($P<0.05$) (Table 3.6), but only ^{238}Pu and $^{239/240}Pu$ were correlated with titanium on the heathland of area 3. Some representative examples of the relationship on area 1 are presented in Figure 3.10.

The overall objective of the sampling was to obtain representative estimates of the radionuclide intake which a grazing animal would consume on each area. Using this sampling technique the coefficient of variation for most nuclides was below 20%, which considering the considerable spatial variability on saltmarshes (see Horrill in this report) was better than expected.

b. Faeces

Faeces could not be collected from every area each month; for example, no faeces were found on area 1 in October and November, area 2 in November and area 3 in May and June. Faeces which were collected from one area would not necessarily have originated from that area, because sheep moved from one area to another. However, the concentration of radionuclides in faeces from each area declined in the order

A1 > A2 > A4 > A3 > A5 > A6

This order of decrease was similar to that of the vegetation, suggesting that at least a proportion of the faeces originated from herbage grazed within the same area.

The full set of results are included in Appendices 8-13. As in the vegetation, so the concentration of radionuclides in the faeces varied considerably during the sampled year (Figures 3.11-3.14). It is inappropriate, however, to look at the content of the faeces from each area in isolation, when attempting to compare the radionuclide content of food and faeces, though some general trends were evident. The radionuclide content of the faeces decreased from February to mid-summer and then increased progressively until September. The atypical peak in late spring observed on area 1 may have been due to the spring high tides contaminating the faeces if they were not as fresh as they appeared. The radionuclide content of the faeces collected in December and January was relatively low, corresponding with the grazing behaviour; in these months relatively little grazing took place on the saltmarshes.

The radionuclide content of faeces collected from areas 3 and 4 was consistently higher than those from 5 and 6, reflecting the movement of sheep into these areas from the saltmarsh. The sheep were often observed moving off the saltmarsh to drink from freshwater ponds on area 4; this probably accounts for the relatively high radionuclide content of faeces from area 4 since most of the herbage originated from the saltmarsh below the high tide mark.

Table 3.6 Correlation coefficients between the concentrations of various radionuclides on the vegetation at the Drigg study site and the titanium content of the vegetation.

Radionuclide	Correlation coefficient (n)		
	Area		
	1	2	3
^{7}Be	0.4346 (10)	*0.6431 (13)	0.2744 (9)
^{40}K	-0.1403 (13)	-0.3910 (13)	-0.4319 (9)
^{60}Co	***0.9441 (13)	n c	n c
^{95}Nb	***0.8689 (13)	***0.8225 (13)	-0.2556 (6)
^{95}Zr	***0.8270 (13)	***0.8757 (13)	n c
^{106}Ru	***0.9023 (13)	***0.9681 (13)	n c
^{134}Cs	***0.8015 (13)	***0.8457 (11)	n c
^{137}Cs	***0.8784 (13)	**0.7228 (13)	-0.4796 (9)
^{144}Ce	***0.7780 (13)	n c	n c
^{154}Eu	***0.9179 (12)	n c	n c
^{238}Pu	***0.9297 (13)	***0.9400 (13)	*0.7801 (9)
$^{239/240}Pu$	***0.9816 (13)	***0.9466 (13)	*0.7031 (9)
^{241}Am	***0.9057 (13)	***0.8880 (13)	0.3992 (9)

n c not calculated

Levels of significance * $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

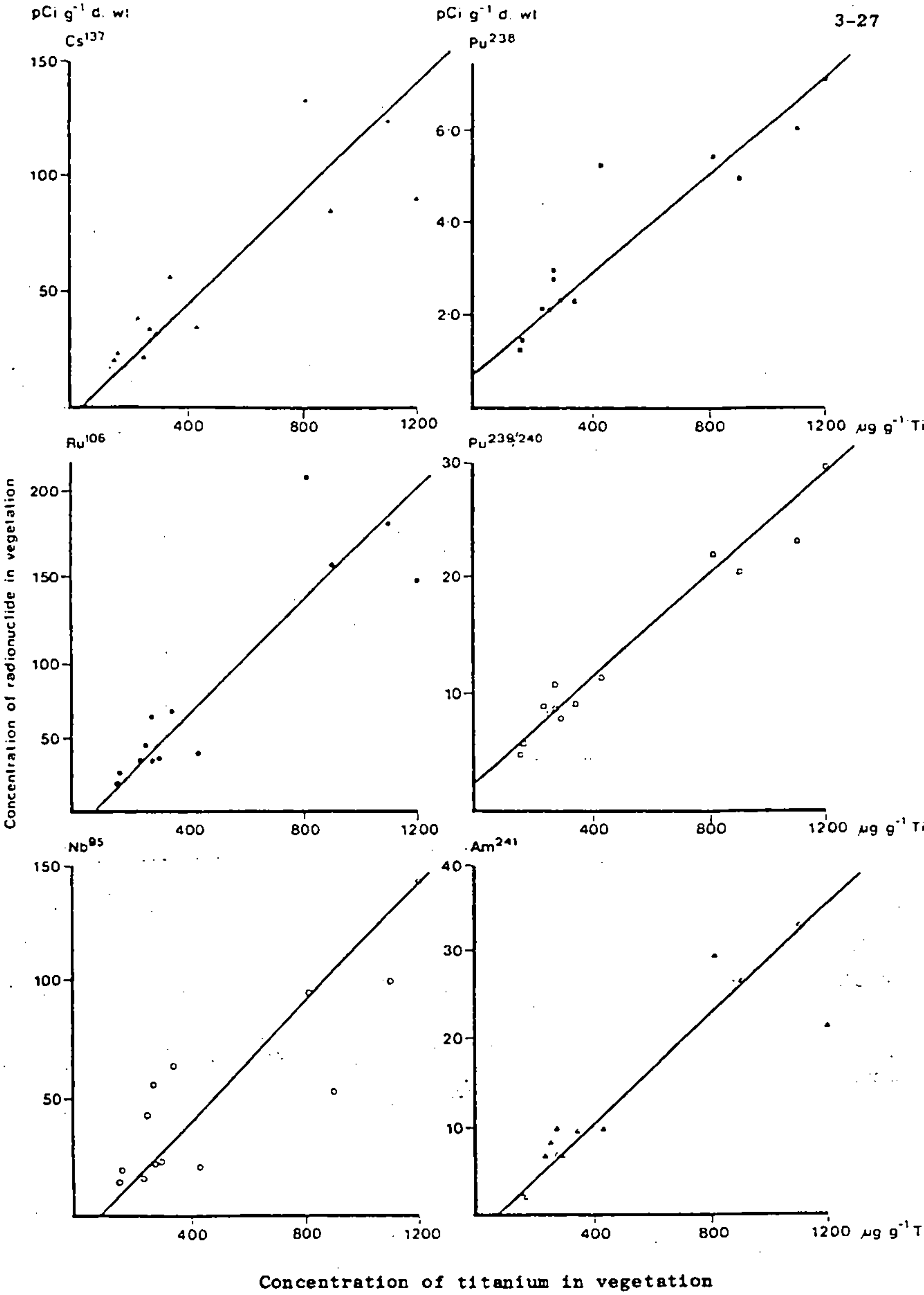

Figure 3.10 Correlations between the concentration of titanium and various radionuclides in vegetation from Area 1.

The ratio of the different radionuclides in the faeces was relatively constant (see Figures 3.11-3.14) but the overall concentration of the radionuclides in the faeces in each area was less than that of the vegetation. This was probably due to the mixing of vegetation from a number of areas in the rumen. If, as suggested by Sumerling (1981), the absorption of radionuclides from saltmarsh vegetation is low, radionuclides should have been concentrated in the faeces. Separate feeding trials were conducted to investigate this relationship (Section 3.6).

3.5.4 Discussion

Much of the radionuclide content of the saltmarsh vegetation was probably present as a surface deposit of silt. The radionuclide concentration varied considerably over the sampling period. The concentrations on the saltmarshes in February 1983 did not return to values as high as those recorded in the previous winter. This suggests that although a seasonal cycle might be expected (Hetherington & Jefferies 1974) its magnitude may vary from year to year. The observation period would have to be extended over several years to determine whether there is a seasonal influence or not.

Temporal variations in the radionuclide concentrations of the vegetation might be due to different extents of tidal inundation. Sediment usually builds up on saltmarshes during the spring and autumn equinoctual tides (Ranwell 1972), but the trend in radionuclide levels of vegetation was of a gradual decrease from a peak in late winter. The correlation between radionuclide and titanium levels on the saltmarsh suggests that the vegetation is covered by relatively more silt (with associated radionuclides) in the winter/spring than in the summer. A similar trend, in which peak concentrations of radionuclides occur in the winter months in the surface sediments of the estuary, was noted by Hetherington & Jefferies (1974) who thought that this was due to winter weather conditions bringing radionuclides into the estuary. The lower concentrations of radionuclides in the saltmarsh in summer are probably enhanced by a relatively high rate of vegetation growth. Hetherington & Jefferies thought that the lag period between discharge and the concentration in estuarine sediment was of the order of a few months, and differed with different nuclides. On the Drigg saltmarsh the ratio of the concentration of all the radionuclides was relatively constant each month, which is not true of the discharges themselves. This suggests that a sufficiently long period elapses, between discharges and radionuclide deposition on the saltmarsh, for a general mixing to take place.

The monthly measurements of the radionuclide concentration of the vegetation was used in conjunction with the observations of sheep grazing behaviour, to estimate the mean daily intake of radionuclides by the sheep, using the formula;

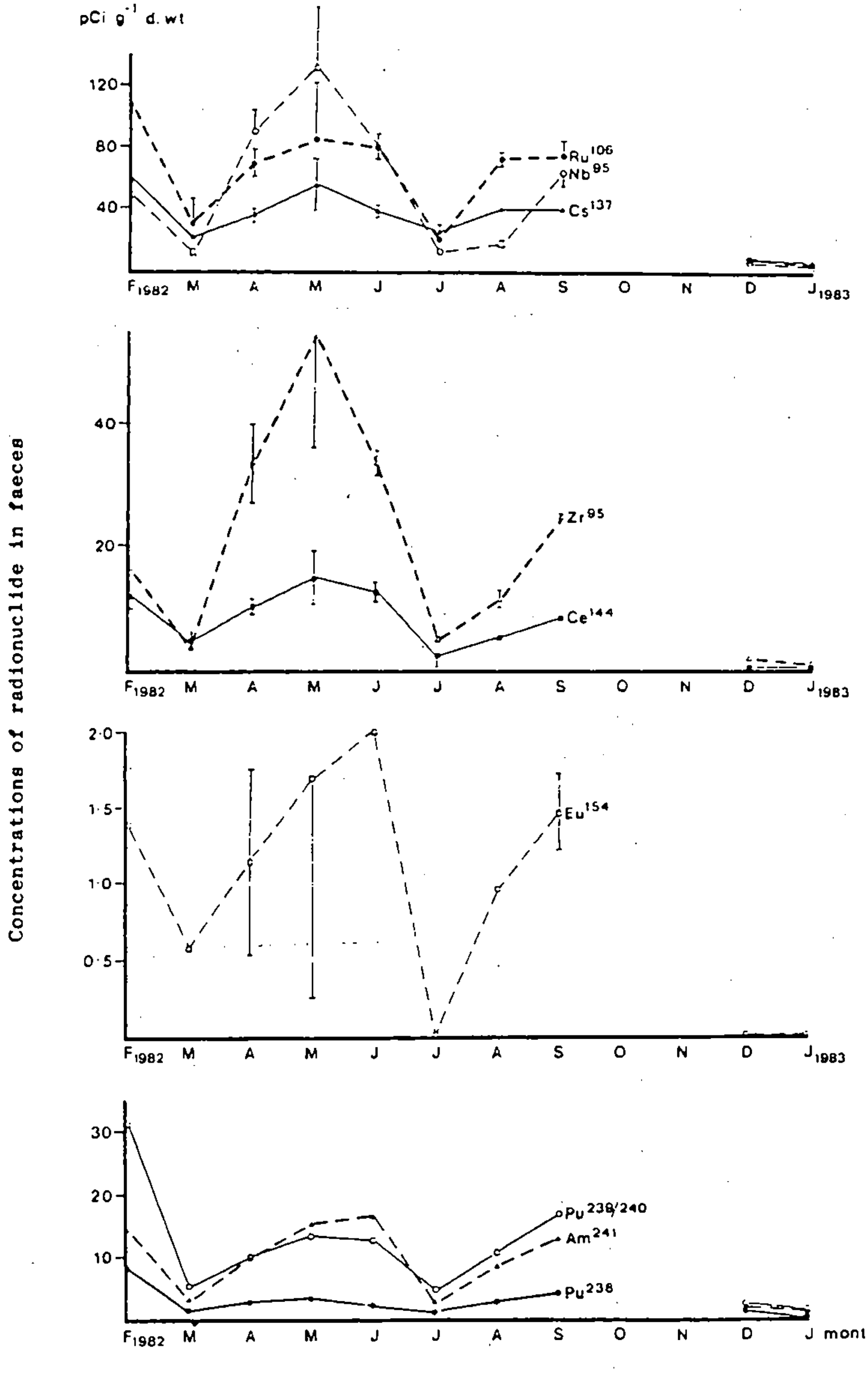

Figure 3.11 Variation in the concentration of various radionuclides in faeces collected from area 1 with time.

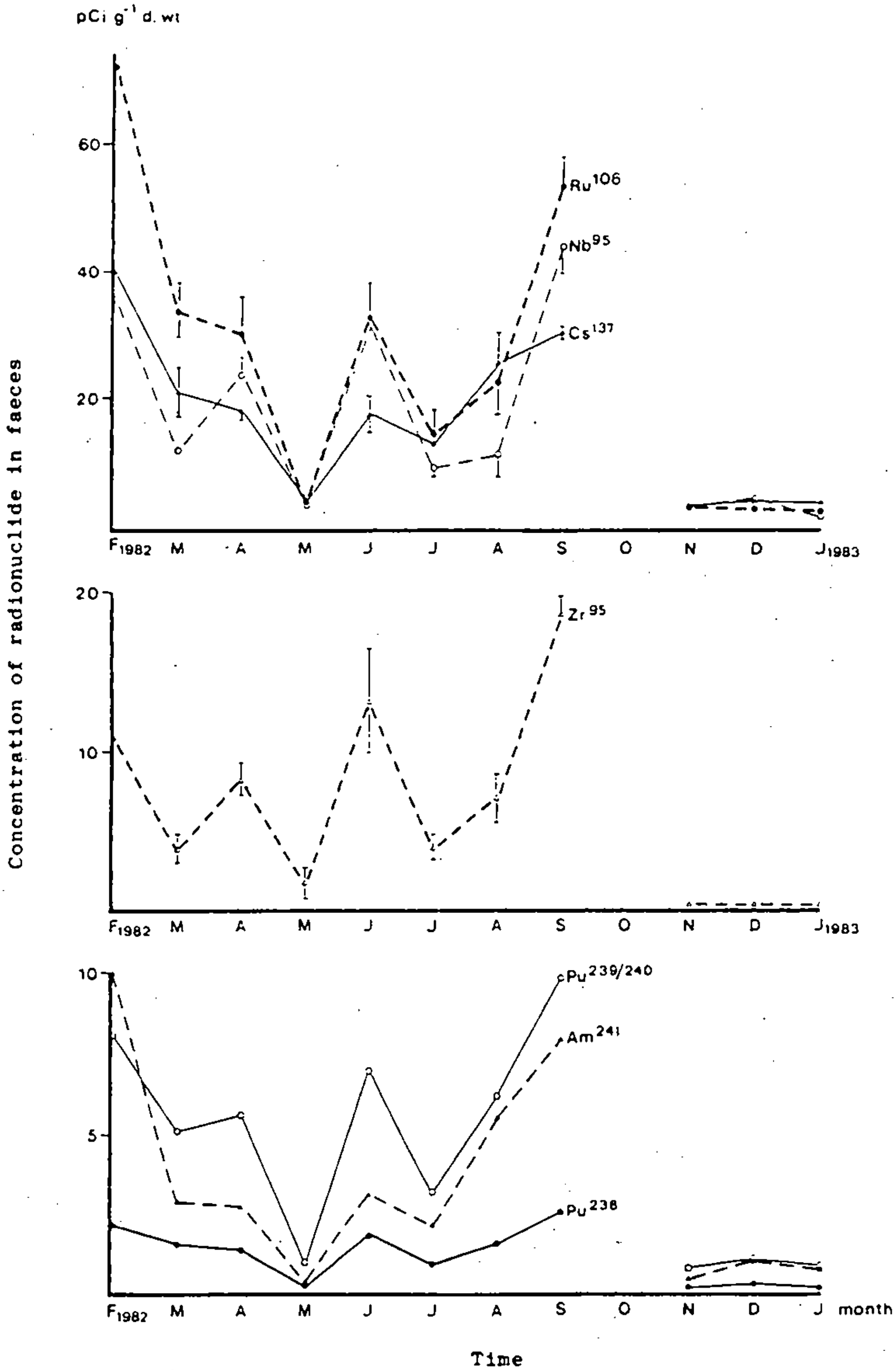

Figure 3.12 Variation in the concentration of various radionuclides in faeces collected from area 2 with time.

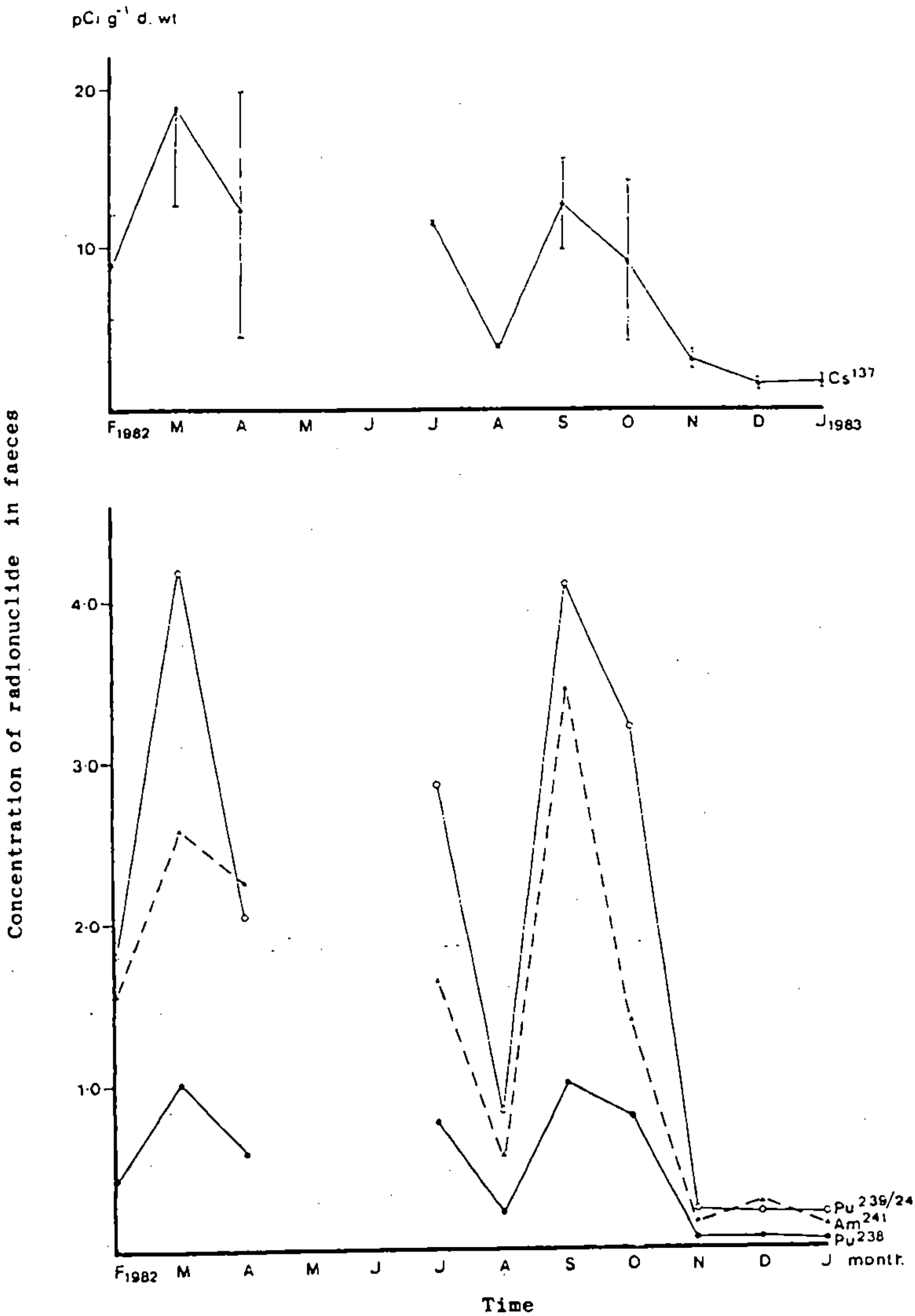

Figure 3.13 Variation in the concentration of various radionuclides in faeces collected from area 3 with time.

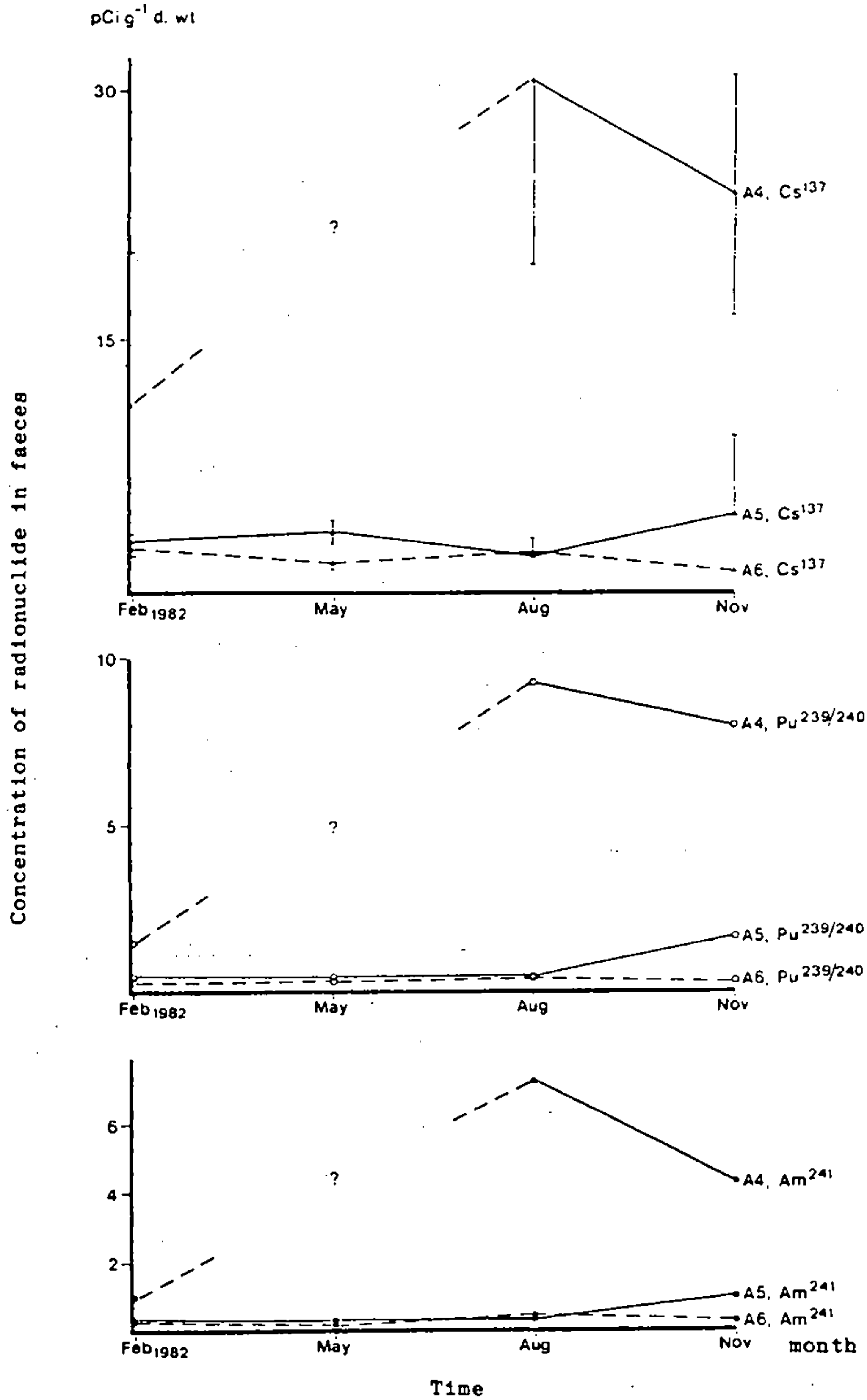

Figure 3.14 Variation in the concentration of various radionuclides in faeces collected from areas 4-6 with time.

$$DI = \frac{\sum_{A1}^{A5} C \times Gd \times G}{N}$$

where

DI = mean daily intake in month (pCi)
A = area
C = mean concentration of the radionuclide in the vegetation for month (pCi g^{-1} dry wt)
Gd = mean number of days spent grazing each area in each month
N = number of days in month
G = daily dry matter intake (g day^{-1}).

The mean daily intakes calculated for each month were highly variable. The data for ^{137}Cs and $^{239/240}Pu$ are presented in Figure 3.15. The daily intake of radionuclides depends upon both the number of days spent grazing an area and the radionuclide concentration in the food. In February 1982 the total radionuclide intake was at its maximum, even though the sheep spent less time on the saltmarsh than in the summer months.

The mean daily intake of ^{137}Cs and $^{239/240}Pu$ has been compared to the mean concentration of these radionuclides in the faeces collected from areas 1-5 in Figure 3.16. The radionuclide concentration in the faeces should, given the relatively low absorption of the radionuclides (Section 3.6), give a good idea of the total radionuclide intake of the sheep. The faeces data appear to corroborate these estimations of daily intake.

$\bar{X} \pm SD.$

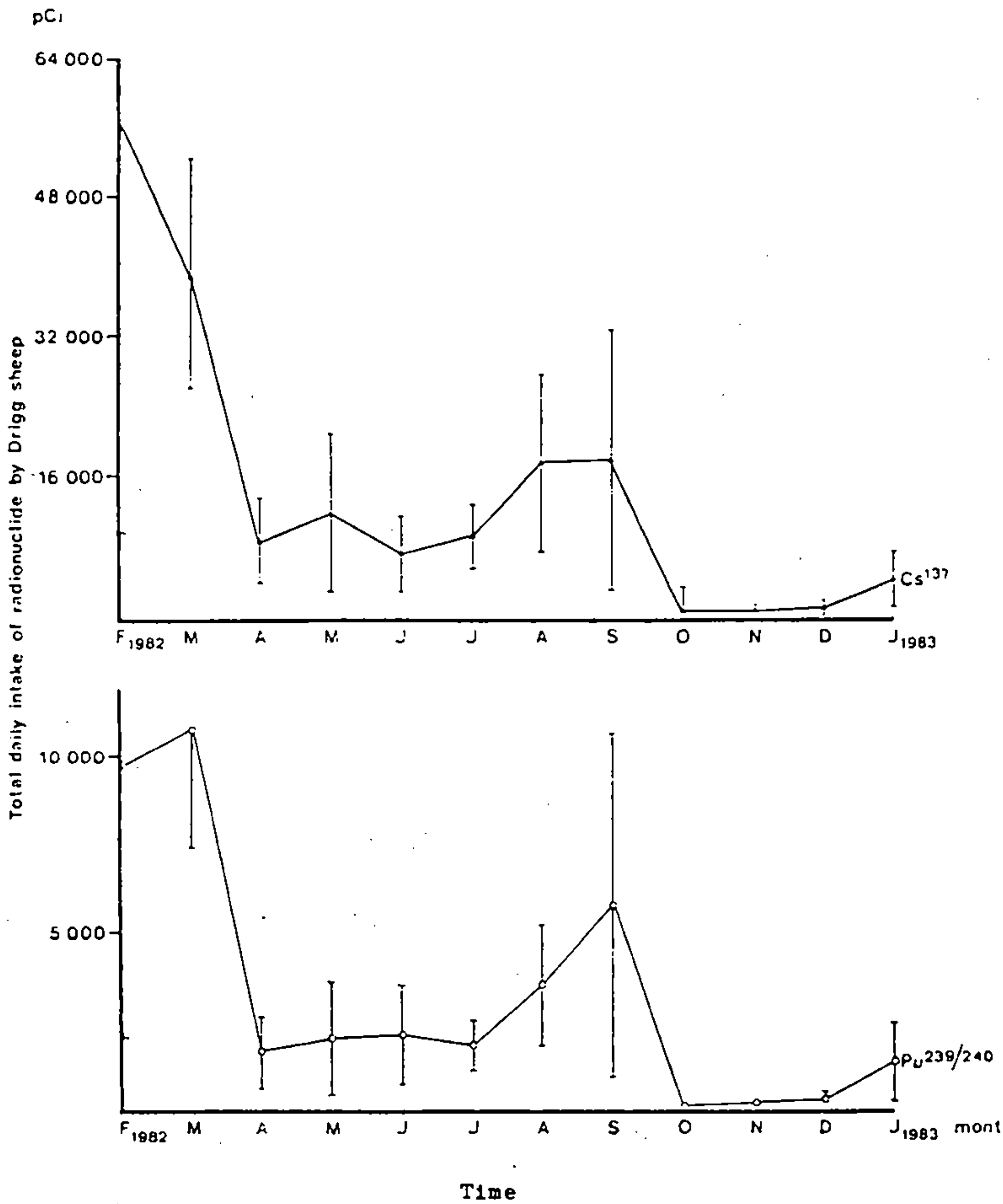

Figure 3.15 Variation in the total daily intake of ^{137}Cs and $^{239/240}Pu$ by sheep with time.

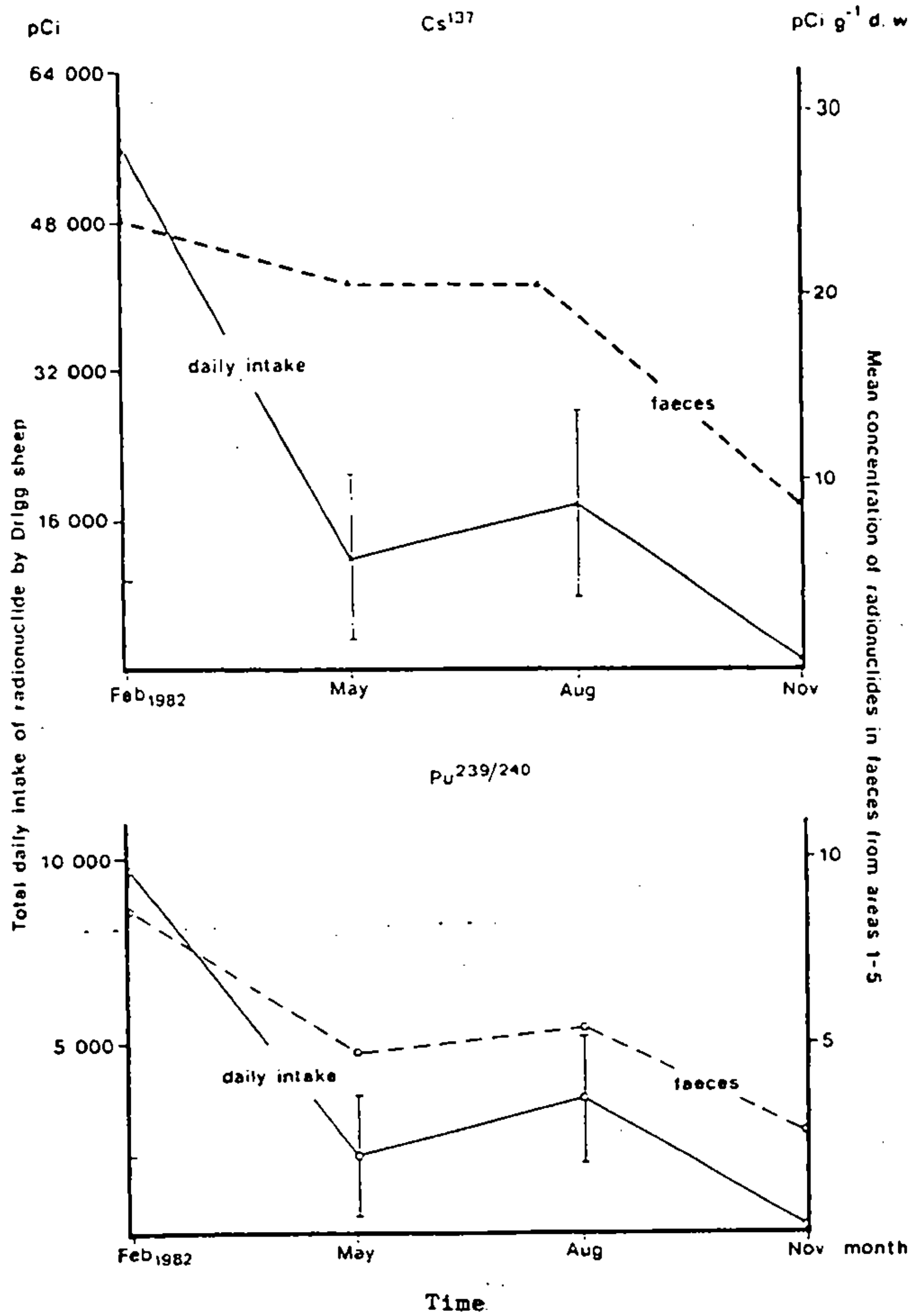

Figure 3.16 Comparison of the total daily radionuclide intake by Drigg sheep with the average concentration of these radionuclides in faeces from areas 1-5.

3.6 The digestibility of saltmarsh vegetation

3.6.1 Introduction

The calculations of daily intake of radionuclides by sheep assume that they consumed 1 kg dry wt of vegetation each day. Estimates of the daily intake of sheep vary widely depending upon the physiological condition of the animal (eg stage of gestation or weaning) and the type of vegetation being grazed (Church 1972). Separate feeding trials were therefore conducted, feeding saltmarsh vegetation to sheep, to obtain an estimate of the dry wt intake. This also allowed a limited investigation of the relationship between the radionuclide concentrations in the vegetation and faeces, as it appeared from the field studies that only a small proportion of the radionuclides was being absorped by the sheep gut.

3.6.2 Materials and methods

Saltmarsh vegetation was collected from the Newbiggin saltmarsh bordering the river Esk (National Grid Reference SD 090940). The vegetation was clipped with shears, cut into small pieces with a Rotocrop compost maker, thoroughly mixed and dried at 105°C.

6 month old black

The feeding trials were conducted at Newton Rigg (Cumbria College
9 of Agriculture). Three ~~c. 1 yr~~ old ~~grey~~-faced sheep were initially fed hay for 7 days to accustom them to individual pens. They were then presented with at least 1 kg dry wt of saltmarsh vegetation each day and adequate water for 18 days. The animals were able to select feed from their troughs, but each new batch of vegetation was mixed with the remainder so that the sheep were not able to discriminate in favour of certain types of vegetation.

The quantity of vegetation consumed each day by each sheep was recorded and the faeces produced each day were collected and weighed. On the last day of the trial the vegetation remaining was also collected to test whether the rejected vegetation was different from that initially presented. The sheep were weighed at the beginning and at the end of the feeding trial.

Five samples of the saltmarsh vegetation, 3 samples of the rejected vegetation and the last 5 samples of faeces produced by each sheep were analysed for gamma-emitting radionuclides, ^{241}Am, ^{238}Pu, $^{239/240}Pu$ and for a range of stable elements.

3.6.3 Results

After penning, one of the sheep (C) was found to have worms; it was treated immediately and recovered before it was fed saltmarsh vegetation. The mean quantity of saltmarsh vegetation consumed by the sheep during the last 10 days of the trial was 0.58 kg with a standard deviation of 0.08. The weights of sheep A, B and C increased during the trial from 31 to 33 kg, 29 to 31 kg and 22 to 26 kg respectively.

The concentration of each constituent in the vegetation and faeces is given in Table 3.7. From a comparison of the concentration of radionuclides in the total vegetation with the rejected vegetation it is evident that the sheep were eating vegetation with lower levels of radionuclides. This is probably because they were selecting vegetation with less silt, which would therefore have had less radioactivity associated with it. Silt might also have fallen off the vegetation as it was removed by the sheep from the trough.

The concentration of all the radionuclides was higher in the faeces than in the vegetation. The apparent digestibility of saltmarsh vegetation was calculated using the formula;

$$\text{Apparent digestibility (\%)} = \frac{\text{faeces produced (kg dry wt day}^{-1})}{\text{vegetation consumed (kg dry wt day}^{-1})} \times 100$$

The apparent digestibility was relatively high (Table 3.8) confirming the high nutritional value of saltmarsh vegetation. In order to assess the absorption of the different radionuclides by the gut of the sheep a null hypothesis was proposed which stated that the nuclides were not being absorbed. If this were true they could be used as tracers to estimate the apparent digestibility of the vegetation. This was calculated from measurements of various constituents using the formula;

$$\text{Apparent digestibility (\%)} = \frac{[\text{constituent}]\ \text{vegetation}}{[\text{constituent}]\ \text{faeces}} \times 100$$

A comparison of the apparent digestibilities calculated in this way with that from the dry wts showed that any gastrointestinal absorption of radionuclides which had occurred was not measurable within the confines of this experiment and was undoubtedly very small. In contrast essential elements such as sodium, potassium (and ^{40}K) and phosphorus were being absorbed by the gut, so that their concentration in the faeces was relatively low.

3.6.4 Discussion

In this limited study, absorption of the radionuclides was too low to measure with the techniques available. The absorption of Pu in hamsters eating food that contained Ravenglass sediments has also been found to be low when compared to that of Pu incorporated in other biological materials (Harrison *et al.* 1981). It is possible that it takes longer for radionuclides in animals grazing on saltmarshes to reach equilibrium than it does for those grazing pastures where the radionuclides are relatively soluble. The fractional gastrointestinal absorption of ^{137}Cs in ruminants is typically about 0.6 (Coughtrey & Thorne 1983). Such a discrepancy between the availability of radionuclides from different sources emphasizes the importance of considering the biological availability of radionuclides when applying transfer coefficients derived from separate experiments.

The daily intake of the c. one year old sheep was 0.58 kg dry wt. Therefore the estimated daily intake figure of 1 kg dry wt, used in this study for mature ewes, seems reasonable considering that lamb-producing ewes should be consuming relatively more vegetation (Church 1972).

Table 3.7. The concentration of various constituents in the vegetation and faeces of the 3 sheep.

(1) Radionuclides

			Concentration (Mean ± SE) ($pCi\ g^{-1}$ dry wt)		
			Faeces		
Constituent	Vegetation	Rejected Vegetation	Sheep A	Sheep B	Sheep C
^{241}Am	20.10 ± 2.26	54.93 ± 1.56	34.70 ± 3.51	36.30 ± 3.78	36.74 ± 3.82
^{144}Ce	12.25 ± 1.19	32.93 ± 0.68	20.00 ± 1.77	20.96 ± 1.69	21.36 ± 1.46
^{60}Co	0.85 ± 0.09	2.12 ± 0.10	1.33 ± 0.11	1.24 ± 0.17	1.40 ± 0.09
^{134}Cs	8.26 ± 0.43	17.70 ± 0.38	13.42 ± 0.98	11.20 ± 2.89	11.23 ± 2.92
^{137}Cs	191.80 ± 10.74	402.67 ± 10.91	292.80 ± 21.25	307.60 ± 18.79	307.80 ± 20.10
^{154}Eu	2.52 ± 0.32	7.20 ± 0.26	4.21 ± 0.40	4.45 ± 0.34	4.50 ± 0.33
^{155}Eu	1.79 ± 0.45	5.13 ± 0.09	3.43 ± 0.33	3.56 ± 0.31	3.63 ± 0.35
^{40}K	10.42 ± 0.40	11.83 ± 0.27	11.26 ± 0.86	11.19 ± 0.62	11.02 ± 0.27
^{95}Nb	43.90 ± 2.78	116.45 ± 3.95	68.20 ± 3.52	72.64 ± 5.12	77.44 ± 7.89
^{106}Ru	101.68 ± 6.03	265.00 ± 7.23	165.40 ± 13.15	217.20 ± 44.90	215.40 ± 36.49
^{125}Sb	1.38 ± 0.42	5.82 ± 0.19	3.28 ± 0.27	2.64 ± 0.64	2.79 ± 0.68
^{95}Zr	12.74 ± 0.64	30.99 ± 0.85	21.26 ± 1.56	22.22 ± 1.48	22.88 ± 1.50

Table 3.7 (contd).

(2) Other constituents

Constituent	Vegetation	Rejected Vegetation	Concentration (Mean ± SE) ($pCi\ g^{-1}$ dry wt) Faeces Sheep A	Sheep B	Sheep C
Ash	27.00 ± 1.79	58.30 ± 1.45	35.40 ± 1.69	36.40 ± 1.69	35.00 ± 1.09
Fibre	15.50 ± 0.87	12.00 ± 0.81	27.40 ± 3.47	24.00 ± 3.05	21.20 ± 2.13
Na	4.26 ± 0.14	2.83 ± 0.18	3.02 ± 0.22	3.42 ± 0.58	2.18 ± 0.38
K	1.44 ± 0.02	1.27 ± 0.09	1.44 ± 0.05	1.72 ± 0.32	1.38 ± 0.06
Ca	0.64 ± 0.04	1.37 ± 0.14	1.09 ± 0.05	1.30 ± 0.21	1.12 ± 0.04
Mg	0.67 ± 0.02	0.80 ± 0.06	0.96 ± 0.02	1.13 ± 0.17	0.95 ± 0.05
Mn	0.03 ± 0.003	0.07 ± 0.01	0.04 ± 0.001	0.05 ± 0.01	0.05 ± 0.002
P	0.26 ± 0.01	0.20 ± 0.01	0.15 ± 0.005	0.20 ± 0.04	0.21 ± 0.04
Ti ($\mu g\ g^{-1}$ dry wt)	684 ± 127.46	2133.33 ± 88.19	1104.00 ± 67.42	1180.00 ± 58.31	1220.00 ± 66.33

Table 3.8 Apparent digestibility of saltmarsh vegetation calculated from different factors including the dry wt of the vegetation and faeces and the concentration of various constituents.

Factor	Apparent digestibility (%) (Mean ± SD)
Dry wt	38.1 ± 8.1
Ash	24.2 ± 12.0
Fibre	35.9 ± 12.3
*Na	-48.3 ± 30.1
*K	4.8 ± 15.9
Ca	45.3 ± 11.4
Mg	33.9 ± 9.3
Mn	46.0 ± 15.6
Ti	44.4 ± 24.7
*P	-39.3 ± 35.8
^{241}Am	44.0 ± 15.9
^{144}Ce	41.0 ± 14.2
^{60}Co	35.8 ± 17.2
^{134}Cs	30.1 ± 19.9
^{137}Cs	36.6 ± 9.6
^{154}Eu	42.5 ± 16.8
^{155}Eu	49.4 ± 28.9
* ^{40}K	6.6 ± 10.5
^{95}Nb	39.7 ± 10.6
^{106}Ru	49.0 ± 13.2
^{125}Sb	52.5 ± 34.8
^{95}Zr	42.4 ± 8.2

*absorbed in the gut

3.7 Radionuclide levels in sheep tissues

3.7.1 Introduction

Sheep from the saltmarsh were sampled at different times during the study year. The emphasis was placed on analysis of replicate samples rather than of individual sheep at regular intervals, because few studies have considered the possible variation in the radionuclide content between tissues from free ranging animals. Initially one ewe, (Ewe 1) which had died accidentally, was analysed in detail in order to identify the most important and/or representative tissues. Subsequently, selected tissues from a ewe and a lamb one month after lambing in May 1982 and from 3 ewes with 3 lambs were analysed in September 1982, at the time when the lambs were sent to market. Draft ewes were brought from Swaledale in the Yorkshire dales (National Grid Reference SD 982004) for restocking the flock in the study area. Tissues from such a ewe were also analysed for comparison with the Drigg sheep.

3.7.2 Materials and methods

The majority of the tissues of Ewe one were analysed (Table 3.9) with the notable exceptions of the pancreas, thyroid, eyes, lymph nodes, rumen and reproductive organs. The skeleton was divided into 9 samples (Table 3.9). Most of the muscles were dissected into samples associated with the major limbs or bones of the body. The tissues which were normally in contact with the environment were repeatedly washed in a detergent followed by distilled water before analysis. Five tissues were taken from all the other sheep (Lamb 1-4, Ewes 2-5) for analysis. These were muscle (hind leg), bone (hind leg), liver, lung and kidney. The sheep were slaughtered at the farm and stored in a cold store (4°C) briefly before dissection. The tissues were weighed both fresh and after drying at 105°C (for analytical details see section 6.2.2). They were analysed, as ash samples, for gamma-emitting radionuclides in petri-dishes (50 x 10 mm) for 175 000 seconds and for ^{238}Pu, $^{239/240}$Pu and ^{241}Am using chemical separation and alpha spectrometry.

3.7.2 Results

a. Ewe 1

The results of the analyses of ^{137}Cs, ^{238}Pu, $^{239/240}$Pu and ^{241}Am in Ewe 1 are presented in Table 3.10. A boxplot univariate analysis (McNeil 1977) of the bone and muscle data was carried out to try to identify outlying values which would not be suitable for use as standard references for routine analysis of sheep tissues. There were no outliers for any of the radionuclides in the bone samples, suggesting that the data were homogeneous and that any easily dissected set of bones such as those of the hind legs could be used. In the muscle samples the concentration of the transuranics in the body wall muscle were outliers, suggesting that the sample had been contaminated by silt during dissection. The muscle and bone selected for routine analyses were taken from the hind leg.

Table 3.9 The tissues dissected from Drigg Ewe 1.

BONES

Front leg (including humerus, radius, ulna, carpus and metacarpus)
Hind leg (including femur, patella, fibia, fibula, tarsus and metatarsus)
Phalanges
Pectoral girdle
Pelvic girdle
Ribs
Skull
Vertebrae (neck and back)
Tail vertebrae

MUSCLES

Back
Bodywall
Cardiac
Diaphragm
Leg (left fore)
Leg (right fore)
Leg (left hind)
Leg (right hind)
Neck
Rib
Shoulder
Skull
Tongue

OTHER INTERNAL TISSUES

Adipose
Brain
Kidney
Liver
Lung
Spleen

'EXTERNAL' TISSUES

Horn
Fleece (washed with 10% vol/vol Decon 90)
Fleece (unwashed)
Skin
Small intestine
Caecum
Colon

Table 3.10 The concentration of certain radionuclides in the tissues of Ewe 1. (pCi g^{-1} dry wt)

Tissue		Radionuclide ^{137}Cs	^{238}Pu	$^{239/240}Pu$	^{241}Am
BONE					
Front leg		0.07	n d	0.012	0.052
Hind leg		0.06	n d	0.010	0.086
Phalanges		0.05	0.004	0.034	0.060
Pectoral girdle		0.03	0.006	0.018	0.046
Pelvic girdle		0.04	n d	0.016	n d
Ribs		0.08	0.008	0.032	0.049
Skull		0.05	n d	0.013	0.070
Vertebrae		0.06	n d	0.029	0.073
Tail vertebrae		0.03	n d	0.026	0.061
	mean	0.05	0.006	0.021	0.062
	CV	40.00	50.00	42.86	22.58
MUSCLE					
Back		1.86	0.007	0.027	0.012
Bodywall		1.27	0.016	0.062	0.057
Cardiac		0.82	0.009	0.026	0.019
Diaphragm		0.85	n d	n d	0.031
Leg (left fore)		2.44	0.006	0.032	0.020
Leg (right fore)		2.59	0.008	0.036	0.021
Leg (left hind)		2.01	0.006	0.028	n d
Leg (right hind)		3.54	0.003	0.010	0.007
Neck		1.52	0.008	0.035	n d
Rib		1.35	0.004	0.016	0.015
Shoulder		0.92	n d	n d	n d
Skull		1.34	0.011	0.041	0.036
Tongue		0.76	0.003	0.011	0.014
	mean	1.64	0.007	0.029	0.023
	CV	50.61	57.14	51.72	65.22
OTHER INTERNAL TISSUES					
Adipose		0.36	0.010	0.043	0.027
Brain		2.25	0.002	0.010	0.037
Kidney		5.50	n d	0.017	0.045
Liver		1.59	0.555	2.191	0.940
Lung		3.81	0.045	0.174	0.095
Spleen		1.10	n d	0.029	0.028
'EXTERNAL' TISSUES					
Horn		0.34	0.027	0.124	0.110
Fleece (washed)		0.41	0.040	0.150	0.060
Fleece (unwashed)		20.53	0.861	3.684	n d
Skin		0.25	0.013	0.058	0.030
Small intestine		4.13	0.393	1.578	n d
Caecum		1.63	0.121	0.465	0.361
Colon		2.13	0.060	0.235	0.156

nd not detected

Other gamma-emitting radionuclides were identified in the liver of ewe 1 were ^{60}Co (0.026 pCi g^{-1} dry wt), ^{106}Ru (0.255 pCi g^{-1} dry wt) and ^{125}Sb (0.06 pCi g^{-1} dry wt).

b. Ewes 2-5, Lambs 1-4

The results of the analyses of ^{137}Cs, ^{238}Pu, $^{239/240}Pu$ and ^{241}Am of tissues from the saltmarsh sheep sampled during the study year and the control ewe (Ewe 6) are presented in Table 3.11. The results are expressed on a dry wt basis; they are also presented as Bg kg^{-1} fresh wt in Appendix 14, to allow comparisons with other studies using these units. In most cases the concentration of radionuclides in the tissue of animals from the study area was at least one order of magnitude higher than those of the control ewe. The main exceptions were the transuranics in the kidney, for instance the level of $^{239/240}Pu$ in the kidney of the control animal was similar to those of ewes on the saltmarsh (2-5). The non-parametric Mann-Whitley-u-test was used to compare the different radionuclide levels in the lambs and ewes slaughtered in September. The ^{137}Cs levels in the lambs were higher than those in the ewes, though not significantly at $p<0.05$ ($p>0.10$). Although a significant difference was not detected it is likely that if the sample size was increased from 3 to 5 then a significant difference would be detected.

Certain other radionuclides were identified in the tissues analysed; ^{134}Cs and ^{60}Co were the most frequently quantified. The concentration of these 2 radionuclides in certain tissues, together with data for ^{95}Nb and ^{106}Ru are presented in Table 3.12.

3.7.4 Discussion

Tissues of the sheep accumulated different radionuclides disproportionately. A range of tissues therefore had to be analysed in order to assess the radionuclide levels in the sheep. Each radionuclide will be considered in turn:

a. ^{137}Caesium

^{137}Cs was distributed relatively uniformly throughout most of the soft tissues of the sheep. This is consistent with the metabolic model adopted by the ICRP (1979) and with previously published data (Coughtrey & Thorne 1983), though sometimes ^{137}Cs can be concentrated in skeletal muscle (Hakonson & Whicker 1971). However, there were some tissues with consistently higher or lower ^{137}Cs concentrations than the majority of soft tissues; (Tables 3.10, 3.11).

1. Kidney

The level of ^{137}Cs in the kidneys of the Drigg sheep was approximately double that of the majority of the soft tissues (Table 3.11). Similar data have been obtained by Popplewell *et al.* (1981) from analyses of the tissues of a sheep that grazed pasture 2 km's east of Sellafield. There is also evidence of slightly higher concentrations of ^{137}Cs in the kidneys of experimentally exposed sheep (Hood & Comar 1953, McLellan *et al.* 1961).

Table 3.11 The concentration of certain radionuclides in selected tissues of Drigg sheep and of a control sheep (pCi g^{-1} dry wt)

A. ^{137}Caesium

SHEEP	*Liver	*Lung	Tissue *Kidney	*Muscle	*Bone
i) May 1982					
Lamb 1	5.64	4.97	11.70	3.68	0.46
Ewe 2	4.44	3.66	5.32	3.08	0.07
ii) September 1982					
Lamb 2	7.94	7.14	17.33	9.17	0.30
Lamb 3	9.37	8.82	23.16	5.54	0.27
Lamb 4	8.32	6.43	20.79	7.53	0.08
mean	8.54	7.46	20.43	7.41	0.22
SE	0.43	0.71	2.61	1.05	0.07
Ewe 3	2.24	3.56	7.88	4.41	0.05
Ewe 4	3.95	3.85	9.78	4.52	0.08
Ewe 5	5.40	3.86	12.72	4.24	0.04
mean	3.86	3.76	10.13	4.39	0.06
SE	0.91	0.10	1.41	0.08	0.01
Ewe 6 (Control)	0.13	0.71	0.26	0.21	<0.01

* ^{137}Cs concentration of September lambs is significantly different from September ewes ($p < 0.1$) using the Mann-Whitney test.

Table 3.11 (continued)

B. ^{238}Plutonium

SHEEP	Liver	Lung	Tissue Kidney	Muscle	Bone
i) May 1982					
Lamb 1	0.024	0.002	0.007	0.003	0.004
Ewe 2	0.066	0.005	0.010	0.001	0.005
ii) September 1982					
Lamb 2	0.036	0.008	0.010	0.002	0.006
Lamb 3	0.029	0.001	0.021	0.002	0.001
Lamb 4	0.017	0.001	0.003	0.001	0.004
mean	0.027	0.003	0.011	0.002	0.004
SE	0.006	0.002	0.005	0.001	0.002
Ewe 3	0.046	0.003	0.011	0.001	0.003
Ewe 4	0.089	0.001	n d	0.002	0.002
Ewe 5	0.018	0.001	0.002	0.003	0.004
mean	0.051	0.002	0.006	0.002	0.003
SE	0.021	0.001	0.004	0.001	0.001
Ewe 6 (Control)	0.001	<0.001	0.002	<0.001	<0.001

n d not detected

Table 3.11 (continued)

C. $^{239/240}$Plutonium

SHEEP

	Liver	Lungs	Tissue Kidney	Muscle	Bone
i) May 1982					
Lamb 1	0.104	0.010	0.039	0.012	0.012
Ewe 2	0.193	0.002	0.021	0.004	0.019
ii) September 1982					
Lamb 2	0.099	0.029	0.039	0.004	0.026
Lamb 3	0.104	0.007	0.062	0.006	0.005
Lamb 4	0.066	0.007	0.017	0.003	0.014
mean	0.090	0.015	0.039	0.004	0.015
SE	0.012	0.008	0.013	0.001	0.006
Ewe 3	0.189	0.013	0.020	0.003	0.010
Ewe 4	0.356	0.017	0.010	0.006	0.007
Ewe 5	0.069	0.003	0.008	0.006	0.013
mean	0.205	0.011	0.013	0.005	0.010
SE	0.083	0.004	0.003	0.001	0.002
Ewe 6 (Control)	0.002	0.001	0.012	0.001	<0.001

Table 3.11 (continued)

D. ^{241}Americium

SHEEP	Liver	Lungs	Tissue Kidney	Muscle	Bone
i) May 1982					
Lamb 1	0.016	0.004	0.014	0.004	0.010
Ewe 2	0.063	0.018	0.026	0.003	0.053
ii) September 1982					
Lamb 2	0.031	0.020	0.011	0.006	0.022
Lamb 3	0.021	0.014	0.052	0.008	0.011
Lamb 4	0.031	0.005	0.020	0.003	0.017
mean	0.028	0.013	0.028	0.006	0.017
SE	0.003	0.005	0.012	0.002	0.003
Ewe 3	0.076	0.017	0.076	0.006	0.033
Ewe 4	0.142	0.023	0.029	0.008	0.040
Ewe 5	0.064	0.006	0.013	0.006	0.040
mean	0.094	0.015	0.039	0.007	0.038
SE	0.024	0.007	0.019	0.001	0.002
Ewe 6 (Control)	0.001	0.001	0.024	0.001	0.006

Table 3.12 The concentration of certain radionuclides in selected tissues of Drigg sheep*. (pCi g^{-1} dry wt)

A. **^{134}Caesium

SHEEP	Liver	Lung	Tissue Kidney	Muscle
i) May 1982				
Lamb 1	0.20	0.15	0.41	0.14
Ewe 2	0.35	0.14	0.20	0.12
ii) September 1982				
Lamb 2	0.35	0.31	0.84	0.34
Lamb 3	0.43	0.40	1.17	0.20
Lamb 4	0.37	0.30	0.84	0.30
mean	0.38	0.34	0.95	0.28
SE	0.02	0.03	0.11	0.04
Ewe 3	0.07	0.11	0.24	0.14
Ewe 4	0.16	0.16	0.46	0.16
Ewe 5	0.24	0.17	0.59	0.11
mean	0.16	0.15	0.43	0.14
SE	0.05	0.02	0.10	0.02

* these radionuclides were not detected in the control ewe 6

** ^{134}Cs was not detected in the bone

Table 3.12 (continued)

B. *^{60}Cobalt

SHEEP	Tissue	
	Liver	Kidney
i) May 1982		
Lamb 1	0.09	n d
Ewe 2	0.74	0.02
ii September 1982		
Lamb 2	0.06	0.04
Lamb 3	0.07	0.09
Lamb 4	0.07	0.05
mean	0.07	0.06
SE	0.01	0.02
Ewe 3	0.02	0.06
Ewe 4	0.07	0.07
Ewe 5	0.05	0.05
mean	0.05	0.06
SE	0.02	0.01

* ^{60}Co was not detected in the lung, muscle or bone of Drigg sheep.

n d not detected

Table 3.12 (continued)

C. ^{95}Niobium

SHEEP	Tissue		
	Liver	Kidney	Bone
i) May 1982			
Lamb 1	n d	n d	0.34
Ewe 2	n d	0.09	n d
ii) September 1982			
Lamb 2	n d	0.22	n d
Lamb 3	n d	0.14	n d
Lamb 4	n d	n d	n d
Ewe 3	n d	n d	n d
Ewe 4	n d	0.11	n d
Ewe 5	0.05	n d	n d

n d not detected

Table 3.12 (continued)

D. *^{106}Ruthenium

SHEEP	Tissue	
	Liver	Kidney
ii) September 1982		
Lamb 2	n d	0.95
Lamb 3	n d	1.70
Lamb 4	n d	1.41
mean		1.35
SE		0.22
Ewe 3	0.09	0.32
Ewe 4	n d	n d
Ewe 5	n d	n d

* ^{106}Ru was not detected in the May sheep

n d not detected

It is not clear whether the affinity of the kidney for ^{137}Cs is associated with its loss in the urine, or whether there is cellular localization of ^{137}Cs in the kidney.

2. Bone

The concentration of ^{137}Cs in bone was lower than that of the soft tissues. The data are consistent with other studies on the distribution of ^{137}Cs and ^{134}Cs eg sheep (McLellan *et al.* 1961) pigs (Nikitina *et al.* 1972) cattle (Sirotkin *et al.* 1972) and deer (Hakonson & Whicker 1971).

3. Adipose tissue

The concentration of ^{137}Cs in the adipose tissue was lower than that of the other soft tissues. Similar results have been obtained in experimentally exposed sheep (McLellan *et al.* 1961) and dogs (Boecker *et al.* 1969).

When the relative mass of the different tissues of the sheep is taken into account it is evident that the muscle contains the major proportion of ^{137}Cs. It is generally assumed that of the ^{137}Cs entering the systemic circulation 70% is deposited in muscle and 30% is distributed throughout all other organs and tissues of the body (Coughtrey & Thorne 1983).

b. Transuranic radionuclides

A majority of the body burden of ^{238}Pu, $^{239/240}Pu$ and ^{241}Am was associated with "external" tissues of the sheep. Because of the relatively low absorption of the transuranics in the gut of many animals (Harrison 1982) their concentration in tissues in contact with the environment is often far greater than that of internal tissues (Hakonson & Nyham 1980).

The principal tissues accumulating transuranic elements in the sheep were the liver and skeleton, which is consistent with the metabolic model of the ICRP (1979). The concentration of ^{238}Pu, $^{239/240}Pu$ and ^{241}Am were higher in the lung (possibly due to inhalation)and kidney than in the muscle, but the overall proportion of the body burden of these transuranics in these organs is relatively small, compared to the liver and skeleton. In sheep injected with ^{239}Pu citrate Buldakov *et al.* (1969) found that the majority of the ^{239}Pu recovered was found in the skeleton and liver with less than 5% in the spleen, lungs and kidney.

c. ^{60}Cobalt

^{60}Co was accumulated in both the liver and kidney of the Drigg sheep (Table 3.12B) both of which have previously been shown to accumulate stable cobalt (Underwood 1977). It has been suggested that the skeleton is the largest reservoir for long-term retention of cobalt (Hollins & McCullough 1971), however, recently the liver have been shown to accumulate cobalt in rats (Thomas *et al.* 1976) and pronghorn (Markham *et al.* 1982).

d. ^{95}Niobium

^{95}Nb was occasionally recorded in the bone and kidney and once in the liver of Drigg sheep (Table 3.12E). ^{95}Nb is usually assumed to accumulate primarily in the bone, with some accumulation in the kidney, spleen and testis (ICRP 1979).

e. ^{106}Ruthenium

^{106}Ru was found in the kidneys of the September lambs and in the liver of one of the September ewes (Table 3.12D). This is consistent with the studies of Furchner *et al.* (1971) who showed that ^{106}Ru concentrates appreciably in the kidneys of rats.

The limited analyses possible in May of just one ewe (2) and one lamb (1) obviously restrict comparisons of these data with those of the September sheep. However, it appears that there is little difference in the radionuclide concentration in the analyzed tissues of the May and September ewes. The concentration of radionuclides in the suckling lamb 1 was generally lower than that of the September lambs, although there were exceptions, eg ^{137}Cs in bone and $^{239/240}$Pu in liver.

In September levels of ^{137}Cs in the tissues were higher in lambs than in ewes. In sheep, which rely totally on intestinal absorption to obtain passive immunity (Harrison 1982) this effect might be expected as higher values for the absorption of radionuclides have often been obtained in young animals (Mraz & Eisele 1977, Harrison 1982). However, Longhurst *et al.* (1967) have shown that in sheep maintained on range land, the concentration of ^{137}Cs in the muscle increases progressively with age. Similarily analyses of tissues from sheep that had grazed inland pasture near Sellafield found that the ^{137}Cs concentration was higher in a ewe than in a 6 month old lamb (Sumerling pers. comm.). It seems therefore that the higher concentration of ^{137}Cs in the lambs relative to the ewes on the saltmarshes at Drigg contradicts these findings. However, Sumerling (1981) also found that young animals grazing saltmarshes had higher levels of ^{137}Cs than mature animals. Using an external gamma counter he found that 3 yearling calves all showed clear evidence for the presence of ^{137}Cs, whereas 2 adult cows, that had grazed alongside them did not. It seems therefore that the binding of ^{137}Cs to silt particles in the Ravenglass estuary alters the relative availability of ^{137}Cs to young and mature animals. This demonstrates the importance of specifying the source of radionuclides and their chemical form when calculating transfer parameters.

The level of ^{238}Pu, $^{239/240}$Pu and ^{241}Am in the ewes was generally greater than that of the lambs, but considering that the ewes had been grazing on the area for at least 6 times as long as the lambs the difference in the transuranic accumulation by the tissues is rather small. (Tables 3.11B, C and D). The mean ^{238}Pu and $^{239/240}$Pu concentration of the kidney in the September lambs was greater than that of the September ewes.

The only published data which can be directly compared to the analyses of the Drigg sheep are those of Popplewell *et al.* (1981); they analysed selected tissues of one ewe that had grazed pasture near Windscale and another ewe from the Ravenglass estuary. The Windscale ewe had higher concentrations of ^{137}Cs in both the liver and muscle than the Ravenglass ewe, but the $^{238/239/240}Pu$ concentration of the Ravenglass ewe was greater. The Drigg sheep analyses have been compared to those of the Windscale and Ravenglass ewes in Table 3.13.

The calculated percentages of the annual limits for intake of the various radionuclides for individual members of the public are presented in Table 3.14. These would be attained by eating the tissues of Drigg sheep at the average consumption rate for the United Kingdom, ie 6.5 kg y^{-1} of sheep meat and 1.7 kg y^{-1} of sheep offal; assumed to be liver or kidney (Popplewell *et al.* 1981). The calculations are based on the annual limits for intakes of radionuclides by workers (ICRP 1979) which have been divided by 10 to conform to the limits set for members of the public.

3.8 Comparisons between the radionuclide levels in the sheep and the vegetation

3.8.1 Introduction

Radiological assessments of the dose to man from radionuclides released to the environment are generally made using mathematical models. These require input parameters such as transfer coefficients in order to determine the concentrations of radionuclides in foodstuffs. Estimates of parameters such as transfer coefficients and concentration ratios are often dependent upon site-specific variables such as soil and crop types (Ng *et al.* 1979), the physical and chemical form of the radionuclide (Harrison 1982) and the stable element content of the diet. This study has attempted to estimate such parameters for the ingestion of radionuclides by the Drigg sheep, although it is recognized that some intake of radionuclides will also occur via inhalation and grooming.

3.8.2 Transfer coefficients

The coefficient of transfer is usually defined as the quotient.

$$\text{*transfer coefficient} = \frac{\text{Concentration of radionuclide in tissue (fresh weight)}}{\text{Daily intake of radionuclide}}$$

*The expression that has been used to estimate the variability of this factor has been included in appendix 15.

This assumes that the levels of the radionuclide are in equilibrium. Because ^{137}Cs is generally assumed to have a relatively short biological half-life (Coughtrey & Thorne 1982) the ^{137}Cs levels in the Drigg sheep might be expected to have reached an equilibrium.

Transfer coefficients for ^{137}Cs have been calculated for both ewes and lambs from Drigg. The mean daily intakes of ^{137}Cs calculated for each month were highly variable (see Section 3.5.4). It therefore seems inappropriate to calculate transfer coefficients for each month

Table 3.13 Comparison of the concentrations of radionuclides in sheep from Drigg, Windscale and Ravenglass. (Bq kg^{-1} fresh wt.)

A. ^{137}Caesium

SHEEP	Tissue		
	Liver	Muscle	Kidney
*Drigg	37.2	42.2	97.2
ϕRavenglass	5.6	7.8	N D
ϕWindscale	10.4	13.8	19.9

B. $^{238/239/240}$Plutonium

*Drigg	2.463	0.183	0.067
ϕRavenglass	11.500	0.053	N D
ϕWindscale	0.100	0.002	0.005

C. ^{241}Americium

*Drigg	0.904	0.067	0.375
ϕRavenglass	6.600	0.130	N D
ϕWindscale	N D	N D	N D

ϕ from Popplewell *et al.* (1981)

* mean of the September ewes

N D not determined

Table 3.14 Percentages of the annual limits for intakes (ALI) of selected radionuclides by a member of the public due to eating tissues from Drigg sheep.

Radionuclide	Percentage of Annual limits of intake					
	LAMBS (September)			EWES (September)		
	Muscle	Liver	Kidney	Muscle	Liver	Kidney
^{137}Cs	1.2×10^{-1}	3.5×10^{-2}	8.4×10^{-2}	6.8×10^{-2}	1.6×10^{-2}	4.1×10^{-2}
*^{238}Pu	4.1×10^{-4}	1.5×10^{-3}	6.0×10^{-4}	4.1×10^{-4}	2.8×10^{-3}	3.3×10^{-4}
*$^{239/240}Pu$	1.2×10^{-3}	7.4×10^{-3}	3.2×10^{-3}	1.6×10^{-3}	1.7×10^{-2}	1.1×10^{-3}
^{241}Am	7.5×10^{-3}	9.1×10^{-3}	9.1×10^{-3}	8.7×10^{-3}	3.1×10^{-2}	1.3×10^{-2}

*Plutonium was assumed to be in its most transportable form with respect to absorption via the gut.

using the sheep tissue determinations for September 1982 alone. The transfer coefficients have therefore been calculated using only the August mean daily intake value because it is probably most relevant in view of the short biological half-life of ^{137}Cs. Transfer coefficients for each tissue examined in the ewes and lambs are presented in Table 3.15. They are higher for the lambs than for the ewes because of the higher concentration of ^{137}Cs in the tissues of the younger animals. The transfer coefficient for lamb muscle, at 1.1×10^{-1} day kg^{-1} is very similar to the value of 1.2×10^{-1} day kg^{-1} derived by Ng *et al.* (1979). Transfer coefficients for the lambs have also been calculated assuming a daily intake of 0.6 kg dry wt of vegetation rather than 1 kg dry wt (Table 3.15) because this seems to be a more realistic estimate of the daily intake of saltmarsh vegetation by young animals (section 3.6.4). In this case the transfer coefficient for lamb muscle is 1.8×10^{-1} day kg^{-1}. Transfer coefficients have also been calculated for the ewes using a mean daily intake value calculated for the intake of a full year, rather than just one month (Table 3.16).

The variability in the ^{137}Cs concentration in the sheep tissues was relatively small when compared with the estimated daily intake, hence variation in daily intake dominated calculations of the transfer coefficient. This emphasizes the need for accurate observations of free ranging animals throughout the year in order to obtain realistic estimates of daily intake. Considering the variation in daily intake each month it is doubtful if the Drigg sheep ever reached equilibrium. It seems therefore that transfer coefficients, calculated from free ranging animals, must be used with some degree of caution.

The transfer coefficient for muscle of Drigg ewes was higher than that determined by Sumerling (1981) for cattle grazing a saltmarsh on the opposite side (east bank) of the river Irt (Drigg Marsh) (ie 6.43×10^{-2} day kg^{-1} for sheep; 4.0×10^{-4} day kg^{-1} for cattle). Sumerling measured the ^{137}Cs concentration in the muscle of the cattle using external gamma-ray counting. The estimated ^{137}Cs levels in the muscle of the cattle was below the detection limits for adult cows in May 1979, but in 3 one year old heifers it ranged from 40-70 Bq kg^{-1} fresh wt. These figures are higher than the ^{137}Cs levels in the muscle of the ewes and lambs sampled in May 1982 (29 and 35 Bq kg^{-1} fresh wt respectively). The ^{137}Cs levels in the cattle (November 1979) were generally lower than those in the muscle of the sheep (September 1982): levels for cattle were 15-24 Bq kg^{-1} fresh wt, for sheep 41-88 Bq kg^{-1} fresh wt. The magnitude of the difference does not however, explain the difference between the calculated transfer coefficients, which might be due to a number of factors:

a. The rate of uptake, retention and loss of ^{137}Cs may differ in cattle and sheep. This seems unlikely since both are ruminants and are generally considered to have a similar metabolism in models of ^{137}Cs absorption, retention and loss (Coughtrey & Thorne 1983).

b. The estimates of daily intake may be inaccurate. Sumerling assumed that the cattle were ingesting vegetation only from the middle and top edge of the saltmarsh. He made no allowance for the cattle grazing the fields above the tideline when not on the marsh (twice each month for 3-4 days each time) ie the marsh would not be grazed for more than 10-12 days on end without a break. It seems therefore,

Table 3.15. Transfer coefficients for ^{137}Cs for selected tissues of Drigg sheep using the August estimates of the daily intake of ^{137}Cs.

1) Assuming a daily intake of 1 kg dry wt. of vegetation

		Transfer coefficient				
		Tissue				
		Liver	Lung	Kidney	Muscle	Bone
EWE		5.7×10^{-2}	5.5×10^{-2}	1.5×10^{-1}	6.4×10^{-2}	1.4×10^{-2}
	SD	2.9×10^{-2}	2.9×10^{-2}	7.7×10^{-2}	3.3×10^{-2}	7.1×10^{-3}
LAMB		1.2×10^{-1}	1.1×10^{-1}	2.9×10^{-1}	1.1×10^{-1}	5.1×10^{-2}
	SD	6.5×10^{-2}	5.6×10^{-2}	1.5×10^{-1}	5.6×10^{-2}	2.7×10^{-2}

2) Assuming a daily intake of 0.6 kg dry wt of vegetation

		Transfer coefficient				
		Tissue				
		Liver	Lung	Kidney	Muscle	Bone
LAMB		2.0×10^{-1}	1.8×10^{-1}	4.9×10^{-1}	1.8×10^{-1}	8.5×10^{-2}
	SD	1.1×10^{-1}	9.4×10^{-2}	2.6×10^{-2}	9.3×10^{-2}	4.5×10^{-2}

Table 3.16 Transfer coefficients for ^{137}Cs for selected tissues of Drigg EWES using a mean daily intake estimate based on the ^{137}Cs intake of a full year.

	Transfer coefficient				
	Tissue				
	Liver	Lung	Kidney	Muscle	Bone
	7.0×10^{-2}	6.8×10^{-2}	1.8×10^{-1}	7.9×10^{-2}	1.7×10^{-2}
SD	6.3×10^{-2}	6.1×10^{-2}	1.7×10^{-1}	7.2×10^{-2}	1.5×10^{-2}

that Sumerling overestimated the daily intake of ^{137}Cs by the cattle, and hence underestimated the transfer coefficient.

Although the Drigg sheep spent most of their time grazing on the saltmarsh in summer, the estimated mean daily intake was considerably reduced by the proportion of their time that they spent off the marsh. The radionuclide content of the vegetation grazed above the tideline by the sheep was incorporated in the estimates of their daily intake.

c. The proportion of ^{137}Cs absorbed from the saltmarsh vegetation in the Ravenglass estuary by the ruminant gut is comparatively low when compared to the 60% recommended by Coughtrey & Thorne (1983). If the rate of transfer of ^{137}Cs (derived from the Sellafield pipeline/sea) through the animals gut is low, it follows that it must take longer to reach equilibrium than it does when the ^{137}Cs results from fallout.

d. The cattle at Drigg are fed hay for at least 6 months in winter and therefore the total time that the animals would have spent on the saltmarsh could not have exceeded 6 months. It seems likely, therefore that the ^{137}Cs levels in the cattle had not reached equilibrium. The sheep were probably nearer to achieving equilibrium because they graze the area continuously all year round, except during lambing and tupping.

3.8.3 Concentration ratios

It is unlikely that the levels of most radionuclides ever reached an equilibrium in the sheep from Drigg. Firstly, because few animals were in the area for more than 5 years and secondly, because the daily intake of radionuclides varied greatly from month to month.

Despite this difficulty however, it was desirable to assess the relationship between the level of each radionuclide in the tissue of the sheep and that in the vegetation. Concentration ratios were calculated using the following formulae;

$$\text{Concentration ratio for EWES} = \frac{\text{concentration of radionuclide in tissue (pCi g}^{-1}\text{ dry wt)}}{\text{mean concentration of radionuclide in the vegetation ingested by the ewes in 1 year (pCi g}^{-1}\text{ dry wt)}}$$

$$\text{Concentration ratio for LAMBS} = \frac{\text{concentration of radionuclide in tissue (pCi g}^{-1}\text{ dry wt)}}{\text{*mean concentration of radionuclide in the vegetation ingested by the lambs in June, July and August (pCi g}^{-1}\text{ dry wt)}}$$

* assuming that the lambs will be grazing vegetation one month after birth.

The calculation of the concentration ratio has obvious limitations; it takes no account of the length of time that the animals have grazed in the area, of the age and past history of the animal and how close the tissue levels of the radionuclide in the animal are to equilibrium. It does, however, allow a limited comparison of the different radionuclides.

The results for ^{137}Cs, ^{238}Pu, $^{239/240}Pu$ and ^{241}Am are presented in Table 3.17. The concentration ration is consistently higher for ^{137}Cs than for the transuranics. This suggests that relatively more ^{137}Cs is

Table 3.17 Concentration ratios for various radionuclides for selected tissues of Drigg sheep.

		Concentration ratio				
		Tissue				
Radionuclide	Sheep	Liver	Lung	Kidney	Muscle	Bone
^{137}Cs	Ewe	2.6×10^{-1}	2.6×10^{-1}	6.9×10^{-1}	3.0×10^{-1}	4.0×10^{-3}
	Lamb	7.1×10^{-1}	6.2×10^{-1}	1.7	6.1×10^{-1}	1.8×10^{-2}
^{238}Pu	Ewe	5.9×10^{-2}	2.3×10^{-3}	7.0×10^{-3}	2.3×10^{-3}	3.5×10^{-3}
	Lamb	3.6×10^{-2}	3.9×10^{-3}	1.4×10^{-2}	2.6×10^{-3}	5.3×10^{-3}
$^{239/240}Pu$	Ewe	6.3×10^{-2}	3.4×10^{-3}	4.0×10^{-3}	1.5×10^{-3}	3.1×10^{-3}
	Lamb	3.4×10^{-2}	5.6×10^{-3}	1.5×10^{-2}	1.5×10^{-3}	5.6×10^{-3}
^{241}Am	Ewe	2.6×10^{-2}	4.1×10^{-3}	1.1×10^{-2}	1.9×10^{-3}	1.0×10^{-2}
	Lamb	1.3×10^{-2}	6.1×10^{-3}	1.3×10^{-2}	2.8×10^{-3}	8.0×10^{-3}

accumulated by the sheep from the vegetation than ^{238}Pu, $^{239/240}Pu$ and ^{241}Am. The concentration of radionuclides in the sheep were generally below those in the vegetation that they had consumed. It is evident that radionuclides are not "concentrating" in the sheep tissues relative to the radionuclide levels in the vegetation, except for ^{137}Cs in the kidney of lambs.

3.9 Conclusion

The results of this study are directly relevant to sheep grazing inundated pastures, especially saltmarshes in Britain, but they must be used with caution when considering other inland pastures.

Sheep grazing inundated pastures are likely to ingest very different quantities of radionuclides at different times of year. This results from a combination of 2 factors, the considerable temporal variation of radionuclide levels on saltmarsh vegetation and the grazing behaviour of the sheep. The transfer coefficient for ^{137}Cs was 1.8×10^{-1} day kg^{-1} for lamb muscle and 6.4×10^{-2} day kg^{-1} for ewe muscle. Considering the large variation in daily intake of radionuclides it is doubtful whether equilibrium in the radionuclide levels in the sheep tissues was ever achieved; further studies would be necessary to determine the biological halflife and the fractional absorption of the radionuclides involved in order to comment further.

It appears that the majority of the radionuclides associated with the vegetation in the saltmarsh were strongly bound to a surface deposit of sediment. The fractional absorption of the radionuclides in the sheep gut was therefore much lower than that occurring with the more soluble forms of radionuclides, eg from stack emissions and fall-out.

The tissue concentration of ^{137}Cs in lambs raised on the saltmarsh was consistently higher than the ewes even though the lambs had grazed the area for a much shorter period of time than the ewes. This implies that the fractional absorption of ^{137}Cs in the lambs gut is greater than that of the ewes. The discrepancy in radionuclide levels in lambs and ewes has implications for routine monitoring of sheep in the Ravenglass estuary. Whilst it might be thought that the ewes would have accumulated higher levels or radionuclides as a result of their longer residence time on the area, this does not appear to be true for ^{137}Cs in tissues generally nor for ^{238}Pu, and $^{239/240}Pu$ in the kidney. It is therefore recommended that lambs as well as ewes should be analysed for monitoring purposes.

The sheep kidney contained higher levels of ^{137}Cs and ^{134}Cs relative to the other tissues; in the liver, ^{60}Co, ^{95}Nb and ^{106}Ru were also often present. As kidney is eaten as offal, it seems prudent to include this tissue in any routine analyses of sheep from West Cumbria, when calculating percentages of the annual limits for intake (ALIs) for man.

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Appendix 1. Analyses of variance of the grazing time spent in the different areas in summer and winter.

1) Winter

Source	Df	SSQ	Mean square	F
Between areas	4	171.358	42.8396	69.7144***
Within areas	195	119.828	0.6145	

*** $p<0.001$

Using Tukeys honestly significant difference test area 3 was significantly different ($p\ll0.001$) from areas 1, 2 and 4 and area 5 was significantly different ($p<0.001$) from all other areas.

2) Summer

Source	Df	SSQ	Mean square	F
Between areas	4	618.358	154.589	187.049***
Within areas	235	194.22	0.8265	

*** $p<0.001$

Using Tukeys honestly significant difference test area 2 was significantly different ($p<0.001$) from all other areas and area 3 was significantly different ($p<0.001$) from areas 1, 4 and 5.

Appendix 2 Radionuclide content of the VEGETATION of the study areas from February 1982 to February 1983.

Radionuclide concentration ± estimated standard deviation (where possible) (pCi g^{-1} dry wt)

Area 1

Month					Nuclide					
	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
1982										
February	26.80± 1.85	12.50 ± 2.58	1.04 ± 0.50	94.06 ± 10.38	33.50 ± 3.00	1.57	210.00± 23.23	<1.03	4.84 ± 0.71	133.00± 14.84
March	19.90± 12.15	9.49 ± 2.78	0.96 ± 0.19	52.83 ± 6.00	19.06 ± 1.94	<0.60	158.00± 23.64	2.96	2.64 ± 0.55	84.90± 10.26
April	<5.28	10.90 ± 2.09	1.13 ± 0.10	99.31 ± 2.67	38.46 ± 1.24	2.49	187.00± 10.00	3.44	6.12 ± 0.62	124.00± 9.15
May	<4.26	14.70 ± 2.22	0.35 ± 0.18	63.89 ± 5.34	25.67 ± 1.92	1.25	60.80± 11.71	<0.64	1.88 ± 0.24	56.30± 8.19
June	<2.53	19.70 ± 2.45	0.28	43.03 ± 4.69	18.59 ± 0.09	0.68	45.00± 2.19	<0.51	0.98	24.20± 0.61
July	2.99	15.70 ± 0.45	0.09	13.98 ± 1.92	5.60 ± 0.96	<0.28	19.60± 1.66	<0.36	0.92 ± 0.02	20.60± 2.36
August	6.22	13.30 ± 0.56	0.27	15.56 ± 7.62	9.74 ± 4.85	0.51	34.40± 17.92	<0.48	1.92 ± 0.91	38.60± 14.98
September	7.76± 0.81	12.60 ± 1.77	0.39 ± 0.06	55.97 ± 4.59	22.56 ± 1.92	0.62	64.30± 5.27	1.08	1.49 ± 0.05	35.20± 5.70
October	10.00± 1.47	8.98 ± 0.13	0.15	19.12 ± 1.37	6.95 ± 0.47	0.37	26.40± 1.15	<0.45	1.03 ± 0.52	23.00± 0.98
November	14.00± 0.74	7.85 ± 0.21	0.34	22.18 ± 1.39	7.68 ± 0.48	<0.37	34.60± 5.46	<0.54	1.02 ± 0.61	27.60± 2.00
December	20.10± 2.11	6.67 ± 1.67	0.34	24.19 ± 5.41	7.82 ± 1.32	0.52	36.30± 6.18	0.59	1.22 ± 0.37	31.60± 7.57
1983 January	20.00± 1.23	4.24 ± 0.39	0.90 ± 0.28	22.57 ± 3.11	7.20 ± 1.16	0.63	39.90± 6.09	<0.51	1.31 ± 0.28	34.40± 5.36
February	10.50± 1.21	11.30 ± 1.61	1.23 ± 0.23	143.45 ± 47.01	40.86 ± 3.12	3.30	147.00± 16.64	<0.83	2.84 ± 0.27	89.40± 7.18

Appendix 2 continued

Area 1

Month	^{144}Ce	^{154}Eu	^{155}Eu	$^{*238}Pu$	$^{*239/240}Pu$	^{241}Am
1982						
February	25.40 ± 2.44	3.12 ± 1.50	2.26	5.44 ± 0.13	21.91 ± 0.28	29.20 ± 1.13
March	15.30 ± 0.09	2.70 ± 0.41	1.80	4.98 ± 0.17	20.40 ± 0.37	26.40 ± 6.59
April	21.60 ± 1.56	3.62 ± 0.47	2.27	6.07 ± 0.16	23.90 ± 0.33	32.80 ± 2.69
May	8.91 ± 0.52	1.04 ± 0.65	0.93	2.28 ± 0.08	9.12 ± 0.18	9.58 ± 1.15
June	7.34 ± 0.40	0.81	1.07	2.11 ± 0.08	8.29 ± 0.18	8.21 ± 2.41
July	3.21 ± 0.28	<0.26	<0.48	1.25 ± 0.06	4.80 ± 0.13	3.34 ± 0.79
August	4.91 ± 2.65	0.82	0.75	2.16 ± 0.07	8.28 ± 0.17	6.64 ± 2.83
September	7.37 ± 0.65	1.26	<0.45	2.96 ± 0.09	11.75 ± 0.19	9.80 ± 3.19
October	3.04 ± 0.43	0.60	<0.55	1.44 ± 0.05	5.75 ± 0.11	2.93 ± 0.75
November	4.00 ± 0.68	1.00	0.63	2.78 ± 0.04	8.72 ± 0.08	6.88 ± 0.25
December	3.78 ± 1.74	0.82	0.80	2.34 ± 0.04	7.80 ± 0.09	6.81 ± 2.00
1983						
January	6.65 ± 0.67	1.40 ± 0.28	0.92	5.24 ± 0.05	11.30 ± 0.08	9.81 ± 3.91
February	10.90 ± 1.11	2.43 ± 0.23	2.02	6.94 ± 0.11	29.60 ± 0.24	20.20 ± 3.30

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 3

Area 2

Month	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
					Nuclide					
1982										
February	24.40 ± 3.57	6.12 ± 1.16	1.01	41.02 ± 7.01	14.24	<0.61	106.00 ± 23.37	1.77	2.81 ± 0.68	60.00 ± 11.79
March	26.80 ± 0.55	6.92 ± 1.45	0.70	24.36 ± 1.10	8.34	<0.55	72.30 ± 6.49	<0.58	1.66 ± 0.19	42.50 ± 2.64
April	17.00 ± 2.11	7.12 ± 1.94	0.58	18.68 ± 1.32	6.33	<0.71	57.00 ± 3.45	<0.39	1.57 ± 0.15	37.00 ± 3.57
May	13.00 ± 0.37	14.70 ± 1.95	0.53	14.61 ± 3.32	5.09	<0.60	46.40 ± 12.57	<0.56	1.88 ± 0.32	38.50 ± 6.61
June	3.42	20.80 ± 0.64	<0.28	6.18 ± 1.70	2.87	<0.22	6.10 ± 2.42	<0.32	0.23	5.90 ± 0.66
July	3.54	19.10 ± 1.44	<0.11	1.94 ± 0.22	0.77	<0.19	3.13	<0.27	0.21	5.06 ± 0.66
August	3.74 ± 0.76	14.30 ± 0.87	<0.11	0.36 ± 0.09	0.25	<0.12	1.53	0.12	0.17	4.93 ± 2.01
September	6.70	17.30 ± 2.08	<0.08	2.17 ± 1.59	1.02	<0.11	2.73	<0.27	<0.08	3.30 ± 0.59
October	10.30 ± 1.12	8.79 ± 1.16	<0.11	1.85 ± 0.51	0.50	<0.29	2.97 ± 1.29	<0.31	0.14	2.81 ± 0.56
November	14.80 ± 0.81	8.72 ± 0.87	<0.14	5.98 ± 0.36	1.70	<0.39	7.13 ± 2.43	<0.39	0.14	5.03 ± 0.60
December	18.90 ± 1.16	5.92 ± 0.54	<0.11	3.48 ± 0.71	1.11	<0.34	5.52 ± 2.02	<0.36	0.14	4.63 ± 1.22
1983										
January	21.20 ± 1.63	5.61 ± 0.93	<0.11	1.75 ± 0.49	0.68	<0.25	3.80 ± 2.23	<0.35	<0.15	3.21 ± 0.83
February	19.30 ± 2.01	8.61 ± 1.96	0.43	91.15 ± 9.46	24.40	2.29	73.40 ± 6.18	<0.57	0.99 ± 0.49	2.53 ± 2.03

Appendix 3 continued

Area 2

Month	^{144}Ce	^{154}Eu	^{155}Eu	*^{238}Pu	*$^{239/240}Pu$	^{241}Am
				Nuclide		
1982						
February	12.60 ± 3.06	1.79	1.63	2.88 ± 0.07	11.36 ± 0.16	15.80 ± 3.21
March	8.13 ± 0.79	1.68	0.89	3.12 ± 0.08	12.64 ± 0.18	14.10 ± 2.74
April	7.12 ± 0.72	1.19	<0.69	2.03 ± 0.07	8.61 ± 0.16	14.40 ± 1.82
May	5.59 ± 0.39	1.05	<0.70	1.75 ± 0.06	7.02 ± 0.83	10.50 ± 1.26
June	1.53	<0.31	<0.44	0.57 ± 0.15	1.51 ± 0.33	*0.98 ± 0.04
July	<0.74	<0.29	<0.44	0.29 ± 0.03	0.77 ± 0.02	*0.55 ± 0.04
August	<0.44	<0.30	<0.27	0.14 ± 0.01	0.42 ± 0.01	*0.52 ± 0.02
September	<0.43	<0.26	<0.29	0.22 ± 0.01	0.78 ± 0.01	*0.46 ± 0.01
October	<0.88	<0.29	<0.49	0.11 ± 0.01	0.44 ± 0.01	*0.34 ± 0.01
November	<1.08	<0.38	<0.60	0.35 ± 0.01	1.44 ± 0.03	*0.81 ± 0.01
December	<0.94	<0.29	<0.50	0.41 ± 0.01	1.56 ± 0.03	*1.05 ± 0.01
1983						
January	<0.93	<0.31	<0.50	0.18 ± 0.01	0.67 ± 0.02	*0.82 ± 0.01
February	3.92 ± 0.68	0.80	<0.66	1.92 ± 0.05	7.96 ± 0.11	6.46 ± 1.34

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 4

Area 3

Month	^{7}Be	^{40}K	^{95}Nb	^{106}Ru	^{137}Cs	^{144}Ce	*^{238}Pu	*$^{239/240}Pu$	*^{241}Am
	Nuclide								
1982									
February	16.20 ± 2.54	4.04± 0.53	0.78 ± 0.50	1.35	1.35 ± 0.21	1.70	0.03 ± <0.01	0.11 ± 0.01	0.08 ± 0.01
March	17.00 ± 1.87	5.54± 2.63	0.45	<0.88	1.27 ± 0.28	1.63	0.04 ± <0.01	0.16 ± 0.01	0.08 ±<0.01
April	11.30 ± 3.18	6.50± 1.10	0.49 ± 0.07	1.20	1.70 ± 0.13	1.07	0.03 ± <0.01	0.14 ± 0.01	0.12 ± 0.01
May	11.40 ± 0.56	11.10± 2.19	0.56	<0.99	1.28 ± 0.22	<0.77	0.01 ± <0.01	0.07 ± 0.01	0.11 ± 0.01
June	4.47 ± 0.31	13.50± 1.21	0.56	<0.86	1.64 ± 0.16	<0.67	0.01 ± <0.01	0.04 ±<0.01	0.06 ±<0.01
July	3.50 ± 0.43	13.50± 2.05	<0.16	<0.76	2.97 ± 1.15	<0.64	<0.01 ± <0.01	0.03 ±<0.01	0.05 ±<0.01
August	3.70 ± 0.57	11.70± 0.81	0.54	<0.55	0.83 ± 0.22	<0.34	0.02 ± <0.01	0.03 ±<0.01	0.04 ±<0.01
September	6.41 ± 0.35	14.90± 0.77	0.29 ± 0.03	<0.44	1.90 ± 0.27	<0.31	0.04 ± <0.01	0.12 ± 0.01	0.08 ± 0.01
October	9.01 ± 0.78	9.50± 2.98	0.24	<0.86	1.08 ± 0.33	<0.77	0.03 ± <0.01	0.11 ± 0.01	0.13 ± 0.01
November	13.70 ± 1.61	7.57± 1.29	<0.17	<0.79	1.21 ± 0.68	<0.75	0.03 ± <0.01	0.10 ± 0.01	0.07 ±<0.01
December	14.10 ± 0.52	7.14± 0.51	<0.34	<0.89	0.70 ± 0.03	<0.86	0.01 ± <0.01	0.04 ±<0.01	0.10 ±<0.01
1983									
January	15.80 ± 2.23	4.50± 0.53	<0.23	<0.82	0.72 ± 0.08	<0.77	0.02 ± <0.01	0.08 ±<0.01	0.14 ± 0.01
February	15.00 ± 3.77	6.02± 1.24	0.76 ± 0.25	2.28	1.16 ± 0.26	<0.78	0.06 ± <0.01	0.20 ± 0.01	0.11 ± 0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 5

Area 4

Month					Nuclide				
	^{7}Be	^{40}K	^{95}Nb	^{106}Ru	^{137}Cs	^{144}Ce	$^{*938}Pu$	$^{*239/240}Pu$	$^{*241}Am$
1982									
February	14.90± 1.54	5.58 ± 0.73	0.77 ± 0.15	0.62	2.22 ± 0.35	2.26 ± 0.86	0.02 ±<0.01	0.11 ± 0.01	0.10 ± 0.01
May	9.95 ± 7.99	6.51 ± 3.16	0.39 ± 0.25	0.57	1.80 ± 1.26	1.48	0.01 ±<0.01	0.08 ± 0.01	0.11 ± 0.01
August	5.79 ± 0.48	8.25 ± 0.82	<0.20	<1.08	0.85 ± 0.15	<0.65	0.01 ±<0.01	0.09 ± 0.01	0.09 ± 0.01
November	12.90 ± 0.75	8.07 ± 0.50	<0.15	<0.72	0.86 ± 0.09	<0.69	0.01 ±<0.01	0.05 ±<0.01	0.06 ±<0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 6

Area 5

Month	^{7}Be	^{40}K	^{95}Nb	^{106}Ru	^{137}Cs	^{144}Ce	$^{*238}Pu$	$^{*239/240}Pu$	$^{*241}Am$
					Nuclide				
1982									
February	15.80 ± 1.23	8.30 ± 1.51	1.01 ± 0.69	2.41 ± 1.10	1.90 ± 0.18	1.79	0.03 ±<0.01	0.14 ± 0.01	0.14 ± 0.01
May	9.98 ± 0.05	6.74 ± 0.92	0.38 ± 0.10	1.02	1.67 ± 0.12	1.01	0.03 ± 0.01	0.13 ± 0.01	0.13 ± 0.01
August	3.19 ± 0.82	8.70 ± 0.77	<0.13	<0.63	0.70 ± 0.26	<0.37	0.01 ±<0.01	0.04 ± 0.01	0.06 ± 0.01
November	14.20 ± 3.64	10.20 ± 1.60	0.60	<0.70	0.93 ± 0.10	<0.68	0.03 ±<0.01	0.14 ± 0.01	0.25 ± 0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 7

Area 6

Month	Nuclide								
	^{7}Be	^{40}K	^{95}Nb	^{106}Ru	^{137}Cs	^{144}Ce	$^{*238}Pu$	$^{*239/240}Pu$	$^{*241}Am$
1982									
February	21.00 ± 2.19	7.01 ± 0.11	0.90	1.79	1.51 ± 0.15	0.50	0.03 ±<0.01	0.12 ± 0.01	0.12 ± 0.01
May	9.35 ± 1.34	15.40 ± 3.95	0.56 ± 0.31	<1.03	1.08 ± 0.02	<0.81	0.03 ±<0.01	0.12 ± 0.01	0.12 ± 0.01
August	2.64 ± 0.36	17.60 ± 1.54	<0.19	<0.69	0.20 ± 0.10	<0.42	0.01 ±<0.01	0.03 ±<0.01	0.05 ± 0.01
November	17.30 ± 5.32	14.90 ± 1.50	<0.40	<0.81	0.48 ± 0.15	<0.79	0.01 ±<0.01	0.06 ± 0.01	0.09 ±<0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 8. Radionuclide content of the DROPPINGS of the study area from February 1982 to January 1983.

Radionuclide concentration + estimated standard deviation (where possible) (pCi g^{-1} dry wt)

Area 1

Month				Nuclide					
	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs
1982									
February	29.30± 12.07	6.58 1.64	0.47 ± 0.27	48.86 ± 6.22	16.53 ± 2.05	0.64	108.00± 13.53	<0.69	2.53 ± 0.33
March	28.30± 0.86	4.81 ± 2.06	0.17	11.86 ± 4.91	3.88 ± 1.61	<0.55	30.90± 14.02	<0.50	0.90 ± 0.39
April	27.10± 4.4	9.13 ± 3.79	0.48 ± 0.31	90.10 ± 11.96	33.72 ± 5.89	2.63 ± 0.30	69.30± 8.29	<0.61	1.71 ± 0.89
May	5.98	11.20 ± 3.73	0.54 ± 0.35	131.82 ± 39.68	54.18 ± 18.03	1.93 ± 0.12	84.60± 33.70	<0.78	2.25 ± 0.81
June	13.40± 2.06	10.30 ± 3.72	0.59	81.46 ± 2.69	33.53 ± 1.76	1.09	80.00± 6.77	<0.83	1.45 ± 0.78
July	11.50± 1.78	3.34	<0.13	13.40 ± 1.95	5.15 ± 0.62	<0.32	20.40± 4.53	<0.42	0.64 ± 0.12
August	11.80± 1.26	4.16 ± 1.38	0.40	18.42 ± 0.91	11.45 ± 0.93	<0.48	73.10± 3.55	<0.50	1.37 ± 0.09
September	14.70± 1.37	3.53 ± 0.45	0.38 ± 0.21	64.07 ± 5.53	24.87 ± 2.39	0.82	74.90± 8.07	0.85	1.75 ± 0.18
October	n a	n a	n a	n a	n a	n a	n a	n a	n a
November	n a	n a	n a	n a	n a	n a	n a	n a	n a
December	36.50± 0.74	8.36 ± 1.62	<0.15	6.49 ± 2.28	1.77 ± 0.58	<0.59	8.92± 2.53	<0.49	0.31
1983									
January	24.00± 1.53	1.41 ± 0.30	<0.14	2.50 ± 0.69	0.96	<0.32	4.66± 0.57	<0.43	0.19

n a - sample not available

Appendix 8 continued

Area 1

Month 1982	Nuclide ^{137}Cs	^{144}Ce	^{154}Eu	^{155}Eu	* ^{238}Pu	* $^{239/240}Pu$	^{241}Am
February	58.20± 5.70	11.90 ± 1.60	1.39	1.72	8.08 ± 0.17	31.35 ± 0.34	14.40 ± 3.25
March	22.40± 9.08	4.58 ± 1.52	0.57	<0.67	1.35 ± 0.09	5.06 ± 0.20	5.96
April	34.90± 3.26	10.30 ± 1.08	1.14 ± 0.60	0.88	2.59 ± 0.10	10.14 ± 0.21	9.89 ± 0.82
May	54.40± 17.90	14.70 ± 4.88	1.70 ± 1.43	1.41	3.34 ± 0.09	13.15 ± 0.20	15.20 ± 7.70
June	39.40± 1.76	12.70 ± 1.13	2.00	1.34	2.34 ± 0.08	12.73 ± 0.24	16.60 ± 5.00
July	25.00± 1.73	2.24	<0.35	<0.60	1.14 ± 0.05	4.60 ± 0.13	3.34
August	40.30± 0.46	5.39 ± 0.80	0.96	1.02	2.74 ± 0.09	10.57 ± 0.19	8.43 ± 0.39
September	40.10± 4.06	8.42 ± 0.38	1.47 ± 0.24	<0.51	4.20 ± 0.10	16.82 ± 0.22	13.00 ± 1.56
October	n a	n a	n a	n a	n a	n a	n a
November	n a	n a	n a	n a	n a	n a	n a
December	7.62 2.05	<1.31	<0.38	<0.67	1.00 ± 0.02	2.27 ± 0.04	*1.72 ± 0.09
1983 January	6.42 1.54	<1.12	<0.36	<0.61	0.36 ± 0.01	1.38 ± 0.03	*1.11 ± 0.05

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 9

Area 2

Month 1982	Nuclide ^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
February	25.30± 0.12	3.12	0.63	35.58 ± 1.65	11.00 ± 3.31	<0.77	72.70± 1.32	<0.62	1.66 ± 0.23	40.30± 2.85
March	33.30± 1.41	4.01 ± 0.79	0.26	12.29 ± 1.74	3.85 ± 0.87	<0.63	33.60± 4.42	<0.50	0.85 ± 0.21	20.90± 3.89
April	25.70± 2.14	6.98 ± 2.53	0.53 ± 0.36	23.68 ± 2.54	8.25 ± 0.97	<0.61	30.40± 5.82	<0.47	0.70 ± 0.41	18.50± 2.00
May	9.78	8.86 ± 3.24	0.18	3.92 ± 0.41	1.61 ± 1.04	<0.34	3.84± 1.34	0.33	0.24	4.43± 0.39
June	9.16± 0.65	6.08 ± 0.87	0.36	32.09 ± 0.67	13.19 ± 3.33	<0.38	32.60± 5.30	<0.51	0.61 ± 0.03	17.70± 2.67
July	9.94± 2.89	5.98 ± 0.85	<0.14	9.87 ± 1.37	3.91 ± 0.80	<0.33	14.50± 3.36	<0.42	0.50 ± 0.19	13.20± 0.64
August	9.14± 2.16	7.88 ± 2.29	<0.31	11.56 ± 3.06	7.13 ± 1.43	<0.53	22.80± 4.62	<0.96	1.08 ± 0.10	25.84± 4.62
September	15.50± 0.46	4.93 ± 1.68	0.35 ± 0.15	49.60 ± 2.42	18.67 ± 1.03	0.54	54.00± 4.54	1.03	1.30 ± 0.14	30.40± 1.03
October	n a	n a	n a	n a	n a	n a	n a	n a	n a	n a
November	32.50± 2.85	2.58 ± 0.27	<0.15	3.51 ± 0.59	<0.48	<0.59	3.51	<0.41	<0.18	3.84± 0.47
December	32.70± 2.60	3.44 ± 0.73	<0.16	4.27 ± 1.89	<0.54	<0.58	3.38	<0.48	<0.22	4.38± 1.20
1983 January	28.00± 0.48	3.92 ± 1.32	<0.14	2.28 ± 1.73	<0.39	<0.34	2.76	<0.43	<0.19	4.17± 1.12

n a - sample not available

Appendix 9 continued

Area 2

Month	Nuclide					
1982	^{144}Ce	^{154}Eu	^{155}Eu	* ^{238}Pu	* $^{239/240}Pu$	^{241}Am
February	9.19 ± 0.99	0.73	<0.81	2.17 ± 0.07	8.09 ± 0.15	10.00 ± 2.65
March	5.17 ± 0.60	<0.45	<0.68	1.57 ± 0.10	5.10 ± 0.21	5.96 ± 0.54
April	4.91 ± 3.01	<0.40	<0.62	1.38 ± 0.07	5.67 ± 0.21	5.29 ± 3.40
May	<0.98	<0.38	<0.53	0.23 ± 0.02	0.95 ± 0.07	0.67 ± 0.04
June	5.28 ± 0.67	0.77	<0.63	1.81 ± 0.06	6.99 ± 0.13	6.89 ± 0.85
July	1.93	<0.34	<0.61	0.95 ± 0.04	3.18 ± 0.09	3.52 ± 2.38
August	3.33 ± 0.84	<0.83	<0.91	1.57 ± 0.04	6.19 ± 0.08	3.55 ± 1.88
September	6.80 ± 0.54	1.01	1.08	2.55 ± 0.05	9.82 ± 0.09	7.94 ± 2.28
October	n a	n a	n a	n a	n a	n a
November	<1.25	<0.41	<0.66	0.20 ± 0.01	0.78 ± 0.02	*0.47 ± 0.01
December	<1.38	<0.44	<0.69	0.29 ± 0.02	1.09 ± 0.06	*1.00 ± 0.05
January	<1.16	<0.39	<0.62	0.19 ± 0.02	0.82 ± 0.05	*0.76 ± 0.05

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

n a - sample not available

Appendix 10

Area 3

Month	Nuclide									
1982	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{134}Cs	^{137}Cs	^{144}Ce
February	21.30± 2.47	2.05 ± 1.11	0.15	5.61 ± 2.15	2.04 ± 0.82	<0.34	11.80 ± 5.20	0.36	8.78 ± 3.12	3.33 ± 1.99
March	27.20± 1.41	2.92 ± 0.58	<0.14	10.14 ± 0.05	3.29 ± 1.54	<0.38	27.90 ± 22.81	0.62 ± 0.24	18.90 ± 6.59	4.41 ± 1.32
April	23.20± 1.57	5.17 ± 3.65	0.30	7.64 ± 1.52	3.45 ± 0.62	<0.27	13.30 ± 7.62	0.50 ± 0.36	12.30 ± 7.66	3.11 ± 1.48
May	n a	n a	n a	n a	n a	n a	n a	n a	n a	n a
June	n a	n a	n a	n a	n a	n a	n a	n a	n a	n a
July	9.44± 1.26	2.32 ± 0.70	<0.08	7.59 ± 4.27	3.05 ± 0.39	<0.19	10.40 ± 1.04	0.43 ± 0.07	11.40 ± 0.98	2.05
August	9.69± 0.91	4.77 ± 1.00	<0.15	1.58 ± 0.62	0.76 ± 0.30	<0.26	3.72 ± 2.05	0.13	3.87 ± 0.85	<0.66
September	14.70± 0.50	6.33 ± 1.50	<0.10	18.66 ± 4.72	7.11 ± 1.55	<0.23	19.80 ± 5.53	0.49 ± 0.14	12.70 ± 2.86	2.62 ± 1.40
October	13.60± 0.92	4.86 ± 1.68	<0.10	9.07 ± 5.70	3.34 ± 2.04	<0.28	10.80 ± 5.50	0.28 ± 0.17	9.15 ± 5.03	1.57
November	29.30± 2.19	2.35 ± 0.34	<0.13	1.09 ± 0.22	<0.38	<0.35	<1.10	<0.15	3.00 ± 0.63	1.06
December	30.70± 2.40	3.78 ± 0.53	<0.11	1.99 ± 0.36	<0.33	<0.31	<0.89	<0.14	1.40 ± 0.20	<0.86
1983										
January	19.80± 2.92	1.07 ± 0.38	<0.12	1.05 ± 0.61	<0.35	<0.30	<1.05	<0.16	1.50 ± 0.37	<0.99

n a - sample not available

Appendix 10 continued

Area 3

Month	Nuclide		
1982	*^{238}Pu	*$^{239/240}Pu$	*^{241}Am
February	0.44 ± 0.02	1.79 ± 0.04	1.54 ± 0.02
March	1.05 ± 0.02	4.18 ± 0.04	2.59 ± 0.03
April	0.60 ± 0.02	2.39 ± 0.04	2.26 ± 0.04
May	n a	n a	n a
June	n a	n a	n a
July	0.77 ± 0.02	2.86 ± 0.05	1.63 ± 0.02
August	0.22 ± 0.01	0.84 ± 0.02	0.57 ± 0.01
September	1.05 ± 0.02	4.10 ± 0.04	3.45 ± 0.05
October	0.80 ± 0.02	3.21 ± 0.04	1.78 ± 0.02
November	0.06 ±<0.0	0.23 ± 0.01	0.16 ± 0.01
December	0.06 ± 0.0	0.21 ± 0.01	0.27 ± 0.07
1983 January	0.05 ±<0.0	0.20 ± 0.01	0.14 ± 0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

n a - sample not available

Appendix 11

Area 4

Month 1982	Nuclide									
	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{125}Sb	^{134}Cs	^{137}Cs
February	23.50± 3.88	6.22 ± 1.84	<0.16	8.13 ± 7.36	2.70	<0.40	18.20± 17.32	<0.40	0.44	11.10± 9.05
May	n a	n a	n a	n a	n a	n a	n a	n a	n a	n a
August	10.50± 0.58	40.80 ±14.28	0.27	21.59 ± 9.25	9.56	0.61	31.50± 16.78	0.68	1.37 ± 0.85	30.80± 11.31
November	25.90± 0.67	6.80 ± 0.77	<0.29	13.86 ± 4.16	4.64	<0.35	20.30± 5.49	<0.50	1.00 ± 0.38	23.80± 7.29

n a - samples not available

Appendix 11 continued

Area 4

Month 1982	Nuclide					
	^{144}Ce	^{154}Eu	^{155}Eu	*^{238}Pu	*$^{239/240}Pu$	^{241}Am
February	3.70 ± 2.07	<0.44	<0.62	0.37 ± 0.01	1.45 ± 0.03	*0.98 ± 0.02
May	n a	n a	n a	n a	n a	n a
August	4.08 ± 2.29	0.71	0.84	2.23 ± 0.08	9.26 ± 0.18	7.28 ± 4.00
November	3.00 ± 1.93	<0.39	<0.68	2.04 ± 0.05	7.97 ± 0.10	*4.17 ± 0.05

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

n a - sample not available

Appendix 12

Area 5

Month 1982	Nuclide								
	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{134}Cs	^{137}Cs
February	26.70± 1.02	8.83 ± 5.44	0.13	1.28 ± 0.17	0.33	0.32	3.25 ± 0.66	<0.15	2.85 ± 0.47
May	17.90± 0.88	10.90 ± 0.99	<0.16	3.52 ± 0.36	1.09 ± 0.65	<0.38	1.98 ± 0.06	<0.19	3.56 ± 0.59
August	9.29± 0.78	6.37 ± 3.38	<0.14	1.57 ± 0.77	<0.40	<0.36	<1.07	<0.13	2.08 ± 0.57
November	23.40± 1.48	2.53 ± 1.18	<0.09	3.43 ± 3.26	1.11	<0.29	4.87 ± 5.68	0.16	4.59 ± 4.68

Appendix 12 continued

Area 5

Month 1982	Nuclide			
	^{144}Ce	*^{238}Pu	*$^{239/240}Pu$	*^{241}Am
February	1.84	0.09 ± 0.01	0.39 ± 0.01	0.31 ± 0.01
May	<1.11	0.07 ± 0.01	0.35 ± 0.02	0.24 ± 0.01
August	<0.67	0.09 ± 0.01	0.34 ± 0.02	0.25 ± 0.01
November	<0.76	0.41 ± 0.01	1.59 ± 0.02	0.85 ± 0.02

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting

Appendix 13

Area 6

Month 1982	Nuclide								
	^{7}Be	^{40}K	^{60}Co	^{95}Nb	^{95}Zr	^{103}Ru	^{106}Ru	^{134}Cs	^{137}Cs
February	28.00± 2.03	8.83 ± 5.20	0.13	1.38 ± 0.20	<0.34	<0.33	3.98 ± 1.21	<0.16	2.59 ± 0.36
May	12.50± 0.81	7.15 ± 0.39	<0.11	1.73 ± 0.13	0.54	<0.16	1.47 ± 0.78	<0.13	1.74 ± 0.15
August	8.54± 0.72	4.06	<0.14	1.43 ± 0.71	0.34	<0.25	1.37	<0.11	2.39 ± 0.72
November	29.30± 5.42	2.12 ± 0.52	<0.11	1.49 ± 0.08	<0.43	<0.47	<0.98	<0.16	1.35 ± 0.13

Appendix 13 continued

Area 6

Month 1982	Nuclide			
	^{144}Ce	*^{238}Pu	*$^{239/240}Pu$	*^{241}Am
February	1.92	0.06 ± <0.01	0.24 ± 0.01	0.30 ± 0.01
May	<0.71	0.05 ± <0.01	0.28 ± 0.02	0.16 ± 0.01
August	<0.59	0.10 ± 0.01	0.39 ± 0.01	0.35 ± 0.01
November	<0.96	0.03 ± <0.01	0.26 ± 0.01	0.20 ± 0.01

* analysed using wet chemistry followed by alpha spectrometry. The error term is ± twice the standard deviation of the alpha counting.

Appendix 14. The concentration of certain radionuclides in the tissues of Drigg sheep and of a control sheep from Swaledale, Yorkshire. (Bq kg^{-1} fresh wt)

A. ^{137}Caesium

SHEEP		Tissue				
		Liver	Kidney	Lung	Muscle	Bone
i) May 1982						
Lamb		54.26	112.55	47.81	35.40	7.32
Ewe		47.71	51.12	35.21	29.63	1.11
ii) September 1982						
Lambs	mean	82.19	196.50	65.39	71.31	3.44
	SE	4.11	16.29	12.30	10.10	1.10
Ewes	mean	37.16	97.16	36.14	42.23	0.90
	SE	8.79	13.75	0.95	0.78	0.19
Ewe 6 (Control)		1.25	2.50	6.83	2.02	<0.16

B. ^{238}Plutonium

SHEEP	Tissue				
	Liver	Kidney	Muscle	Lungs	Bone
i) May 1982					
Lamb	0.231	0.067	0.029	0.019	0.064
Ewe	0.635	0.096	0.010	0.048	0.080
ii) September 1982					
Lambs mean	0.260	0.106	0.019	0.029	0.064
SE	0.055	0.050	0.006	0.022	0.028
Ewes mean	0.491	0.058	0.019	0.019	0.048
SE	0.200	0.033	0.006	0.006	0.009
Ewe 6 (Control)	0.010	0.019	<0.010	<0.010	<0.016

C. $^{239/240}$Plutonium

SHEEP	Tissue				
	Liver	Kidney	Muscle	Lungs	Bone
i) May 1982					
Lamb	1.000	0.375	0.115	0.096	0.191
Ewe	1.857	0.202	0.038	0.019	0.302
ii) September 1982					
Lambs mean	0.866	0.375	0.038	0.144	0.239
SE	0.117	0.122	0.006	0.072	0.101
Ewes mean	1.972	0.125	0.048	0.106	0.159
SE	0.800	0.033	0.011	0.039	0.028
Ewe 6 (Control)	0.192	0.115	0.010	0.010	<0.016

D. ^{241}Americium

SHEEP	Tissue				
	Liver	Kidney	Muscle	Lungs	Bone
i) May 1982					
Lamb	0.154	0.135	0.038	0.038	0.159
Ewe	0.606	0.250	0.029	0.173	0.843
ii) September 1982					
Lamb mean	0.269	0.269	0.058	0.125	0.265
SE	0.033	0.117	0.017	0.044	0.051
Ewe mean	0.904	0.375	0.067	0.144	0.599
SE	0.233	0.183	0.006	0.067	0.037
Ewe 6 (Control)	0.010	0.231	0.010	0.010	0.095

Appendix 15. Calculation of the variance associated with the transfer coefficient.

The formula used to calculate the variance associated with the transfer coefficient was:

$$\text{Variance of transfer coefficient} = V\left[\frac{y_1}{y_2}\right] = \left[\frac{y_1}{y_2}\right]^2 \left[\frac{V(y_1)}{y_1^2} + \frac{V(y_2)}{y_2^2}\right]$$

where:

V	=	variance
y_1	=	concentration of radionuclide in sheep tissue (fresh wt basis)
y_2	=	daily intake of radionuclides
$V(y_1)$	=	variance of y_1
$V(y_2)$	=	variance of y_2