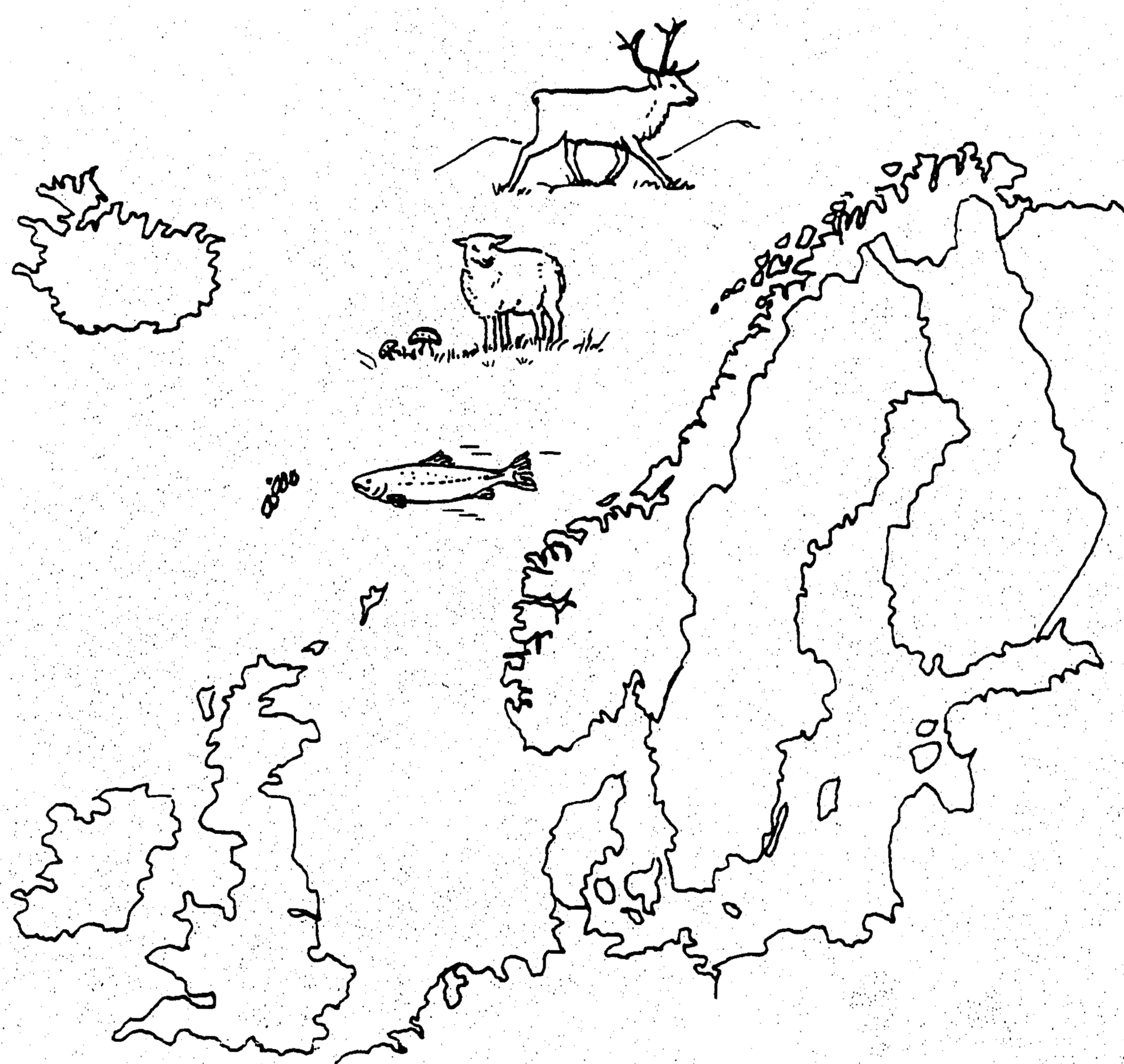
TECHNICAL REPORT EKO-2.1

THE SHEEP PROJECT 1994 AND 1995

TR-EKO-2(1995)1



NORDISK KJERNESIKKERHETSFORSKNING

INTRODUCTION

The EKO-2 project, "Long ecological half-lives in semi-natural systems", consists of three subprojects; sheep grazing on uncultivated pasture, mushroom and freshwater fish. The main aim is to identify the contribution from semi-natural systems, by determining ecological half-lives for specific foodstuffs from these areas, and thus determine dose to man.

By producing models that can decrease the uncertainties in dose calculations, it is possible to quickly develop a picture of possible consequences in a fallout situation, and implement appropriate countermeasures. Foodstuffs from semi-natural areas (such as uncultivated pastures) accounts for a considerable portion of the dose to man.

The study of transfer of radiocesium and radiostrontium from soil to vegetation and sheep are performed in «the sheep-project». The soil - vegetation - sheep - system is studied in five countries; Iceland, The Faeroe Islands, Denmark, Sweden and Norway. Co-ordinated collection of soil, vegetation and meet samples (as well as live animal monitoring) have been performed during the period 1990-1994. This sampling gives good basis for calculating the ecological half-lives in the different areas studied.

Large differences in transfer are found, and by studying the production intensitivity, biomass production, climatic conditions, the presence of mushrooms, intake of soil and experimental studies of labile/stable fractions of stable cesium in soil, some of the differences will be explained. Since soil represents an important reservoir for radionuclides in the terrestrial system, the soil characteristics will be of importance for the different transfer factors that have been observed in the different grazing areas for radiocesium from soil to meat.

This technical report consists of the results from the sheep project during the two last years (1994 and 1995).

Please do not refer to the results given in this report without prior consent of the authors. The material will later be published in an international scientific journal.

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TABLE OF CONTENT

MOBILITY OF CS IN SOIL

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INTRODUCTION

Soil represents the major sink for radionuclides released into the terrestrial environment. Hence, the mobility of any radionuclide and its subsequent transfer through food chains will be dependent, to some degree, on its interactions with soil components. In any soil-plant-animal system, time dependent changes in vegetation and animal activity levels can reflect a number of factors. For example, *ecological half-lives* can be influenced by the rate at which radionuclides are *physically* removed from soil rooting zones (i.e., run-off, transport down the soil profile) and by the rate at which radionuclides are transformed *chemically* to species that are less available for biological uptake (e.g., diffusion of radiocaesium into the clay mineral lattice) (Fig. 1). Providing that environmental and agricultural parameters remain constant, long-term (i.e., over a number of years) changes in soil-to-plant *transfer factors* usually reflect a change in chemical specitation of the radionuclide. A number of soil processes can influence radionuclide speciation, including soil biology (i.e., microorganisms). Of course, if radionuclides are deposited in an inert form (i.e., uranium oxide fuel particles) weathering to more mobile species may lead to an increase in transfer factors. In summary, the variations in both ecological half-lives and transfer factors between different soil-plant-lamb ecosystems may reflect site-specific parameters (i.e., soil characteristics, vegetation type, climate conditions and agricultural practice) and/or the source term of fallout radionuclides.

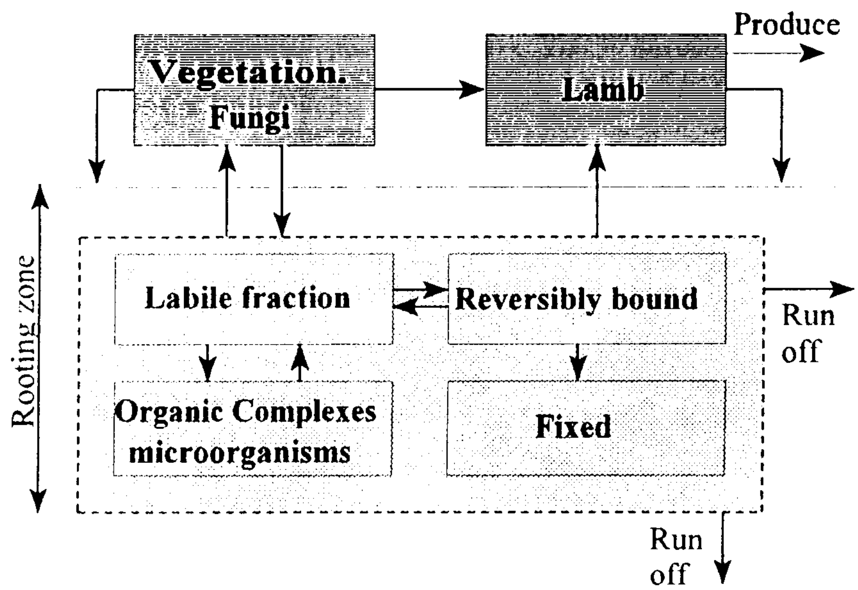

Figure 1. Major soil processes influencing ecological half-lifes in a soil-plant-sheep ecosystem.

It has been known for many years that the mobility of radiocaesium is limited by interactions with clay minerals (Sawnhey, 1960; Shultz et al., 1960; Sawnhey, 1972; Evans et al, 1983). The highly selective sorption of caesium to clay minerals is thought to take place in the interlayer spaces between the frayed particle edges (Sawnhey, 1972). Non-expanded layer silicates such as illite and micas show a greater retention of caesium than the expanded layer silicates vermiculite and montmorillonite (Tamura and Jacobs, 1960). However, in recent years, interest has been directed towards the relationship between caesium mobility and the *kinetics* of interactions with soil components (Absalom et al., in press) and, in particular, on the reversibility of caesium sorption processes (Comans et al., 1991; Comans and Hockley, 1992). Laboratory tracer studies on illite (Comans et al., 1991), soils (Absalom et al, in press) and freshwater sediments (Evans et al., 1983) have indicated a slow fixation of radiocaesium, with reaction times of months to years. It is clear that the kinetics of such sorption processes will influence both the mobility and the ecological half-life of radiocaesium. Hence, the aim of this work was to study the kinetics of radiocaesium and radiostrontium sorption in soils, and to relate results to environmental studies of ecological half-lifes and transfer factors.

Samples used in these studies were collected from sites that have been included, for the past 6 years, in a unique monitoring programme of radioceasium transfer in Nordic soil-plant-lamb food chains (Hove et al., 1994; Rosén et al., 1995). Sorption kinetics in soils were studied using controlled laboratory tracer (^{134}Cs and ^{85}Sr) experiments. These experiments enable us to determine the extent to which soil parameters alone (as compared to environmental and agricultural parameters) might account for observed differences in ecological half-lives between the Nordic sites. Particular emphasis was placed on the rates of change of radionuclide mobility, sorption mechanisms and speciation in soils. Desorption studies included the application of sequential extraction techniques, wherein the speciation of tracers was compared to that of "natural" radionuclides (^{137}Cs and ^{90}Sr) and naturally-occuring stable analogues (Cs and Sr).

Variations in ^{137}Cs transfer factors have been observed between the different Nordic sites (Hove et. al., 1994). This could be due to site-specific environmental parameters such as soil characteristics or agricultural practice, or it might reflect varying degrees of isotopic exchange --- confounded by the fact that the sites have varying contributions from weapons and Chernobyl fallout. In order to determine the extent to which environmental parameters can account for the differences in radiocaesium transfer, concentrations of the naturally-occuring Cs analogue has been measured in the soil-plant-lamb systems. Deposited ^{137}Cs should be acting as a tracer for the stable Cs: isotopic exchange will occur between radiocaesium and stable caesium. Stable Cs levels will reflect the equilibrium distribution in the ecosystem.

MATERIALS AND METHODS

Soils have been received from Tjøtta, Norway (1995); Blomhöjden, Sweden (1994 and 1995); Hestúr, Iceland (1994), and Ribe, Denmark (1995). Soils were air dried (<60°C) prior to extraction and tracer studies. Standard soil characteristics were measured in all soil samples included in tracer studies. Parameters include: pH, dry weight (105°C), organic content by loss on ignition (LOI), cation exchange capacity (CEC), major available macro elements, and base saturation. Stable Cs and other trace element concentrations were determined by neutron activation analysis (NAA). Details of soil and NAA methods can be found in Øien and Krogstad (1987) and Oughton and Day (1993) respectively.

Vegetation samples have been recieved from Iceland, Sweden and Norway. These samples were dried, homogenised and subject to stable Cs and trace element analysis (NAA).

Lamb tissue samples (Sweden 1994 and 1995, Iceland 1994, and Norway 1995) were ashed (350°C) prior to determination of stable Cs and trace element concentration (NAA).

Tracer Kinetic Studies

Tracer solutions (^{134}Cs and ^{85}Sr) in artificial rainwater (pH 5.2) were added to air-dried soils, and the mixture homogenised gently using a food mixer. The volume of water added was enough to ensure that the soil was evenly wet without being waterlogged. All samples were stored at 4°C in aerobic conditions. Aliquots of soil were removed as a function of time and extracted first with water and then with 1 M NH_4Ac (soil pH). The solid (dry weight) to liquid ratio was ca. 1:20 and extraction time was 1 hour. Extracts and residues were counted, and the rate of adsorption calculated as a function of time after addition. In order to provide more detailed information on soil-radionuclide interaction, some aliquots were subject to more thorough sequential extraction procedures, including extraction with 1M NH_4Ac (pH 5) and dissolution with H_2O_2 and 7M HNO_3. The distribution of tracers between extracts has been compared to both ^{137}Cs and ^{90}Sr and stable analogues. Full details of sequential extraction methods can be found elsewhere (Oughton et.al. 1992). All analyses were carried out in duplicate.

RESULTS

Characterisation of Soils

Available data on soil characteristices is given in Tables 1-3. Obtained values for LOI, pH and available major cations (Tables 1 and 2) show good agreement with reported average values for 1990 soil samples (Hove et.al., 1994). Ribe and Hestúr soils were rather homogenous, whereas characteristics of Blomhöjden and Tjøtta soils (LOI, pH, CEC) varied between the different plots. Trace element analysis revealed that concentrations of the alkali metals Cs and Rb in Hestúr soils were a factor of 10 lower, and the transition metals Co, Fe and Zn significantly higher, than in Blomhöjden soils (Table 3). Blomhöjden soils showed between 5 and 30% enchancement of Cs, Rb, Sc, Fe, Cr, Co and Ce in the mineral layer as compared to the upper organic layer. Zinc was the only element to show conistently higher levels in the organic layer. No consistent depth variation could be observed for Hestúr soils. In vegetation, concentrations of Co and Fe were higher in Hestúr, however, despite the large difference in soil concentration levels, Cs and Rb levels were similar at the two sites. Caesium transfer factors will be discussed in more detail later.

Table 1: Cation Exchange Capacity, Major Available Cations meq/100g.

	Na	Mg	Ca	K	H^+	Fe (ppm)	CEC
Tjøtta 1	0.53	0.96	28.21	0.15	0	0.15	29.9
Tjøtta 2	1.52	5.28	42.08	1.10	38.59	0.46	88.7
Tjøtta 5	1.37	6.94	42.04	1.47	35.92	0.12	87.9
Hestúr 1	1.14	7.54	7.02	1.09	17.59	0.15	34.4
Hestúr 2	1.14	4.52	5.76	1.64	28.09	0.38	41.2

Table 2: General Soil Characteristics

	pH water	pH $CaCl_2$	LOI %	CEC meq/100g	Base sat^n %
Tjøtta 1*	6.6	-	21.1	29.9	100
Tjøtta 2*	5.2	-	61.4	88.7	56.5
Tjøtta 5*	5.4	-	77.5	87.9	59.1
Tjøtta 1	6.5	-	6.7		
Tjøtta 2	6.7	-	16.5		
Tjøtta 3	5.3	-	18.1		
Tjøtta 4	5.1		29.4		
Tjøtta 5	5.7		49.4		
Tjøtta 6	5.6		90.9		
Hestúr 1	6.0	5.3	35.5	34.4	48.9
Hestúr 2	5.3	4.8	44.4	41.2	31.8
Blomhöjden 1	4.7	-	26.6		
Blomhöjden 2	5.5	-	10.8		
Blomhöjden 3	5.5	-	44.4		
Blomhöjden 4a	5.9	-	28.7		
Blomhöjden 4b	5.4	-	29.6		
Blomhöjden 4c	4.3	-	37.7		
Blomhöjden 5	4.5	-	6.3		
Ribe 1	4.9	-	10.5		
Ribe 2	4.9	-	10.5		
Ribe 3	4.7	-	8.6		
Ribe 4	5.5	-	11.7		
Ribe 5	5.4	-	7.3		
Ribe 6	5.8	-	7.2		

* 1993 samples

Table 3a: Trace Element Concentrations ($\mu g/g$) in Whole Soil Samples (NAA analysis). Mean ± SEM (range).

	Ce	Co	Cr	Cs	Eu	Fe mg/g	Rb	Sc	Se	Sr	Zn
Tjøtta n=12											
Hestúr n=11	18.5 ± 1.3 (10-25)	33 ± 5 (19-67)	73 ± 3 (49-85)	0.11 ± 0.01 (0.08-0.13)	1.00 ± 0.07 (0.63-1.4)	51 ± 8 (31-122)	ND	16.6 ± 0.8 (10-20)	1.4 ± 0.1 (1.0-1.7)	154 ± 23 (87-293)	176 ± 10 (127-215)
Blom-höjden n=19	15.3 ± 0.8 (9.5-20.6)	8.1 ± 1.3 (3.5-24)	98 ± 6 (59-152)	1.25 ± 0.07 (0.8-2.0)	0.56 ± 0.04 (0.36-1.1)	23 ± 1 (14-35)	46 ± 3 (28-66)	10.8 ± 0.5 (7-15)	0.9 ± 0.3 (0.7-1.3)[a]	192 ± 6 (148-255)	126 ± 13 (81-161)
Ribe n=12											

a: 3 results

Table 3b: Trace Element Concentrations ($\mu g/g$) in Mixed Vegetation Samples (NAA analysis). Mean ± SEM (range).

	Ce	Co	Cr	Cs	Eu pg/g	Fe	Rb	Sc	Se	Sr	Zn
Tjøtta n=8											
Hestúr n=10	0.16 ± 0.02 (0.08-0.24)	0.7 ± 0.1 (0.5-1.4)	ND	0.13 ± 0.01 (0.09-0.22)	5.9 ± 0.7 (2.6-9.3)	412 ± 63 (131-744)	11 ± 2 (4-20)	0.09 ± 0.01 (0.04-0.17)	ND	27 ± 1 (23-32)	23 ± 3 (14-45)
Blom-höjden n=24	ND	0.16 ± 0.03 (0.03-0.2)	ND	0.13 ± 0.02 (0.03-0.57)	ND	48 ± 3 (30-97)	38 ± 3 (15-66)	0.006 ± 0.001 (0.002-0.07)	ND	23 ± 2 (10-48)	83 ± 20 (19-351)

Kinetic Tracer Studies
Tracer experiments enable the kinetics of radionuclide interactions with soil components to be followed under controlled laboratory conditions. Studies have been divided into adsorption and desorption (sequential extraction) experiments. During 1995, experiments of more than 8 months contact time have been carried out on Tjøtta and Hestúr soils; results of these studies are presented here. Studies on Blomhöjden and Ribe soils are underway; Faroe Island and new Iceland soils will be sent in 1996.

Sorption Studies

Results from sorption studies showed that both ^{134}Cs and ^{85}Sr became rapidly associated with soil components. After 1 hour contact time with soils, more than 90% of the total activity was adsorped to soils (Fig. 2). However, soil-bound ^{85}Sr was significantly more mobile than ^{134}Cs: between 50 and 80% could be displaced from binding sites by a single extraction with NH_4Ac, compared to 0 to 30% for ^{134}Cs (Fig. 3). Both nuclides showed a time-dependent increase in the degree of sorption to soils, the percentage extracted both by water and by NH_4Ac decreasing with contact time (Figs. 1 and 2). Soils types showed clear differences in the degree of tracer sorption. After 6 months, ^{134}Cs was much more mobile in Hestúr than in Tjøtta soils, up to 30% remained extractable by NH_4Ac compared to less than 2 % in Tjøtta soils (Fig. 3). For ^{85}Sr, two of the Tjøtta soils showed rather low extractability into NH_4Ac, about 38%, the other Tjøtta soil and both Hestúr soils giving between 50 and 70% extractability into NH_4Ac. Results of modelling and correlations with soil characteristics will be discussed after a presentation of sequential extraction data.

Sequential Extraction

Results of sequential extraction studies showed that ^{134}Cs was both rapidly and strongly adsorbed to all soils (Figs. 4-6). The site appears to be the main factor govening NH_4Ac extractability of ^{134}Cs. However, the full extraction carried out after 5 months indicated significant differences in the distribution of ^{134}Cs between H_2O_2 (the oxidisable "organic" fraction) and HNO_3 (strongly bound) fractions. The two Tjøtta soils having a high organic content showing 48 ± 4 % extraction into H_2O_2 (Fig. 6). These two soils also indicated a enhanced extraction of ^{85}Sr in the oxidisable fraction, 16 ± 1 %, and a significant enhancement of ^{85}Sr extraction into NH_4Ac at pH 5 as compared to the other soils.

Comparisons of the tracer distribution in Tjøtta soils with that observed for fallout ^{137}Cs and ^{90}Sr, as well as stable analogues (Fig. 7) indicate that the tracer studies are giving a relatively good picture of environmental processes. The higher percentages found in residue for the fallout radionuclides undoubtedly reflect the longer contact time and diffusion of Cs into the clay mineral latice. However, extraction of ^{137}Cs into NH_4Ac was greater than that of the tracer. This is thought to be because sequential extraction was carried out on soil samples from the upper 2 or 3 cm (i.e., those having high enough ^{137}Cs levels to give good counting statistics), whereas tracer studies were carried out on soils taken from 0-5 cm. Previous studies have shown that ^{137}Cs is more mobile in the upper litter and organic rich soil layers (Oughton and Salbu, 1992). Sequential extraction studies (full procedure) are underway on 0-5 cm soil samples from 1995. These samples will also be analysed for ^{137}Cs, ^{90}Sr and stable analogues.

Modelling and relation of results to soil characteristics

Sorption and desorption studies indicated that sorption of both the tracers could be described by a two stage process, probably reflecting a rapid adsorption to exchangeable sites and a slower removal to less available binding sites (Fig. 8). K_{dl} represents the distribtion between water and labile compartments, and is used instead of K_d because K_d schanges with time whereas K_{dl} is rather constant (Absalom et al., in press). The decrease in activity in water and NH_4Ac was modelled using a simple box model (SB Modelmaker, 1994). When attempting to parameterize the models, attention was paid to both sequential extraction data and to soil chemistry. If must be stressed that the model represents a mathematical interpretation of the data, intended to aid in soil-specific comparisons, and that we areaware that a multitude of sorption and desorption processes can be responsible for the overall trend.

Mobility of ^{85}Sr seems to be negatively correlated with organic content, CEC and available Ca. This could reflect Sr association with organic material in the two peaty Tjøtta soils. The water:NH_4Ac ratio (k_{dl}) was higher for ^{85}Sr in Tjøtta soils than Hestúr soils, which may indicate increased competition for binding sites in the calcium rich Tjøtta soils. Strontium sorption could be described by model incorporating a rapid equilibrium between the soil solution and easily-exchangeable sites (half life in the order of minutes) followed by a slower removal to reversibly bound and "fixed" sites, possibly represented by amophous carbonate or organic material. Examples of data modelling are shown in figure 9. Although soils do appear to be showing different fixation rates, because of the small number of points it seems premature to present individual rate constants at this stage. However, the rate constant, k_3, range from between 0.004 to 0.016 d^{-1}. The data will be fully analysed for each soil after the next two sampling points.

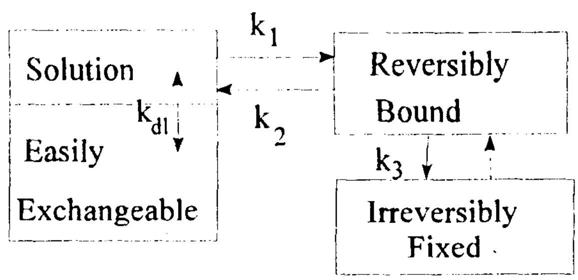

Figure 8. Box model for Cs and Sr adsorption in soils

Caesium interaction with soil seems to be more dependent on site than on any one soil characteristic. This could reflect the importance of soil minerology on Cs uptake (i.e., clay type), although a combination of factors may be responsible. It is possible that the low water: NH_4Ac ratio (k_{dl}) in Norway 1, reflects the low concentration of available K in this soil. Caesium sorption could be described by a rapid uptake to *both* easily-exchangeable and bound sites. Whereas the labile fraction (NH_4Ac exchangeable) is in rapid equilibrium with soil solution, the reversibly-bound Cs is only slowly released to soil solution. Half-times appear to be in the order of a few days ($k_2 = 0.20 \pm 0.15\ d^{-1}$). There was also evidence for a long term "fixation" of Cs in most soils, but more points are needed before any differences between soils can be resolved with any confidence. However the rate constant for fixation, k_3 appears to be in the order of $0.0009 \pm 0.0007\ d^{-1}$. Examples of data/model extrapolations are shown in figure 10.

Stable Cs Analysis in Soil-Plant-Sheep System

Determination of ^{137}Cs concentrations throughout soil-plant-lamb systems revealed large variations in transfer factors between different Nordic sites, both soil-to-plant and plant-to-animal (Hove, 1994). Many factors are known to influence transfer factors, including physical, chemical, biological, physiological, environmental and agricultural processes. However, the observed differences between these countries are complicated by the fact that the countries have different source terms of ^{137}Cs, namely different relative levels of weapons and Chernobyl fallout. It follows that variations in transfer factors might also be influenced by differences in the degree to which deposited ^{137}Cs has reached equilibrium within the ecosystem, either because of different contact times (e.g., weapons vs. Chernobyl fallout) or different rates of isotope exchange. One way of removing this extra "noise" is to analyse the levels of naturally-occuring stable analogues in the ecosystem, namely stable Cs.

Results of Hestúr and Blomhöjden samples are given in Table 4. Although Hestúr had lower concentrations of Cs in soils, the levels of Cs in vegetation was similar. This corresponds with the relatively high mobility of Cs in Hestúr soils. Plant-to-sheep concentration ratios were similar to averages presented for ^{137}Cs over the past 4 years (Hove et.al., 1994; Andersson et al., 1994); the value for stable Cs was a little higher than the 1994 value for ^{137}Cs for the Blomhöjden lambs (Andersson et al., 1994). It seems reasonable to conclude that ^{137}Cs is more or less in equilibrium with stable Cs as far as plant to sheep transfer is concerned, and that there is little significant difference between the Hestúr and Blomhöjden sheep. It will be extremely interesting to compare data from the Faroe Island sheep in this repect.

Table 4: Concentrations and concentration ratios (CR) of naturally-occurring stable caesium in soil-plant-sheep system. Mean ±SEM (Range). Units: ug/g.

	Soil DW	Plant DW	Sheep 1994 FW	CR soil-veg	CR veg-sheep
Hestur 1994	0.107 ± 0.007 (0.08 - 0.13)	0.127 ± 0.015 (0.084 - 0.22)	0.069 ± 0.004	1.19 ± 0.23	0.54 ± 0.08
Blom. 1994	1.25 ± 0.07 (0.83 - 2.0)	0.107 ± 0.015 (0.038 - 0.29)	0.092 ± 0.012 (0.48 ewe)	0.086 ± 0.017	0.85 ± 0.23
Blom. 1995	Counting	Counting	Counting		
Tjotta 1995	Counting	0.098*	0.076*	0.12**	0.78*
Ribe 1995	Counting	-	-		

Iceland: 22 soil, 6 veg, 6 lambs
Sweden: 19 soil, 24 veg, 1 ewe, 6 lambs
* One sample only
** 1991 sample

Soil to plant concentration ratios were higher for ^{137}Cs than for stable Cs both for Blomhöjden and Tjotta soil-plant systems (0.57 ± 0.08 and 0.87 ± 0.19 for Blomhöjden and Tjøtta, respectively). Data on Bq/kg soil for Hestúr soils is not available, but the few measurements of samples carried out at LAK, indicate that stable and ^{137}Cs transfer factors are of a similar order of magnitude. We conclude that the decrease of ^{137}Cs in vegetation (and sheep) in Hestúr is more likely to be driven by the physical removal of ^{137}Cs from the rooting zone, than by chemical fixation in soils. In Blomhöjden and Tjøtta, removal of ^{137}Cs to irreversibly fixed (at least in terms of the radiological half-life of ^{137}Cs) sites could lead to reduction in transfer factors.

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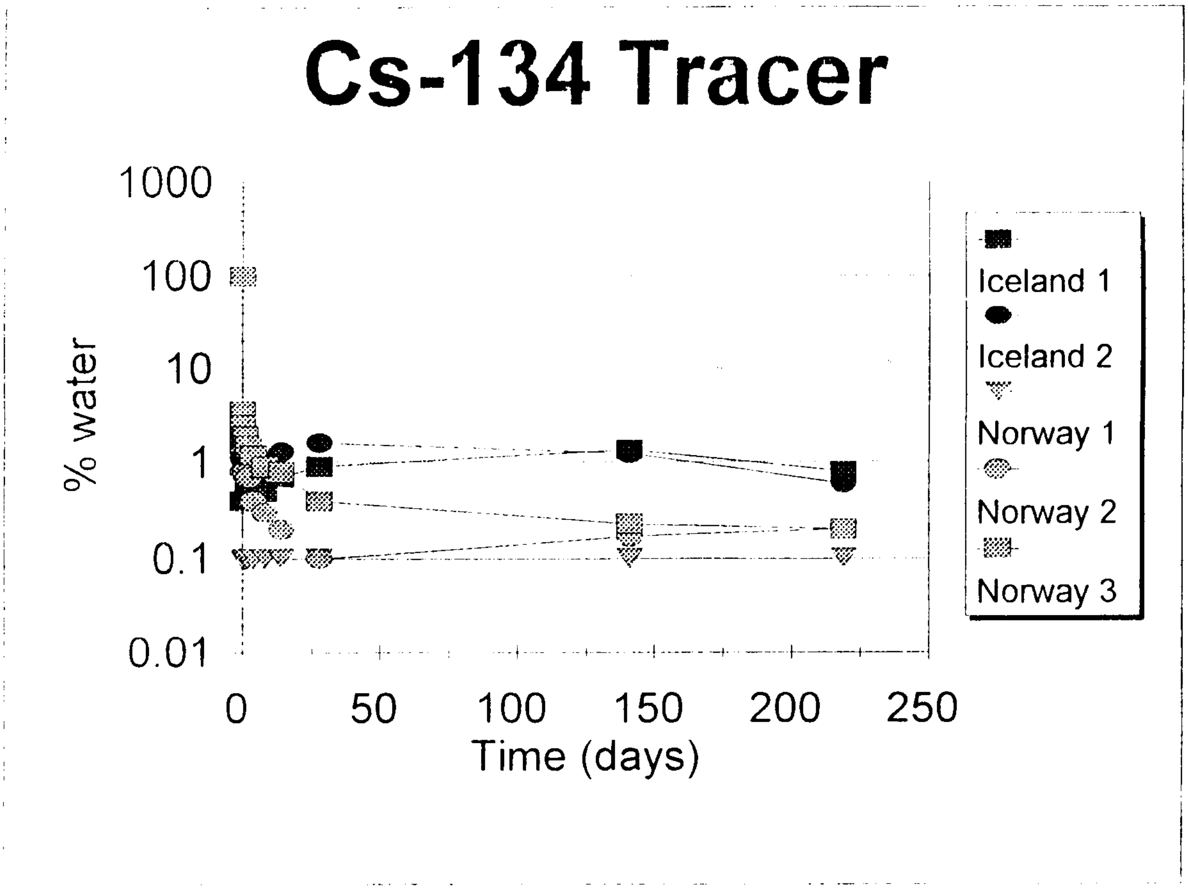
Figure 2: Decrease of ^{134}Cs and ^{85}Sr in water soluble fraction as a function of contact time. Tracer added as ionic solution pH 5.2.



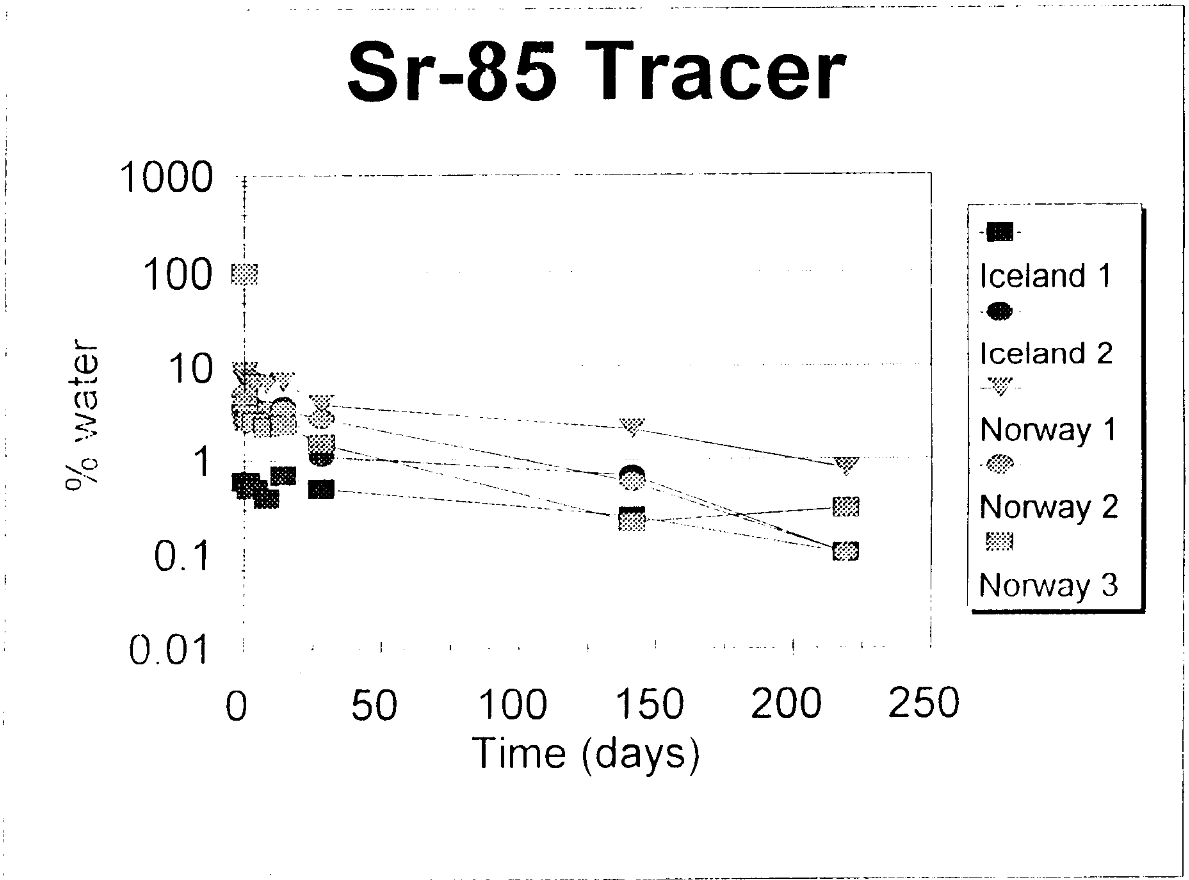
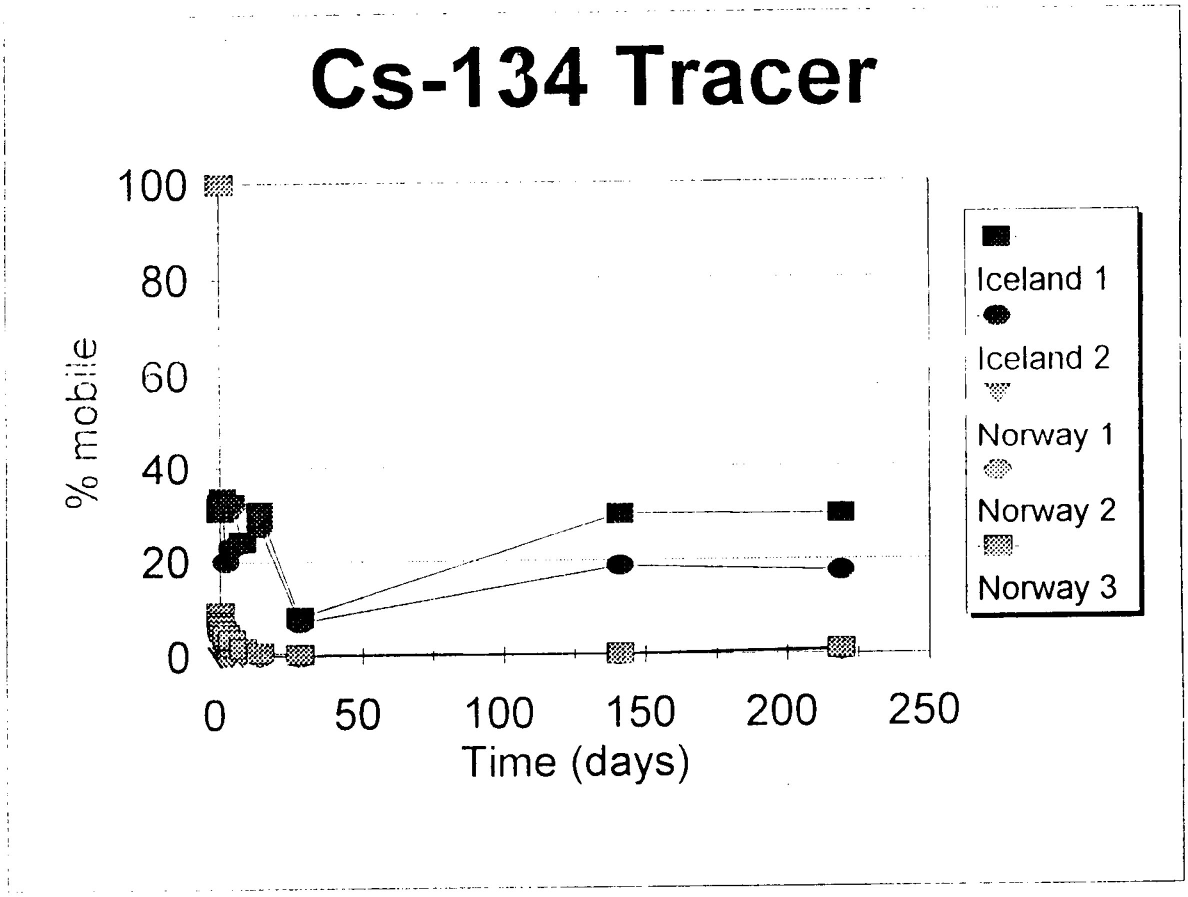


Figure 3: Decrease of ^{134}Cs and ^{85}Sr in "labile" fraction (extractable with NH_4Ac at soil pH).



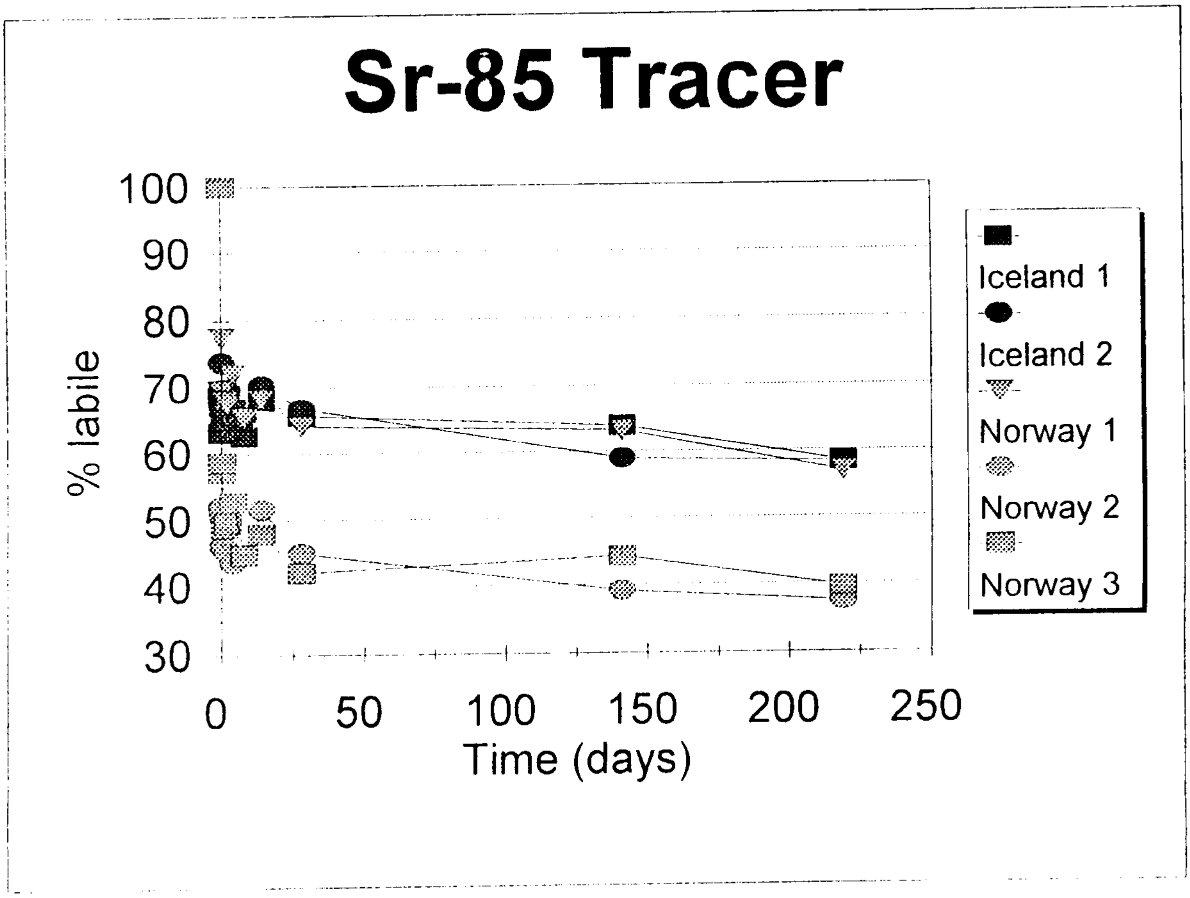
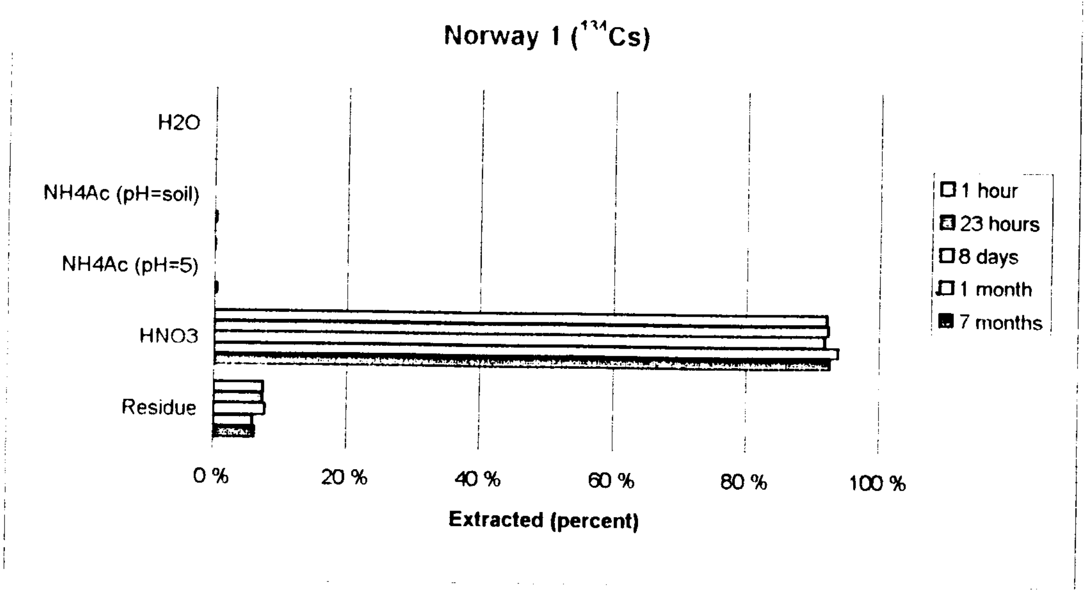
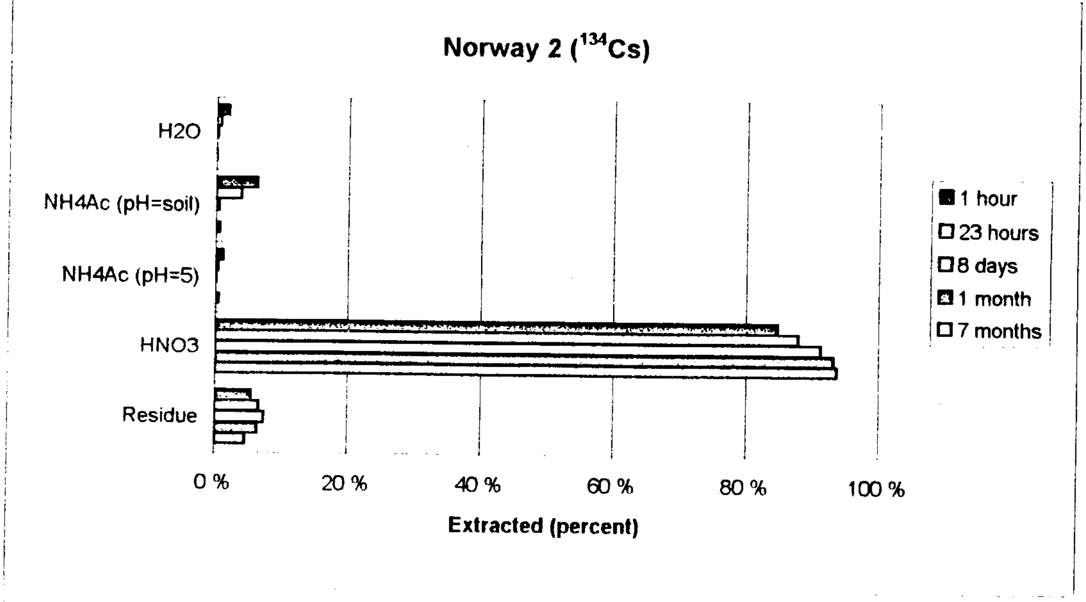
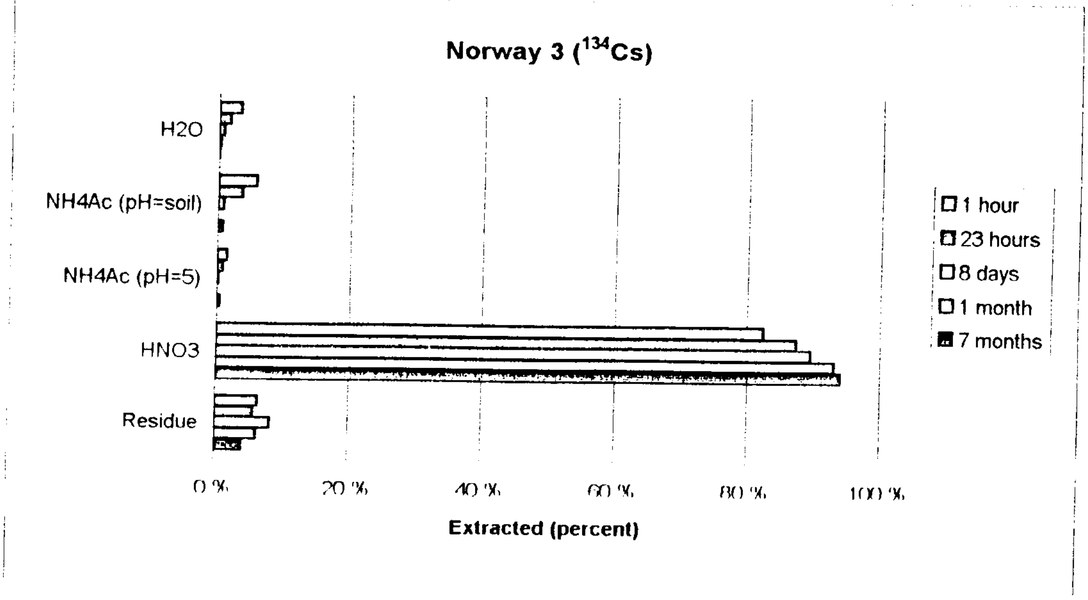
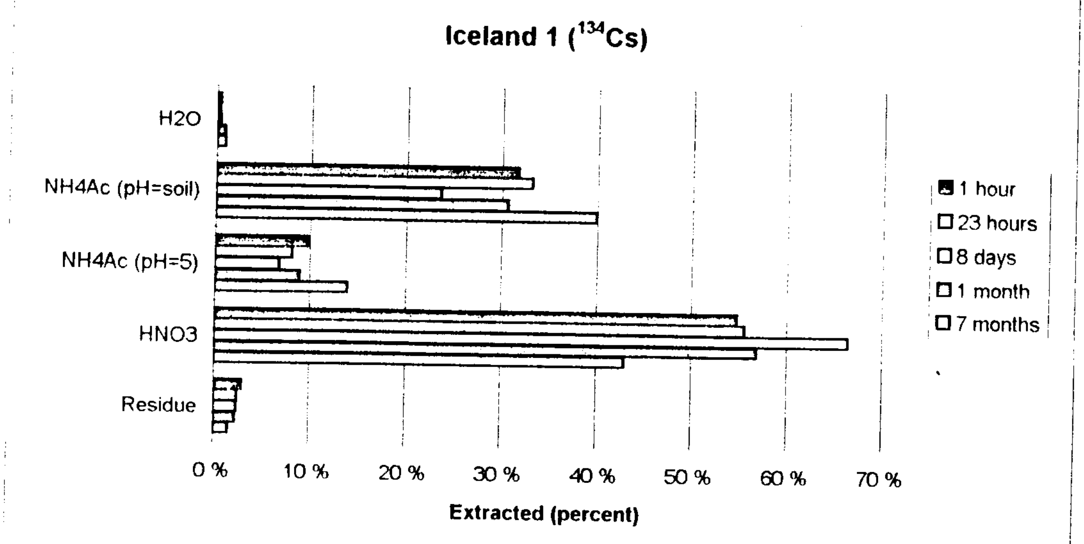


Figure 4a and 4b: Sequential extraction (simple procedure) of ^{134}Cs tracer in Tjøtta (a) and Hestúr (b) soils as a function of contact time.

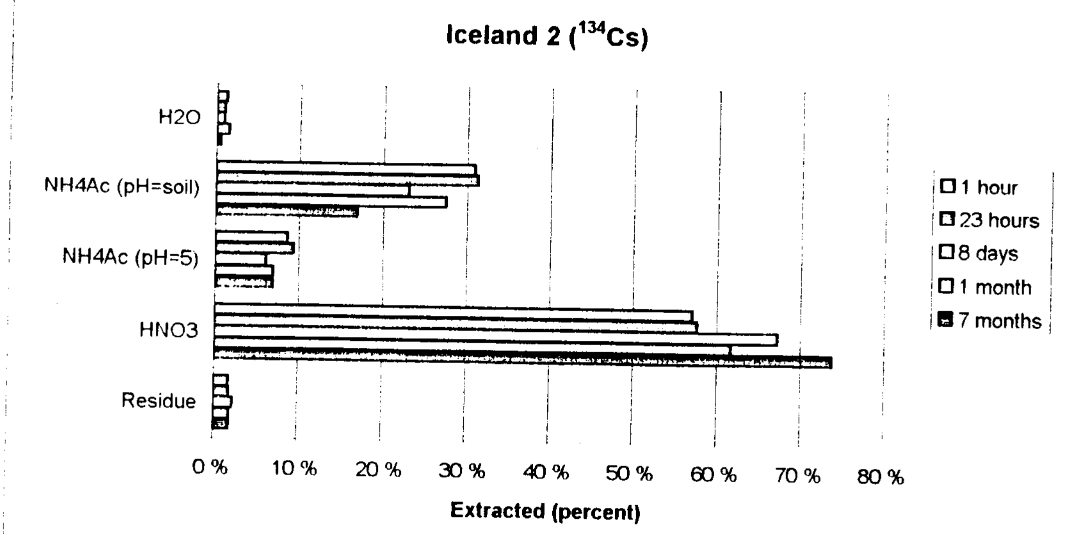






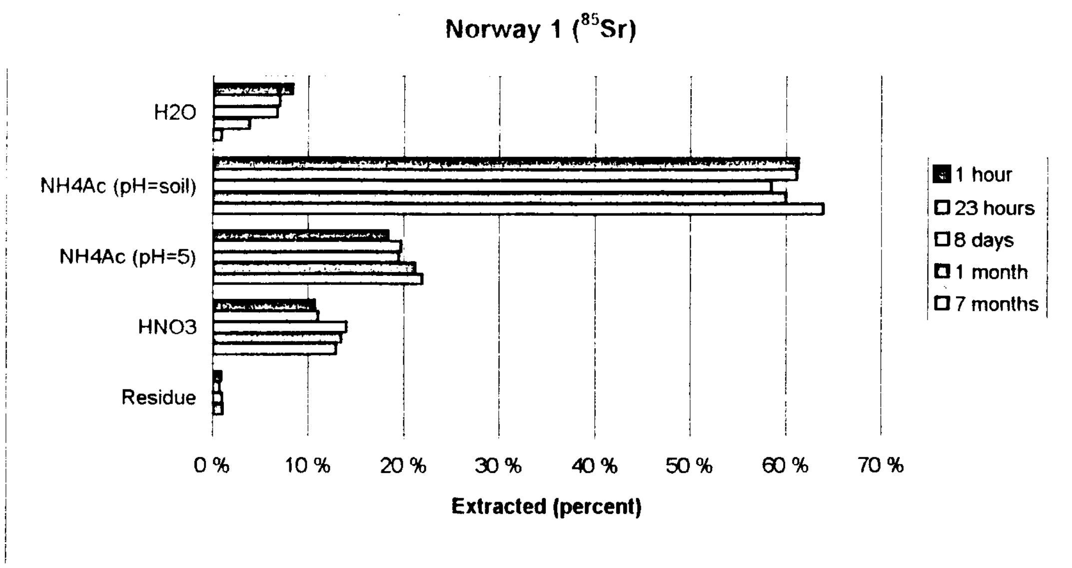


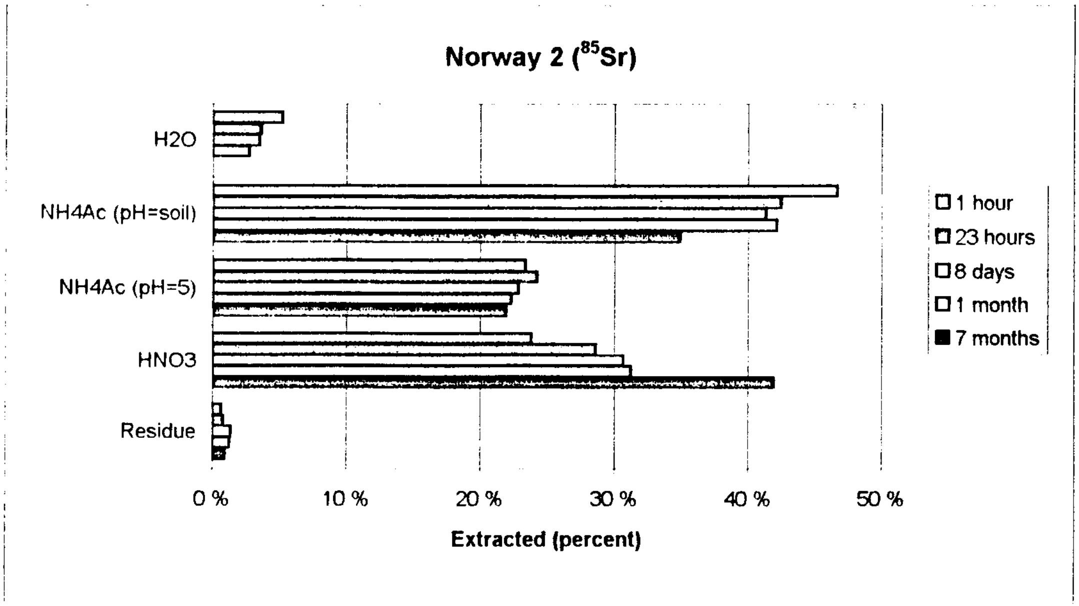
Iceland 1 (^{134}Cs)
H2O
NH4Ac (pH=soil)
NH4Ac (pH=5)
HNO3
Residue
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
Extracted (percent)
1 hour
23 hours
8 days
1 month
7 months

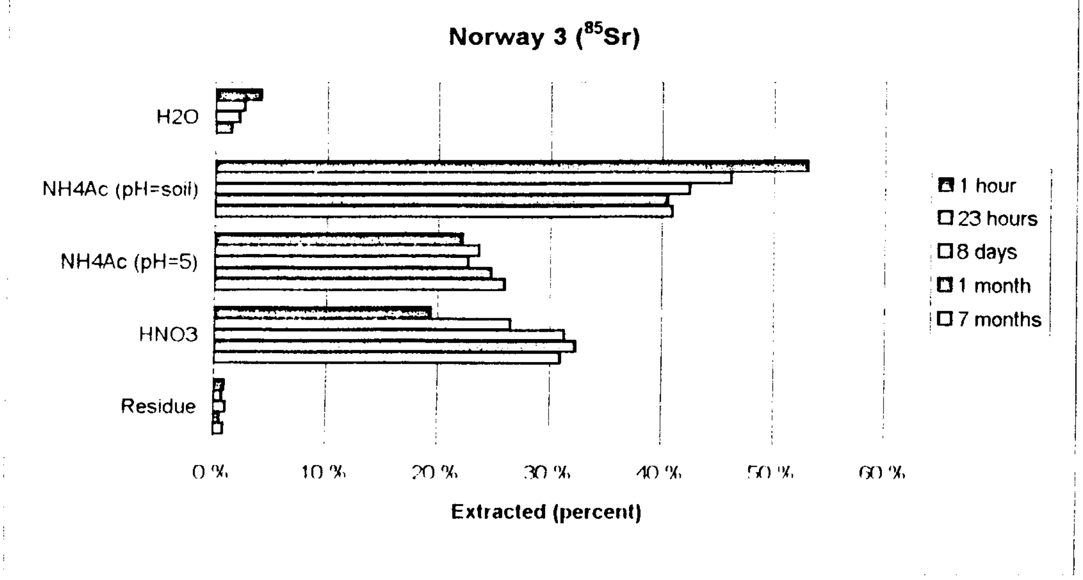


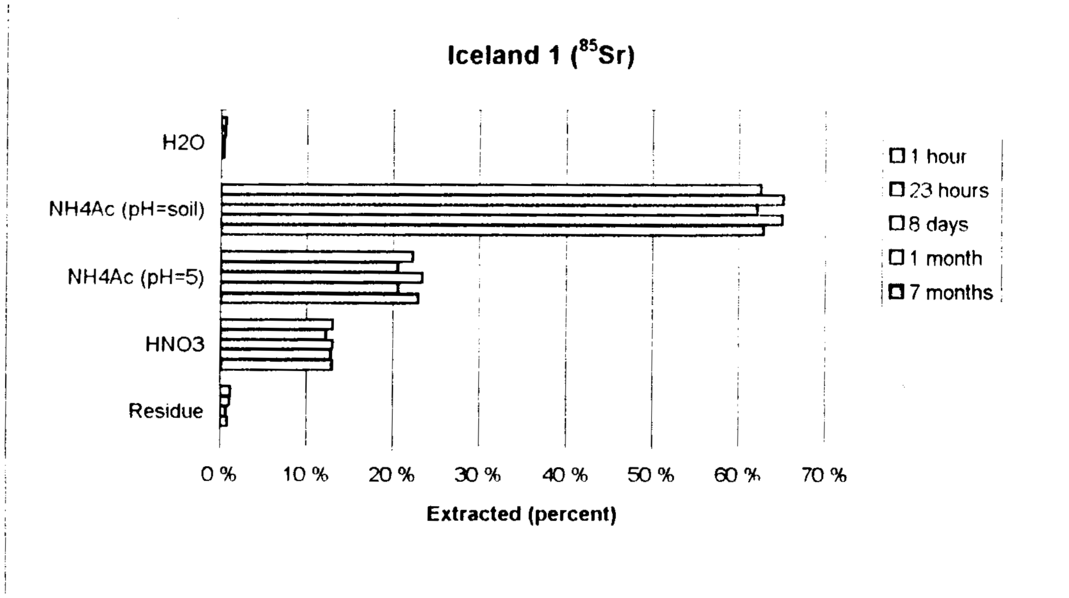
Iceland 2 (^{134}Cs)
H2O
NH4Ac (pH=soil)
NH4Ac (pH=5)
HNO3
Residue
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
80 %
Extracted (percent)
1 hour
23 hours
8 days
1 month
7 months

Figure 5a and b: Sequential extraction (simple procedure) of ^{85}Sr tracer in Tjøtta (a) and Hestúr (b) soils as a function of contact time.

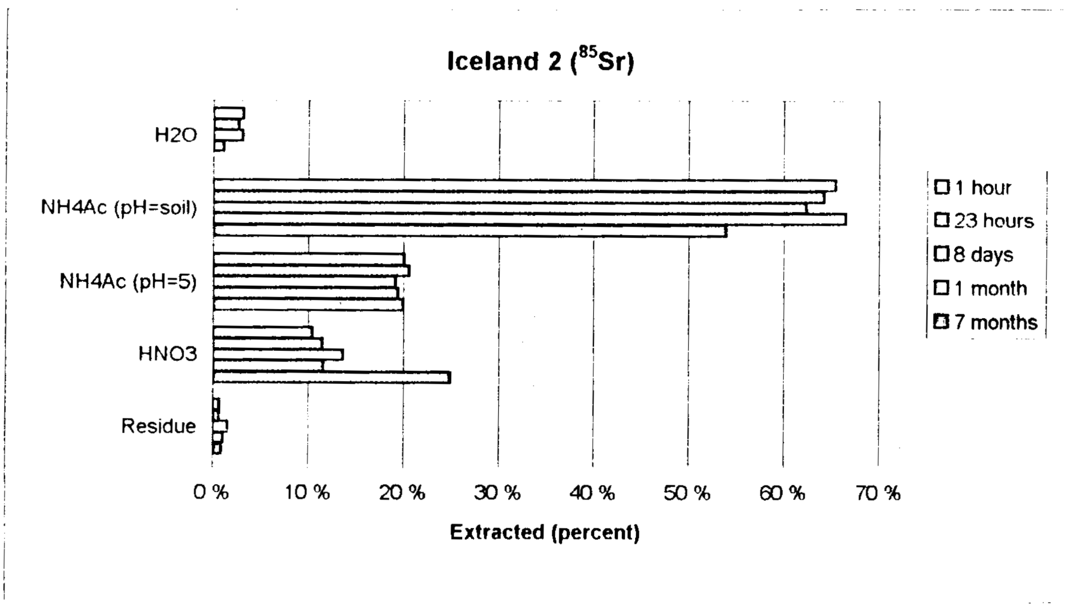








Iceland 1 (^{85}Sr)
H2O
NH4Ac (pH=soil)
NH4Ac (pH=5)
HNO3
Residue
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
Extracted (percent)
1 hour
23 hours
8 days
1 month
7 months



Iceland 2 (^{85}Sr)
H2O
NH4Ac (pH=soil)
NH4Ac (pH=5)
HNO3
Residue
0 %
10 %
20 %
30 %
40 %
50 %
60 %
70 %
Extracted (percent)
1 hour
23 hours
8 days
1 month
7 months

Figure 6a and b: Sequential extraction (full procedure) of ^{134}Cs (a) and ^{85}Sr (b) tracer from Tjøtta and Hestúr soils after 5 months contact time.

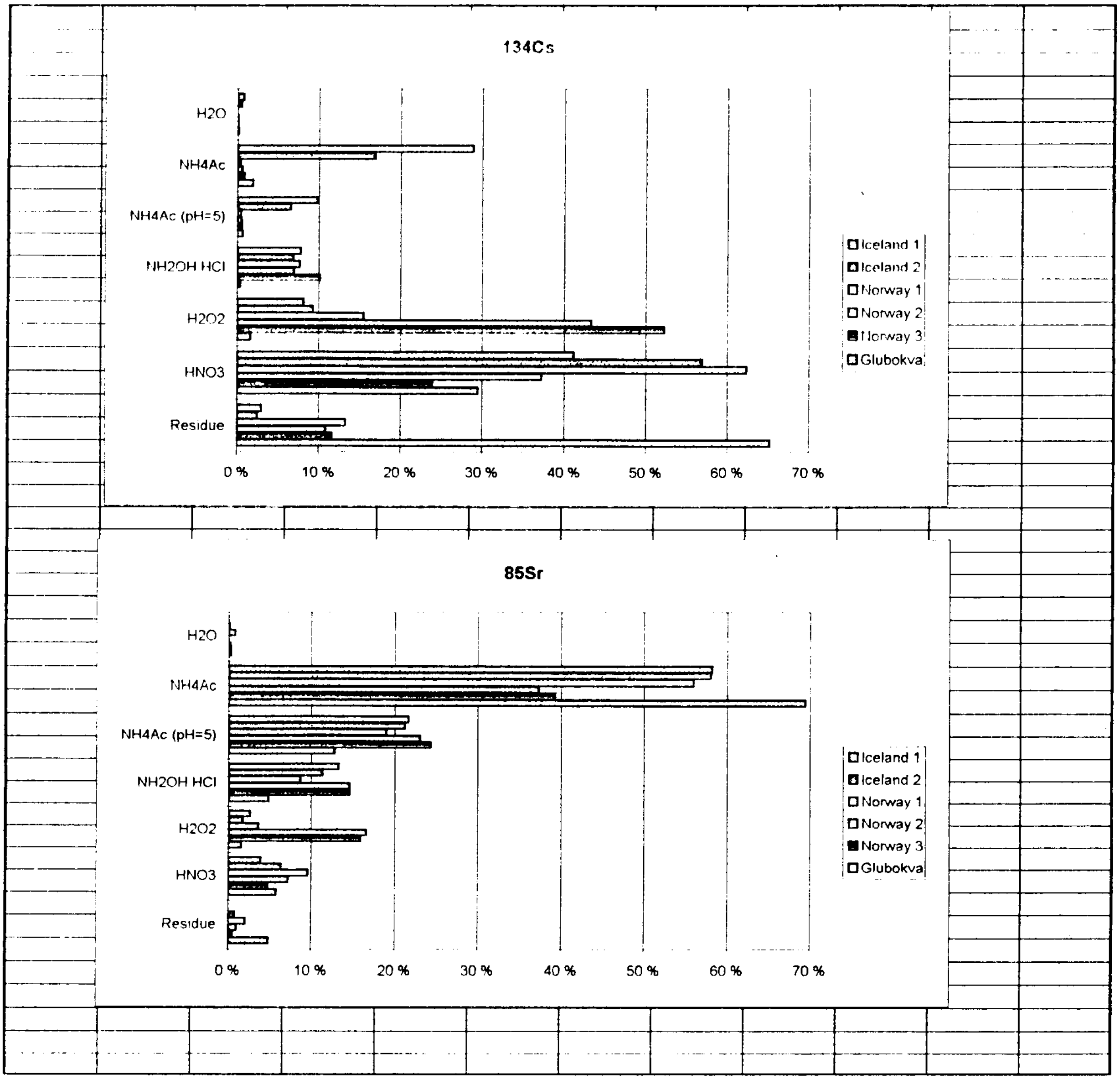
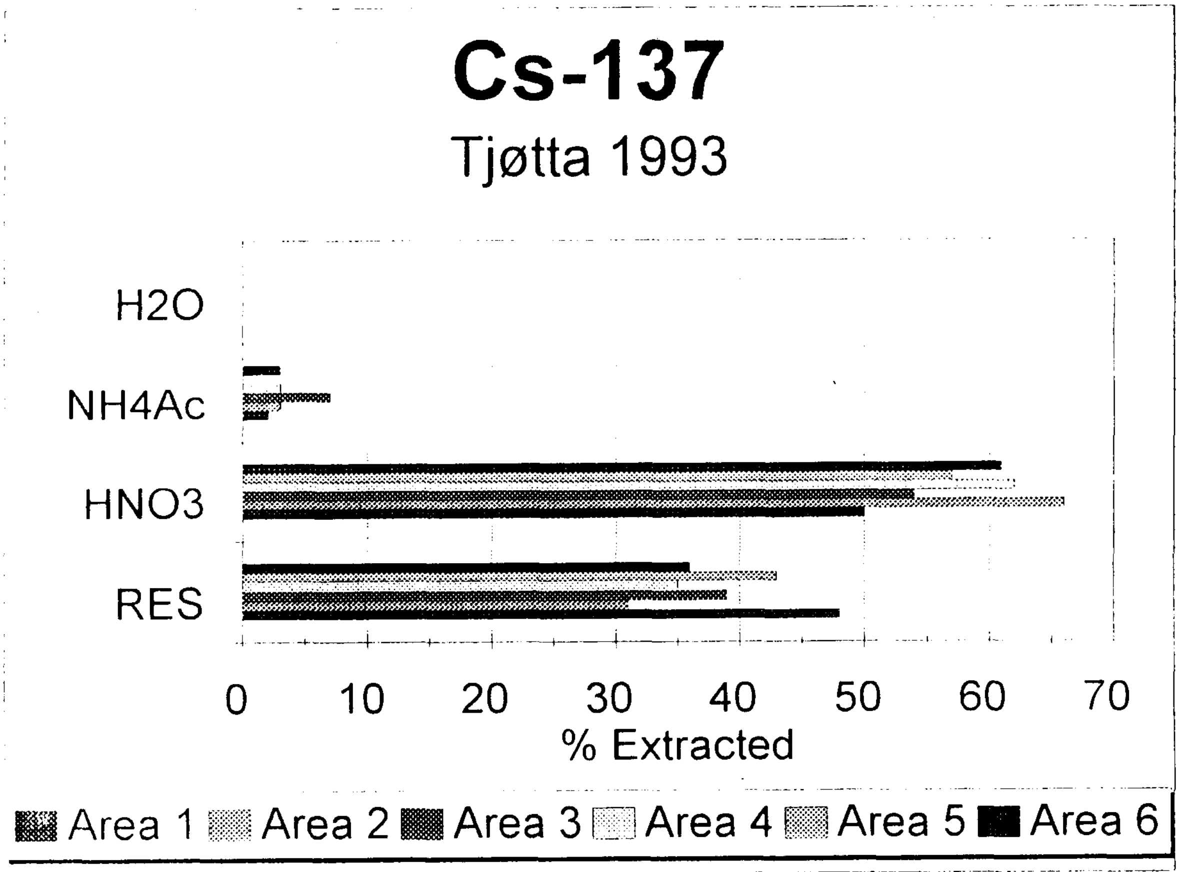


Figure 7: Distribution of Chernobyl ^{137}Cs and ^{90}Sr in Tjøtta soils (0-2 cm), 1993.



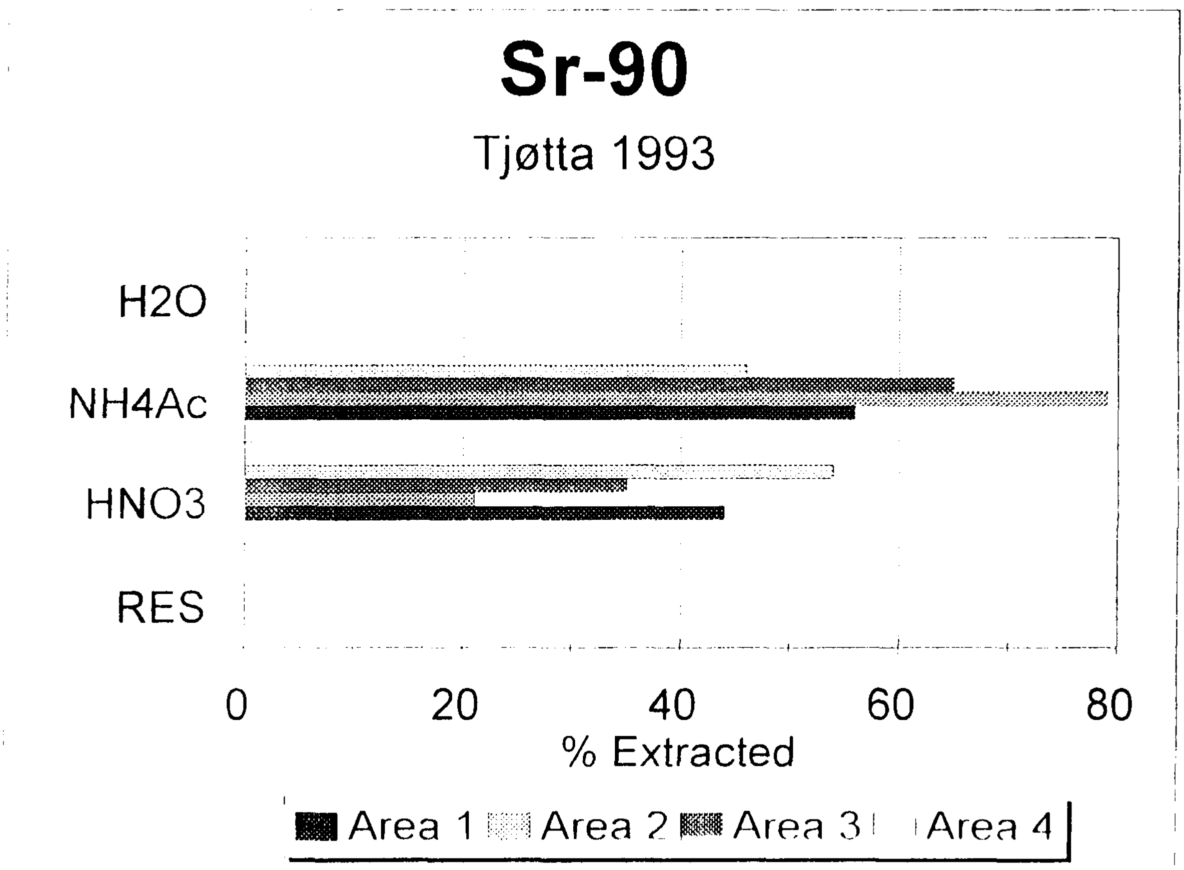
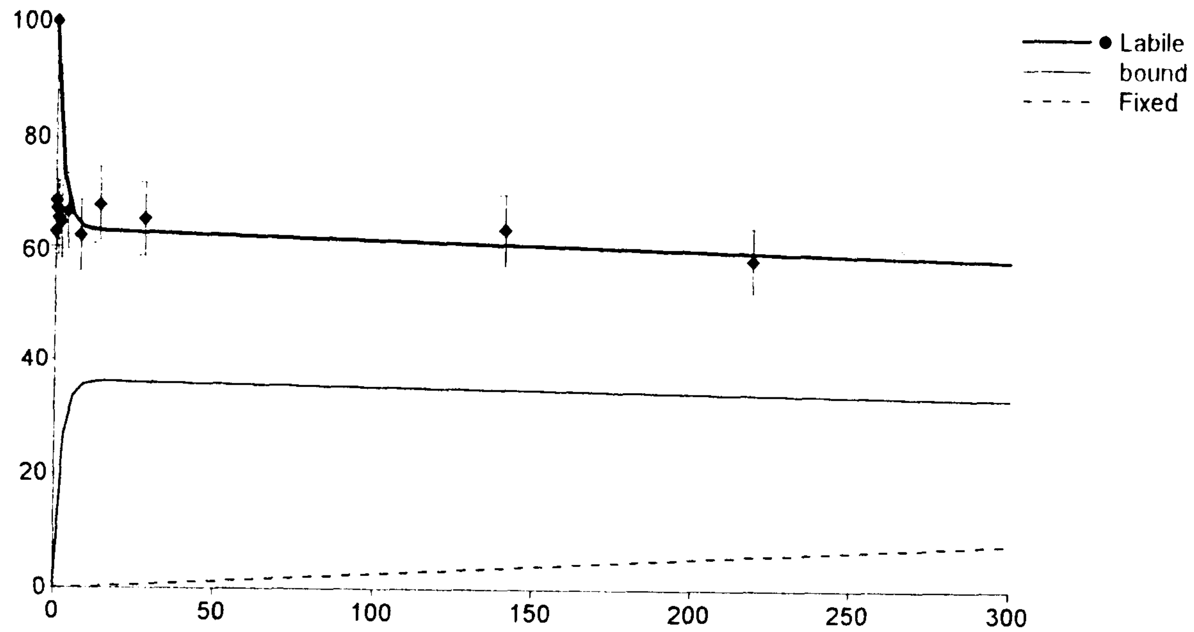


Figure 9. Example of ^{85}Sr model for Hestúr 1 and Tjøtta 3.



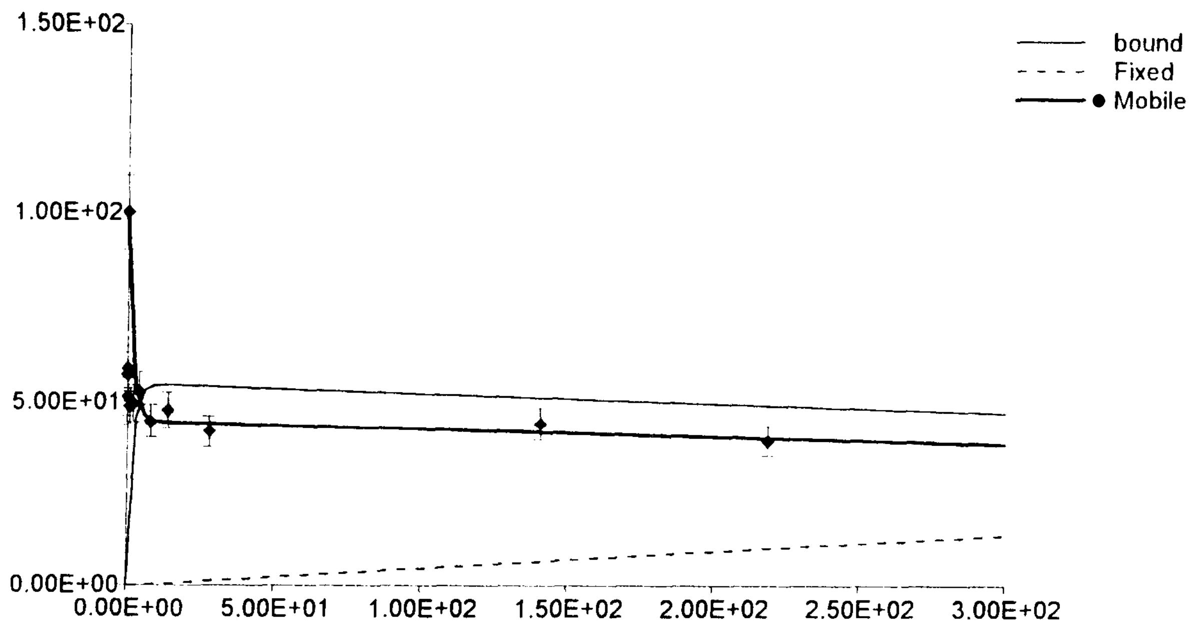
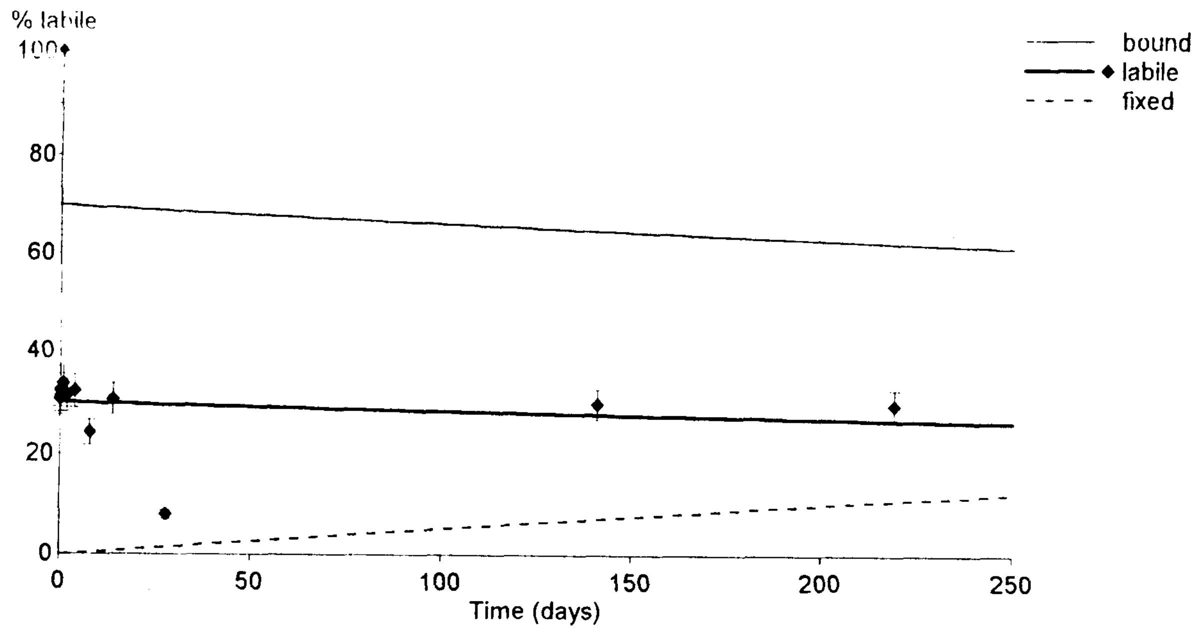
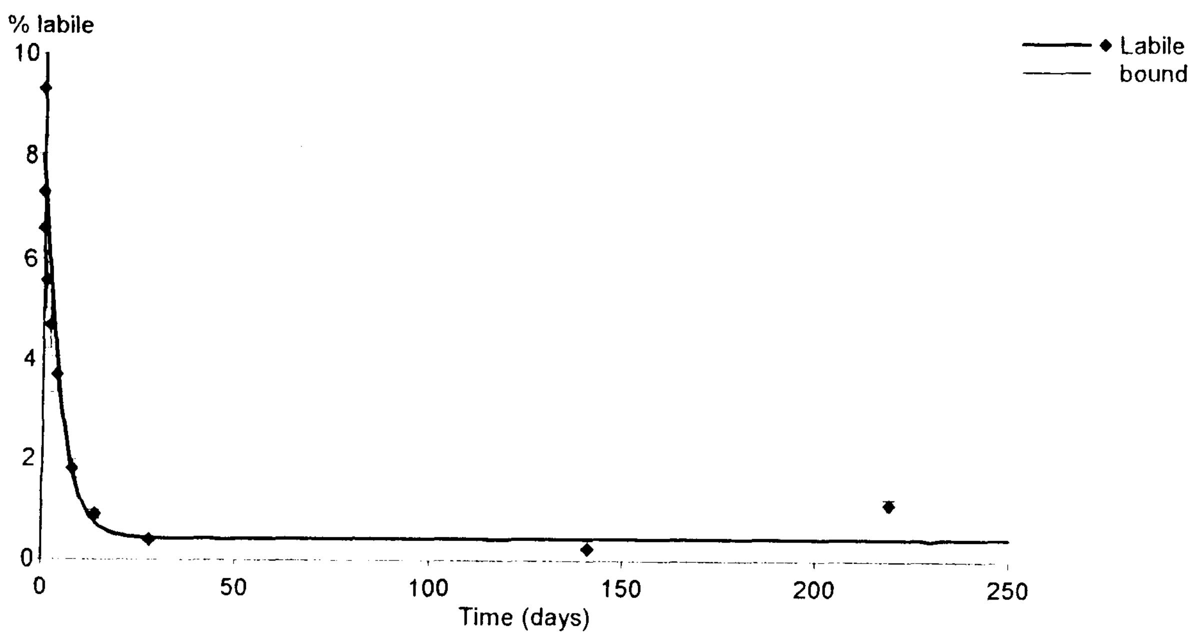


Figure 10. Example of ^{134}Cs model for Hestúr 1 and Tjøtta 3.





THE FAROE ISLANDS

Sampling campaigns have been carried out in the Faroe Islands covering soil, water, grass, milk and lamb at a number of locations. The results were used to investigate the behaviour of the Chernobyl radiocaesium relative to that from the weapons fallout. The general trend known from previous results is that the relative reduction with time of the radiocaesium in the Faroese ecosystem from the Chernobyl accident is much faster than that from the weapons fallout. This is apparent from Figure 1 which shows the levels of ^{137}Cs in Faroese milk since 1962. The trend indicates that the rate of reduction with time becomes identical for the two sources of contamination. The effective half life of ^{137}Cs from global fallout was found at 3 years, while ^{137}Cs from Chernobyl decayed with a half life of 2 years. Figure 2 shows the levels of ^{90}Sr in milk where the effective half life has remained at a value of 4 years.

These effective half lives for weapons fallout have been incorporated into transfer coefficients for ^{137}Cs and ^{90}Sr shown in Table 1 which demonstrates the increased sensitivity of the semi-natural Faroese environment to radioactive contamination. The table gives transfer coefficients for a range of foodstuffs including total diet from the Faroe Islands and Denmark. The higher radioecological sensitivity of the Faroese ecosystem is mainly explained by two factors: 1) plant uptake of radionuclides from Faroese soils with high organic content is much higher than from clayish Danish soils, and 2) drinking water in the Faroe Islands is produced from surface water while drinking water in Denmark is derived mainly from ground water. The sensitivity for ^{90}Sr in total diet, however, is found to be larger in Denmark than in the Faroe Islands. This is due to Faroese import of food products important for the ^{90}Sr contribution (milk, bread and potatoes) from Denmark and other countries thus reducing the influence of local food products.

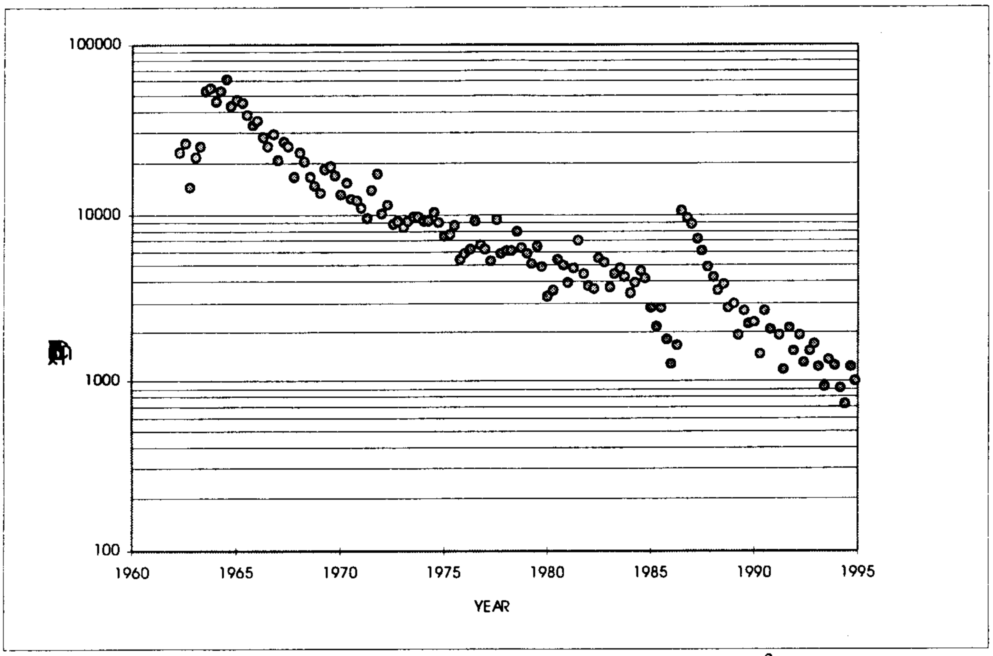


Figure 1. Caesium-137 in Faroese milk, 1962-1994 (Bq m^{-3}).

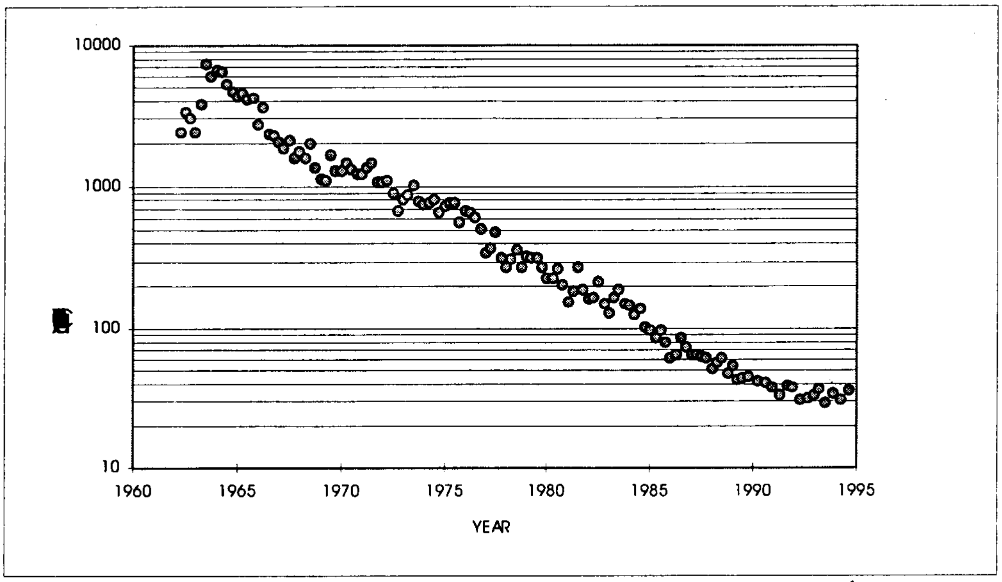


Figure 2. Strontium-90 in Faroese milk, 1962-1994 (Bq (kg Ca)$^{-1}$).

Table 1. Integrated environmental response in Denmark and the Faroe Islands to a contamination of 1 Bq m^{-2}; observations from nuclear weapons fallout.

SAMPLE TYPE		Denmark	Faroe Islands
Drinking water,	Sr-90 (mBq y m^{-3})	9	110
Grass	Sr-90 (mBq y kg^{-1})	38	270
	Cs-137 (mBq y kg^{-1})	24	520
Milk	Sr-90 (mBq y (g Ca)$^{-1}$)	3.3	8.6
	Cs-137 (mBq y (g K)$^{-1}$)	3.4	35
Meat*	Sr-90 (mBq y kg^{-1})	1.4	3.1
	Cs-137 (mBq y kg^{-1})	27	210
Total diet#	Sr-90 (Bq cap^{-1})	3.2	2.2
	Cs-137 (Bq cap^{-1})	5.6	15

*beef and pork in Denmark, lamb in the Faroe Islands

* including imported food products in the Faroe Islands (e.g. grain, vegetables, fruits)

TRANSFER OF CS-137 THROUGH THE SOIL-GRASS-LAMB FOODCHAIN

The observations of the transfer of ^{137}Cs through the soil-grass-lamb foodchain at Ribe in Southern Jutland have been continued in the EKO-2 project. The project was initiated in the previous NKS/RAD-3 project in 1990 and observations have been made every year except for 1994 where the new NKS programme was prepared.

A new analysis of the data from Ribe has been made. Previous interpretations of the results were based on the information available from total ^{137}Cs comprising the component from nuclear weapons testing (1.7 kBq m^{-2} total deposition by 1990) as well as that from the Chernobyl accident (1.5 kBq m^{-2} total deposition by 1990). The analysis illustrates the extent to which different transfers are obtained for the two caesium isotopes.

Soil samples collected at Ribe since 1990 have covered the two depth intervals 0-5 cm and 5-10 cm. An analysis of variance on the decay-corrected data shows significant differences between the depth layers only, not between the years. Chernobyl radiocaesium has only been detected in the upper soil layer. Grass samples have been taken from the location several times over the growing season and the radiocaesium concentrations in the grass are seen to vary accordingly. However, for the purpose of relating the concentrations of radiocaesium in the grass to those in the lamb, interpretations of the data have been restricted to include only those grass samples that are most representative for the time of slaughter of the lambs.

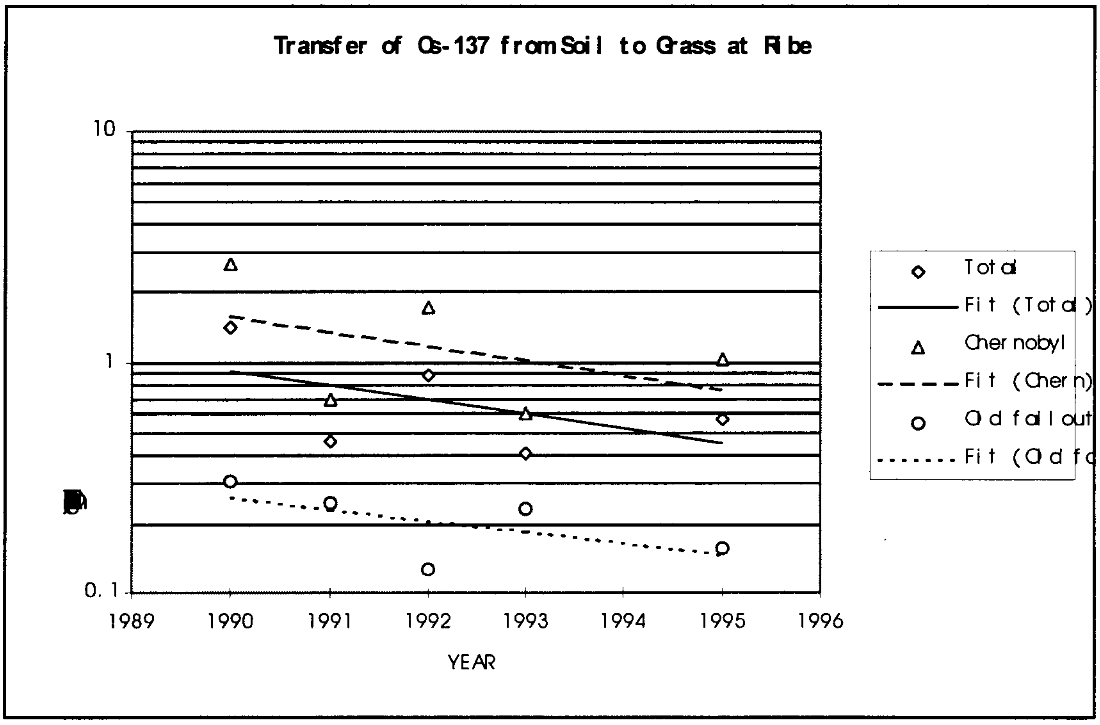
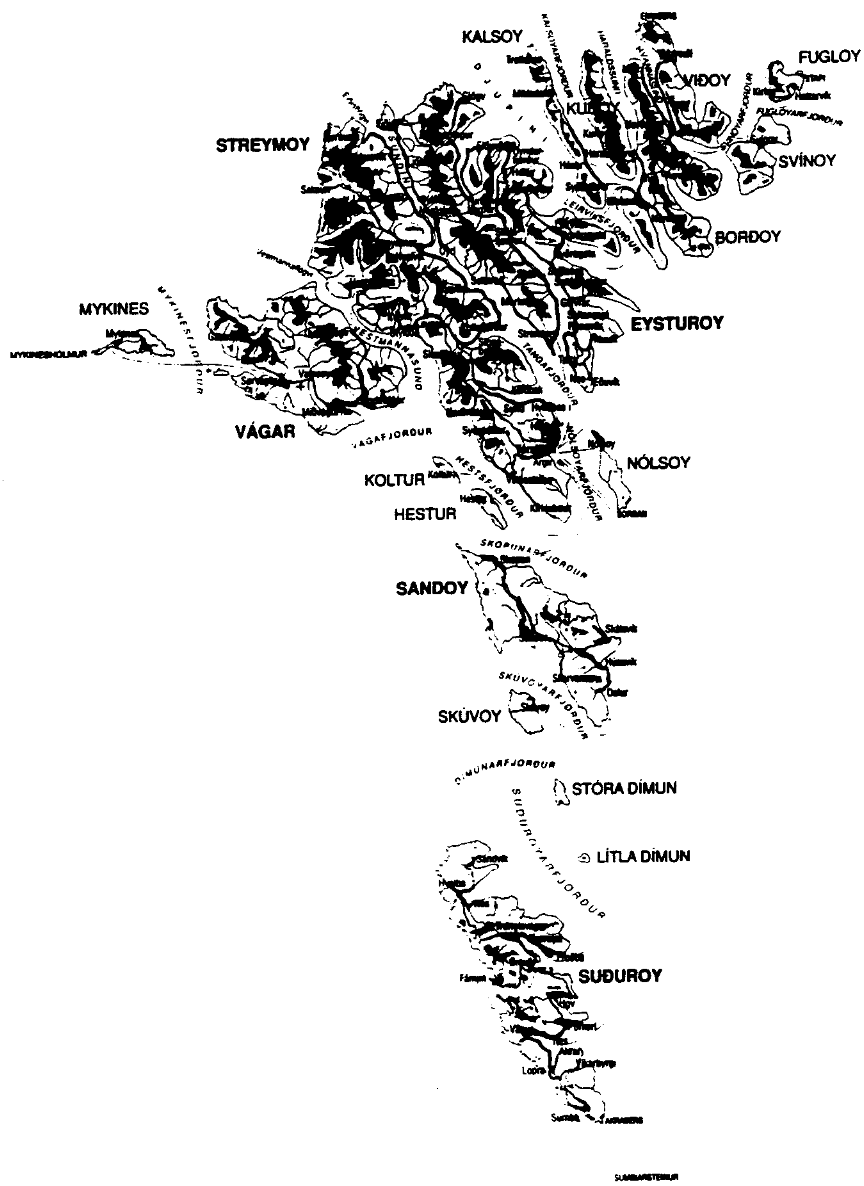


Figure 3. Transfer of ^{137}Cs from soil to grass at Ribe analyzed for three components: total radiocaesium, Chernobyl radiocaesium, and radiocaesium from old (nuclear weapons) fallout.

The analysis of the data has been based on an assumption of an activity ratio of $^{134}Cs/^{137}Cs$ of 0.55 at the time of the Chernobyl accident. The results of the transfer from soil to grass are shown in Figure 3 which gives the transfer factors for total ^{137}Cs and for the two components as a function of time including lines of regression fitted to the data. The transfer factor used here is the dry weight concentration of ^{137}Cs in grass divided by the total deposition (Bq kg^{-1} dw per Bq m^{-2} = m^2 kg^{-1}). It is noted that the transfer from soil to grass of radiocaesium from the Chernobyl accident is about five times higher than from nuclear weapons fallout, and that the transfer is decreasing with time for both components. The decrease for the Chernobyl caesium corresponds to an ecological half life of 6 years, while that for the nuclear weapons fallout corresponds to an ecological half life of 8 years. However, due to the large variations from year to year, there are large uncertainties associated with these half lives which, in fact, are not significantly different from infinity.

At the time of writing, the data on radiocaesium in lamb from 1995 were not available. The analysis of the transfer of radiocaesium from grass to lamb shows no significant difference between the two source components, but again the year-to-year variation is rather large corresponding to a standard variation of about 30%. The average observed ratio between the concentrations of radiocaesium in lamb and those in dry grass is found at a value of 0.70±16% (1 SE). The aggregated transfer factor of the transfer from soil to lamb again indicates a transfer of the Chernobyl radiocaesium about a factor of five higher than that from nuclear weapons fallout.

EKO-2 Meeting 6-8 November 1995. Asker, Norway.



Radioecological investigations in the Faroe Islands 1990-1995
A data report

Joensen, H.P. & Vestergaard, T.
University of the Faroe Islands
Dept. of Natural Sciences
1995

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A data report.
EKO-2 Meeting 6-8 November, Asker 1995.

Joensen, H.P., Vestergaard, T.
Dept. of Natural Sciences, University of the Faroe Islands, 1995.

Abstract

The report contains results from the Faroese part of the RAD3-programme and the subsequent EKO-2 programme, being radioecological programmes from 1990 to 1993 and from 1993 to 1997, respectively, under the Nordic Committee for Nuclear Safety research, NKS.

The transfer of radiocaesium from soil to grass and further to lamb has been investigated in 9 uncultivated pastures in the Faroe Islands. Neck muscles and internal organs were used from the lambs. Faeces were sampled in 1995.

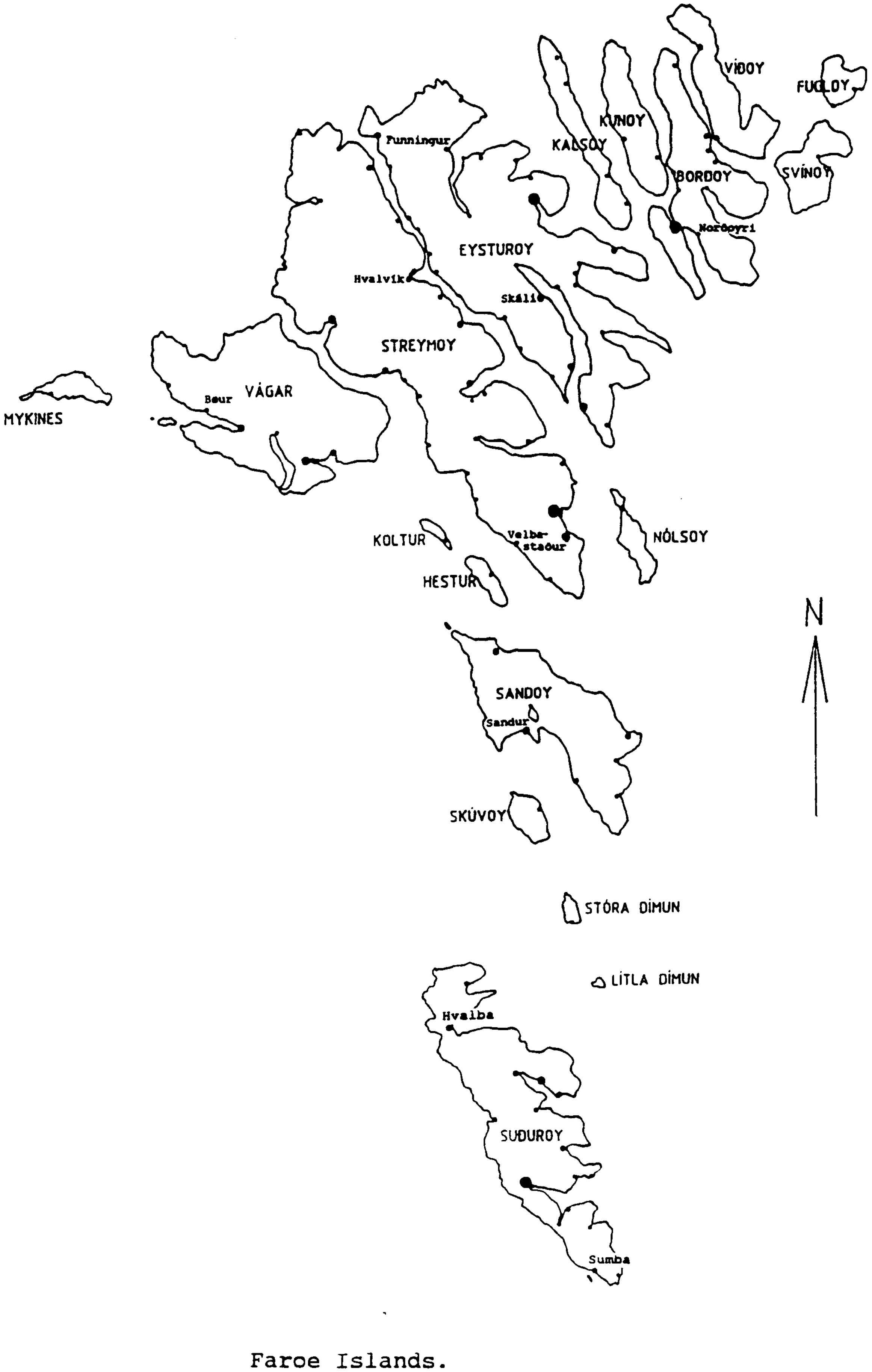
The annual per capita consumption of lamb meat in the Faroe Islands is about 10kg, making lamb an important source for the transfer of radiocaesium to man. The sheep is the most abundant domestic animal in the Faroe Islands.

The ratio between the content of Cs-137 in meat and grass is observed to be lower in the Faroe Islands than in other Nordic countries. A controlled feeding experiment with two male twin lambs confirmed the results. The aggregated transfer factor from soil to meat as well as the observed transfer factor from soil to grass is lower in the Faroe Islands than in other nordic countries with similar soil types as the Faroese.

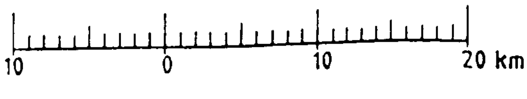
Despite the limited geographical extent of the Faroe Islands, the geographical variation in the contamination and transfer factors is highly significant.

Estimates of effective ecological halflives of Cs-137 are presented, although the project has been going on for only six years.

Chemical properties of the soil are included in the report.



Faroe Islands.



Introduction

The transfer of radiocaesium from soil to grass and further to lamb has been investigated since 1990 as part of the programmes RAD-3 and EKO-2. They are radioecological programmes under the Nordic Committee for Nuclear Safety research, NKS. Nine uncultivated pastures covering six islands have been selected for the project. Chemical properties of the soil have also been investigated, and the results are included in the report.

1. Material and methods

Nine uncultivated pastures, between 50 and 240 meters above sea level and covering 6 of the 18 islands of The Faroe Islands, have been selected for the project. Samples cover soil, mixed grass and individual plant species, meat and internal organs from lambs. Faeces were sampled in 1995 at the same sites.

In 1990, two or three 1 m^2 areas were randomly chosen in each pasture and divided into four 1/4 m^2 microplots for soil and grass sampling. The soil cores - taken with a corer with 6.0cm inner diameter - were split up into an upper 2cm layer followed by 5cm layers. However, in two pastures, Sandur and Sumba, the samples were taken from four randomly chosen 1/4 m^2 microplots and the cores were split up into 1cm layers down to 5cm followed by two 2.5cm thick layers from 5 to 10cm depth. This technique was requested by the participating laboratories. (Only Sandur and Sumba remained to be sampled when the description of the sampling technique was received).

Since 1991 the soil has been sampled with a (standardized) swedish corer, having inner diameter and length of 5.7cm and 10cm, respectively. Four 1/4 m^2 microplots were randomly selected in each pasture. The cores were split up into an upper and a lower 5cm layer except for 1992, when they were split up into 1cm layers down to 5cm depth and 2.5cm layers further down to 10cm depth.

Measurements were carried out on every core disc in 1990. Three cores were typically taken from each 1/4 m^2 microplot. Since 1991 three cores were taken from each 1/4 m^2 microplot, whereupon one mixed sample was made for each soil layer for measurement.

Chemical analyses have been carried out on the soil samples in addition to the radioactive analyses.

The mixed grass samples were collected every year by cutting the grass in each 1/4 m^2 microplot before the soil sampling. Individual plant species were picked by hand in a much wider area in order to get enough material for measurement.

The stock of sheep in the pastures varied from 65 to 260. When the lambs were slaughtered, meat (neck muscle), liver, kidney and heart were collected according to an arrangement made with the farmers, emphasizing the importance of taking the meat and internal organs from the same lamb. Measurements were carried out on samples from 30-38 lambs each year. The time of slaughter was typically in October when they were about 6 months of age. The carcass weight was around 12-13 kg.

All samples, except for the lamb samples, have been dried before measurement. The soil was dried at room temperature, while the grass and individual plant species were dried at 105 degrees Celsius. A lead shielded Ge-detector was used for the measurements. The software OMNIGAM from EG & G Ortec was used for the spectral analyses.

Table 1.1. The stock of sheeps, area and approximate height above sea level of the selected pastures. Local names are included.

	Bøur, N.í Haga	Velbastað, Lambhagi	Hvalvík, Miðdalah.	Skáli, Hegnið	Funning., I. í Haga	Norðoyri, Mið&Lýðh	Sandur, Skálsafjórð	Hvalba, S.í Haga	Sumba, Skúvabøli
Area, km^2	3.16	2.01	5.75	3.60	3.67	4.21	4.32	0.96	1.45
Height, m	100	150	50	70	100	160	240	100	200
Stock	128	150	260	105	-	160	200	65	100

2. Climate conditions

Local phenomena do certainly affect the climate conditions in the pastures. There are no weather stations close to the pastures, but the table below with data from the Faroese capital, Tórshavn, may indicate the interannual variation in precipitation and temperature.

Table 2.1 Accumulated precipitation (mm) in Tórshavn, the capital of the Faroe Islands. Data for May-September (i.e. 5 months. Ref: The Danish Met. Institute).

1990	1991	1992	1993	1994	1995	1961-81
330	340	393	286	376	262	426

Table 2.2 Mean temperatures (Celsius) in Tórshavn, the capital of the Faroe Islands. Data for May-September (i.e. 5 months. Ref: The Danish Met. Institute).

1990	1991	1992	1993	1994	1995	1961-88
9.9	10.2	9.8	8.3	8.8	9.1	9.2

3. Results

3.1. Chemical analyses of the soil

The mean values of pH, ignition loss, concentration of easily soluble potassium and sodium in the uppermost 10cm of the soil is presented in tables below and in Figs 3.1.1-3.1.4. The content of potassium is mostly between 300 mg/kg and 600 mg/kg, but values of about 1000 mg/kg are also observed. The concentration of sodium is generally at the same level as for potassium, but higher values are observed in Sumba and particularly in Hvalba. The pH values are generally below 5.3. The soil is organic, as can be seen from the ignition loss. (Chemical analyses remain to be done for 1995-samples).

Table 3.1.1. Results for pH in the 0-10cm soil layer.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	5.0	5.6	4.5	4.8	4.6	4.7	4.6	-	4.8
1991	4.8	5.1	4.8	5.1	5.0	5.0	4.7	5.1	4.9
1992	4.9	5.2	4.8	4.8	4.7	4.8	5.3	5.2	4.8
1993	5.0	5.3	5.0	5.2	5.0	5.3	5.3	5.2	5.2
1994	4.7	4.5	4.7	4.7	-	4.4	4.5	4.8	4.5

Table 3.1.2. The ignition loss (%) in the 0-10cm soil layer.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	40	15	27	67	57	66	59	-	75
1991	67	45	73	60	59	64	73	65	71
1992	48	25	73	65	40	55	37	62	50
1993	63	29	65	64	49	54	33	62	42
1994	55	31	53	53	-	69	50	70	34

Table 3.1.3. Content of easily solluble potassium (mg/kg) in the 0-10cm soil layer.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	547	587	293	469	333	529	430	-	997
1991	340	582	340	868	459	706	604	780	675
1992	457	395	516	493	334	616	486	730	444
1993	873	833	781	1044	694	752	577	1030	723
1994	981	880	847	947	-	919	879	1027	823

Table 3.1.4. Content of sodium (mg/kg) in the 0-10cm soil layer.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	403	460	230	230	230	460	460	-	805
1991	216	546	187	503	244	345	402	1466	748
1992	446	366	323	388	403	558	422	1494	631
1993	560	540	630	490	400	650	450	1550	660
1994	452	439	385	379	-	544	472	1165	512

In 1992 the analyses were carried out for every 1cm layer down to 5cm depth and for each 2.5cm layer further down to 10cm depth. The concentration of calcium has been measured in addition to the parameters mentioned above (in the uppermost 5cm of the soil). The results presented in Table 3.2.8 are based on samples prepared for Cs-134 analyses (cf. § 3.2).

3.2. Radiocaesium in the soil

The soil sampling took place in July every year except for 1990, when it was carried out in August. The measurements of Cs-137 are presented in tables below and in figures at the end of the report. Estimates for the whole country can be found in Table 3.2.1 (all samples are considered as a pool).

Table 3.2.1. Deposition and concentration of Cs-137 in the 0-10cm soil layer (dried material). Overall means ± pooled standard deviations.

Year	1990	1991	1992	1993	1994	1995
Bq/m²	5867±1483	5462±1144	5375±1078	5004±954.1	5946±1962	5967±877.0
Bq/kg	228±90.0	283±64.3	240±67.8	238±59.9	317±41.1	282±78.9

The deposition of Cs-137 in the 0-5cm soil layer relative to the deposition in the 0-10cm layer is shown in Table 3.2.2 and Figure 3.2.1. 60-80% of the deposition is found to be in the uppermost 5cm of the soil. The relative distribution between the layers is practically the same every year for most pastures. A declining trend is observed in some pastures (e.g. Bøur).

Table 3.2.2. The deposition of Cs-137 in the top 0-5cm soil layer relative to the deposition in the top 0-10cm layer (in %).

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	60.1	50.9	59.9	65.0	66.5	67.2	80.1	-	66.1
1991	57.8	55.1	59.8	50.5	79.0	63.6	82.1	56.5	65.0
1992	68.8	56.4	55.8	68.2	78.6	62.0	78.3	64.4	78.2
1993	50.9	58.2	63.1	47.6	62.6	55.1	69.1	57.2	62.2
1994	43.7	52.3	47.8	41.2	-	58.8	79.0	48.1	51.9
1995	39.6	66.2	64.1	44.3	-	68.0	73.7	34.5	58.2

The Cs-134/Cs-137 ratio in the uppermost 5cm of the soil is shown in Tables 3.2.3-3.2.4 (-no data for Skáli and Sandur in 1991). Cs-134 was not detected in 1990.

Table 3.2.3. The Cs-134/Cs-137 ratio in the 0-5cm soil layer. (No data for 1990).

	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sand.	Hvalba	Sumba
1991	0.045	0.056	0.036	-	0.029	0.044	-	0.050	0.065
1992	0.029	0.037	0.039	0.023	0.018	0.037	0.030	0.049	0.040
1993	0.027	0.024	0.028	0.017	0.018	0.024	0.020	0.035	0.034
1994	0.022	0.023	0.014	0.010	-	0.023	0.013	0.026	0.025
1995	0.013 N=2	0.023 N=1	N.D.	0.010 N=1	-	N.D.	0.011 N=1	0.021 N=3	0.018 N=4

Table 3.2.4. The Cs-134/Cs-137 ratio in the 5-10cm soil layer. (N.D.: Cs-134 not detected).									
	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sand.	Hvalba	Sumba
1993	N.D.	N.D.	N.D.	0.013 N=1	N.D.	0.011 N=2	N.D.	0.018 N=1	N.D.
1994	N.D.	N.D.	0.014 N=2	0.008 N=3	-	0.019 N=1	N.D.	0.022 N=1	0.009 N=1
1995	0.013 N=2	N.D.	N.D.	0.008 N=1	-	N.D.	N.D.	0.013 N=1	N.D.

The Cs-137 concentration and deposition in the uppermost 10cm of the soil are presented in Figures 3.2.2 and 3.2.3, respectively. The error bars represent one standard error. More detailed results can be found in Tables 3.2.5 - 3.2.6.

Table 3.2.5. The concentration (Bq/kg ± 1 stds) of Cs-137 in the 0-10cm soil layer.									
Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	166±22.4	95±15	286±174	331±44.1	257±96.5	233±85.6	269±20.0	-	377±51.7
1991	260±53.2	226±54.7	299±27.3	254±60.6	217±55.1	414±70.0	241±86.8	290±47.3	343±97.3
1992	236±65.8	132±37.0	274±86.1	214±33.1	194±31.7	355±111	180±75.4	269±31.7	303±85.4
1993	263±22.5	123±23.3	241±39.4	305±81.3	243±75.5	264±83.7	188±73.2	255±12.5	258±35.3
1994	286±31.2	104±14.0	330±21.0	336±77.1	-	385±50.1	282±26.8	322±29.8	388±29.0
1995	155±56.0	128±13.5	284±53.4	312±34.9	-	301±173	257±35.6	352±43.6	435±50.5

Table 3.2.6. The deposition (Bq/m^2 ± 1 stds) of Cs-137 in the 0-10cm soil layer.									
Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	3338±377	8147±1082	8004±2927	4710±1266	5845± 618	4396±1135	5029±1181	-	4362±1016
1991	5592±399	4701± 908	6344±1632	4839± 958	5247± 458	7770±1260	4466±1676	5105±1140	4944± 942
1992	5732±923	5320± 769	4652± 923	4563±1084	6409±2098	6031±1278	5706± 539	4956± 298	5009± 757
1993	4943±578	4829± 876	4055± 828	5957±1194	5563±1186	5824±1000	3759± 635	4270± 623	5835± 934
1994	4617±188	4181± 576	5812±3655	8613±1832	-	6609±2748	6804± 922	3676±1269	6373±1161
1995	5521±295	4899± 111	4155±1064	8315±991	-	7267± 457	6053± 628	4475± 177	6456±1600

In order to get enough material for Cs-134 detection in 1992, mixed samples were prepared for each soil layer. Cs-134 has only been measured in the uppermost 5cm except for Norðoyri, where the Cs-134/Cs-137 ratio was found to be 0.017 in the 5-10cm layer. In 1992 the soil cores were split up in a 0-5cm layer and a 5-10cm layer only in Norðoyri. Results from mixed samples from each 1/4m^2 area can be found Table 3.2.7.

Table 3.2.7 Results from chemical and radioactive analyses in 1992. Sampling dates are included.

	Depth cm	Ign. loss %	pH	Sodium mg/kg	Potassium mg/kg	Calcium mg/kg	Cs-137 Bq/(gK)	Cs-137 Bq/kg	Cs-137 Bq/m2	Chernobyl Cs-137 Bq/kg	Fallout Cs-137 Bq/kg	Cs-134/ Cs-137
Beur	0-1	72.1	4.9	933	922	681	256	236	415	160	76	0.0528
16/7-92	1-2	62.3	4.8	447	589	616	637	375	834	267	109	0.0552
	2-3	64.2	4.7	670	662	616	627	415	918	127	288	0.0238
	3-4	60.5	4.8	533	516	474	748	386	861	69	317	0.0139
	4-5	52.8	4.9	584	422	310	743	314	903	56	257	0.0140
	5-7.5	41.2	5.0	402	450							
	7.5-10	35.0	5.1	240	260							
			4.9									
Velbastad	0-1	37.0	5.4	493	1300	1840	125	162	390	73	89	0.0350
13/7-92	1-2	32.9	5.2	392	537	1430	330	177	572	92	85	0.0403
	2-3	30.8	5.3	361	402	1660	426	171	673	71	100	0.0325
	3-4	32.4	5.2	392	339	1330	501	170	690	77	93	0.0353
	4-5	27.0	5.2	321	267	1060	549	158	680	89	69	0.0437
	5-7.5	23.5	5.2	420	380							
	7.5-10	17.3	5.0	300	260							
			5.2									
Hvalvik	0-1	80.9	4.8	493	1420	1030	136	193	200	114	80	0.0457
19/7-92	1-2	69.9	4.8	371	1070	1030	333	357	573	208	149	0.0454
1.FERD	2-3	82.6	4.8	412	714	867	550	393	687	202	190	0.0401
	3-4	80.8	4.8	295	547	714	655	358	840	177	182	0.0383
	4-5	78.2	4.8	348	516	627	593	306	602	121	185	0.0307
	5-7.5	74.4	4.9	324	420							
	7.5-10	64.4	4.8	252	200							
			4.8									
Skáli	0-1	87.8	4.9	751	1350	1430	198	268	406	142	126	0.0411
13/7-92	1-2	79.2	4.7	665	849	1080	520	442	692	169	272	0.0296
	2-3	76.6	4.7	432	558	812	895	499	825	118	382	0.0184
	3-4	71.6	4.8	356	402	834	1035	416	790	91	325	0.0170
	4-5	67.2	4.7	356	339	485	1038	352	776	80	271	0.0178
	5-7.5	56.5	4.9	312	430							
	7.5-10	59.0	4.7	312	320							
			4.8									
Funningur	0-1	80.1	4.7	427	1220	998	350	427	701	292	135	0.0531
13/7-92	1-2	60.1	4.6	700	630	703	897	565	1312	130	435	0.0179
	2-3	53.8	4.6	624	526	539	976	513	1316	97	416	0.0147
	3-4	49.4	4.7	311	318	376	1235	393	1190	51	342	0.0101
	4-5	49.7	4.7	300	277	332	1016	281	879	29	252	0.0061
	5-7.5	31.7	4.8	378	330							
	7.5-10	27.5	5.0	360	120							
			4.7									
Sandur	0-1	67.4	5.3	462	1570	1860	162	255	541	223	32	0.0680
15/7-92	1-2	50.8	5.3	427	672	985	430	289	906	141	148	0.0379
	2-3	42.2	5.2	366	433	823	719	311	1096	98	213	0.0246
	3-4	39.5	5.3	392	350	681	765	268	1037	60	207	0.0176
	4-5	36.2	5.2	361	287	648	692	199	806	49	150	0.0192
	5-7.5	29.1	5.2	462	450							
	7.5-10	32.1	5.3	432	380							
			5.3									
Hvalba	0-1	79.6	5.7	1140	1510	1900	183	277	403	272	5	0.0764
14/7-92	1-2	74.6	5.4	984	697	1170	601	419	611	399	20	0.0741
	2-3	71.0	5.4	1030	634	1360	686	436	702	295	141	0.0526
	3-4	66.2	5.3	1430	707	1500	657	464	777	217	247	0.0363
	4-5	63.9	5.2	1370	551	1260	678	374	743	111	262	0.0231
	5-7.5	55.8	4.9	1722	650							
	7.5-10	53.3	4.4	1728	700							
			5.2									
Sumba	0-1	69.7	5.1	700	1390	1040	408	567	755	438	128	0.0601
14/7-92	1-2	65.0	4.9	705	734	910	1074	788	1035	687	102	0.0677
	2-3	61.0	4.9	675	474	627	1230	583	815	216	367	0.0288
	3-4	60.6	4.8	786	381	627	1379	525	726	107	418	0.0159
	4-5	58.2	4.8	650	318	507	1271	404	582	43	362	0.0082
	5-7.5	45.7	4.7	660	350							
	7.5-10	37.6	4.4	510	260							

3.3 Mixed grass

The Cs-137 activity in mixed grass is presented in Figure 3.3.1 as mean values and +1 standard error, showing a decreasing trend with time. The overall means for the country and for each pasture are presented in Tables 3.3.1 and 3.3.2, respectively. The yield can be seen in Table 3.3.3.

Table 3.3.1. The Cs-137 concentration (Bq/kg;dw) in mixed grass. Overall means ± pooled standard deviations.

1990	1991	1992	1993	1994	1995
162±92.0	106±65.0	63.1±34.9	45.3±27.4	41.0±35.4	48.1±28.7

Table 3.3.2. The concentration of Cs-137 in mixed grass in each pasture. Mean values ± 1 standard deviation (Bq/kg;dw).

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	91.0±35.0	70.0±43.8	302 ±179	119± 70.6	247 ±95.2	236 ±87.7	217± 105	20.0±6.10	97.0±68.1
1991	48.2±27.8	56.5±83.5	225 ±120	61.8±34.5	249 ±75.1	88.0±26.3	109± 67.3	11.0±5.10	106 ±61.0
1992	43.9±19.6	31.2±41.3	177±57.3	69.1±46.7	98.0±26.6	51.2±34.9	9.56±4.38	10.3±3.11	77.5±37.9
1993	30.0± 8.8	13.0± 5.4	152±42.0	68.0±40.0	80.0±54.0	22.0± 7.2	16.0±15.6	9.60±2.20	17.3± 9.6
1994	8.56±5.0	-	92.8±80.4	71.6±16.1	-	63.0±14.7	5.40 (N=1)	12.3±7.30	39.0±36.5
1995	14.1±14.5	27.2±32.7	142±57.1	50.1±22.1	-	59.7±22.0	9.93±6.74	10.4±4.33	37.9±17.3

Table 3.3.3. The yield of mixed grass in the pastures (g(dw)/m²). Mean values ± 1 standard deviation.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	40±10	28±18	52±16	70±18	29±8.3	182±17	79±53	53±16	49±17
1991	97±58	172±28	67±23	121±7.5	37±10	267±16.7	154±37	184±51	137±35
1992	48±16	113±28	78±17	55±32	42±12	108±58	93±64	116±31	46±19
1993	58±8.4	97±26	72±31	85±48	37±4.1	72±22	92±45	189±30	171±39
1994	95±44	103±3.1	78±17	71±7.1	-	222±18.6	84±10	148±29	127±23
1995	115±20.4	131±29.5	50±18	40±10	-	127±35.4	58±13	143±30	152±37

The Cs-134/Cs-137 ratio is presented in Table 3.3.4. Cs-134 was not detected in 1992. In 1993 Cs-134 was only observed in a sample from Hvalvík; the Cs-134/Cs-137 ratio was

0.051. Cs-134 has not been detected in grass samples since 1993.

Table 3.3.4. Cs-134/Cs-137 ratio in mixed grass.

	Bøur	Velbastað	Hvalvík	Skáli	Funningur	Norðoyri	Sandur	Sumba
1990	0.188	0.172	0.080	0.120	0.032	0.112	0.139	0.171
1991	-	0.041	0.059	-	0.027	-	-	0.095

Since the concentration of radiocaesium in the grass is time dependent, grass sampling was carried out several times in 1991 and 1992 and two times in 1993. The results for Cs-137 as well as the yield (g(dw)/m^2)) can be found below. The highest concentration is between mid July and August.

Table 3.3.5. Time variation of the Cs-137 *concentration* ± 1 standard deviation (Bq/kg(dw)) in mixed grass.

1991, Cs-137 Bq/kg(dw)	Week 26	Week 28	Week 29	Week 32	Week 38	Week 39
Velbastað		56.5 ± 83.5				52.1 ± 87.0
Hvalvík	142.7 ± 59.7		224.6 ±120.5	259.1 ± 94.8	160.7 ± 42.7	
Skáli		61.8 ± 34.5			59.2 ± 34.4	
Funningur		249.1 ± 75.0			280.0 ± 82.4	
Sandur		109.3 ± 67.4				40.5 ± 41.1

Table 3.3.6. Time variation of the *yield* ± 1 standard deviation (g(dw)/m^2). Results based on mixed grass samples.

1991, Yield g(dw)/m^2	Week 26	Week 28	Week 29	Week 32	Week 38	Week 39
Velbastað		172.2 ± 28.2				181.9 ± 25.2
Hvalvík	32.7 ± 5.5		67.0 ± 22.5	61.0 ± 16.0	43.2 ± 20.2	
Skáli		120.5 ± 7.5			40.9 ± 24.1	
Funningur		36.6 ± 10.1			36.8 ± 8.9	
Sandur		154.2 ± 36.9				184.7 ± 28.0

Table 3.3.7. Time variation of the Cs-137 *concentration* ± 1 standard deviation (Bq/kg(dw)) in mixed grass. (*): Results based on *one* sample from a *1 m²* sampling area.							
1992, Cs-137 Bq/kg(dw)	Week 27	Week 28	Week 33	Week 38	Week 41	Week 44	Week 45
Velbastað		31.2±41.3	70.1 (*)			7.5 (*)	
Skáli		69.1±46.7	46.7 (*)	28.5 (*)			
Funningur		98.0±26.6	55.0 (*)				
Norðoyri	51.2±34.9				60.2 (*)		
Sandur		9.6±4.4					7.3 (*)
Hvalba		10.3±3.1					16.3 (*)
Sumba		77.5±37.9					19.8 (*)

Table 3.3.8. Time variation of the Cs-137 *yield* ± 1 standard deviation (g(dw)/m²) of mixed grass. (*): Results based on *one* sample from a *1 m²* sampling area.							
1992, Cs-137 g(dw)/m²	Week 27	Week 28	Week 33	Week 38	Week 41	Week 44	Week 45
Velbastað		113.1±27.7				54.7 (*)	
Skáli		54.8±32.3	15.6 (*)	25.3 (*)			
Funningur		41.5±11.8	19.1 (*)				
Norðoyri	134.2±12.4				44.7 (*)		
Sandur		92.8±64.0					55.9 (*)
Hvalba		116.3±30.8					41.6 (*)
Sumba		46.0±18.5					50.4 (*)

Special attention was given to Hvalvík in 1992, where sampling was carried out from June to October with a high frequency. (Hvalvík was chosen for practical reasons).

Table 3.3.9. Time variation of the Cs-137 *concentration* ± 1std (Bq/kg(dw)) in mixed grass from Hvalvík **(1992).** (*): Result based on *one* sample from a *1 m²* sampling area.								
22/6-92	6/7-92	19/7-92	3/8-92	17/8-92	1/9-92	14/9-92	28/9-92	11/11-92
160±74	170±29	177±57	242±19	173±29	221±124	95±27	113±46	90 (*)

Table 3.3.10. Time variation of the Cs-137 *yield* ± 1std (Bq/kg(dw)) in mixed grass from Hvalvík (1992). (*): Result based on *one* sample from a *1 m²* sampling area.								
22/6-92	6/7-92	19/7-92	3/8-92	17/8-92	1/9-92	14/9-92	28/9-92	11/11-92
46±15	52±5.0	81±13	91±30	114±40.0	90±29	105±26	73±15	44 (*)

In 1993 a later grass sampling was carried out in most pastures in September/October. The results from the measurements are presented in Tables 3.3.11 and 3.3.12.

Table 3.3.11. The Cs-137 *concentration* in mixed grass ±1 standard deviation (Bq/kg(dw)). Second sampling in 1993. (*: refers to measurement on a single mixed sample).					
Bøur 1/9-93	Velbastað 2/10-93	Hvalvík 10/10-93	Skáli 26/9-93	Hvalba 6/11-93	Sumba 6/11-93
28±12	13±5.3	167±132	57±30	16*	13*

Table 3.3.12. The *yield* of mixed grass ±1 standard deviation (g(dw)/m²). Second sampling in 1993. (*: refers to measurement on a single mixed sample).					
Bøur 1/9-93	Velbastað 2/10-93	Hvalvík 10/10-93	Skáli 26/9-93	Hvalba 6/11-93	Sumba 6/11-93
124±46.8	114±24.5	74.1±13.2	34.1±10.4	21.6±9.64	25.6±6.21

3.4. Individual plant species

Some individual plant species have been collected. The content of Cs-137 in the species is shown in Tables 3.4.1 - 3.4.3.

Table 3.4.1. Content of Cs-137 in individual plant species in 1991.

Cs-137 Bq/kg, 1991	Potentilla erecta	Festuca rubra	Anthoxanthum odoratum	Nardus stricta	Deschampsia flexuosa	Dactylorchis maculata
Bøur	41.9	26.8	98.2		32.9	93.8
Velbastað	12.5		13.9	10.4		
Hvalvík	265.8	114.9	237.2			
Skáli	139.0		67.0	45.5		
Funningur				71.5		
Norðoyri	96.7	14.0	38.5			
Sandur	133.7	10.8	12.9			
Hvalba	24.3		10.2			
Sumba	75.3	33.2		51.9		

Table 3.4.2. Content of Cs-137 in individual plant species in 1992.

Cs-137 Bq/kg, 1992	Potentilla erecta	Festuca rubra	Anthoxanthum odoratum	Nardus stricta
Bøur	28.0	19.0	22.7	
Velbastað	11.9		9.9	
Hvalvík	73.8	55.6	138.0	
Skáli	33.8			64.7
Funningur				28.6
Norðoyri	37.6	33.9	15.9	
Sandur	30.0	32.8	26.6	
Hvalba	Bel.Det.Lim.		Bel.Det.Lim.	
Sumba	34.1	37.3	65.1	

Table 3.4.3. Content of Cs-137 in individual plant species in 1993.			
Cs-137 Bq/kg, 1993	Potentilla erecta	Festuca rubra	Anthoxanthum odoratum
Bøur	24.2	10.2	26.3
Velbastað	9.0		
Hvalvík	76.2	67.6	123.6
Skáli	49.9		
Norðoyri	20.5	32.7	

3.5. Lamb

The results for lamb meat and entrails 1990-1994 are presented in Figs. 3.5.1-3.5.2. A decreasing trend with time is observed. The results are shown in more detail in the tables below. Lamb samples from 1995 remain to be analyzed.

The overall mean concentration of Cs-137 in meat and internal organs, based on single lamb measurements, are presented in Table 3.5.2. The time of slaughter was from late September to early November.

Table 3.5.1. Content of Cs-137 (Bq/kg;fw) in lamb meat and internal organs. Overall means ± pooled standard deviations.

Year	1990	1991	1992	1993	1994
Meat	28.8±19.1	19.8±19.6	10.6±3.50	9.4±5.0	19.8±13.0
Liver	15.0±6.00	14.4±9.60	7.3±2.3	6.5±3.1	16.6±10.4
Heart	15.2±5.40	12.4±7.60	7.5±2.3	6.2±3.1	16.6±11.8
Kidney	28.6±10.6	18.7±16.0	14.0±18.2	10.7±5.7	30.9±20.7

Information about the carcass weights can be found in Tables 3.5.2.

Table 3.5.2. Carcass weight (kg;fw). Overall means (from single lambs). Minimum and maximum weights are included.

1990			1991			1992			1993			1994		
Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
12.7	9.5	16.5	12.9	10.0	16.5	12.2	9.5	18.5	12.4	8.0	17.5	13.9	10.5	21.0

Table 3.5.3. Cs-137 (Bq/kg;fw) in *meat* from the neck of the lambs. Mean values ± 1 standard deviation.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	7.6±6.2	4.8±2.3	60.8±37.4	54.0±13.0	-	28.0±22.0	33.0±1.41	4.1	16.0±3.70
1991	8.7±7.8	4.6±1.8	60.3±40.6	30.9±25.9	-	13.1±6.40	17.4±11.9	3.2±1.0	18.1
1992	7.3±2.1	4.3±3.4	17.5±5.50	21.5±1.90	-	13.8±4.30	8.5	2.9±0.62	13.7
1993	6.8±3.2	2.6±0.92	19.2±10.4	26.0±10.2	-	7.8±2.2	10.4±2.20	3.2±0.96	5.5±3.0
1994	6.3±5.0	3.1±2.2	13.5±11.6	49.5±19.8	-	45.7±26.7	25.0±2.98	3.4±1.7	10.7±3.19

Table 3.5.4. Cs-137 (Bq/kg;fw) in *liver*. Mean values ± 1 standard deviation.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	5.5±4.3	2.5±1.1	-	34.5±7.50	-	-	28.0±9.60	1.8	-
1991	7.8±8.6	2.7±0.87	44.3±10.6	18.8±18.0	-	12.4±7.31	10.7±7.91	3.3±1.1	9.9
1992	4.6±1.7	-	11.3±3.06	11.8±3.19	-	8.2±2.5	-	2.4±0.28	-
1993	3.6±2.6	1.9±1.2	12.4±6.89	16.3±5.44	-	6.1±2.2	7.7±2.4	3.4±0.60	4.8±2.6
1994	6.4±4.1	1.9±1.0	30.4±16.1	30.7±14.1	-	26.8±16.4	19.6±1.03	3.3±1.2	6.6±1.7

Table 3.5.6. Cs-137 (Bq/kg;fw) in *heart*. Mean values ± 1 standard deviation.

Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	3.7±3.0	4.0±2.4	-	37.9±8.10	-	-	20.9±0.42	3.40	-
1991	7.6±6.4	2.2±0.82	32.3±9.23	19.0±13.4	-	12.2±6.77	10.1±6.96	2.82±1.54	11.7
1992	4.8±1.4	-	13.3±3.53	11.6±2.29	-	7.1±2.4	-	2.32±0.66	-
1993	3.6±2.1	1.9±0.9	11.7±6.42	16.6±4.30	-	5.8±2.2	6.4±1.5	4.00±1.56	3.86±2.84
1994	3.5±1.6	1.6±0.66	29.4±12.9	33.8±14.9	-	28.8±22.2	15.9±1.52	3.17±1.18	4.41±2.10

Table 3.5.7. Cs-137 (Bq/kg;fw) in *kidney*. Mean values ± 1 standard deviation.									
Year	Bøur	Velbastað	Hvalvík	Skáli	Funning.	Norðoyri	Sandur	Hvalba	Sumba
1990	16.0±10.2	8.0±2.1	-	62.5±14.0	-	-	36.9±3.80	7.60	-
1991	13.9±11.3	5.2±1.4	35.4±4.65	41.2±37.5	-	12.0±5.64	18.7±11.8	4.94±1.91	17.2
1992	8.4±2.6	-	25.2±7.32	20.1±3.39	-	13.8±3.83	-	4.71±1.02	-
1993	7.6±5.3	2.8±2.1	21.2±12.2	27.2±5.11	-	8.5±2.5	11.1±3.55	6.80±2.24	6.93±5.04
1994	7.5±3.7	2.72 (N=1)	53.1±18.2	58.3±22.2	-	52.7±41.4	36.4±9.89	3.96±1.93	9.78±3.43

The average **Cs-134/Cs-137 ratio** in meat, based on single lamb measurements, was 0.117 in 1990 and 0.067 in 1991. The Cs-134 concentration could be measured significantly in only 5 lambs in 1992 (all from different pastures), giving the mean value 0.065. In 1991 the Cs-134/Cs-137 ratio in kidney, heart and liver was 0.053, 0.075 and 0.074, respectively (-no data for other years).

3.6. Concentration ratios and transfer factors

The observed concentration ratios are presented in Figs. 3.6.1-3.6.2 and in Tables 3.6.1.-3.6.6.

For each 1/4 m^2 microplot (cf. § 1) in a particular pasture, the grass/soil concentration ratio has been calculated from the concentraion (Bq/kg(dw)) in the 0-10cm soil layer and the concentration in grass. The average of these ratios is used as an estimate for the pasture.

For each pasture the meat/grass concentration ratio is calculated from the ratio between the concentration in each lamb (Bq(kg(fw)) and the mean concentration in grass. The meat/soil concentration ratio is calculated from the ratio between the concentration in each lamb and the mean concentration in the 0-10cm soil layer of the pasture.

The observed soil-to-grass (m^2/kg(dw)) and soil-to-meat transfer factors (m^2/kg(fw)) are presented in Figs. 3.6.3- 3.6.4 and Tables 3.6.7-3.6.9. The factors have been calculated in the same way as the concentration ratios, using the deposition (Bq/m^2) in the 0-10cm soil layer.

Mean values for the country can be found in Table 3.6.10.

Table 3.6.1. Observed concentration ratios in 1990.

1990	Concentration ratio*10³ Soil-Grass transfer			Concentration ratio *10³ Grass-Meat transfer			Concentration ratio *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	531.2	333.1	682.1	83.5	30.8	200.0	45.7	16.9	109.5
Velbastað	393.4	233.3	678.4	68.6	41.4	115.7	49.8	30.1	84.0
Hvalvík	1009.2	410.9	1840.5	202.0	119.5	387.1	213.5	74.2	409.1
Skáli	530.0	420.0	640.0	454.0	280.7	570.6	163.2	101.0	205.2
Funningur	969.4	400.0	1746.1	-	-	-	-	-	-
Norðoyri	586.6	478.9	673.0	119.0	38.1	280.1	120.0	38.5	283.2
Sandur	616.8	541.0	645.2	151.0	146.0	155.0	121.4	117.8	125.0
Hvalba	-	-	-	-	-	-	-	-	-
Sumba	310.6	77.0	499.7	165.0	127.0	201.0	42.4	32.6	51.7

Table 3.6.2. Observed concentration ratios in 1991

1991	Concentration ratio *10³ Soil-Grass transfer			Concentration ratio *10³ Grass-Meat transfer			Concentration ratio *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	217.6	173.0	275.0	181.0	32	437	33.6	6.0	81.0
Velbastað	242.2	43.5	770.0	82.0	29.7	119	20.6	7.45	29.9
Hvalvík	734.7	506.5	1200.6	268.4	100.3	518.6	201.9	75.5	390.0
Skáli	260.3	158.2	368.3	500.3	98.7	1160.0	121.9	24.1	282.6
Funningur	960.1	795.1	1278.3	-	-	-	-	-	-
Norðoyri	224.9	112.7	342.6	149.0	99.0	27.6	31.7	24.0	58.7
Sandur	510.7	180.5	934.1	158.8	33.4	231.6	71.9	15.1	104.9
Hvalba	37.4	15.5	45.9	287.2	157.6	409.1	10.9	9.61	15.5
Sumba	330.3	63.9	433.2	170	-	-	43.6	-	-

Table 3.6.3. Observed concentration ratios in 1992.

1992	Concentration ratio *10³ Soil-Grass transfer			Concentration ratio *10³ Grass-Meat transfer			Concentration ratio *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	200.3	82.6	385.4	166.0	113.1	235.5	30.8	21.0	43.8
Velbastað	236.7	65.7	496.5	138.8	34.9	320.3	32.7	8.23	75.4
Hvalvík	750.8	382.2	1338.4	98.8	57.1	138.9	63.9	36.9	89.7
Skáli	320.4	111.3	648.2	311.2	287.7	337.8	100.5	91.2	109.0
Funningur	490.4	392.4	754.8	-	-	-	-	-	-
Norðoyri	133.6	49.3	189.7	268.6	135.7	355.8	38.8	19.6	51.4
Sandur	60.3	19.3	109.8	889.1	-	-	47.1	-	-
Hvalba	38.4	23.6	51.1	277.5	212.1	353.1	10.6	8.11	13.5
Sumba	256.8	184.5	425.9	176.4	-	-	45.2	-	-

Table 3.6.4. Observed concentration ratios in 1993

1993	Concentration ratio *10³ Soil-Grass transfer			Concentration ratio *10³ Grass-Meat transfer			Concentration ratio *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	113.5	76.8	142.4	225.4	110.1	398.3	25.7	12.6	45.5
Velbastað	101.9	67.5	140.0	202.3	73.3	283.0	20.9	7.56	29.2
Hvalvík	653.8	386.9	942.8	126.5	45.5	226.9	79.7	28.7	143.1
Skáli	230.9	103.5	433.5	385.5	229.8	511.7	86.2	51.4	114.4
Funningur	324.3	180.0	559.7	-	-	-	-	-	-
Norðoyri	85.9	69.4	115.2	350.0	244.9	529.6	29.6	20.7	44.9
Sandur	86.4	38.3	179.0	637.8	504.3	850.7	55.6	43.9	74.1
Hvalba	37.9	26.1	47.6	328.4	238.4	469.4	12.4	8.98	17.7
Sumba	66.8	33.3	105.0	318.1	121.1	543.7	22.5	8.57	38.5

Table 3.6.5. Observed concentration ratios in 1994.						
1994	Concentration ratio *10^3 Soil-Grass transfer			Concentration ratio *10^3 Grass-Meat transfer		
	Mean	Min	Max	Mean	Min	Max
Bøur	27.8	9.7	40.2	730.8	110.0	1450
Velbastað	-	-	-	-	-	-
Hvalvík	255.0	46.4	501.5	145.4	70.0	290.0
Skáli	196.0	171.5	273.7	691.0	230.0	970.0
Funningur	-	-	-	-	-	-
Norðoyri	123.0	80.3	212.4	724.5	240.0	1340
Sandur	10.1			4632	3870	5180
Hvalba	31.0	10.5	46.1	277.6	120.0	460.0
Sumba	76.0	7.71	140.1	275.4	150.0	350.0

Table 3.6.6. Observed concentration ratios in 1995.						
1995	Concentration ratio *10^3 Soil-Grass transfer			Concentration ratio *10^3 Grass-Meat transfer		
	Mean	Min	Max	Mean	Min	Max
Bøur	40.0	6.35	66.7			
Velbastað	322	98.4	546			
Hvalvík	532	210	822			
Skáli	157	94.5	222			
Funningur	-	-	-	-	-	-
Norðoyri	153	71.1	257			
Sandur	34.1	18.5	49.6			
Hvalba	32.0	19.1	52.7			
Sumba	89.0	29.4	120			

Table 3.6.7. Observed transfer factors ($m^2/kg(dw)$) in 1990 and 1991.

	1991						1990					
	Transfer factor *10³ Soil-Grass transfer			Transfer factor *10³ Soil-Meat transfer			Transfer factor *10³ Soil-Grass transfer			Transfer factor *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	10.4	6.62	14.9	1.56	0.42	3.76	26.5	17.9	34.1	2.28	0.78	4.92
Velbastað	15.5	1.41	53.2	0.99	0.36	1.44	4.66	2.60	8.20	0.59	0.32	0.90
Hvalvík	38.0	22.3	75.3	9.50	3.55	18.4	35.5	15.4	60.5	7.62	2.39	13.2
Skáli	14.2	6.38	18.4	6.39	1.26	14.8	37.2	34.4	40.0	11.5	6.40	13.0
Funningur	39.7	30.4	47.1	-	-	-	42.5	17.4	67.9	-	-	-
Norðoyri	11.7	5.70	15.2	1.69	1.12	31.3	32.9	29.0	36.1	6.37	1.85	13.6
Sandur	32.0	9.77	79.4	3.89	0.82	5.67	30.3	24.7	38.8	6.50	6.30	6.70
Hvalba	2.19	0.82	2.91	0.62	0.34	0.88	-	-	-	-	-	-
Sumba	24.7	3.84	37.0	2.62	-	-	28.4	7.40	55.6	3.67	2.82	4.47

Table 3.6.8. Observed transfer factors ($m^2/kg(dw)$). 1993 compared to 1992

	1993						1992					
	Transfer factor *10³ Soil-Grass transfer			Transfer factor *10³ Soil-Meat transfer			Transfer factor *10³ Soil-Grass transfer			Transfer factor *10³ Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	6.28	3.57	8.73	1.37	0.67	2.42	7.47	3.54	10.1	1.27	0.87	1.80
Velbastað	2.60	1.70	3.57	0.53	0.19	0.74	6.60	1.45	22.0	0.81	0.20	1.88
Hvalvík	39.5	18.3	50.2	4.75	1.71	8.52	37.7	30.5	49.2	3.76	2.17	5.27
Skáli	12.2	5.73	25.4	4.40	2.63	5.85	18.2	3.88	44.4	4.72	4.28	5.12
Funningur	15.0	8.13	31.9	-	-	-	17.1	9.60	30.9	-	-	-
Norðoyri	3.81	3.31	5.10	1.34	0.94	2.03	8.72	1.93	13.8	2.28	1.15	3.02
Sandur	4.83	1.96	12.9	2.77	2.19	3.70	1.69	0.78	2.79	1.49	-	-
Hvalba	2.17	1.60	2.76	0.74	0.54	1.06	2.07	1.26	2.57	0.58	0.44	0.73
Sumba	3.08	1.17	5.09	0.79	0.30	1.35	15.3	10.2	15.0	2.73	-	-

Table 3.6.9. Observed transfer factors (m^2/kg(dw)) in 1994 and 1995. Meat from 1995 remains to be analysed.												
	1995						1994					
	Transfer factor *10^3 Soil-Grass transfer			Transfer factor *10^3 Soil-Meat transfer			Transfer factor *10^3 Soil-Grass transfer			Transfer factor *10^3 Soil-Meat transfer		
	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Bøur	1.35	0.19	2.14				1.83	0.63	2.59	1.35	0.20	2.69
Velbastað	8.04	2.71	13.4				-	-	-	0.74	0.28	1.50
Hvalvík	38.5	12.1	49.7				22.0	3.10	50.3	2.32	0.65	4.63
Skáli	6.15	3.04	9.43				8.85	6.45	14.8	5.75	1.95	8.04
Funningur	-	-	-	-	-	-	-	-	-	-	-	-
Norðoyri	7.11	4.57	9.46				11.2	5.80	20.7	6.91	2.32	12.8
Sandur	1.66	1.00	2.33				0.94			3.68	3.07	4.11
Hvalba	2.36	1.62	3.63				3.02	1.04	4.84	0.92	0.39	1.52
Sumba	6.64	1.72	11.5				6.64	0.74	14.0	1.68	0.91	2.14

The arithmetic means of the concentration ratios and the transfer factors are presented in Table 3.6.10.

Table 3.6.10	Concentration ratios * 10^3			Transfer factors * 10^3 m^2/kg	
	Grass/Soil	Meat/Grass	Meat/Soil	Grass/Soil	Meat/Soil
Faroes 1990	618	181	108	29.7	5.51
Faroes 1991	390	225	68	20.9	3.54
Faroes 1992	276	291	46	12.8	2.21
Faroes 1993	189	322	42	9.95	2.09
Faroes 1994	103	406 *)		7.78	2.92
Faroes 1995	170			8.97	

*) Sandur excluded (cf. Table 3.6.5)

The observed grass-to-meat ratios are low compared to other Nordic countries with similar soil types as the faroese. However, it should be considered that (for practical reasons) the grass has been collected in July (August 1990) while the meat is from the time of slaughter, i.e. typically in October. Taking account of the time variation of the activity in the grass, this time delay affects the estimate for the grass-to-meat transfer.

To test the "delay effect", extra grass sampling was carried out in some pastures within about a month from the time of slaughter. The results are in Tables 3.6.11 and 3.6.12, giving the arithmetic mean $617 \cdot 10^{-3}$ (or $431 \cdot 10^{-3}$ if the extreme value for Sandur resulting from the very low activity in the grass is excluded) for 1992 and $270 \cdot 10^{-3}$ for 1993. The averages for the same pastures based on the results in Tables 3.6.3 and 3.6.4 are $309 \cdot 10^{-3}$ (or $212 \cdot 10^{-3}$ if Sandur is excluded) in 1992 and $264 \cdot 10^{-3}$ in 1993. Thus it may be concluded that the time delay between the sampling of grass and meat is not a single explaining factor for the low concentration ratio between the meat and the grass.

Table 3.6.11. The observed grass-to-meat concentration ratio $*10^3$, based on the **second** grass sampling in **1992**. The time of sampling is noted.

Velbastað Grass 30/10 Meat 17/10	Hvalvík Grass 28/9 Meat 31/10	Skáli Grass 20/9 Meat 9/10	Norðoyri Grass 7/10 Meat 25/9	Sandur Grass 29/10 Meat "Oct"	Hvalba Grass 7/11 Meat 20/10	Sumba Grass 7/11 Meat "Oct"
579	154	756	229	1735	176	692

Table 3.6.12. The observed grass-to-meat concentration ratio $*10^3$, based on the **second** grass sampling in **1993**. The time of sampling is noted.

Bøur Grass 1/9 Meat 7/9	Velbastað Grass 2/10 Meat 3/11	Hvalvík Grass 10/10 Meat 13/11	Skáli Grass 26/9 Meat 16/10	Hvalba Gras 6/11 Meat 21/10	Sumba Grass 6/11 Meat 12/10
238	202	115	458	194	416

4. Feeding experiment

A feeding experiment was set up in 1993 to check the low ratios between the concentrations of Cs-137 in grass and lamb meat.

Two lambs, male twins, grazed in a fenced area from 1 September 1993 to 17 September 1993, whereupon they were feeded with grass from the fenced area in a stable at Royndarstøðin í Kollafirði (the Faroese Agricultural Research Station) until 18 October 1993. They were slaugthered on 19 October 1993, about 6 months of age. The amount of food is registrated in Table 4.1. Royndarstøðin í Kollafirði was responsible for the feeding.

Table 4.1. Feeding pr. day of twin lambs. Food from the same grass sample was used for 3 days.

Date	g(fw) of food to both lambs	g(dw) of food to both lambs	Dry-weight percent
20.09.93	3250	611	18.8
21.09.93	3310	622	18.8
22.09.93	3410	641	18.8
23.09.93	3190	600	18.8
24.09.93	3080	647	21.0
25.09.93	3070	645	21.0
26.09.93	3150	662	21.0
27.09.93	3180	668	21.0
28.09.93	3650	748	20.5
29.09.93	4040	828	20.5
30.09.93	4110	842	20.5
01.10.93	3940	894	22.7
02.10.93	3840	872	22.7
03.10.93	3725	846	22.7
04.10.93	3690	1100	29.8
05.10.93	3330	992	29.8
06.10.93	3210	957	29.8
07.10.93	3090	921	29.8
08.10.93	3010	897	29.8
09.10.93	2890	861	29.8
10.10.93	2780	828	29.8
11.10.93	2820	750	26.6
12.10.93	2805	746	26.6

13.10.93	2790	742	26.6
14.10.93	2705	720	26.6
15.10.93	2680	817	30.5
16.10.93	2700	824	30.5
17.10.93	2780	848	30.5
18.10.93	2810	857	30.5

The Cs-137 activity in the grass can be seen in Table 4.2.

Table 4.2. The Cs-137 activity in the food. The 1 std counting uncertainty is included.

Date	20.09.93	24.09.93	28.09.93	01.10.93	04.10.93	07.10.93	15.10.93
Bq/kgdw	137.0±5.04	93.0±6.06	91.5±4.47	109.8±5.06	87.9±4.46	87.0±3.96	63.2±3.63

The quality of the was analyzed by the Agricultural University of Norway. The results are presented in Table 4.3.

Table 4.3. Chemical analyses of the food used in the feeding experiment. All data have the unit g/kg.

Date	Dry Matter	Ash	Ether-extract	Fibers	Kjeldahl-N	Potass-ium	Sodium	Calsium
24.09.93	940	48	21.9	293	13.3	9.4	1.6	2.8
28.09.93	939	56	20.0	275	13.0	13.2	1.6	3.0
01.10.93	937	59	22.3	263	13.3	12.2	1.7	4.0
04.10.93	940	45	21.1	296	12.6	9.7	1.3	2.3
07.10.93	938	53	20.0	265	12.7	9.9	3.1	3.2
11.10.93	938	52	19.2	293	11.9	9.0	2.1	2.7
15.10.93	939	57	16.7	272	13.9	11.4	1.8	2.9

The content of Cs-137 in muscles and internal organs is presented in Table 4.4. The distribution is practically identical except for testicle. Control measurements of the testicles gave the same results.

Using the average concentration of Cs-137 in grass for the period 1 October - 15 October (87.0 Bq/kg) we get concentration ratios between grass and meat consistent with the results in §3.6.

The carcass weights are low relative to the age of the lambs.

Table 4.4. The Cs-137 activity in the lambs ± counting uncertainty (Bq/kg(fw)±1std). LH: left hand. RH: right hand.			Observed grass-to-meat concentration ratio $*10^3$	
Organ	**Lamb 1**	**Lamb 2**	Lamb 1 Meat/Grass	Lamb 2 Meat/Grass
Heart	20.3±1.31	22.3±1.30	233	256
Liver	23.6±1.17	23.4±1.25	271	269
Kidney	29.4±1.32	31.8±1.62	338	366
Testicle	14.7±0.95	24.0±0.94	169	276
Lung	16.8±1.45	17.9±1.09	193	206
Belly cover	18.4±1.34	20.7±0.98	211	238
LH rear leg	41.6±1.13	42.8±1.43	478	492
RH rear leg	40.8±1.77	39.7±1.10	469	456
LH foreleg	37.1±1.20	30.5±1.36	426	351
RH foreleg	36.2±1.52	33.9±1.53	416	390
Neck	31.7±1.29	29.5±1.45	364	339
Carcass weight	8 kg	11 kg	8 kg	11 kg

The highest activity is observed in rear leg. The neck, which is used by the Faroe Islands in both the RAD-3 and the EKO-2 programme, has an activity in the high end of the activity range from about 17 Bq/kg(fw) to about 40 Bq/kg(fw). The mean activities of 28.2 Bq/kg(fw) in lamb 1 and 28.8 Bq/kg(fw) in lamb 2 indicate that neck muscles repressent the animal fairly well.

It is noted that the concentration ratios in Table 4.4 and the observed concentration ratios between meat and grass reported in §3.6 (e.g. Table 3.6.10) are of the same order of magnitude. Thus the feeding experiment does not answer the question about the low values, but confirms the results found in the RAD-3 and EKO-2 programmes.

5. Halflife

Assuming an exponential decrease with time of the activity (Bq/kg) and doing a linear regression analysis of the semi-logarithmic relation between time and activity gives the results in Table 5.1 which includes R^2, i.e. the square of the linear regression coefficient. It has not been possible to distinguish between the halflife for Chernobyl- and fallout-caesium, because the Cs-134 activity was often below the detection limit.

Table 5.1. Effective ecological halflives on the assumption of exponential decay. R^2 from the linear regression between time and natural logarithm of activity is shown in paranthesis. No data if $R^2<0.49$.

	Bøur	Velbastað	Hvalvík	Skáli	Funningur	Sandur	Hvalba	Sumba
Grass 1990-95	1.63 (0.846)	2.86 (0.490)	3.69 (0.753)	6.24 (0.530)	1.61 (0.861)	1.04 (0.733)		2.64 (0.494)
Meat 1990-94	11.2 (0.653)	4.81 (0.716)	1.67 (0.828)					3.47 (0.447)
Liver 1990-94		7.70 (0.803)					5.59 (0.498)	4.13 (0.498)
Heart 1990-94		3.50 (0.823)						1.94 (0.816)
Kidney 1990-94	3.27 (0.868)	2.48 (0.951)						3.07 (0.567)

Since we do only have data for 5-6 years, it is not possible to give a qualified estimate of the halflives. The observations until now, however, indicate that the decay model is more complicated then simple exponential and that processes in the soil must be considered

6. Faeces

Faeces from lamb have been analysed in 1995. The results are presented in Table 6.1.

Table 6.1. Cs-137 (Bq/kgdw) in faeces, date corrected to 1 July 1995. Sampling dates are included. The *) marks samples from the date of grass and soil sampling.

Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
57.0 95.06.22	63.8 95.06.27	40.5 95.06.27	120.9 *) 95.07.19	98.2 *) 95.07.20	111.0 *) 95.07.18	33.6 95.06.21	38.8 95.06.23
32.6 *) 95.07.31	59.2 *) 95.07.18	61.5 *) 95.08.07	120.9 95.07.19			23.2 *) 95.08.05	69.0 *) 95.08.06
112.8 95.10.13	13.7 95.10.20	118.6 95.10.23				13.4 95.10.27	43.8 95.10.27

The ratio between the Cs-137 concentration (Bq/kg(dw)) in faeces and mixed grass sampled at the same dates is set up in Table 6.2.

Table 6.2. Upper row: Ratio between Cs-137 (Bq/kgdw) in faeces and in mixed grass (faeces/grass). **Lower row:** Ratio (multiplied by 1000) between Cs-137 concentration in faeces and the Cs-137 deposition (Bq/m^2) in the 0-10cm soil layer.

Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
2.31	2.18	0.433	2.41	1.64	11.2	2.23	1.82
5.90	12.1	14.8	14.5	13.5	18.3	5.18	10.7

The faeces/grass concentration ratio in Hvalvík and Sandur differ from the values found in other pastures. Concerning the transfer factor from soil to faeces it is noted that Bøur and Hvalba tend to have lower values than other pastures. Further analyses concerning faeces remain to be done, e.g. in relation to analyses of meat samples.

7. Discussion (preliminary)

The report presents Faroese results of measurements carried out for 6 years in the RAD-3 programme and the EKO-2 programme. Radiocaesium has been measured in soil, grass and lambs from nine uncultivated pastures, 50 to 240 meters above sea level.

Chemical soil parameters have been measured in addition to radiocaesium. The soil type is peaty with PH below 5.3. The ignition loss is generally around 50-70%. The content of potassium and sodium is mostly in the range 300-600 mg/kg.

The ratio between the depositions in the top 5cm of the soil and the 0-10cm soil layer has a range from 0.5 to 0.8 every year. Profile studies carried out in 1992, when the upper 5cm of the cores were split up into 1cm layers, showed that the content of caesium from Chernobyl was highest in a depth of 1-3cm (cf. Table 3.2.7). The highest Cs-134/Cs-137 ratios were found in the southern part of the country.

A considerable amount of Cs-137 from the weapon tests is still found in the upper soil layers. Chernobyl-caesium as well as fallout-caesium (from the weapon tests) show significant geographical variation (cf. Table 3.2.7). The geographical variety of the ratio between Chernobyl-caesium and fallout-caesium is significant as well. Weather and climate conditions are considered as important explaining factors for the differenses.

The deposition of Cs-137 in the 0-10cm soil layer has not changed significantly from 1990 to 1995. For the country as a hole the value is around 5-6 kBq/m^2.

The level of the concentration of Cs-137 in grass has lowered since 1990. High within pasture variation is observed between the selected 1/4m^2 microplots, indicating the difficulty of taking representative grass samples. These circumstances may reflect a difference in botanical composition.

In order to investigate the time variation of the activity in grass, sampling was carried out several times in the years 1991, 1992 and 1993. Particular attention was given to Hvalvík (chosen for practical reasons), but grass was also sampled several times in other pastures. The results indicate that the time of maximum activity is between mid July and mid August.

The observed concentration ratios and transfer factors vary significantly both geographically and within the pastures. The average ratio between the concentration (Bq/kg) of Cs-137 in meat and grass is observed to be a factor 2-3 lower in the Faroe Islands than in Norway, having similar soil types as the Faroe Islands. A controlled feeding experiment with two male twin lambs confirmed the observed ratios. The average aggregated transfer factor (m^2/kg) from soil to meat is a factor about 15-20 lower than in Norway, while the average observed transfer factor from soil to grass is a factor 3-10 lower than in Norway. Details of the observations can be found in §3.6.

A scatterplot of some of the obseravtions can be found in Figs. 7.1-7.4 (covering the RAD-3 period). However, in a big plot like this, some graphs make little or no sense. The correlations between the parameters is weak in most cases. The grass/soil concentration ratio is negatively correlated to PH in the soil and possitively correlated to the ignition loss of the soil; to some extent it is negatively correlated to potassium in the soil. The meat/gras concentration ratio tends to be possitively correlated to PH in the soil. A negative correlational trend is found between PH in the soil and the meat/soil concentration ratio and the soil-to-grass and soil-to-meat transfer factors. The Cs-137 concentration in meat, grass and soil tends to be negatively correlated to PH and possitively correlated to the ratio between Bq/kg Cs-137 and grams of sodium in the 0-10cm soil layer.

Estimates of effective ecological halflives are given on the assumption of a simpel exponential decrease with time. For mixed grass, covering 6 years of data, the range is 1.04-6.24 years, and for meat and internal organs (covering 5 years) it is 1.94-11.2 years. However, the simpel exponential model is found to fit badly to the data in most cases. The decay model will presumeably be more complicated, and it should be considered to take soil processes into account.

Acknowledgements
The authors like to thank Anna av Kák and Johanna Zachariassen for doing a good and professional job in the laboratory as well as in the field.

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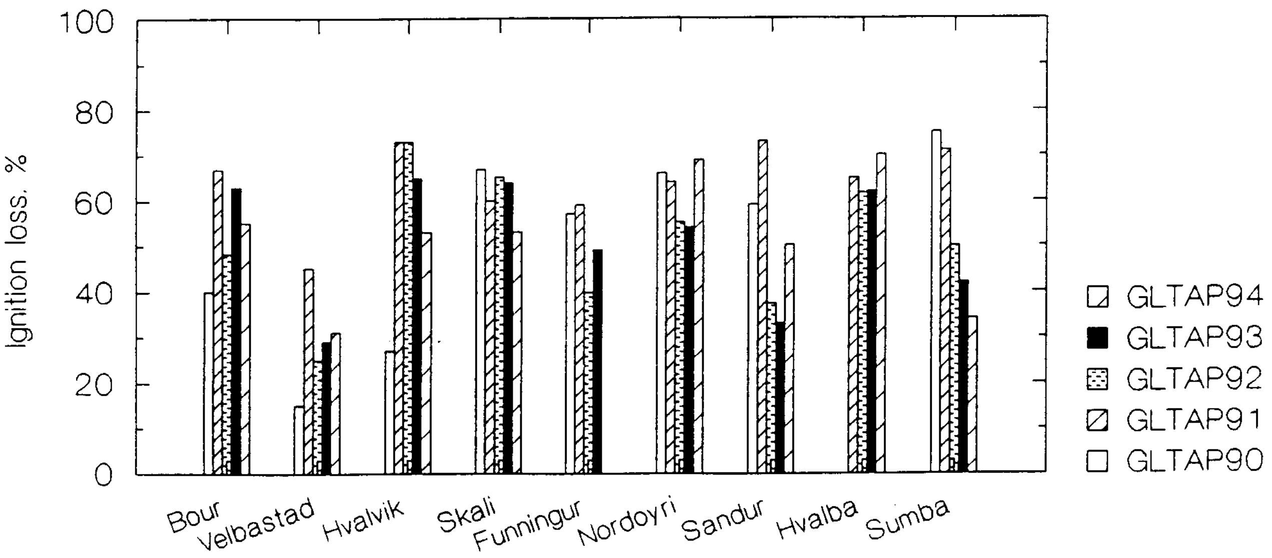

Figure 3.1.1 Ignition loss in the 0-10cm soil layer. Mean values for the pastures.

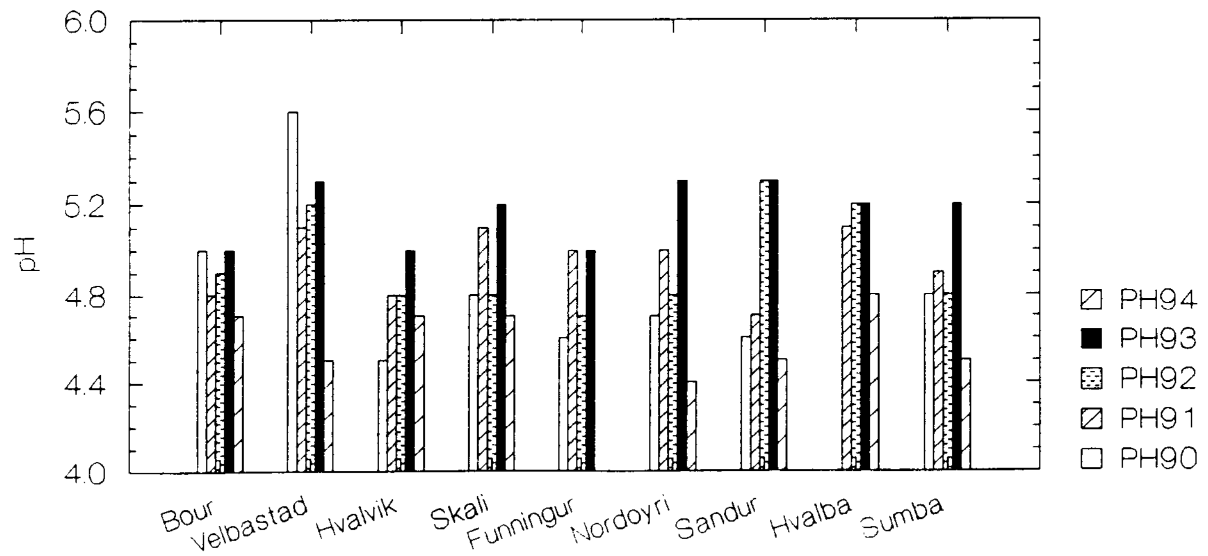

Figure 3.1.2 PH in the 0-10cm soil layer. Mean values for the pastures.

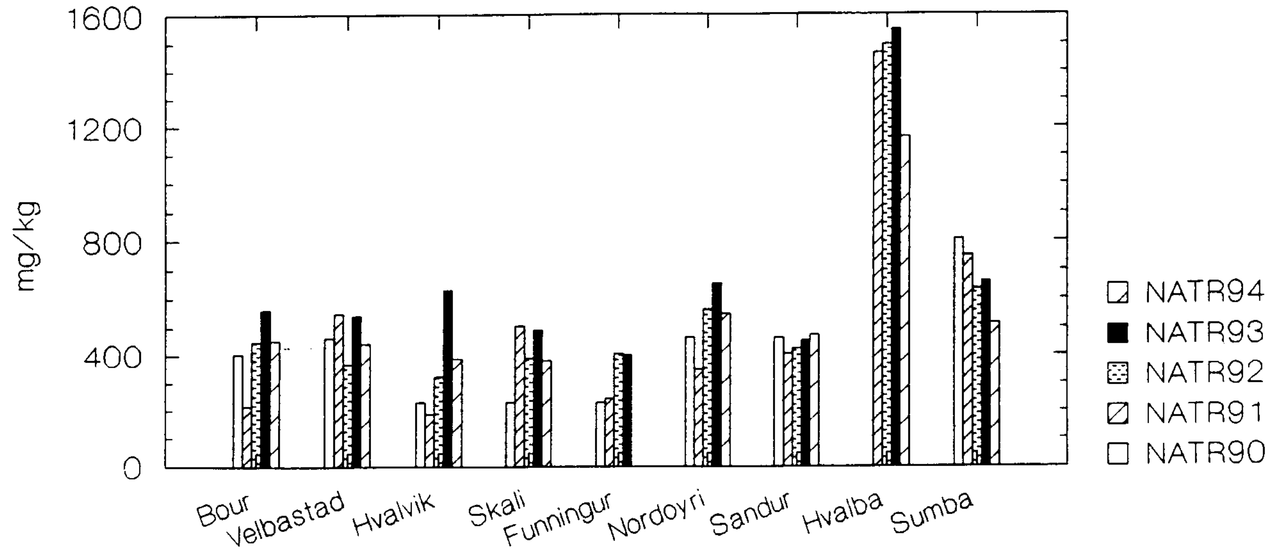

Figure 3.1.3 Sodium in the 0-10cm soil layer. Mean values for the pastures.

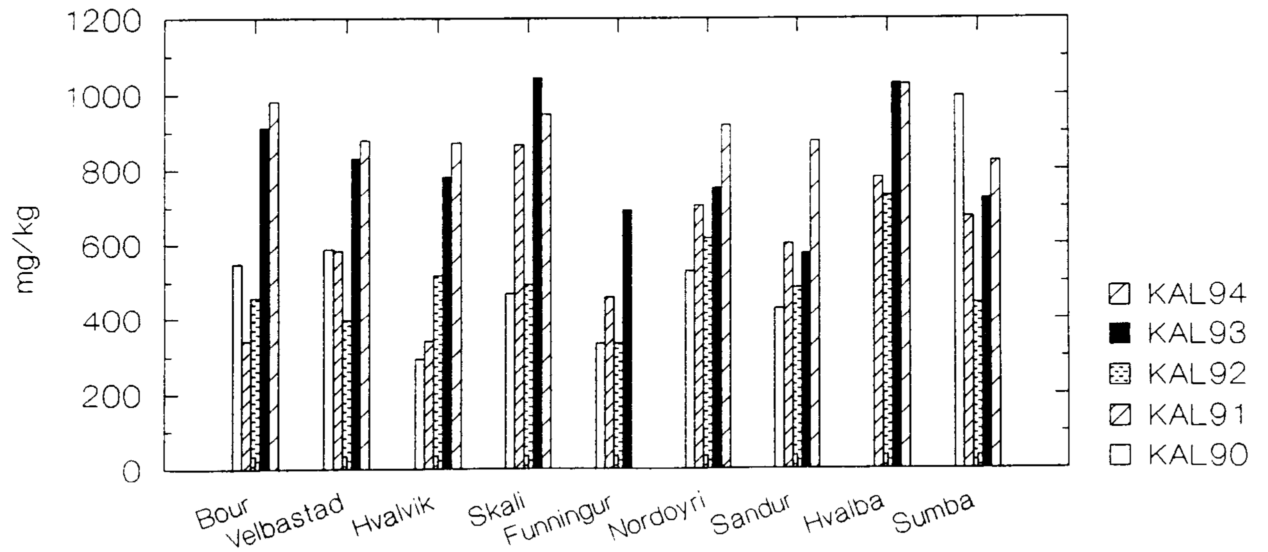

Figure 3.1.4 Easily solluble potassium in the 0-10cm soil layer. Mean values for the pastures.

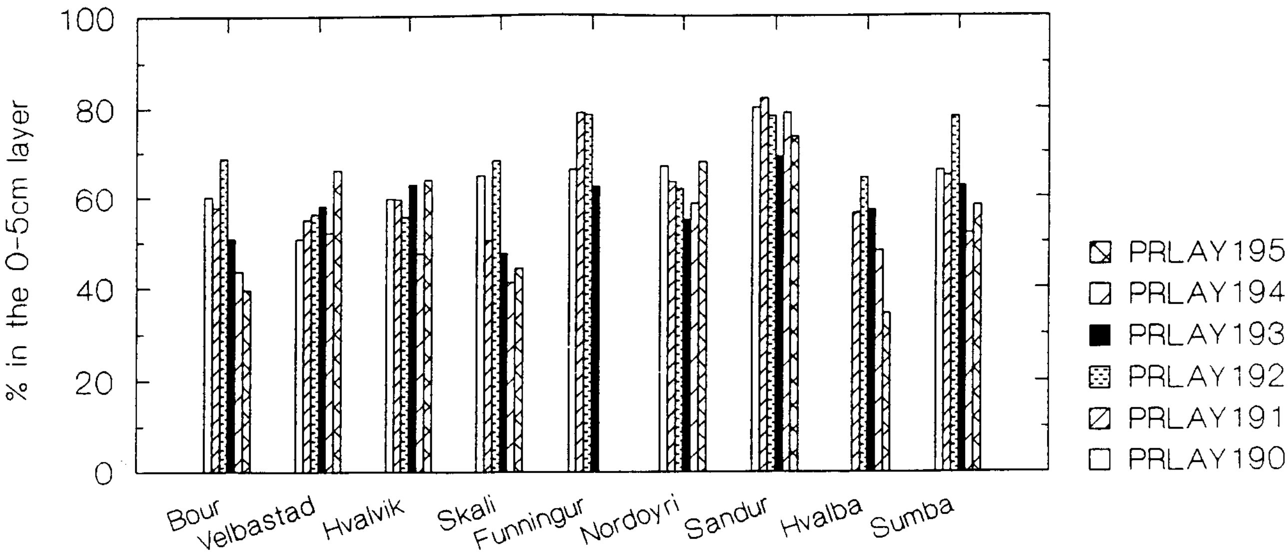

Figure 3.2.1 Cs-137 deposition in the 0-5cm soil layer relative to Cs-137 deposition in the 0-10cm soil layer.

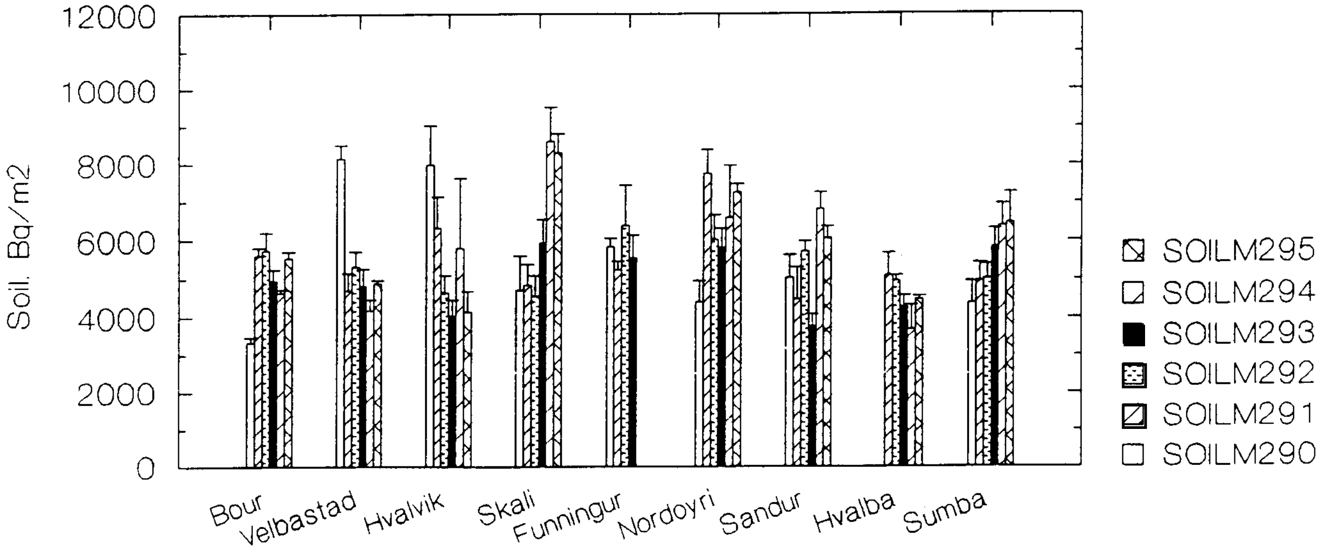

Figure 3.2.2 Cs-137 deposition in the 0-10cm soil layer. The error bars represent 1 standard error.

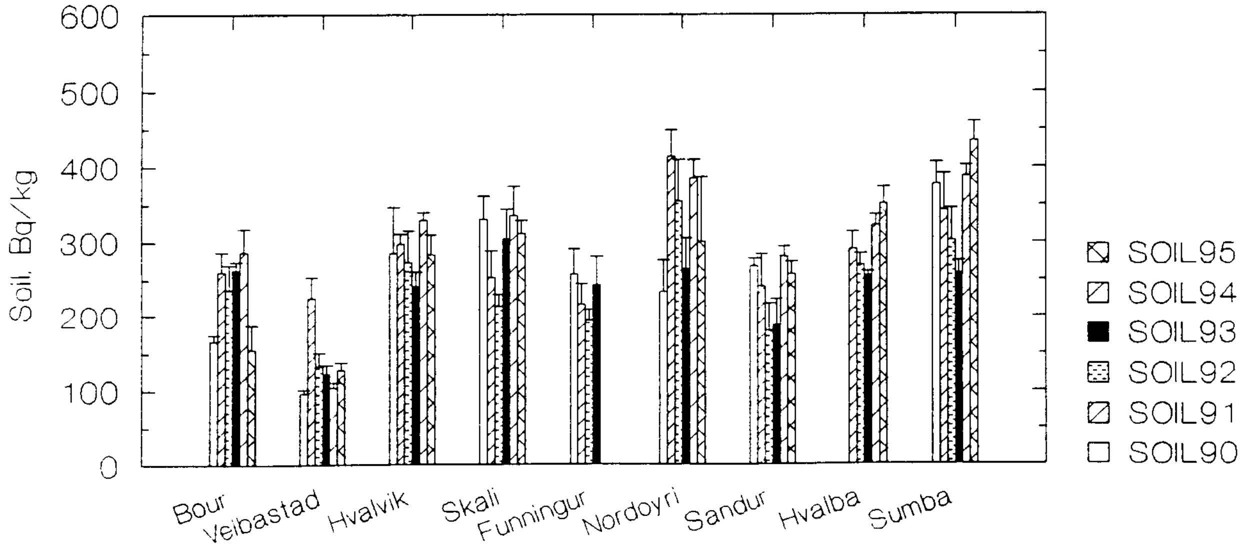

Figure 3.2.3 Concentration of Cs-137 in the 0-10cm soil layer. The error bars represent 1 standard error.

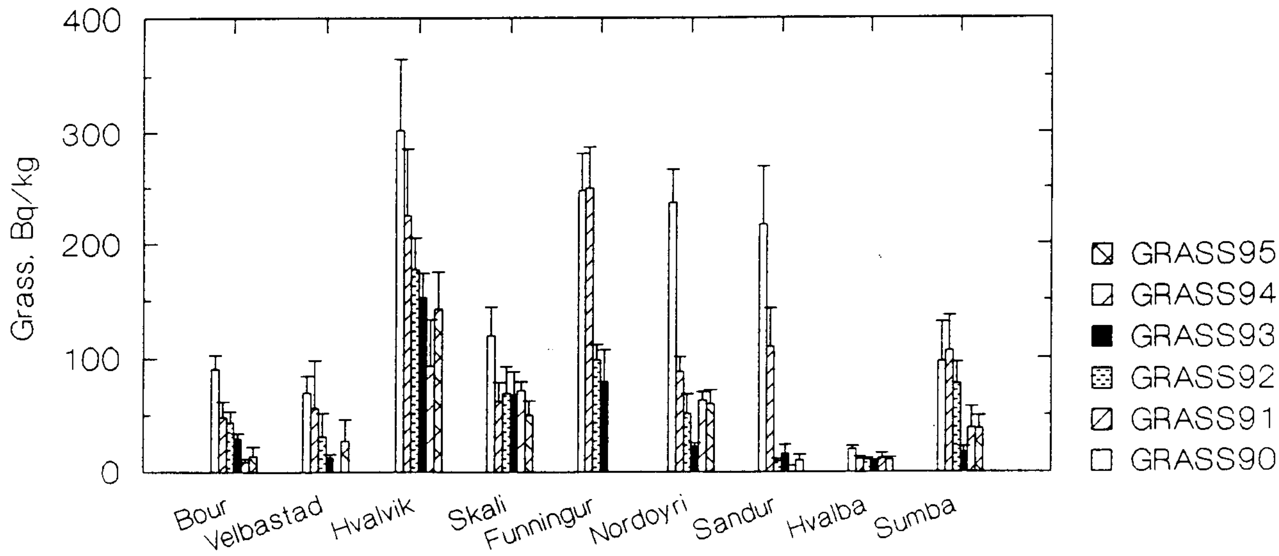

Figure 3.3.1 Concentration of Cs-137 in mixed grass. The error bars represent 1 standard error.

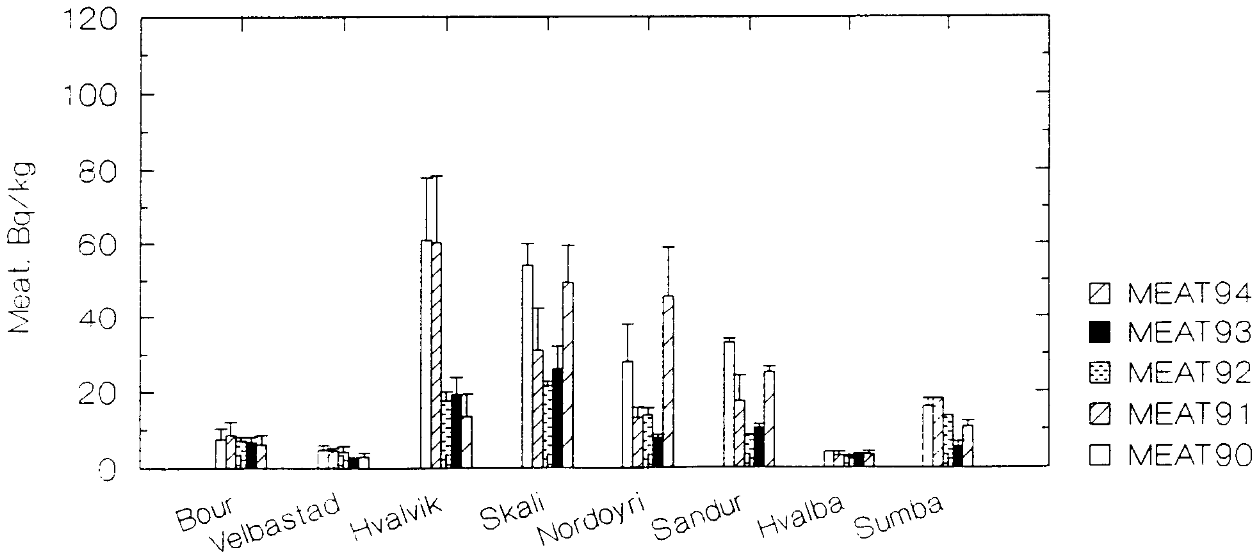

Figure 3.5.1 Concentration of Cs-137 in lamb meat. The error bars represent 1 standard error.

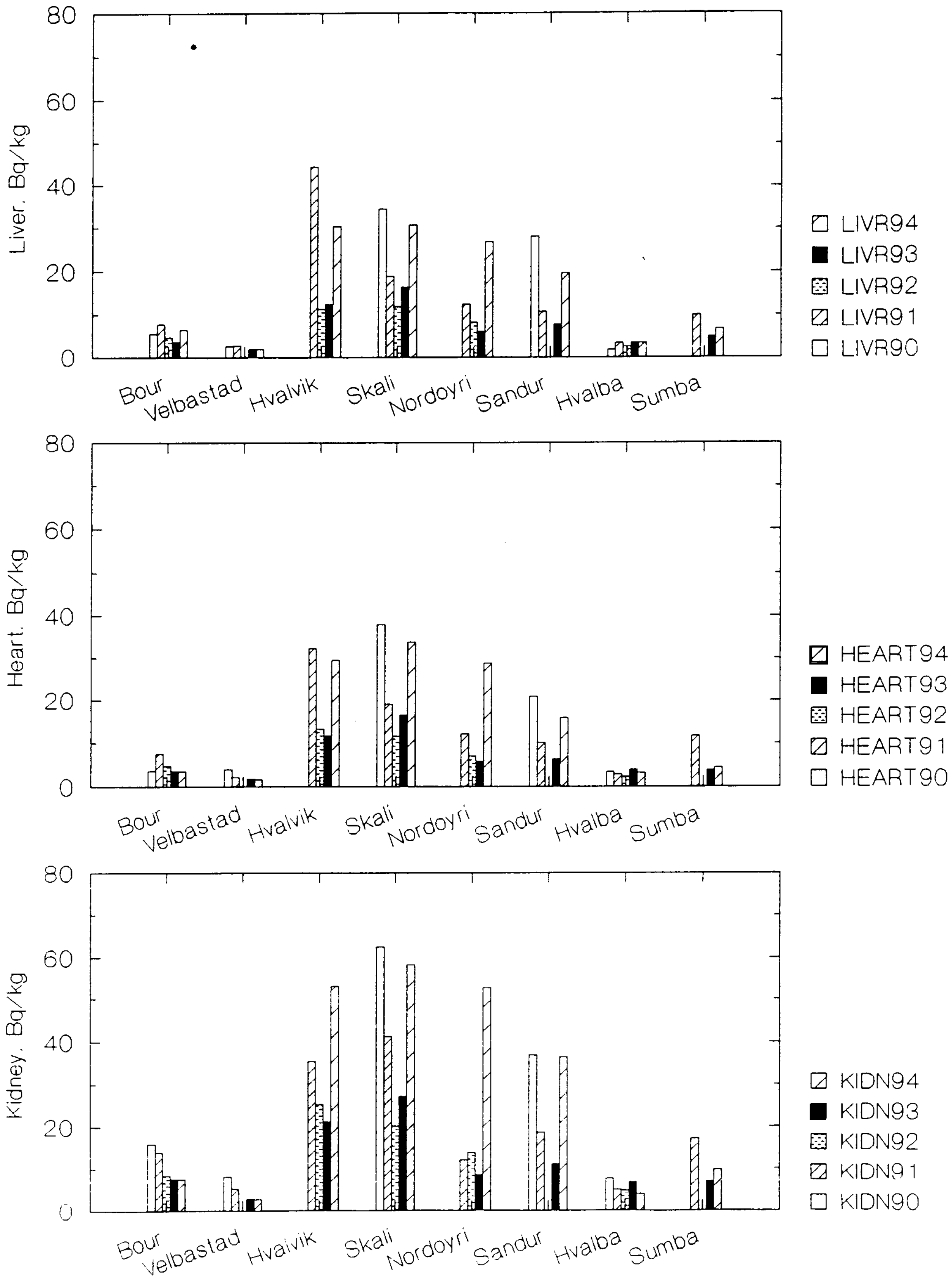

Figure 3.5.2 Concentration of Cs-137 in internal organs of lamb. More detailed results are found in Tables 3.5.4-3.5.7.

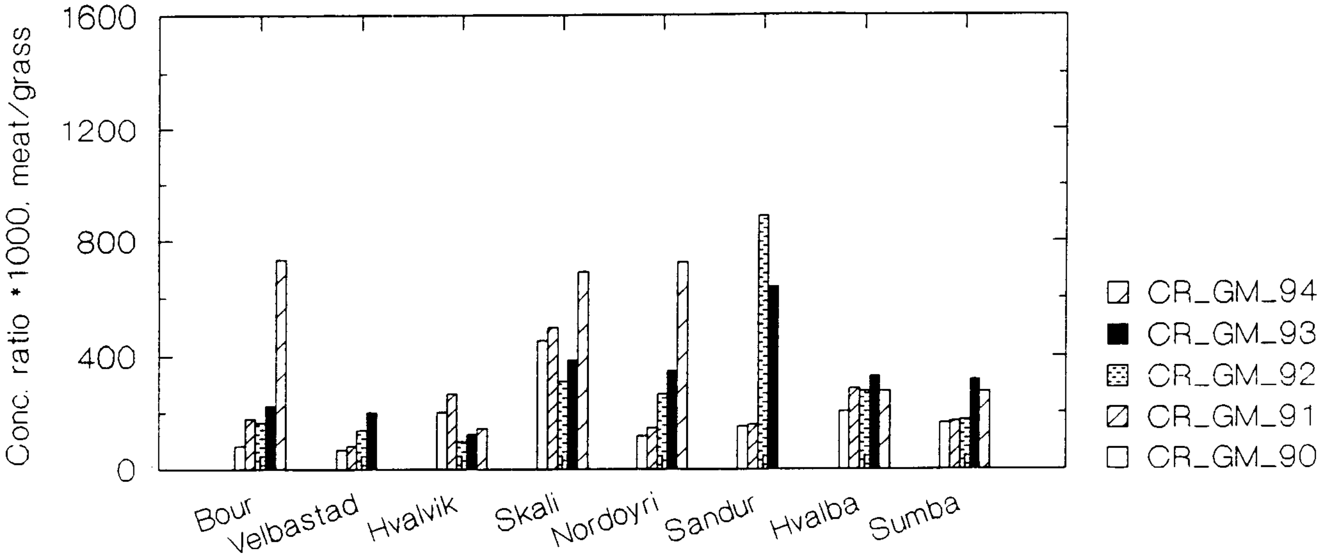

Figure 3.6.1 Meat/grass concentration ratios of Cs-137.
More detailed results are found in Tables 3.6.1-3.6.6.

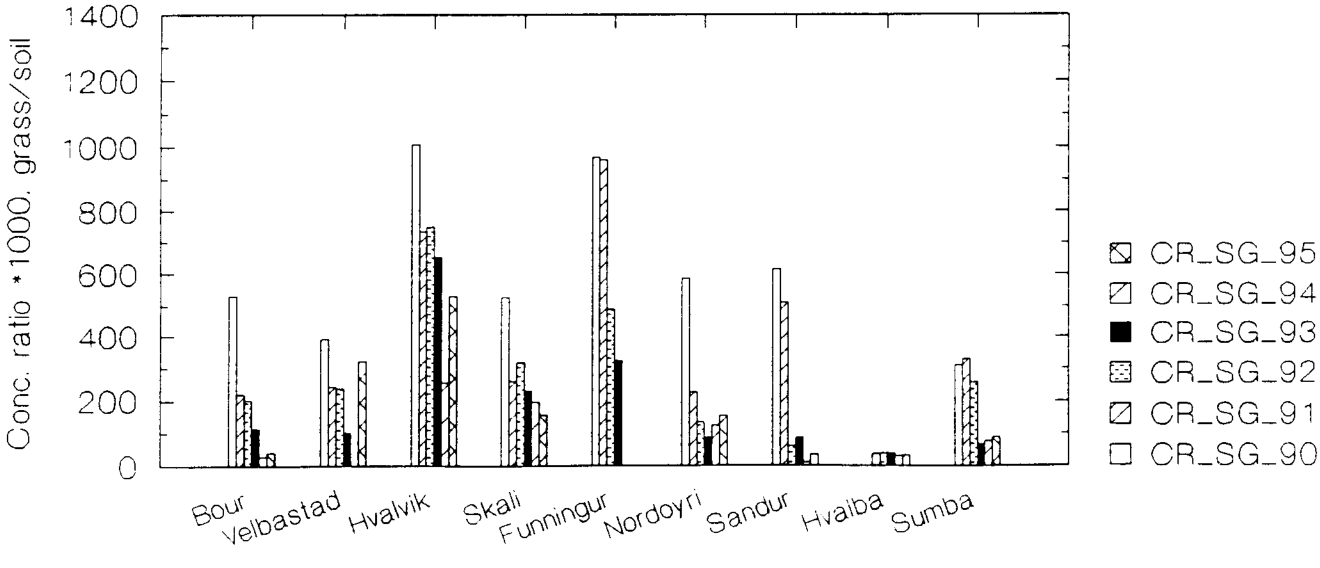

Figure 3.6.2 Grass/soil concentration ratios of Cs-137.
More detailed results are found in Tables 3.6.1-3.6.6.

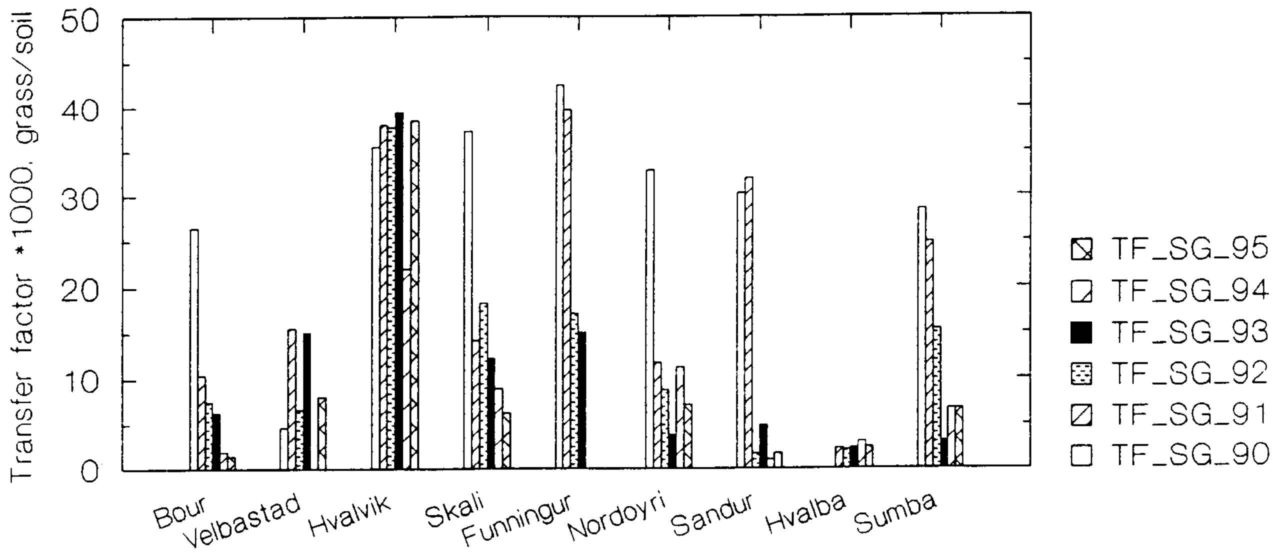

Figure 3.6.3 Soil-to-grass transfer factor of Cs-137.
More detailed results are found in Tables 3.6.7-3.6.9.

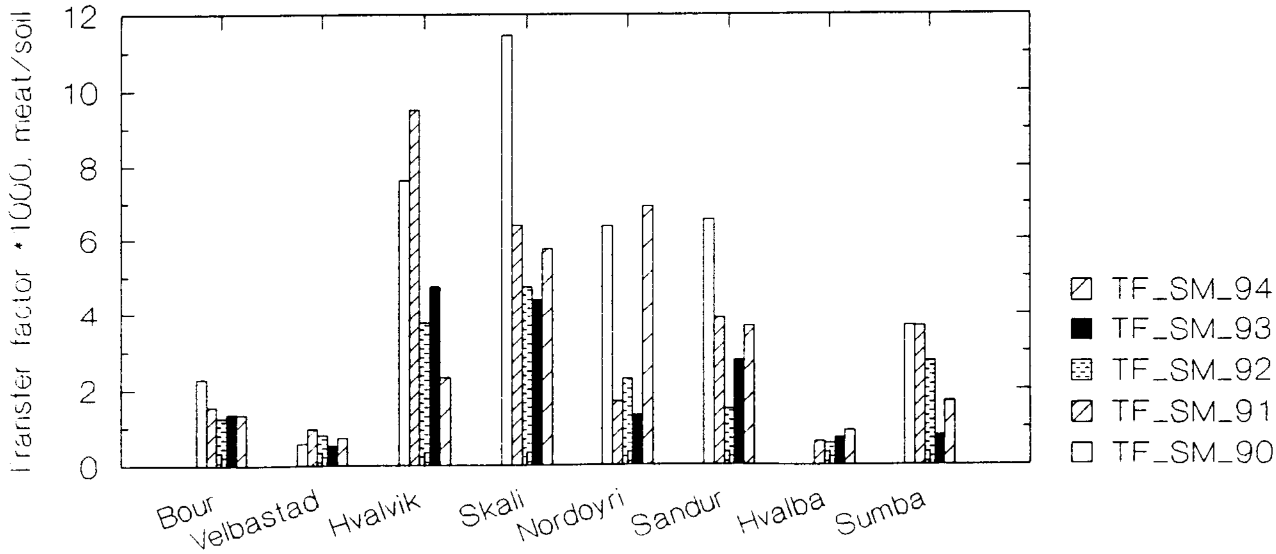

Figure 3.6.4 Soil-to-meat transfer factor of Cs-137.
More detailed results are found in Tables 3.6.7-3.6.9.

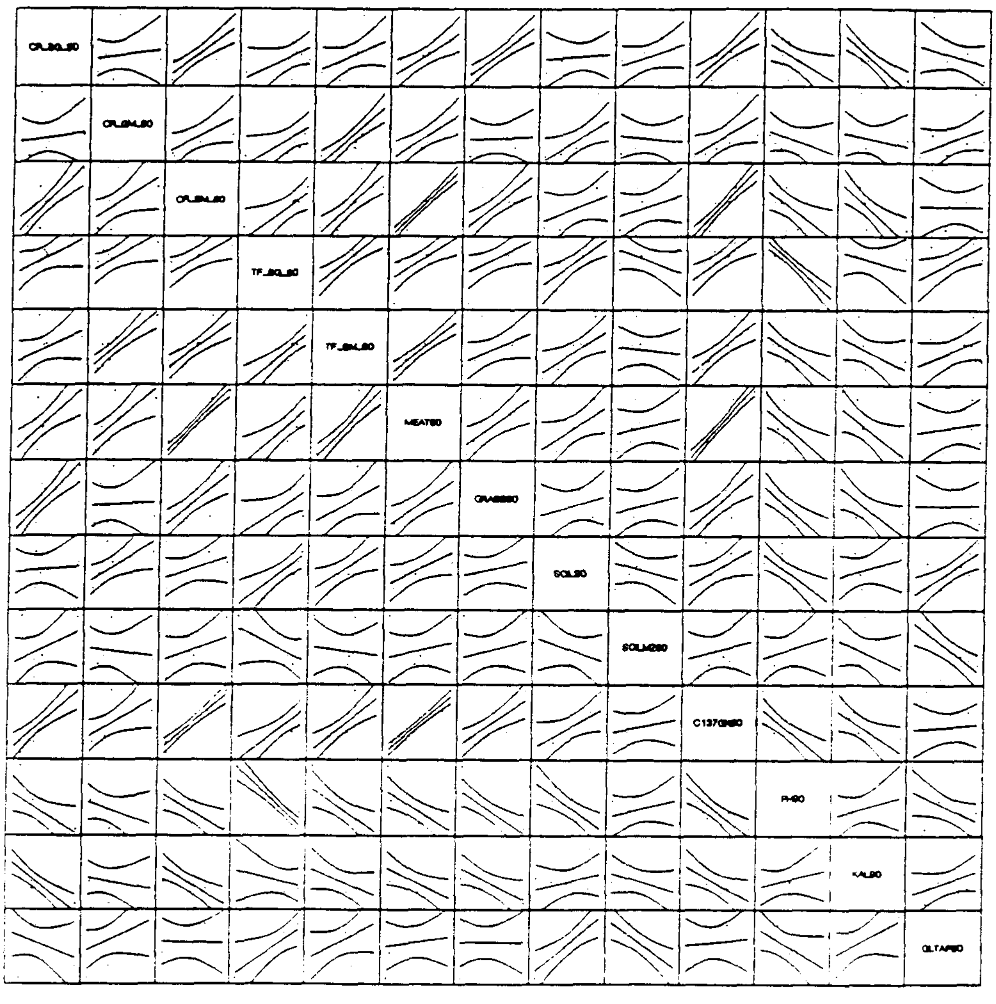

Figure 7.1 Scatter plot of results from 1990. The regression line and the 65% confidence interval is included.

Abreviations: CR_SG= (Grass Bq/kg)/(Soil Bq/kg). **CR_GM=** (Meat Bq/kg)/(Grass Bq/kg). **CR_SM=** (Meat Bq/kg)/(Soil Bq/kg). **TF_SG=** (Grass Bq/kg)/(Soil Bq/m^2). **TF_SM=** (Meat Bq/kg)/(Soil Bq/m^2). **MEAT**: Bq/kg in meat. **GRASS**: Bq/kg in grass. **SOIL**: Bq/kg in 0-10cm soil. **SOILM2**: Bq/m^2 in 0-10cm soil. **CS137GK**: (Bq/kg Cs-137 in 0-10cm soil)/(gram K in 0-10cm soil). **PH**: pH in 0-10cm soil. **KAL**: Potassium in 0-10cm soil. **GLTAP**: Ignition loss in 0-10cm soil.

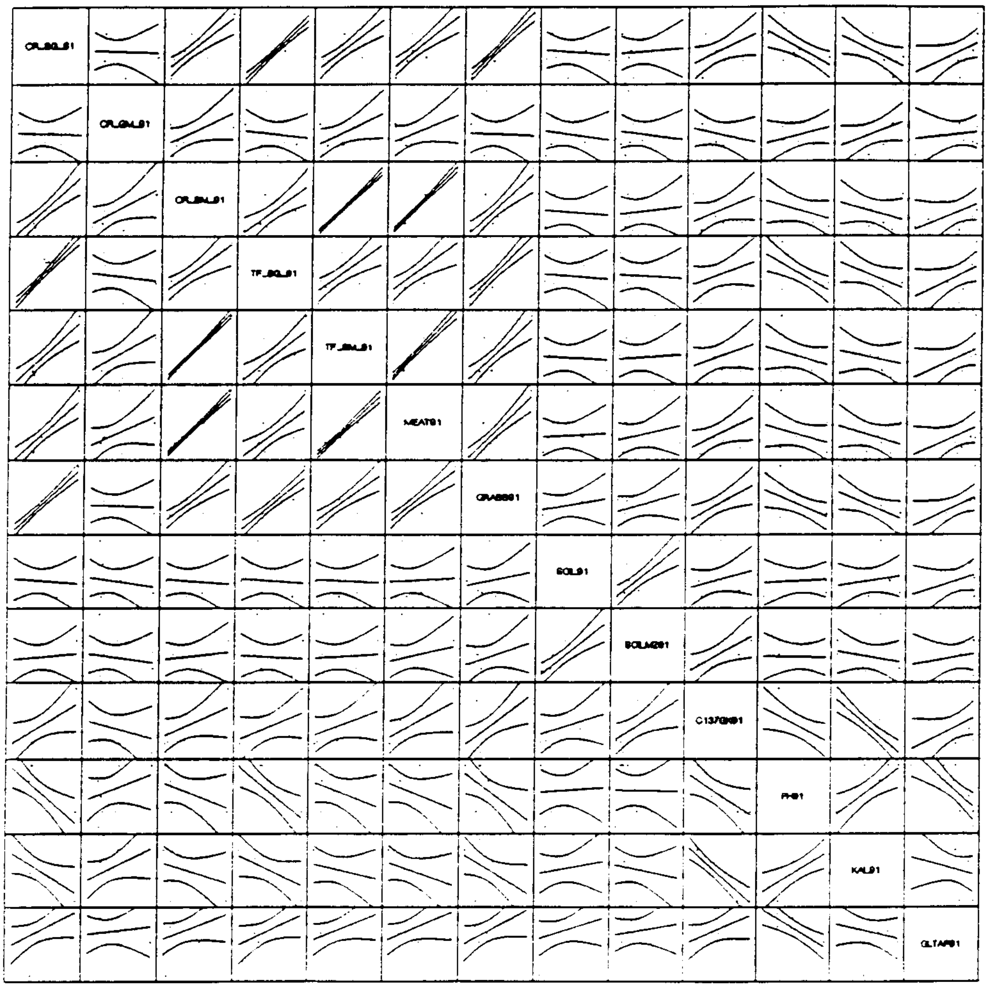

Figure 7.2 Scatter plot of results from 1991. The regression line and the 65% confidence interval is included.

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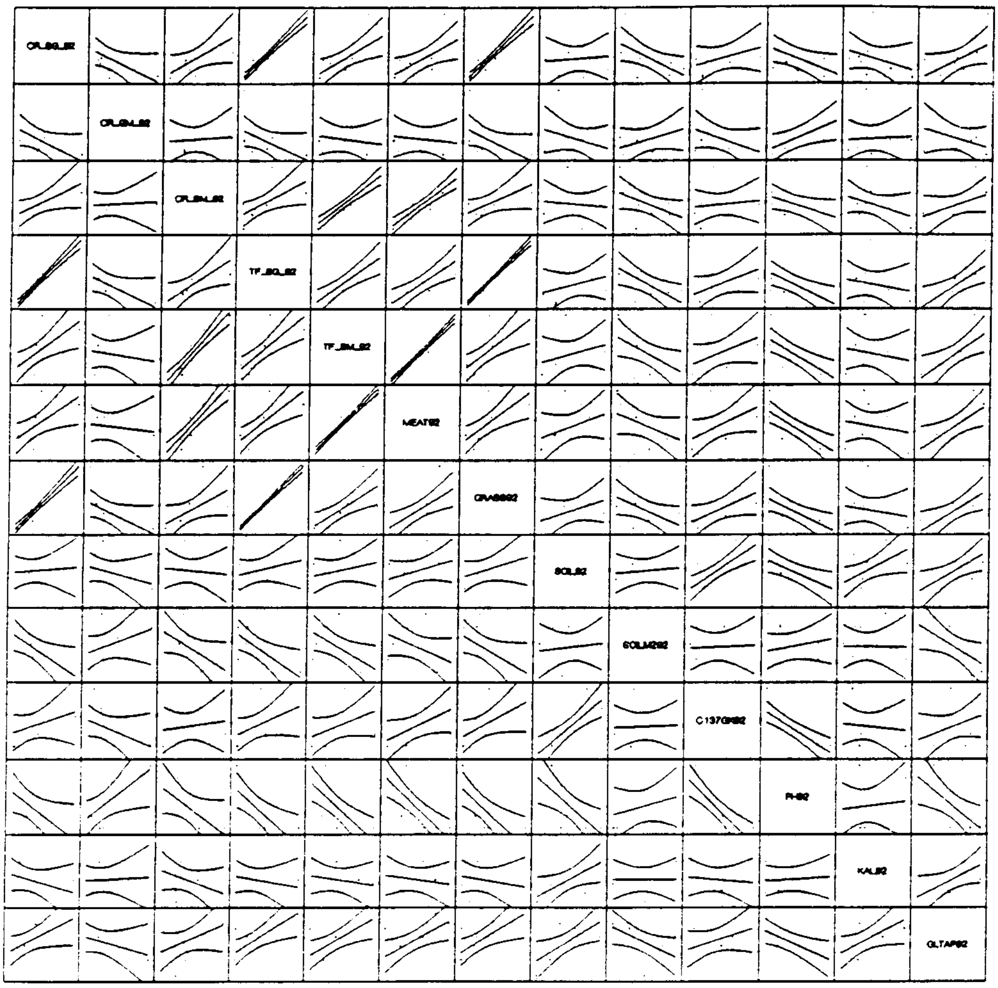

Figure 7.3 Scatter plot of results from 1992. The regression line and the 65% confidence interval is included.

Abreviations: CR_SG= (Grass Bq/kg)/(Soil Bq/kg). **CR_GM=** (Meat Bq/kg)/(Grass Bq/kg). **CR_SM=** (Meat Bq/kg)/(Soil Bq/kg). **TF_SG=** (Grass Bq/kg)/(Soil Bq/m^2). **TF_SM=** (Meat Bq/kg)/(Soil Bq/m^2). **MEAT**: Bq/kg in meat. **GRASS**: Bq/kg in grass. **SOIL**: Bq/kg in 0-10cm soil. **SOILM2**: Bq/m^2 in 0-10cm soil. **CS137GK**: (Bq/kg Cs-137 in 0-10cm soil)/(gram K in 0-10cm soil). **PH**: pH in 0-10cm soil. **KAL**: Potassium in 0-10cm soil. **GLTAP**: Ignition loss in 0-10cm soil.

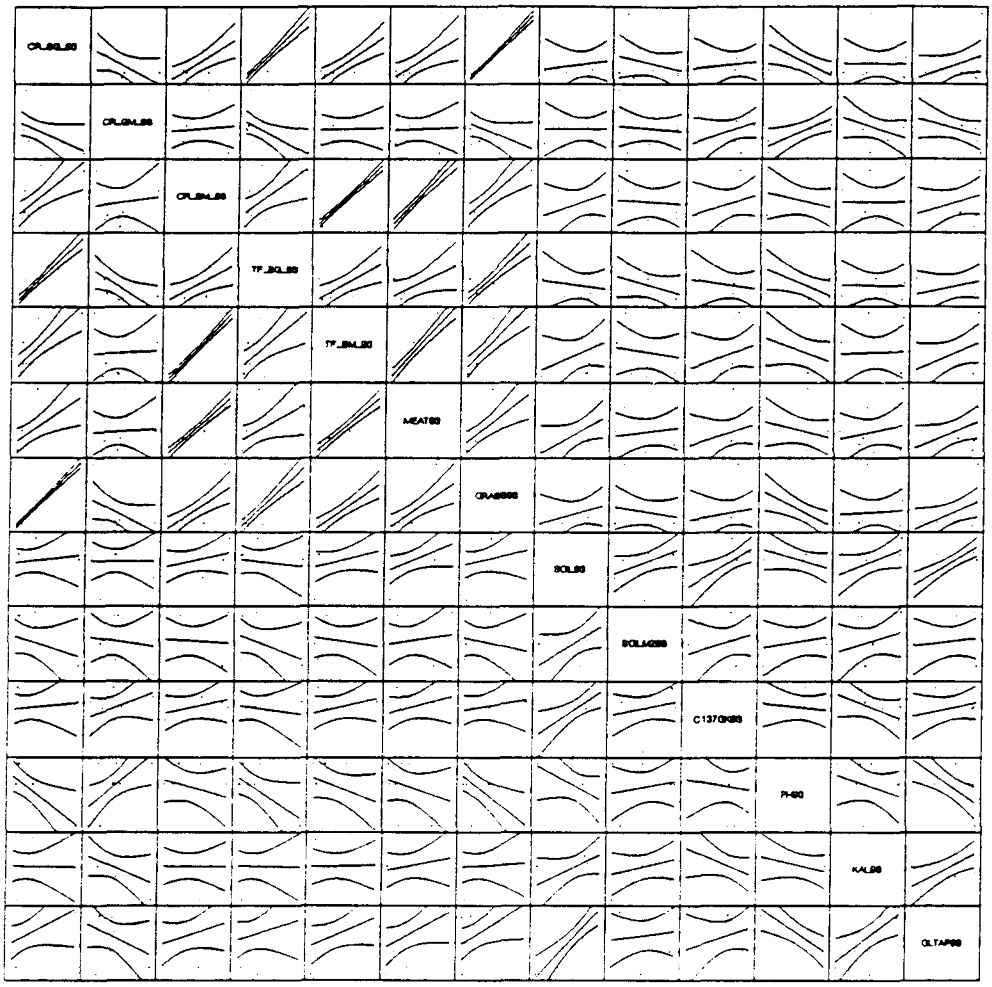

Figure 7.4 Scatter plot of results from 1993. The regression line and the 65% confidence interval is included.

Abreviations: CR_SG= (Grass Bq/kg)/(Soil Bq/kg). **CR_GM=** (Meat Bq/kg)/(Grass Bq/kg). **CR_SM=** (Meat Bq/kg)/(Soil Bq/kg). **TF_SG=** (Grass Bq/kg)/(Soil Bq/m^2). **TF_SM=** (Meat Bq/kg)/(Soil Bq/m^2). **MEAT**: Bq/kg in meat. **GRASS**: Bq/kg in grass. **SOIL**: Bq/kg in 0-10cm soil. **SOILM2**: Bq/m^2 in 0-10cm soil. **CS137GK**: (Bq/kg Cs-137 in 0-10cm soil)/(gram K in 0-10cm soil). **PH**: pH in 0-10cm soil. **KAL**: Potassium in 0-10cm soil. **GLTAP**: Ignition loss in 0-10cm soil.

NKS / EKO-2.1

Status report from Iceland, November 1995

Transfer of Radiocaesium from Soil to Vegetation and to Grazing Lambs in Iceland

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Jóhann Þórsson, Agricultural Research Institute
Sigurður E. Pálsson , Icelandic Radiation Protection Institute

Results given in this report must not be quoted without prior consent of the authors.

Introduction

This purpose of this report is to give a brief overview of the EKO-2 lamb project in Iceland as it stands in November 1995. The EKO-2 project began in 1994 and will continue until 1997. It is to a certain degree based on work carried out in the previous NKS period in the RAD-3 project during the years 1990-1993. Partial results have now been published (Hove et al., 1994). However, more emphasis has now been put on collecting a wider spectrum of samples (collection of sheep's milk is an example of this). Sampling and analysis will continue also in 1996.

This project is done in co-operation between the Icelandic Radiation Protection Institute and the Agricultural Research Institute. A.R.I. is responsible for providing the experimental sites and animals, and all data collecting on animal performance and vegetation. Chemical analysis of herbage are carried out at A.R.I. Icelandic Radiation Protection Institute is responsible for all ^{137}Cs analysis and soil sampling, including composite plant sampling.

Currently the data acquired already in the project is being compiled, evaluated and prepared for publication. The first publication is planned for next year and until then the distribution of data from the project will be limited. Full access to data has and will however be given to experts in the group working on modelling and even others that might need it for their own research. Samples have also been provided to other participants in the project for specialised analysis (D. Oughton, M. Strandberg) and results of these will be reported by the respective researchers.

Despite the fact that only 5% of the labour force are engaged in farming, agriculture is of great economic and social importance in Iceland. Sheep production accounts for a quarter of the total meat consumption of the total population of Iceland, now numbering 264.000. It plays a crucial role in maintaining the rural population, especially in remote districts.

Background

Lamb meat is the main meat product of the traditional Icelandic agriculture. This is reflected in the number of livestock for 1994 (human population is 265.000):

Dairy cows	Other cattle	Sheep[1]	Horses	Pigs
30.518	41.405	**499.110**	78.517	3.752

[1]Number of winterfed animals, during summer the number is at least two times higher.
(The Icelandic Agricultural Information Service, 1995)

The lamb meat consumption is also much higher in Iceland than in the other Nordic countries, as can be seen in the following table (kg year^{-1} cap^{-1}):

	Denmark	Faeroe Isl.	Finland	Iceland	Norway	Sweden
lamb	1	18,5	0,2	**24**	6	1
pork, beef	55	18,5	35	**15**	40	48

(AArkrog 1994)

It is therefore obvious that due to high lamb meat consumption in Iceland, it can be a major pathway for ^{137}Cs transfer to humans when agricultural systems are considered.

Site description and procedures

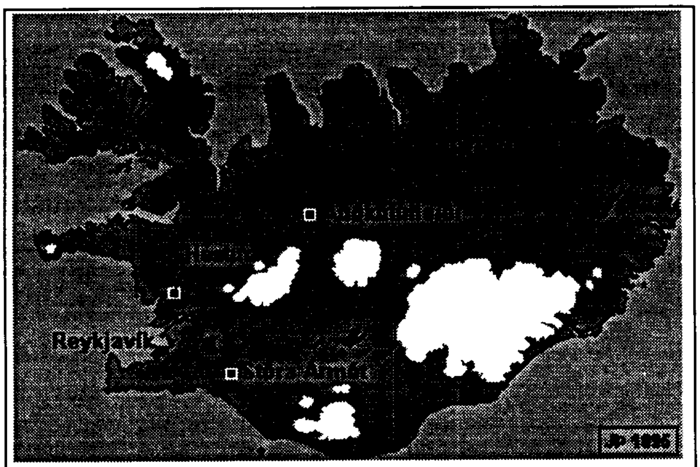

Figure 1 Sampling locations in RAD-3 and EKO-2.1 projects

The EKO-2 project has been conducted at two sites the last two years. In 1994 the EKO-2 project was conducted at the same site as RAD-3, at the experimental farm Hestur in the Borgarfjördur area.
This year the experiment was moved to the experimental farm Stóra Ármót in the Selfoss area (see figure 1).
The experimental farm Hestur was chosen in the spring of 1990 at the beginning of the RAD-3 project, although it was known that the site at Hestur could not be looked at as a typical grazing field used for sheep grazing in Iceland. At that time the Animal Nutrition Division of the

Agricultural Research Institute was conducting a grazing experiments there where intake and digestibility of grazing sheep grazing at lowland mire, was being studied, and the RAD-3 project fitted well within that program. The RAD-3 experiment was also being conducted at Auðkúluheiði, a common highland grazing district in north central Iceland. Thereby it was felt that a wide range of some typical land types used for sheep grazing was covered. However, the pastures there

Table 1 Site statistics for Hestur and Stóra Ármót

	Hestur 1994	Stóra Ármót 1995
size (ha)	12	12
location	64°35'N 21°38' W	63°60'N 20°55'W
shortest dist. from ocean	5.5 km	19.5 km
height above sea level	20 m	20 m
ewes	8	8
lambs	10	14
mean temp. 1992	3.7°C	4.2°C
max. temp. 1992	21.0°C	17.8°C
min. temp. 1992	-18.7°C	-16.3°C
precipitation 1992	1338 mm	1667 mm

were flooded in 1991 as a water reservoir for the Blanda hydraulic power station was formed. Other experiments than the intake study have been conducted at Hestur, parallel to the RAD-3 project. In 1993 a behaviour study was carried out, focusing on how grazing patterns change with time. We believe that, when the analysis of samples and data from these experiments has been finished, it will give us valuable information on grazing patterns, intake and digestibility of the sheep used, which can be used for modelling and interpreting the data collected in the RAD-3 program.

The same flock has been at the experimental farm Hestur since 1951. It has been used for breeding since then, and is without doubt one of the better known flocks in the world when physiological and genetic properties are considered.

The pasture at Hestur cannot be considered as a typical pasture for the whole country. Therefore it was decided to move the experiment to another site with different vegetation, resembling more the mountain grazing pastures used during the summer grazing season. The experimental farm Stóra Ármót in the Selfoss area was therefore chosen. It is our opinion that it gives us more information changing the sampling place, rather than continue on the same through the EKO-2 period, and this will also give broader spectrum of data for interpretation.

The Hestur experimental site has been described in previous RAD-3 status reports, but is included here for convenience.

Hestur:

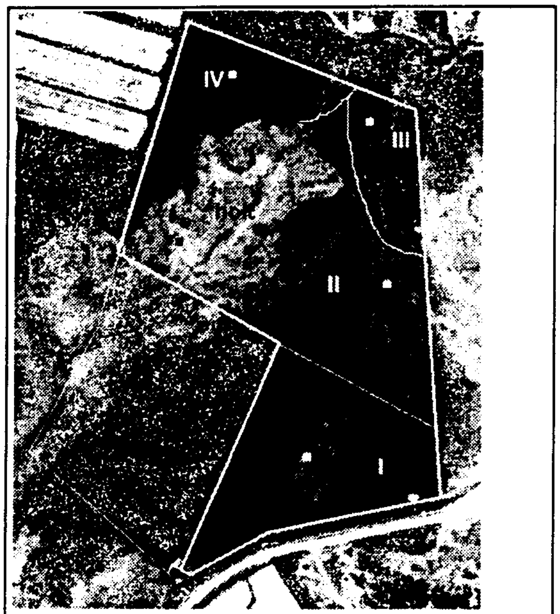

Figure 2 The experimental site at Hestur. The sub areas mentioned in the text can be seen, sub

The study area is a 12 ha uncultivated lowland mire. It slopes a little from east towards west, and in a small part of the area there is an elevated gravel ridge with well drained soil. The uppermost and the gravel parts are the driest areas. The surface is hummocky, except for the gravel ridge. Wetland vegetation is dominant within the pasture used, and the most common plant species are *Carex nigra* (common sedge), *Equisetum palustre* (marsh horsetail), *Calamagrostis stricta* (smallreed) and *Carex panicea* (carnation sedge). In the uppermost parts of the pasture, grasses like *Deschampsia caespitosa* (tufted hair-grass), *Agrostis capillaris* (common bent-grass) and *Poa pratensis* (common meadow-grass) are frequent. The most common species on the gravel ridge are *Festuca richardsonii* (creeping fescue), *Festuca vivipara* (northern fescue) and *Carex bigelowii* (stiff sedge). Due to differences within the pasture, it dealt into five sub areas, area three being the wettest, two and four intermediate and one the driest. The gravel ridge is marked as "holt" on figure 2. Soil and vegetation sampling was done within these sub areas.

Stóra Ármót:

The new study area is a 12 ha uncultivated lowland pasture. The surface is level, but considerably hummocky. When the vegetation is considered, the whole area is very homogenous in appearance. The dominating species of the vegetation is *Rhacomitrium hypnoides* (moss), low growing shrubs like *Salix lanata* (woolly willow) and *Vaccinium uliginosum* (bog bilberry), grasses like *Festuca vivipara* (northern fescue) and *Poa pratensis* (common meadow-grass). Other dominating species are *Calluna vulgaris* (ling, heather), *Carex bigelowii* (stiff sedge) and *Carex nigra* (common sedge). The pasture has been divided into three sub-areas, where soil and vegetation has been sampled.

Sampling and sample preparation

Each summer has been divided into three periods:

I. Sheep released (middle of June) - End of July

II End of July - Late August

III Late August - Time of slaughter (end of Sept. / beginning of Oct.)

The weight gain in each period was investigated by measuring the weight of the animals at the beginning and end of each period. Soil and vegetation samples were collected at the same time. Milk was sampled during the early part of the summer, and more frequently before the sheep were released.

Table 2: Samples taken for Cs-137 analysis at the experimental farm "Hestur" 1994

DATE	19/5	26/5	2/6	8/6	16/6	20/6	28/7	8/8	6/9	29/9	Samples 1994	Samples 1995
milk	5	8	8	8	8	8	6				51	36
lamb meat	5									7	12	6
faeces									6		6	44
soil						24	41		12	12	89	86
hay						2					2	3
comp. pl. sp.*						8	5		5	12	30	18
plant species							4		6	3	13	15
*Composite plant species										Total	203	208

Sampling at Hestur 1994.

Eight ewes were used in 1994. All of them were used for faecal and milk sampling during the summer, but at the end of the sampling period, six of them were then chosen, based on a) how many samples had been successfully collected from them during the summer (milk, faeces) and b) how "normal" they were in terms of their lamb health, average weight gain etc. (i.e. "abnormal" animals were rejected).

Milk was collected by dosing the ewes intramuscularly with the hormone ocytocin and milking two minutes later. During the first half of the period, this usually resulted in adequate samples, but at the end of July the ewes had mostly stopped milking. Last samples of milk were therefore collected on 28.07 in 1994.

One lamb from each of these six ewes was randomly chosen for meat sampling. It was however tried to take samples from three male lambs and three females. Right foreleg was taken for meat sampling.

Faeces sampling has been carried out by placing sampling collection bags and harnesses on the sheep. This eliminates the risk of getting the samples contaminated by soil or other particles .

Several soil samples were collected in each area. Each sample consisted of three subsamples giving a horizontal cross section of 75 cm^2. The samples were taken to 30cm depth and sectioned into 5cm depth zones.

Composite plant species were collected from all five areas five times during the experimental period. Each sample was taken annually from 4 plots of approximate area 0,25 m^2. Two samples of hay were taken 20/6.

Seven plant species were chosen for sampling at Hestur 1994: *Carex lyngbyei, Carex bigelowii, Festuca ssp, Carex nigra, Agrostis capillaris* and *Deschampsia caespitosa.* This was based on a) the availability, b) how feasible they are for grazing and c) where they grow within the pasture (at least one species was taken from each sub-area).

Sampling at Stóra Ármót 1995

At Stóra Ármót 1995 seven species were chosen, based more or less on the same criteria as before: a) the availability, b) how feasible they are for grazing and c) it was tried to chose the same species as had been collected at Hestur the previous years.

Eight ewes were used in the experiment 1995 as in 1994. In 1995 it was however possible to collect milk until beginning of September, due to the fact that the lambs used in 1995 were born later than in 1994. Different vegetation also has its effect on the milk production.

The ^{137}Cs values for soil samples show high variance. This is also a common problem elsewhere. The terrain at Stóra Ármót is very uneven, as is typical for Icelandic heath areas. In 1995 samples were taken from tussocks and adjacent basins to investigate whether some of the variance could be attributed to these terrain features.

Related sampling

Biomass estimation (harvesting samples) is done to estimate the standing dry matter in the pasture. This method has been called "Double sampling", it includes a combination of visual estimation and real weight of samples (Brown 1954, Tadmor et al., 1975). The combined sample from the pasture which results from the sampling is used for chemical analyses and is thought to be representative for the average chemical composition of the vegetation in the pasture. The samples have been analysed for following: Ash, crude protein, crude fat, crude fibres, P, Ca, Mg, K, Na, Neutral Detergent Fibres (NDF), Acid Detergent Fibres (ADF) and lignin. All analysis are carried out at the A.R.I. chemical laboratory, using standard methods. These samples should not be confused with the composite plant samples taken at the same sites as the soil samples, and used for the ^{137}Cs analysis in total vegetation. Biomass estimation is always conducted at the same time as the animals are weighed.

Samples from lamb meat for monitoring are also taken each year from the four biggest slaughterhouses in Iceland. The houses are located in each part of the country, and should give an average value for Cs-137 in lamb meat in Iceland.

Measurements

A high purity germanium detector system was used for measurements of the samples. The gamma spectra was analysed using software developed by Geislavarnir. Typical counting times were 4-48 hours.

Experimental Results, Analysis and Discussion

A. Agricultural Research Institute

As has been said before A.R.I. has been responsible for collecting data on animal performance and vegetation. Chemical analysis of herbage have also been carried out at A.R.I. Results presented below are for 1994 and 1995. These results must be considered as preliminary, as statistical analysis have not been finished, and thus the data has not been fully evaluated at the time this report was finished.

Analyses for all samples of standing herbage have now been carried out for 1990 - 1995, except for NDF, ADF and lignin, and some results for 01.10. 1995. As can be seen in table 3 some differences are between these two sites, due to different vegetation.

Table 3: Nutrients and elements in vegetation at Hestur and Stóra Ármót.

		Ash	Crude Protein	Crude Fat	Crude Fibre	P	Ca	Mg	K	Na	NDF	ADF	Lignin
Hestur	**20.06**	8,4	10,3	1,4	22,6	0,14	0,30	0,17	0,75	0,03	NA	NA	NA
Hestur	**28.07**	8,2	12,9	1,4	21,8	0,17	0,31	0,24	1,40	0,03	NA	NA	NA
Hestur	**06.09**	8,6	11,0	1,6	21,3	0,14	0,36	0,26	1,26	0,06	NA	NA	NA
Hestur'	**28.09**	8,0	8,0	1,7	23,4	0,09	0,33	0,22	0,72	0,06	NA	NA	NA
Stóra Ármót	**21.06**	6,1	11,1	3,3	20,1	0,21	0,37	0,19	0,86	0,03	NA	NA	NA
Stóra Ármót	**01.08**	5,8	9,4	3,6	23,4	0,13	0,46	0,22	0,81	0,04	NA	NA	NA
Stóra Ármót	**06.09**	5,8	8,8	3,6	22,3	0,13	0,54	0,23	0,69	0,03	NA	NA	NA
Stóra Ármót	**01.10**	6,3	6,5	4,4	27,0	NA	NA	NA	NA	NA	NA	NA	NA

NA: Results not currently available.

As an example of this is the ash content shown in figure 3. The ash content is much lower at Stóra Ármót than at Hestur. At Hestur, most of the plants are sedges and grasses, but at Stóra Ármót flowering plants are more abundant. This is reflected in the chemical content. On both sites protein content drops over the summer, as might be expected.

Differences between these two sites are also reflected in the biomass, or standing herbage, figure 4. The pasture at Hestur has relatively high plant biomass production, up to 9 hkg/ha (90 g/m^2), whereas the biomass at Stóra Ármót is approximately 3 hkg/ha (30 g/m^2). The growth pattern at these two sites is also quite different, indicating differences in grazing pressure. At Hestur the biomass increases in the beginning, but at Stóra Ármót it decreases from the beginning of the summer.

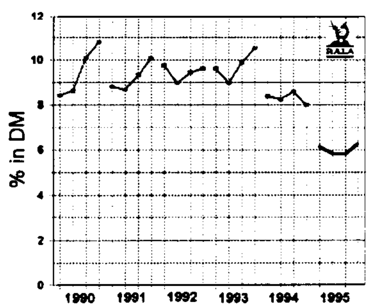

Figure 3 Total ash content in vegetation at Hestur and Stóra Ármót

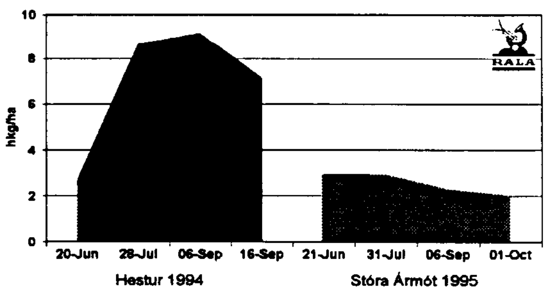

Figure 4 Standing herbage at Hestur and Stóra Ármót asmearured by the "Double Sampling" technique

As might be expected these differences have its effects on both grazing pressure and performances of the animals. The grazing pressure shows this (figure 5). Grazing pressure is defined as weight of animals on a defined area with a defined DM (dry matter) weight of vegetation. To get a little closer to the metabolic need of the animals, an adjusted weight is used instead of the true weight. This adjusted weight is: mass^{0,75} (often presented as kg^{0,75} as is done here).
The pasture at Stóra Ármót has much higher grazing pressure than Hestur, and it increases steadily during the summer, as the herbage diminishes and the lamb gain weight.

Ewes tend to loose weight during the first half of the summer, mostly due to their milk production. As they stop producing milk, they start gaining weight, however. Ewes live weight can be seen on figure 6. Both at Hestur and Stóra Ármót the ewes loose weight during the first half of the summer, but then they start gaining weight again. The average ewe weight for the whole summer at Hestur 1990 - 1994 and Stóra Ármót 1995 has been analysed by using ANCOVA, using the initial weight of the ewes as covariate. There is statistical difference between these two sites between years, Stóra Ármót being the lowest ($P \leq 0,001$). Analyses within years for each site (between periods) have not been carried out yet.

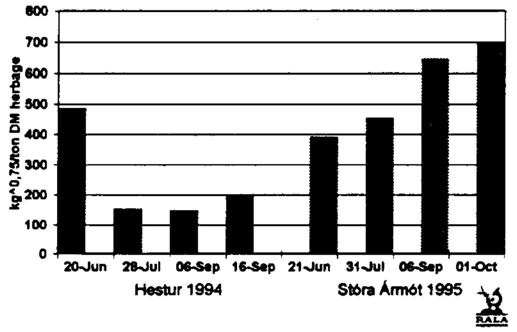

Figure 5 Grazing pressure at Hestur and Stóra Ármót

Figure 7 shows ewes growth (g/head/day). As can be seen, ewes at Hestur stop loosing weight in the 2nd period of the summer, whereas the ewes at Stóra Ármót gain on the average no weight. As said before, this is most likely due to differences in their milking pattern. The variation in growth is quite high, and no statistical differences are encountered between Hestur 1994 and Stóra Ármót 1995 when average growth for the whole summer is considered. Analyses within years for each site (between periods) have not been carried out yet.

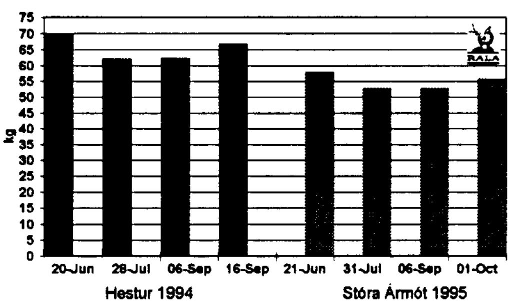

Figure 6 Ewes average live weight at Hestur and Stóra Ármót

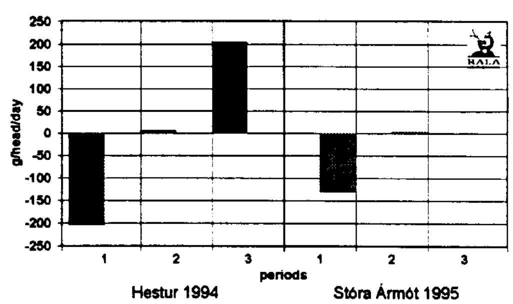

Figure 7 Ewes average ldaily gain at Hestur and Stóra Ármót

Lamb live weight is shown in figure 8. Lambs at Stóra Ármót were born later than at Hestur, and that is reflected in their weight. The data for Hestur 1990 - 1994 and Stóra Ármót 1995 has been analysed by using ANCOVA (using the initial weight as covariate). By doing that, statistical difference between these two sites are found between years, Stóra Ármót being the highest (P≤0,001). Analyses within years for each site (between periods) have not been carried out yet. Results for Duncan's Multiple Comparison Test on corrected lamb weight are shown in table 4.

TABLE 4. Duncan's Multiple-Comparison Test on corrected lamb weight. NB. At Stóra Ármót in the year 1995.

YEAR	1990	1991	1992	1993	1994	1995
1990	24,22					
1991	S	22,85				
1992	S		23,23			
1993		S	S	24,58		
1994	S	S	S	S	18,41	
1995		S	S		S	24,57

Shaded cells: Average for each year. S = significant difference. $\alpha=0{,}050$ $df=375$ $MSE=6{,}34$

Figure 9 shows the lamb growth (g/head/day). There is statistical difference between Hestur 1994 and Stóra Ármót 1995 (P≤0,001) when the average growth for the whole summer is considered. Analyses within years for each site (between periods) have not been carried out yet.

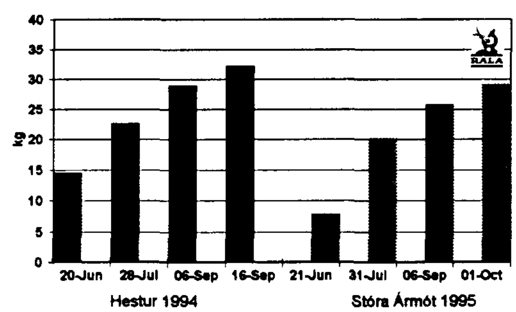

Figure 9 Lamb live weight at Hestur and Stóra Ármót

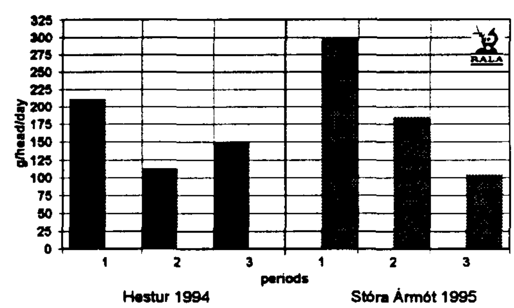

Figure 8 Lamb average daily gain at Hestur and Stóra Ármót

The site at Stóra Ármót is thought to resemble more the highland pastures traditionally used for sheep grazing during the summer. Although standing herbage is low and grazing pressure high, the carcasses produced on such land tend to be of higher quality than from animals grazing on lowland grassrich areas. The reason for this difference is not clear, but this can be seen in the carcass weight and meat dressing percent of Hestur and Stóra Ármót (figure 10).

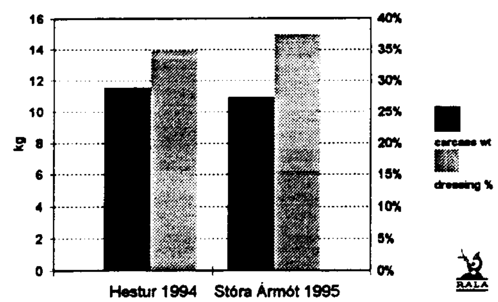

Figure 10 Lamb carcass weight and dressing percent at Hestur and Stóra Ármót

Although there is no statistical difference on carcass weight between Hestur 1994 and Stóra Ármót 1995 (these are preliminary ANOVA results), the lamb from Stóra Ármót have significantly higher dressing percent than at Hestur (1990 - 1994 vs.1995 compared, ANCOVA, using day of birth as covariate; $P \leq 0,001$). This shows the difference between these two land types, and supports our theory that the land at Stóra Ármót resembles typical sheep grazing pastures more than the pasture at Hestur.

A. Icelandic Radiation Protection Institute

Table 5 shows the average and range of Cs-137 in samples taken at the experimental farm Hestur 1994.

Table 5: Cs-137 in samples taken at Hestur 1994

	Average Bq/kg	Range Bq/kg	n
milk (ewes indoor)	5,9	4,0 - 6,8	45
milk (ewes outdoor)	24,7	17 - 28	6
lamb meat	43	22 - 68	12
faeces	137	109 - 206	6
soil (0-10cm)	190	20 - 415	21
hay	32	29 & 35	2
composite plants sp. (1)	88	29 - 141	12
composite plants sp. (2)	3	2 - 5	3
plant species		1,4 - 85	6

(1) wet and intermediate and wet area
(2) dry area

The sheep's milk shows in most cases no significant changes during the period the sheep are indoors. The average concentration of Cs-137 in the milk was 5,9 Bq/kg. The difference between ewes was significant. In the beginning of July the ewes were let out to graze and the average concentration in the milk a month later had increased four fold but the relative spread of values was the same (Figure 11).

The concentration of Cs-137 in lamb meat appears to have been decreasing slightly from 1991 - 1994, but this change is hardly significant.

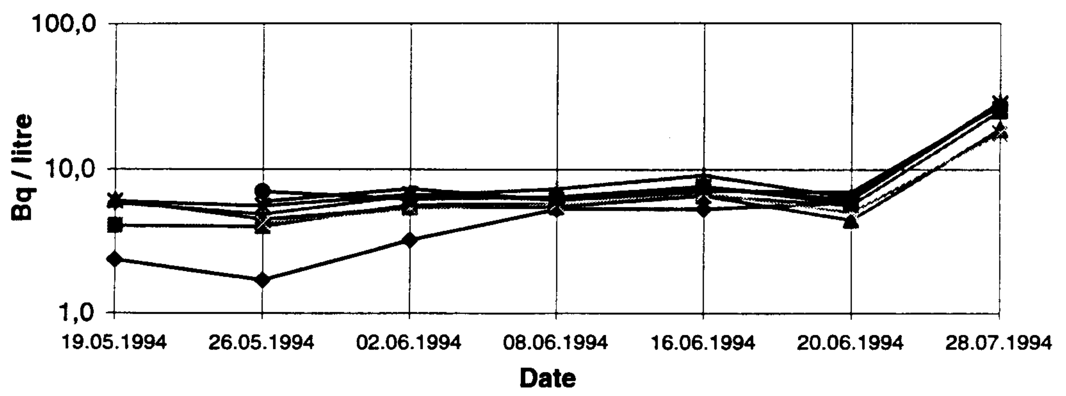

Figure 11 Cs-137 in sheep's milk at Hestur, 1994 (8 ewes)

Correlation could be found between the concentration in milk (both when the ewes were indoors and outdoors) and lamb meat, but none of these factors could be correlated with the concentration in faeces (ewes).

Concentration of Cs-137 in lamb meat has been monitored in samples from all over Iceland since 1989. Comparison of these results (n=96, from the years 1989-1994) with results from Hestur show the following:

- The monitoring samples are very well described by a lognormal distribution(figure 12)

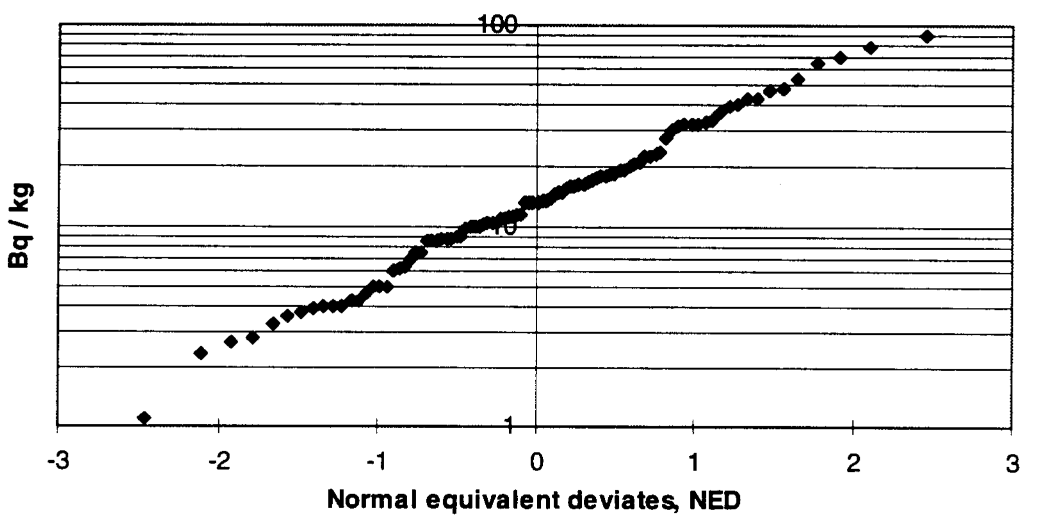

Figure 12 Monitoring samples: Cs-137 in sheep meat 1989 - 1994 (n=96)

- Samples from experimental areas Hestur show in each area a much smaller relative spread than is observed in the country wide monitoring values.

Transfer of Cs-137 from soil to plant and to lamb muscle

During the time the ewes were inside their dry matter intake was estimated as 2,3 kg/d. IAEA Tech. Rep. Series No. 364 *(Handbook of Parameter Values for the*

Prediction of Radionuclide Transfer in Temperate Environments) gives an expected value of 1,3, with a range of 1,0 - 2,5 kg/d. The transfer coefficient for feed to milk was 0,08 (Bq/L) / (Bq/d) which is slightly higher than IAEA's expected value of 0,058 but well within the quoted range of 0,006 - 0,12.

Effective ecological half-lives of Cs-137 in lamb meat in Iceland

Cs-137 is currently disappearing very slowly from the Icelandic terrestrial ecosystem. This could e.g. be observed in the RAD-3 project from the previous NKS period. Comparison of current data with data from the mid sixties shows a similar trend in decline of Cs-137 values in lamb meat and in cow's milk from three different regions.

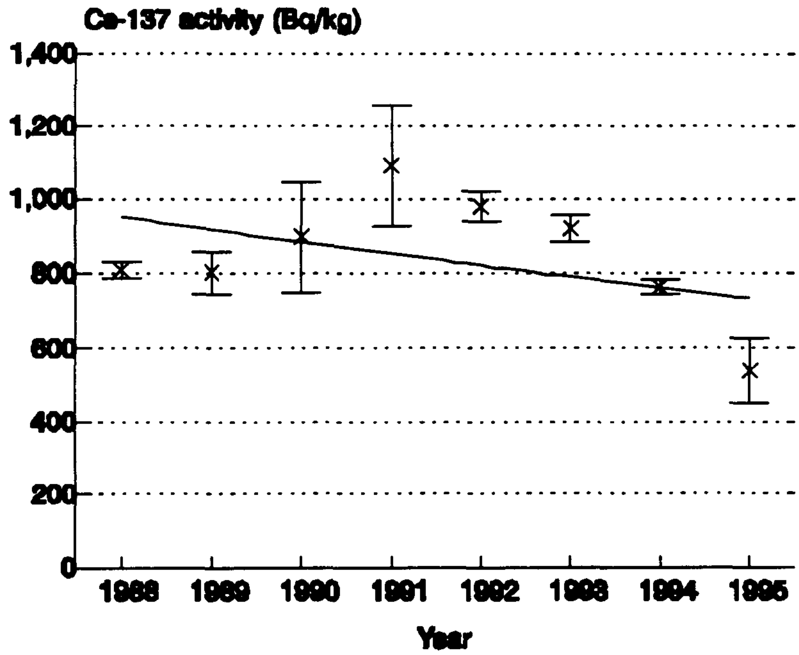

Figure 4. Cs-137 (Bq/kg) in ewes at the equilibrium state. Mean and standard deviatiation of measurements are shown for the weeks 8-12 after the animals were released to the pasture.

Table 8. Aggregated transfer coefficients and transfer coefficients to lambs meat.

Year Coefficient	1988	1990	1991	1992	1993	1994	1995
T_{ag} soil-meat	31.0	36.8	47.5	39.5	36.9	36.8	19.2
T_{ag} soil-gras		61.0	72.0	76.6	60.2	65.1	14.0
CF grass-meat		0.60	0.71	0.52	0.61	0.57	1.4

The aggregated transfer coefficient was somewhat higher in 1991 than in 1990 (10 and 8 for lambs and ewes, respectively). This could be due to the overgrazing of the paddock, which could result in a much higher intake of soil in 1991 than 1990. The overgrazing was shown by the live weights wich did not increase during the last 3 weeks of the experiment. The aggregated transfer coefficints and the transfer coefficient has not changed significantly during the periode of 1990-1994. However in 1995 the aggregated transferfactors decreased significantly. Also the CF grass-meat changed markedly and was increased by a factor of two compared to previous years.

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REPORT FROM THE NKS-EKO-2 EXPERIMENT IN NORWAY 1990-1995
TRANSFER OF ^{137}Cs FROM SOIL TO PLANTS AND SHEEP, TJØTTA

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[2] Agricultural University of Norway
November 1995

MATERIALS

The study was conducted at Tjøtta Rural Development Center located on the coastline in Nordland county (66.6°N), which received Chernobyl fallout from the first plume that reached Norway. A fenced area of 0.4 ha of a natural pasture on a sandy soil and a vegetation dominated by Poa spp, Festuca spp, Trifolium spp and Ranunculus spp. Four to six exclusion cages (130 cm * 220-260 cm) were placed on the pasture in 1990. The cages were turned 30-45° each year to avoid to have the hole from previous years soil sampling in the cages. In 1995 six additional cages (90*150)were put out to estimate the biomassproduction or for collection of mushrooms. Two of the old cages (nr. 1 and 6) were substituted by the new ones. The paddock was grazed by 15 or 30 sheep from June to August or September every year in 1990 to 1995 (Table 1).

METHODS

Soil samples.

From four to six soil samples were taken from the exclusion cages at the end of August each year. A core with a diameter of 10.3 cm was taken to a depth of 10 cm and imidiately divided into 1 or 2.5 cm disks. They were dried to constant weight at 65° C , homogenised and measured for content of ^{137}Cs.

Vegetation samples.

Percentage cover of the major genus/species in the different cages were visualy estimated on one occation in 1990 to 1995 except in 1992 when it was estimated at three occations. In 1992 the percentage cover was divided into grass, herbs and other species, and the different genus/species present were noted. Mixed species samples were taken from exclusion cages at 9 September 1990, 28 August 1991, 8 July 1992, 5 August 1992, 14 September 1992, 6-9 September 1993, 16 September 1994 and 15 September 1995. The mixed species samples were cut with a Elite Lawn Mower to a height of 5-10 cm, 5 cm and 2-5 cm at first, second and third harvest in 1992. The harvested area was in 1991 228*80 cm. In addition single genus samples were collected from the pasture at the same dates as the mixed species samples. All samples were dryed at 65° C, ground and measured for content of ^{137}Cs.

Biomass production

The vegetation in Cage 7-9 were taken 4 times during the grazing season. It was cut at 3 cm above ground level before it was weighted both raw and dry.

Meteorological conditions

The data on precipitation and temperature are taken from the weather station located at Tjøtta just 4-500 m from the experimental field.

Mushrooms / feacal samples

A few samples of mushroomswere collected at pasture, most of them in the middle of August.

Samples of faeces were taken three times during the grazing season, 5 of July, 2 of August and 12 of September. Five fresh samples were taken from the ground each representing feaces taken from 4-5 ewes.

Animals.

The paddock was grazed by 15 to 30 sheep of the breeds Dala or Speel during the summer (Table 1). The animals were live monitored for content of ^{134}Cs + ^{137}Cs weekly. The animals were monitored in 60 second by use of a Canberra Serie 10 multichannel analyser equipped with a 3 • 3 NaI(Tl) detector

Radiometry.

The ^{137}Cs analysis of soil and vegetation was performed with NaI(Tl) scintillator detector (Minaxi auto gamma 5000 series or 1480 Wizzard, Wallac). The live monitoring of the animals was performed with a portable counter (Canberra Series 10, Canberra Industries) with a 7.5 cm NaI(Tl) scintillator.

Calculations.

The aggregated transfer coefficient (T_{ag}) and the transfer coefficient (CF) is calculated as followes: T_{ag} soil-meat: Bq/kg FW meat per Bq/kg DM grass. T_{ag} soil-gras: Bq/kg FW meat per kBq/m^2 soil. CF grass-meat: Bq/kg DW grass per Bq/kg FW meat. The activity in lambs are based on live monitoring as the average measurements in the weeks 8-12 after they have been released to the pasture.
The ecological halflilve of ^{137}Cs is calculated by taken the average activity in the meat measured by live monitoring in the periode 8-12 weeks after they are let out on the pasture. An exponential regressian curve is fitted to the data to estimate the ecological halflife.

RESULTS AND DISCUSSION

Soil.

The mean deposition of ^{137}Cs in the paddock was about 35 kBq m^{-2} (Table 2). More than 70 % of the ^{137}Cs remain in the top 3 cm of the soil (Fig. 1). The content of ^{137}Cs has decreased in the top 1 cm soil from 1992 to 1995 and there was a tendency of ^{137}Cs to move downwards (Fig. 1).

Mushrooms.

There are reported to be very little mushrooms in this pasture during the whole periode of the experiment. However only in 1995 it was studied specifically. No mushrooms were observed in any of the 12 cages. However a few species where found outside the cages. The following specious were found: Leccinum versipelle, L. scabrum, Russula vesca, Hypholoma capnoides, C. asema, C. dryphila and R. fragilis.

Vegetation.

Up to 1994 the content of ^{137}Cs in mixed species samples varied between the different cages with a factor of 10 from about 400 Bq kg^{-1} DM to 4500 Bq kg^{-1} DM. In 1995 it was a marked decreasing level in the activity from five of the the six cages. The content of ^{137}Cs in pasture vegetation has been relatively contstant in the periode 1990-1994 for the pasture was about 2000 Bq kg^{-1} DM. The ^{137}Cs content in vegetation from cage 2 was particularly low at samplings (Table 3).

The percentage of cover of vegetation in the exclusion cages was mainly dominated by Trifolium spp, Poa spp, Deschampsia caespitosa and Ranunculus spp estimated at the end of the grazing period. In 1992 the percentage cover of grass and herbs were highest at the beginning of the grazing period and decreasing towards the end of the summer as the vegetation was lower and realtively more moss covered the ground. In cage 5 and 6 the grass cover decreased from 90% to 50% during the summer.

The production of biomass decreases during the grazing periode (table 5). In July the production was in the range 41-119 g/m^2, in August 23-67 g/m^2 and little production was measured in the first half of September (< 21 g/m^2).

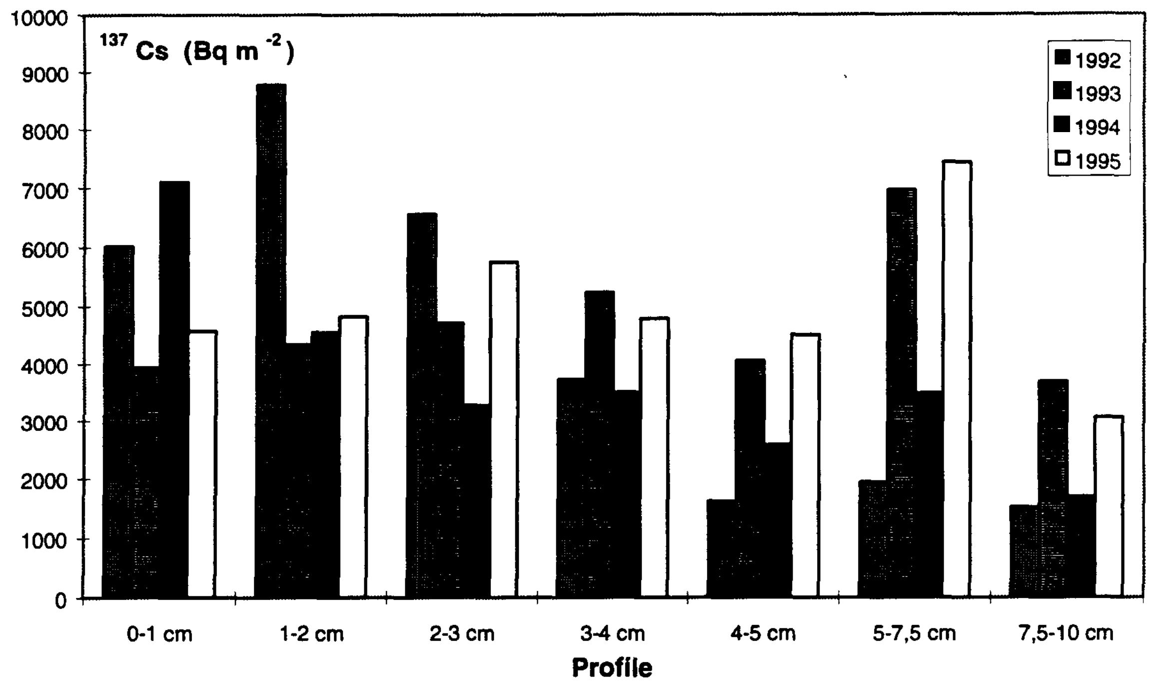

Figure 1. Cs-137 in soilprofiles (Bq/m^2) from the years 1992-1995

Table 1. Number of animals and duration of the grazing period in 1990-1995.

Year	Ewes	Lambs	Start	End
1990	10	20	28 May-1 June	8 September
1991	10	20	29 May	13 September
1992	5	10	26 May	27 August
1993	5	10	28 May	6 September
1994	5	10	8 June	31 August
1995	5	10	31 May	11 September

Table 2. Caesium-137 contamination (kBq m^{-2}) in soil of each cage and mean for the paddock estimated 1990 to 1995.

Year	Cage 1	2	3	4	5	6	Mean±Sd
1990	24.3	36.7		34.9	29.0		31.2± 5.7
1991	35.5	29.1	34.6	83.3	41.9	44.4	44.8±19.6
1992	36.6	34.7	21.4	31.5	33.2	17.4	29.1± 7.8
1993	51.6	16.8	29.9	40.9	21.2	36.7	32.9±11.8
1994	26.2	33.2	19.2	26.5	25.8	25.8	26.2±4.0
1995	47.9	46.2	25.3	29.1	35.6	24.9	34.9±10.2

Table 3. Caesium -137 content in mixed species samples (Bq kg^{-1} DM) from the exclusion cages and the dry matter content (DM).

Date:	Sept. 1990		Aug. 1991		July 1992		Aug. 1992		Sept. 1992		Sept.93		Sept 94		Sept 95	
Cage	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}	DM %	^{137}Cs Bq kg^{-1}
1		2460		1460	23.4	1158	13.5	1771	18.8	1432	23	714		609		208
2		497		530	25.2	369	15.3	434	23.1	484	21	402		421		74
3		.		3680	24.0	3158	14.2	4512	24.1	4610	22	4421		554		163
4		1008		1950	30.4	1389	17.9	1173	26.0	1874	21	2899		2195		402
5		3650		4200	27.8	2044	15.9	1969	30.1	1289	26	2426		2002		788
6				2900	30.2	2148	15.7	2753	32.9	3690	26	1032		1456		1285
Mean±SD Bq kg^{-1} DM		1904±1430		2453±1392		1711±960		2101±1414		2230±1581		1982±1548		1706±1154		487±466

Cage	#1	#2	#3	#4	#5	#6
Trifolium spp	0	0	0	0	0	<1
Poa spp	40	25	15	15	25	14
Agrostis spp	30	25	15	35	15	15
Deschampsia cesp	0	5	15	20	30	50
Festuca spp	18	20	10	10	5	5
Carex spp		25	10			
Ranunculus spp	5	5	10	<1	5	10
Other	17	10	25	<10	20	5

Table 4 Percentage cover of the major plant genus in the different exclusion cages in 1995

Date	26 June	26 July	25 August	19 September
Cage nr.	(gram / m^2)			
1	260			151
6	168			94
7	476	119	67	21
8	176	41	25	1
9	436	56	65	11
10		286	33	10
11		72	23	2
12				52

Table 5 Biomass production (g/m^2) in different cages at four different dates in 1995.

PLANT	1990	1991	1992	1993	1994	1995
	Cs-137 (Bqkg^{-1} DM)					
Trifolium spp		2380	2380		911	2194*
Poa spp	623	1210	1210		950	210
Agrostis spp	2045	1720	1720		2215	260
Deschampsia cesp	1165	1700	1700		514	180
Festuca spp	4201	2340	2340		636	255
Rumex spp	1620	6210	6210		6074	
Ranunculus spp	736	1480	1480		1176	463
Salix spp	41				29	
«Høymole»		1193	1193			
Sorbus aucuparia					142	
Anthoxanthum odoratum					630	
Carex spp					3210	558
Betula pubescens					45	
Juniperus communis					83	

Table 6 Cs-137 activity (Bq/kg DM) in the major plant genus as an average from the exclution cages (* only from cage 6).

MONTH	1994		1995	
	Precip.(mm)	Temp (°C)	Precip.(mm)	Temp (°C)
May	23,9	6,6	13,1	8,4
June	92,5	9,1	82,5	10,1
July	41,8	13,7	114,3	11,7
August	15,6	14,1	165,3	11,1
September	87,4	9,7	100,5	10,5

Table 7 Precipitation and temperature at Tjøtta during the grazing season in 1994 and 1995. The precipitation is the sum of the rainfall in each month (mm). The temperature is the average temperature (°C) in that month.

Animals

The live monitoring measurements included both ^{134}Cs and ^{137}Cs. Each ewe have two lambs. Figure 2 and 3 shows the average radiocaesium activitylevels in ewes and lambs, respectively. The standard deviatiation is shown for the latest years.

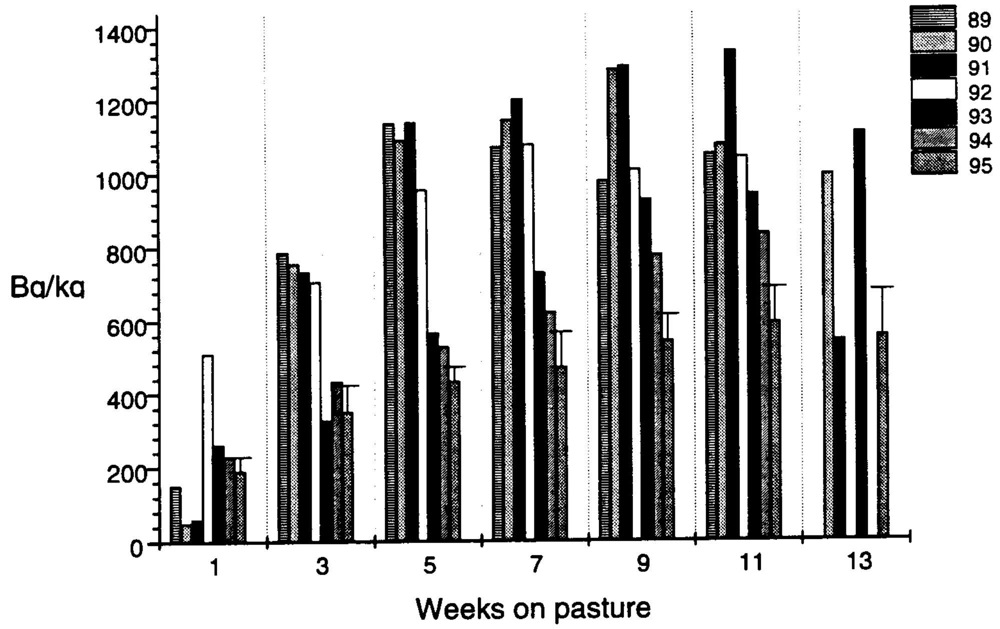

Figure 2. Radiocaesium concentration (^{137}Cs + ^{134}Cs) in ewes meat (Bq/kg) at different times after the animals were released on the pasture. The standarddeviatiation is shown for 1995.

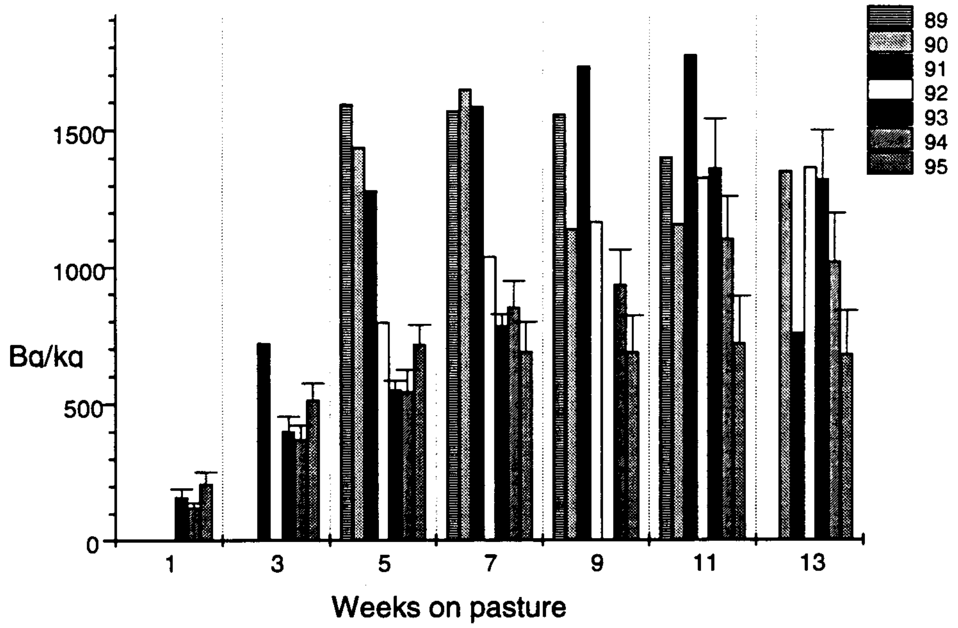

Figure 3. Radiocaesium concentration (^{137}Cs + ^{134}Cs) in lambs meat (Bq/kg) at different times after the animals were released on the pasture. The standarddeviatiation for 1993-1995 is given.

In 1991 a decreased level of radiocesium in the animals was observed day 63. This was caused by the feeding of some less contaminated roughage that was given because the vegetation was too poor to supply the animals at the end of the grazing period.

When estimating the ecological halflife of Cs-137 the contribution of Cs-134 is subtracted according to the reported ratio of ^{134}Cs and ^{137}Cs in the fallout in Norway. Figure 4 shows the average levels of Cs-137 in ewes at the time periode of 8 to 12 weeks on pasture. A trend of decreasing levels of radiocaesium in ewes and lambs can be seen. This is particularly clear for the years 1993-1995 in the time periode before the equilibrium state is reached (week 1 to 7). The equilibrium state seem to have changed from approximately five weeks the first four years, to 9 or 10 weeks for the years 1993-1995. The data fits poorly to the eksponential regression curve with a R-squared of 14 %. The ecological halflife is estimated to 19 years.

Preliminary report from Sweden
for the study years 1994 and 1995.
NKS-seminar, Asker, Norway.
6-8 Nov. 1995.

Transfer of Radiocaesium and Radiostrontium from Soil to Vegetation and to Grazing Lambs in a Mountain Area in Northern Sweden. Ecological Half-lives of the Nuclides

Project within the Nordic Nuclear Safety Research (NKS) programme, subgroup EKO-2.1

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ABSTRACT

Within the research programme of NKS (Nordic Nuclear Safety Research), RAD-3, radio-ecological studies in the chain soil-grass-lamb were carried out in natural or semi-natural areas in the Nordic countries in 1990-1993. Further studies are made in the same places during another 4-year period in order to *i.a.* get information on the ecological and the effective ecological half-lives of the radionuclides studied, mainly Cs-137, but also Sr-90. The possible activity contribution by mushroom and soil ingestion of the lambs will be studied.

In Sweden the studies are located to a mountain farm in the Chernobyl fallout area in the county of Jämtland. The study lambs are grazing freely in a mountain area covering about 10 km^2. In the present paper the main study results obtained in Sweden in 1994 and 1995 are given. Comparisons are made with the published results of the previous study years.

The mean Cs-137 deposition in soil (average of samples taken to a depth of 10 cm in the soil layer in five fixed localities distributed over the grazing area) was in 1994 12.49 kBq/m^2. Values for 1995 are so far not present. In 1990-1994 the time-corrected values (corrected to August 1990) were 17.62, 14.56, 16.66, 14.07 and 13.69 kBq/m^2, respectively, indicating a decrease of the Cs-137 content in soil. In 1994 89 % of the Cs-137 was found in the upper 5 cm soil layer, which was similar to the mean percentage in 1990-1993.

The mean Cs-137 concentrations in herbage were 802 and 695 Bq/kg dry weight (d.w.) in 1994 and 1995, respectively. In 1990-1995 the time-corrected values (corrected to August 1990) were 1175, 1125, 960, 900, 879 and 779 Bq/kg d.w., respectively, indicating an ecological half-life of 8.5 years. The Cs-137 content in single plant species showed

about the same ranking order in 1994 as in the previous years with herbs and grasses > woody plants, shrubs and trees.

Totally 18 species of mushroom were identified in 1994 with a great variation of Cs-137 concentration, 189 Bq/kg d.w. in samples of *Russula vinosa* and 46857 Bq/kg d.w. in *Russula aeruginosa*. Results of samples collected 1995 are so far not present.

The average Cs-137 concentration in the abdomen wall muscle of lamb carcasses was 463 and 609 Bq/kg wet weight (w.w.) at slaughter in September 1994 and 1995, respectively. In 1990-1995 the time-corrected values (corrected to August 1990) were 1090, 684, 538, 640 509 and 684 Bq/kg w.w., respectively. Based on these values the ecological half-life could be estimated to 8.0 years. During the period 1991-1995 the 137-Cs concentrations were, however, fairly unaltered, indicating a very long ecological half-life, > 100 years, while the effective ecological half-life during the same period could be calculated to 24.1 years (thus approaching the physical half-life of the nuclide). Still 9 years after the Chernobyl fallout all individual lambs exceeded the Swedish intervention level of 137-Cs for human consumption.

Values of transfer factors are given as follows: TF*soil to plant* (Bq/kg d.w. plant per kBq/m^2 soil) 74.3, 72.3, 64.7, 57.2 and 68.6 for the years 1990-1994, respectively ; TF*plant to muscle* (Bq/kg w.w. muscle per Bq/kg d.w. plant) 0.93, 0.61, 0.56, 0.71, 0.58 and 0.88 for the years 1990-1995. TF*soil to muscle* (Bq/kg w.w. muscle per kBq/m^2 soil) 61.9, 47.0, 32.3, 45,5 and 37.2 for the years 1990-1994. The transfer factors except the TF*plant to muscle,* showed minor decreases. Further studies until 1997 will give more information on possible trends.

Data on Sr-90 concentrations, further data on mushroom and so on are not yet present.

INTRODUCTION

Within the research programme of the NKS organisation (Nordic Nuclear Safety Research), subgroup RAD-3, radioecological studies were performed in 1990-1993 in all the Nordic countries, i.e. Denmark, the Faroe Islands, Finland, Iceland, Norway and Sweden. The purpose was to study the transfer of radiocaesium from soil to plants and further to lamb in natural or semi-natural areas over the years and to study factors that may possibly influence the transfer when no counter-measures had been taken after the radioactivity fallout.

The studies and the results were presented by Hove *et al.* (1994). The Cs-137 contamination of the topsoil layer ranged from 3 to 30 kBq between the countries. The deposition was predominately of Chernobyl origin in Finland, Norway and Sweden, whereas in Iceland the contamination was primarily of nuclear weapon test origin, and in Denmark and the Faroe Islands it derived from both sources. Soil-to-herbage radiocaesium transfer factors were high in the organic and acidic soils of the Faroe Islands, Iceland, Norway and Sweden, averaging 18-82 Bq Cs-137 per kg d.m. of herbage related to a soil deposition of 1 kBq Cs-137 per m^2, and much lower in the sandy soils in Denmark and clay soils in Finland

(0.4-0.8). Herbage-to-lamb concentration factors were generally more homogeneous with 4-year mean values ranging from 0.27 to 0.70, indicating that the absorption of Cs-137 from herbage was similar in the different countries. It was demonstrated that a Cs-137 deposition of 1 kBq per m^2 of soil gave much lower concentrations in lamb meat at the sites in Denmark, the Faroe Islands and Finland (4-year mean values of 0.5-3.0 Bq per kg) than in Iceland, Norway and Sweden (15-47 Bq per kg). A more detailed report on the studies in Sweden was given by Rosén *et al.* (1995).

The results from the studies in the Nordic countries implied further investigations. Another research programme was therefore started within the NKS organisation for the period 1994-1997. The plan of the project is presented in Nordisk kernesikkerhedsforskning (1994). The plan demonstrates the main parts of the the lamb project (EKO-2.1) distributed in different years: Production methods (1994-1997), mushroom ingestion (1994 - will be extended to 1996), soil ingestion (1996-1997), mobility of stabile forms of Cs and Sr (1995-1996). The purpose of the project is thus as follows:

* Study the transfer of Cs-137 and Sr-90 in the ecosystem in the same grazing areas and in the same sheep herds as were studied in 1990-1993.

* Study possible factors that may have caused the differences or comformities between the mentioned results. Such factors may be:
  Soil characteristics
  Migration rate of nuclides in the soil profile. Mobility of stabile Cs and Sr
  Thickness of the vegetation cover and its root distribution in the soil profile
  Botanical composition of the uncultivated pasture
  Consumptional preference of pasture vegetation species by the lambs
  Nutritional value of the pasture vegetation
  Number of animals kept on the grazing area (stock density)
  Mushroom consumption of the lambs
  Soil contamination of the pasture vegetation
  The lambs' soil ingestion, inadvertently or through the pasture vegetation
  Climate- and weather conditions, especially precipitation
  Bioavailability of the nuclides at the uptake/intake by plants and animals

* Demonstrate the ecological or effective ecological half-life of Cs-137 during the 8-year period and possibly also of Sr-90 during the 4-year period.

In the following the Swedish part of the project in 1994 and 1995 is presented. Comparisons with results from the previous 4 years will be made.

MATERIALS AND METHODS

Description of the grazing area

The same grazing area covering about 10 km^2 was utilized as in the study 1990-1993, namely the mountain areas around the farm Blomhöjden situated at 64.4° N and 14.4° E in the northern part of the county of Jämtland in Sweden and at an altitude of about 600 m with surrounding mountain ridges of ca. 1200 m above sea level (details are given by Rosén *et al.*, 1995). The Blomhöjden area was hit by the Chernobyl fallout in May 1986 with a ground deposition in the range of 10 to 30 kBq Cs-137 per m^2, as determined by inflight measurements performed in May-October 1986 (Swedish Geological Company, 1986).

Precipitation in 1994 recorded at two climate stations (situated 4 km and 30 km, respectively, from Blomhöjden and 480 m and 328 m above sea level) were given. The mean monthly precipitation values during the vegetation period, June-September, were 58 mm and 53 mm, respectively with a total precipitation for the period of 232 mm and 213 mm, respectively. Total values for the year were 698 mm and 655 mm. The air temperature measured at the latter one of the stations, expressed as monthly 24-hours mean temperature, was 8.2, 14.9, 12.2 and 6.3° C for the months June-September and with a mean for the whole year of 1.2° C (Swedish Meteorological and Hydrological Institute, 1995). Data of 1995 are not present.

Vegetation and soil sampling, preparation and analyses

Vegetation (herbage and single plant species) and soil were sampled as in the earlier study (see Rosén *et al.*, 1995) in the last week of August (22-24 August, 1994 and 21-23 August 1995) at five localities (Nos. 1-5), each representing about 1000-5000 m^2 of the grazing area. In 1995 vegetation samples were also cut in the last week of July .Within each locality, representative sampling sites of about 100 m^2 were selected for soil and herbage sampling. Localities 1, 3 and 5 were mainly covered by one vegetation type within the area concerned. Localities 2 and 4 comprised different vegetation types and therefore soil and herbage were sampled at two and three different sites, respectively, (2a, 2b and 4a, 4b, 4c).

In the following the expression *sampling sites* or *sites* is used, representing also the extended sampling within some of the localities. (Number of sampling sites = 8).

The same sampling technique, preparation and detection procedures for Cs-137 were applied in 1994 and 1995 as were described by Rosén *et al.* (1995).

Description of the soil

The dominating soil type in the grazing area is a slightly podsolized gravely and sandy moraine with low content of clay as indicated by K_{HNO_3}, low concentrations of labile Ca (mean values for the upper 10 cm layer of 32 mg and 36 mg per 100 g soil, respectively) and low pH-values (mean 4.6) (Rosén *et al.*, 1995). The depth of the humus layer varied between the sampling sites from 2.5 cm to 5.0 cm (according to analyses in 1994, *cf.* Table 3).

Animals

Number of lambs studied, their carcass weight and other data are given in Table 1. This table also includes corresponding data from the previous years, 1990-1993.

In 1994 three female lambs, born in March-April, were studied. They grazed freely on the mountain pasture from the turn of the months June-July, until slaughter on 26 September. Mean carcass weight was 23 ± 3 kg (Table 1). Data were also collected of 12 male lambs born in March and after the mountain grazing period slaughtered on 1 August (carcass weight 19 ± 2 kg. Data on these lambs are, however, not included in the here presented results on the Cs-137 transfer, as vegetation sampling had not been performed at the time for the lambs' slaughter.

In 1995 12 lambs (11 male and 1 female lamb), born in the beginning of April, were studied. They were grazing freely in the mountain area from the last week of June until slaughter on 4 September. Mean carcass weight was 19 ± 3 kg (Table 1).

In 1994 live monitoring of the three female lambs and of three male fenced lambs from the same herd was performed on 23 August by means of the computer-aided counter, Canberra Series 10 (Strand & Brynhildsen, 1990; Andersson-Sørlie *et al.*, 1992) as is described in the earlier study (Rosén *et al.*, 1995). The relationship between the Cs-137 concentration according to live monitoring and the subsequently recorded concentration in carcass meat sample was calculated. Live monitoring was not successfully performed in 1995.

Muscle samples were taken in both years from the abdomen wall of all lamb carcasses immediately for radiocaesium and radiostrontium analyses (the latter ones will be made either at the Agricultural University of Norway or at the Swedish University of Agricultural Sciences).

Mushroom and lamb faeces sampling and analyses

Samples of mushroom were collected in the sampling sites 1, 2, 3 and 5 in both years. Species identification of the mushroom and the following detection of radiocaesium as well as analyses of the content of potassium were made on the material collected in 1994 at the Risø National Laboratory, Denmark (Strandberg, 1994). The material collected in 1995 has so far not been identified or measured.

Sampling of fresh lamb faeces was made in the grazing area (in samplig site 3, near to the salt lick) before the mushroom season (on 25 July, 1994) and during the mushroom season (on 23-24 August, 1994). Faeces samples were also collected after the mushroom season (on 12-14 January, 1995), but in this case the samples originated from the stable housed sheep herd. Analyses of mushroom spores and radiocaesium and potassium contents in faeces were made (Strandberg, 1994).

In 1995 a similar sampling schedule for faeces on pasture was applied. Additionally, rectal faeces samples were collected from each lamb at the same time as they were live-monitored. The samples were taken for analyses of soil content and for activity measuring. The analyses will be performed at the Agricultural University of Norway.

Transfer factors and transfer coefficients

Similar expressions for nuclide transfer are used as in the earlier study reported by Rosén *et al.* (1995), namely:

$TF_{soil\ to\ plant}$	Bq/kg dry weight plant per kBq/m^2 soil.
	Unit: m^2/10^{3}kg dry weight.
$TF_{plant\ to\ muscle}$	Bq/kg wet weight muscle per Bq/kg dry weight plant.
	Unit: kg dry weight/kg wet weight.
$TF_{soil\ to\ muscle} = T_{ag}$	Bq/kg wet weight muscle per kBq/m^2 soil.
	Unit: m^2/10^{3}kg wet weight.

Note that in the present paper the soil content of Cs-137 is thoroughly expressed as kBq/m^2 and used in the TF-expressions.

Statistical analyses will be made at the end of the study period, 1997.

RESULTS AND DISCUSSION

Results of the Sr-90 analyses are so far (1 November 1995) not present. Other data not yet available are: Cs-137 concentration in soil samples taken in 1995, Cs-137 concentration in single plant species in 1995, Cs-137 concentration in faeces samples in 1995, identification of mushroom species collected in 1995, mushroom spore content in lamb faeces 1995 and soil content in individual lamb faeces samples.

Deposition and distribution of radiocaesium in the soil

The deposition of Cs-137 in the 0-10 cm soil layer in the different sampling sites and the overall mean for 1994 is shown in Table 2. As was demonstrated in the earlier study (Rosén *et al.*, 1995) the fallout was still relatively homogeneously distributed between the sampling sites, with a range of 9.30-15.06 kBq/m^2. The time-corrected mean Cs-137 ground deposition of 1994 (corrected for physical decay to August 1990), 13.69 kBq/m^2, can be compared with the corresponding means in 1990, 1991, 1992 and 1993, 17.62, 14.56, 16.66, and 14.07 kBq/m^2, respectively (Table 2). The series indicate a decrease in the soil radiocaesium content. The overall time-corrrected mean for 1990-1994 was 15.34 kBq/m^2 (Table 2).

The percentage distribution of Cs-137 on the humus layer and mineral soil layer below, to a depth of 10 cm, as determined in 1994 is shown in Table 3. On average 71 % of the activity was found in the humus layer and the remaining 29 % in the mineral soil layer. There was, however, some variation between the sampling sites with a range for the humus bound fraction from 51 % to 85 % and a corresponding range for the mineral soil fraction from 15 % to 49 %.

The percentage distribution of Cs-137 on different levels in the soil layer from 0 cm to 10 cm depth in two sampling sites, 1 and 4a, in 1994 is shown in Table 4. Of the total Cs-137 83.6 % and 93.4 %, respectively, was found in the upper 0-5 cm layer. The results were similar to the overall mean for 1990-1993. It was also shown in sampling site 1 that 20.8 % of the Cs-137 was found in the vegetation e.g., mosses, close to the ground layer.

Herbage density

Data on herbage density (kg d.w.per m^2) in the different sampling sites for 1994 and 1995 as well as for the previous years are given in Table 5. The yearly means which also are illustrated in Fig.1 were of about the same order of magnitude, the range being 0.116-0.172 kg d.w. per m^2. It should be noted that the values represent the yield of one cut/harvest during the vegetation period. As was mentioned above additional cuts were made in each site in July 1995. The overall mean of this yield was 0.077 kg d.w. per m^2 (Table 5). It can be concluded that the herbage yield per unit area was rather low. The total grazing area available for the sheep herd was, however, very large (about 10 km^2 for ca 15 ewes and their lambs together with a goat herd of about 10 heads). Overgrazing did not therefore exist.

Radiocaesium concentration in herbage and single plant species

The Cs-137 concentrations in the herbage cut in the different sampling sites in August 1994 and 1995 are given in Table 6, the means being 802$\pm$472 Bq/kg d.w. (range 370-1729) and 695$\pm$472 Bq/kg d.w. (range 236-1703) in the respective year. There was thus a great variation between the sampling sites. The mentioned means can be compared with those in the previous years, 1990-1993; 1175, 1100, 920, and 840 Bq/kg d.w. (Fig. 2). Table 7 and Fig. 3 give the time-corrected (to August 1990) values, the means being 1175, 1125, 960, 900, 879 and 779 Bq/kg d.w. in the respective years 1990-1995. A gradual decrease in Cs-137 content could thus be demonstrated. Estimations of the ecological and of the effective ecological half-life were made (see below).

In Table 6 data is also given on the Cs-137 concentration in herbage cut in July 1995. The mean, 659 Bq/kg d.w. (657 Bq when time-corrected to August the same year), was similar to the mean recorded in August, 695 Bq/kg d.w.

The Cs-137 concentrations in single plant species collected in 1994 are shown in Table 8 (values representing date for sampling and values time-corrected to August 1990, respectively). For grasses and herbs a gradual decrease in the Cs-137 concentration could in most cases be demonstrated as compared with the values in 1990, 1991, 1992 and 1993 given by Rosén *et al.* (1995), while for woody plants, shrubs and trees this effect was not so apparent.

Radiocaesium concentration in mushroom

Data for 1994 are given by Strandberg (1994) and will be detailly discussed in a separate paper. So far it can be mentioned that among the collected mushroom samples, totally 18 species were identified and analysed for, *i.a.*, radiocaesium. There was a great variation in the Cs-137 concentration between the species, 189 Bq/kg d.w. in samples of *Russula vinosa* and 46857 Bq/kg d.w. in samples of *Russula aeruginosa* and 39267 Bq/kg d.w. in samples of *Rozites caperatus*. Results from the mushroom collection of 1995 are not yet available.

Radiocaesium concentration in lamb muscle

Results on Cs-137 content in muscle samples, expressed per kg wet weight (w.w.), taken from the lamb carcasses in 1994 and 1995 are given in Table 9, the mean values being 463 Bq/kg and 609 Bq/kg, respectively. All individual values exceeded the Swedish intervention level of 300 Bq/kg and thus the carcasses were discarded for human consumption. Corresponding mean values at slaughter of the lambs in 1990, 1991, 1992 and 1993 were 1087, 668, 513 and 597 Bq/kg, respectively (Table 9; Fig. 4). Time-corrected values are also given in Table 9, those corrected to August 1990 being 1090, 684, 538, 640 and 509 Bq/kg in the years 1990-1995 (see also Fig. 5). There was thus a marked decrease in the Cs-137 content between 1990 and 1991, but thereafter the levels were about the same. Effective ecological and ecological half-lives of Cs-137 in lamb muscle are given below in this paper.

The results from 1994 were based on only three lambs. However, the values were similar to those recorded in a herd grazing in the mountain area next to Blomhöjden. Five lambs from the mentioned herd that were slaughtered on the same day as those from Blomhöjden had a mean Cs-137 concentration of 483 (range 439-537) Bq/kg. This strenghtens the results based on the small number of lambs from Blomhöjden.

The twelve male lambs of the Blomhöjden herd that were kept on the mountain pasture in 1994 until slaughter on 1 August had a markedly higher average Cs-137 concentration in the muscle samples (709 Bq/kg or 707 Bq/kg when time-corrected to 26 Sept.) than the mentioned three female lambs, slaughtered 26 September. These results indicated that it might be of interest to sample the herbage for activity measurements also at the turn of July-August. This was done in the following year, 1995, but as was discussed earlier in the present report, the activity concentration in herbage was about the same in the last week of July and as one month later.

The relationship between the live monitoring results (y) and Cs-137 in muscle samples (x) of the three female lamb carcasses is shown in Fig. 6 (muscle sample values time-corrected to the day of live monitoring). The calculations are based on a very small number of data, anyhow the relationship indicates that it is possible to predict the activity concentration also at this activity level. Corresponding calculations for three other lambs from the same herd (not included in the study as they were not grazing in the mountain area) and with a far lower mean activity level (166 Bq/kg) was not useful for such predictions ($y = 422.911 - 0.991x$; $R=0.75$; $p=0.56$).

Radiocaesium and potassium concentrations in lamb faeces

The average radiocasium concentrations samples of lamb (or sheep) faeces collected on three occasions (each of three days) representing the pre-mushroom grazing period, the mushroom period and the post-mushroom (stable) period 1994/95 are given in Table 10 (Strandberg, 1994; Strandberg, personal communication). There were no marked differences between the content of Cs-137 during the pre-mushroom period (1753 Bq/kg d.w.) and during the mushroom period 1785 Bq/kg d.w.). During the stable period when the sheep were fed less contaminated feed the Cs-137 content was much lower, 88 Bq/kg d.w.

Others

Additionally, it should be mentioned that the ratio of Cs-134/Cs-137 in samples of soil, herbage, single plant species, mushroom, lamb muscle and lamb faeces in 1994 was within the range of 3.8 %-4.5 %. In two mushroom species, however, the ratio was 7.3 % and 7.4 %, respectively.

Mushroom spores in lamb faeces

The results will be published by Strandberg in a separate paper.

Transfer of Cs-137 from soil to plant and to lamb muscle

Transfer of Cs-137 from soil to plant

The transfer factor from soil to plant was 68.6 in 1994 (overall mean of sites 1-5). This values can be compared with the corresponding values from the previous 4 years; 74.3, 72.3, 64.7 and 57.2 (Table 11 and Table 12, the latter summarizing the main results of the study hitherto). During the last four years the values thus seem to be of the same order of magnitude. As mentioned before, soil activity values of 1995 are so far not present.

TF-values for single plant species will be given in the final report 1997.

Transfer of Cs-137 from plant to lamb muscle

$TF_{plant\ to\ muscle}$ values were 0.93, 0.61, 0.56, 0.71, 0.58 and 0.88 in 1990, 1991, 1992, 1993, 1994 and 1995, respectively, demonstrating that there was some variation in the transfer between the 6 years. During the last 5-year period there was a tendency of increasing values.

Transfer of Cs-137 from soil to lamb muscle

$TF_{soil\ to\ muscle}$ values was somewhat higher in 1990, 61.9, than in the following 4 years, 47.0, 32,3, 45.5 and 37.2. Soil values of 1995 must be available before the tendency can be seen for the period after 1990.

Effective ecological and ecological half-lives of Cs-137

Estimated effective ecological half-life and ecological half-life of Cs-137 (the latter with correction for physical decay) were as follows:

Herbage, 1990-1995: Effective ecological half-life, 6.6 years. (*cf.* Fig. 2).
Herbage, 1990-1995: Ecological half-life, 8.5 years (*cf.* Fig.3).

Lamb muscle, 1990-1995: Effective ecological half-life, 6.3 years (*cf.* Fig. 4).
Lamb muscle, 1991-1995: Effective ecological half-life, 24.1 years (*cf.* Fig. 4).
Lamb muscle, 1990-1995: Ecological half-life, 8.0 years (*cf.* Fig. 5).
Lamb muscle, 1991-1995: Ecological half-life, 125.4 years (*cf.* Fig. 5).

The Cs-137 concentration in herbage decreased continuously over the years 1990-1995, while the lamb muscle concentration decreased markedly only the first year, whereafter the levels were generally unaltered. In the period 1991-1995 the effective ecological half-life therefore was approaching the physical half-life of the nuclide.

The reason of the generally unaltered Cs-137 level in lamb muscle during the last 5 years during which period the activity level in herbage seemed to decrease ought to be investigated. Data from another two years, until 1997, will give more information on this trend as well on the ecological half-lives of the nuclide.

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TABLE 1. Number of lambs studied. Slaughter data. (Values of 1990-1993 according to Rosén *et al.*, 1995)

	1990	1991	1992	1993	1994	1995
Number of lambs	13	1	6	7	3	12
Sex	♂ and ♀	♂	♀	♀	♂	♂ and ♀
Day of slaughter	1 Oct.	23 Aug.	15 Oct.	30 Aug.	26 Sept.	4 Sept.
Age at slaughter, months	8	7	8	5	5	5
Carcass weight, kg						
Mean	22.0	18.0	17.7	15.8	23.0	19.2
SD	2.4		2.5	2.8	3.5	2.9
Range	18-26		15-22	12-20	21-27	15-24

TABLE 2. Deposition of Cs-137, kBq/m^2, in the 0-10 cm soil layer in different sampling sites in August 1994 (means and coefficients of variation, CV, %). Corresponding data for each of the years in 1990-1994 and means for 1990-1994, corrected for decay to August 1990. (Data of 1990-1993 according to Rosén *et al.*, 1995)

Site	1994		1990	1991	1992	1993	1994	1990-1994	
no.	Mean[1]	CV, %	Mean[1]	Corr. mean[1]	Corr. mean[1]	Corr. mean[1]	Corr. mean[1]	Corr. mean[2]	CV, %
1	14.10	18.1	19.96	14.96	17.74	11.70	15.46	15.96	20.1
2a	15.06	30.4	18.27	19.77	26.73	15.84	16.51	19.42	22.5
2b	11.88	41.5	-	-	-	-	13.03	-	-
3	14.31	27.0	17.25	15.81	12.41	21.93	15.69	16.62	20.8
4a	9.30	16.0	13.90	11.29	11.71	10.15	10.20	11.45	13.3
4b	12.86	24.9	17.99	14.53	14.17	13.94	14.11	14.95	11.5
4c	10.43	24.5	20.09	12.40	17.88	11.46	11.44	14.65	27.6
5	11.96	13.9	15.90	13.16	15.95	13.50	13.11	14.32	10.3
Mean (1-5) (n=8)	12.49	24.5	17.62	14.56	16.66	14.07	13.69	15.34	18.0

[1] Mean for 4 soil cores with a total area of $0.0102\ m^2$ within each sampling site.
[2] Mean for 1990-1994 (n=5).

TABLE 3. Percentage distribution of Cs-137 on the humus soil layer and the underlying mineral soil layer, down to a depth of 10 cm, at sampling in August 1994

Sampling site	Humus layer Mean depth, cm	Distribution of Cs-137, %, on Humus layer	Mineral soil layer
2a	3	58.9	41.1
2b	5#	50.6	49.4
3	2.5	79.7	20.3
4b	3	77.7	22.3
4c	4.5	85.0	15.0
5	2.5	71.8	28.2
Mean		70.6	29.4
CV, %		18.8	45.2

Carex bog. Organogenic soil, sliced 0-5 cm and 5-10 cm.

TABLE 4. Percentage distribution of Cs-137 on different depths in the 0-10 cm soil layer in the sampling sites no. 1 and 4a in August 1994

Depth, cm	Sampling site no.1	Sampling site no. 4a
	20.8#	-
0-1	20.8	29.1
1-2	15.6	30.8
2-3	9.4	16.9
3-4	8.4	10.9
4-5	8.6	5.7
5-6	4.0	2.1
6-7	4.0	2.1
7-8	3.2	1.4
8-9	2.6	0.5
9-10	2.6	0.5
Total	100.0	100.0

In the vegetation, e.g., mosses, close to the ground layer.

TABLE 5. Herbage density, kg dry weight/m^2, in each year, referring to the annual cut in August and mean for the period 1990-1995. Data of additional cuts in July 1995. (Data of 1990-1993 according to Rosén *et al.*, 1995)

Site	Herbage density, kg d.w./m^2								
	1990	1991	1992	1993	1994	1995	1995 (July)	1990-1995 (for values in August)	
								Mean	SD
1	0.092	0.173	0.188	0.217	0.220	0.208	0.092	0.183	0.048
2a	0.129	0.150	0.149	0.165	0.143	0.129	0.084	0.144	0.014
2b	0.087	0.103	0.103	0.063	0.137	0.060	0.043	0.092	0.029
3	0.121	0.141	0.141	0.179	0.139	0.112	0.090	0.139	0.023
4a	0.062	0.077	0.145	0.198	0.177	0.116	0.102	0.129	0.054
4b	0.173	0.090	0.161	0.167	0.126	0.094	0.060	0.135	0.037
4c	0.146	0.107	0.228	0.222	0.179	0.332	0.088	0.202	0.078
5	0.119	0.125	0.127	0.163	0.188	0.146	0.059	0.145	0.027
Mean	0.116	0.121	0.155	0.172	0.164	0.150	0.077	0.146	
SD	0.035	0.032	0.050	0.050	0.032	0.085	0.021	0.034	

TABLE 6. Cs-137 concentration, Bq/kg dry weight, in the herbage cut in an area of totally 1 m^2 in each sampling site in 1994 and 1995. Values given refer to the date of sampling in August 1994, July 1995 and August 1995

Site	1994 August	1995 July	1995 August
1	610	444	545
2a	656	166	236
2b	1729	1662	1703
3	370	616	641
4a	1310	954	1012
4b	428	463	660
4c	563	533	317
5	748	431	445
Mean	802	659	695
SD	472	461	472

TABLE 7. Cs-137 concentration in herbage, Bq/kg dry weight, from the sampling sites in different years and mean for the period 1990-1995. Values are corrected for physical decay to August 1990. (Data of 1990-1993 according to Rosén *et al.*, 1995)

Site	Cs-137, Bq /kg d.w.							
	1990	1991	1992	1993	1994	1995	1990-1995	
							Mean	SD
1	1330	1310	740	680	669	611	890	336
2a	510	760	650	250	719	265	526	224
2b	2120	1730	1490	1880	1896	1909	1838	211
3	1270	910	730	900	406	718	822	285
4a	1920	1500	2260	1360	1436	1134	1602	412
4b	980	960	940	980	469	740	845	205
4c	690	890	350	460	617	355	560	212
5	580	940	530	760	820	499	688	178
Mean	1175	1125	960	900	879	779	971	
SD	605	345	625	515	518	529	484	

TABLE 8. Cs-137 concentrations, Bq/kg dry weight, in the most common single plant species in different sampling sites in August 1994. Means and coefficients of variation, %, for values in August 1994 and corrected to August 1990, respectively

Plant species	Sampling site					Mean	CV, %	Mean (corr.
	1	2	3	4	5	(1994)		to 1990)
Grasses								
Molinia caerulea	1693	-	-	-	-	1693	-	1856
Descampsia caespitosa	603	-	526	488	997	654	35.8	717
Descampsia flexuosa	622	262	-	337	342	391	40.6	429
Nardus stricta	952	719	374	455	510	602	38.8	660
Herbs								
Rumex acetosa	938	632	-	-	-	785		861
Cornus suecia	940	-	795	-	-	838		952
Solidago virgaurea	878	919	-		1796	1198	43.3	1313
Filipendula ulmaria	-	-	374	-		339		372
Alchemilla vulgaris	-	-	-	24	-	24		
Woody plants, shrubs and trees								
Vacccinium myrtillius	612	432	375	421	381	444	21.8	487
Empetrum nigrum	559	-	-	294	-	426		468
Betula tortuosa	168	148	320	242	257	227	30.8	249
Betula nana	237	236	-	146	-	206	25.3	226
Salix spp.	374	231	471	387	935	480	56.1	526

TABLE 9. Radiocaesium concentration, Bq/kg wet weight, in lamb abdomen muscle samples at slaughter and corrected to different dates. Means ± SD. (Data of 1990-1993 according to Rosén *et al.*, 1995)

	1990	1991	1992	1993	1994	1995
Number of samples	13	1	6	7	3	12
Cs-137 [a]	1087±195	668	513±65	597±117	463±43	609±66
Cs-137 [b]	1090±196	668	515±65	597±117	468±42	610±66
Cs-137 [c]	1090±196	684	538±68	640±125	509±47	684±74
Cs-134 [a]	-	61	-	33±5	18±0	18±3

[a] At slaughter.
[b] Corrected to the day of herbage sampling (August) in each year.
[c] Corrected to the day of herbage sampling in August 1990.

TABLE 10. Radiocaesium (Bq) and K (g) concentrations per kg dry weight of faeces from the sheep herd collected on the pasture (July and August 1994) and in the stable (January 1995). Means of 3 days, respectively

	Cs-137 Bq/kg d.w.	Cs-134 Bq/kg d.w.	K g/kg d.w.
25 July 1994	1753	77	12
23 August 1994	1785	78	8
13 January,1995	88	4	11

TABLE 11. Transfer of Cs-137 from soil to plant ($m^2/10^3kg$) in each site in different years and mean for the period 1990-1994. (Data of 1990-1993, see Rosén *et al.*, 1995)

Site	1990	1991	1992	1993	1994	1990-1994 (Mean±SD)
1	82.7	81.5	46.0	42.3	43.3	59.2±21.0
2a	25.3	37.7	32.3	12.4	43.5	30.2±12.0
2b	105.2	89.3	71.0	93.3	145.5	100.9±27.8
3	75.4	54.0	43.5	53.4	25.9	50.4±18.0
4a	163.3	127.6	192.2	115.6	140.8	147.9±30.4
4b	65.3	63.3	62.0	58.7	33.2	56.5±13.2
4c	37.5	60.8	34.3	29.8	53.9	43.3±13.4
5	39.7	64.3	36.2	52.0	62.5	50.9±12.8
Mean	74.3	72.3	64.7	57.2	68.6	67.4
SD	44.7	27.4	53.3	33.2	47.4	38.4

TABLE 12. Transfer of Cs-137 in the soil-plant-lamb chain. Mean values for each year and for the period 1990-1995 (or 1994). Given mean values of Cs-137 concentration are corrected to August 1990. (Data of 1990-1993 according to Rosén *et al.*, 1995)

	1990	1991	1992	1993	1994	1995	1990-1994/ 1990-1995 (Mean)
Cs-137 concentration in							
Soil, kBq/m^2	17.62	14.56	16.66	14.07	13.69	-	15.34
Herbage, Bq/kg d.w.	1175	1125	960	900	879	779	971
Muscle, Bq/kg w.w.	1090	684	538	640	509	684	691
Transfer factors (TF)							
$TF_{soil\ to\ plant}$ (Bq/kg d.w. plant per kBq/m^2 soil)	74.3	72.3	64.7	57.2	68.6	-	67.4
$TF_{plant\ to\ muscle}$ (Bq/kg w.w. muscle per Bq/kg dry w. plant)	0.93	0.61	0.56	0.71	0.58	0.88	0.71
$T_{ag}=TF_{soil\ to\ muscle}$ (Bq/kg w.w. muscle per kBq/m^2 soil	61.9	47.0	32.3	45.5	37.2	-	44.8

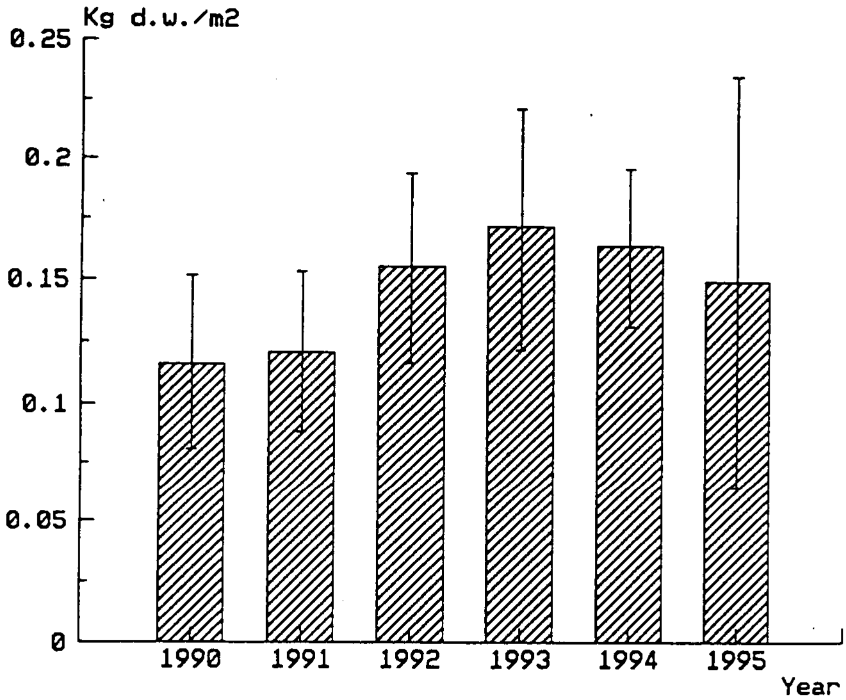

Fig. 1. Herbage density, kg dry weight/m^2, referring to the cut/sampling in August each year. Means and standard deviations for the sampling sites.

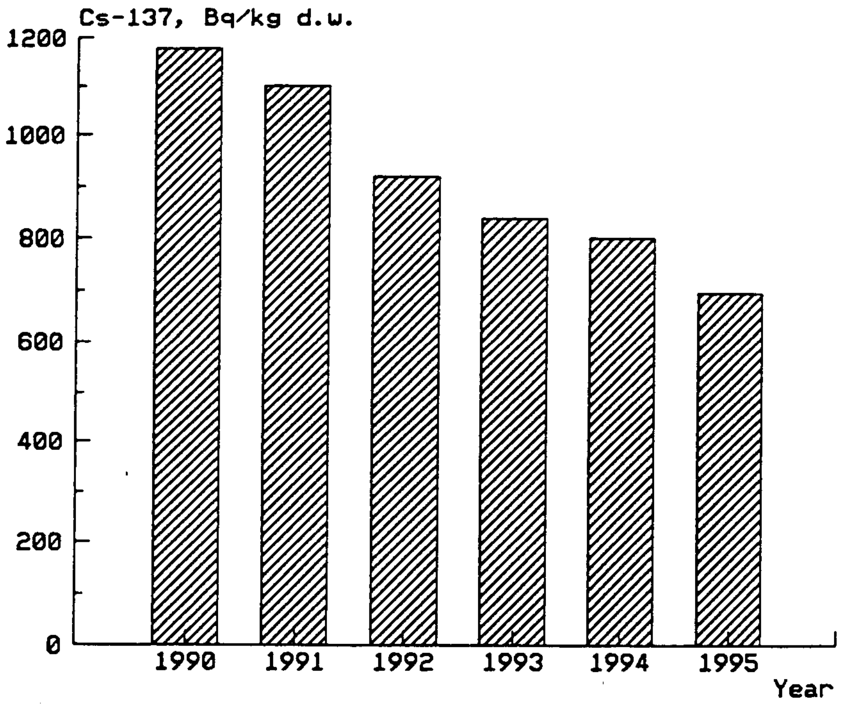

Fig. 2. Cs-137 concentration in herbage, Bq/kg dry weight, referring to the cut in August each year. Means for the sampling sites.

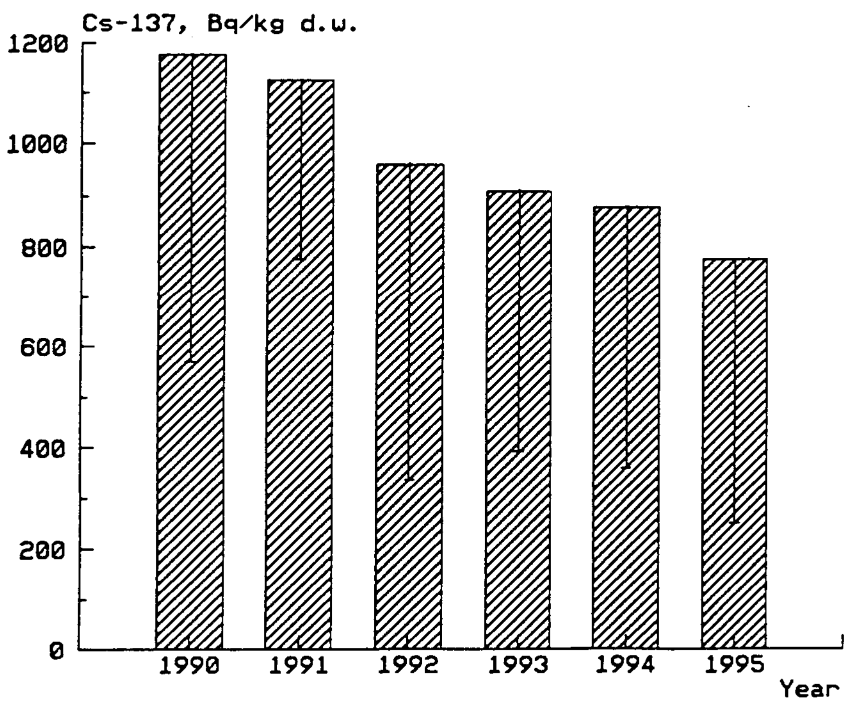

Fig. 3. Cs-137 concentration in herbage, Bq/kg dry weight, each year. Values are time-corrected to August 1990. Means and standard deviations for the sampling sites.

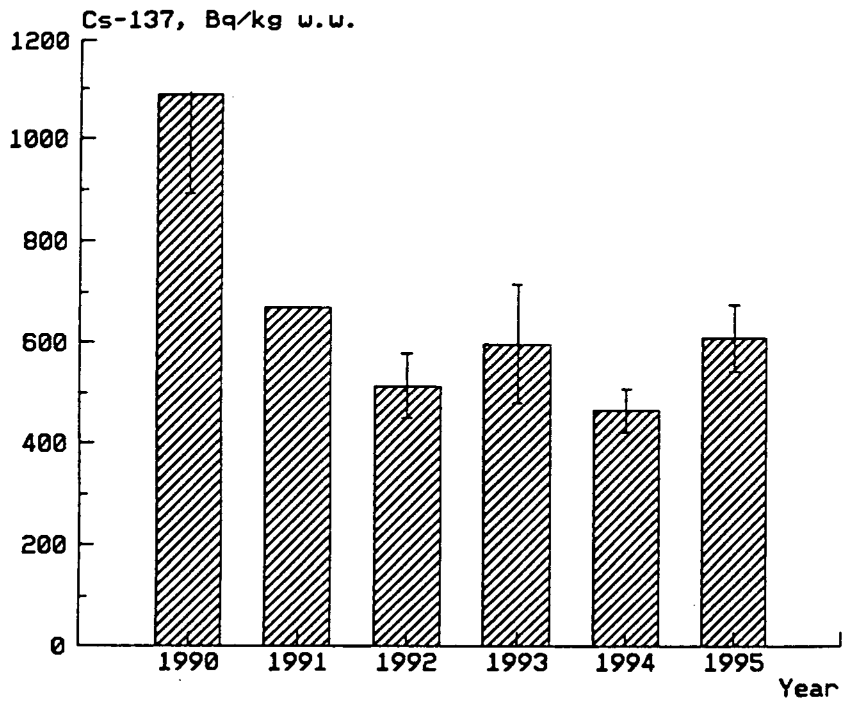

Fig. 4. Cs-137 concentration in abdomen wall muscle samples of lamb carcasses, referring to the date of slaughter each year. Means and standard deviations.

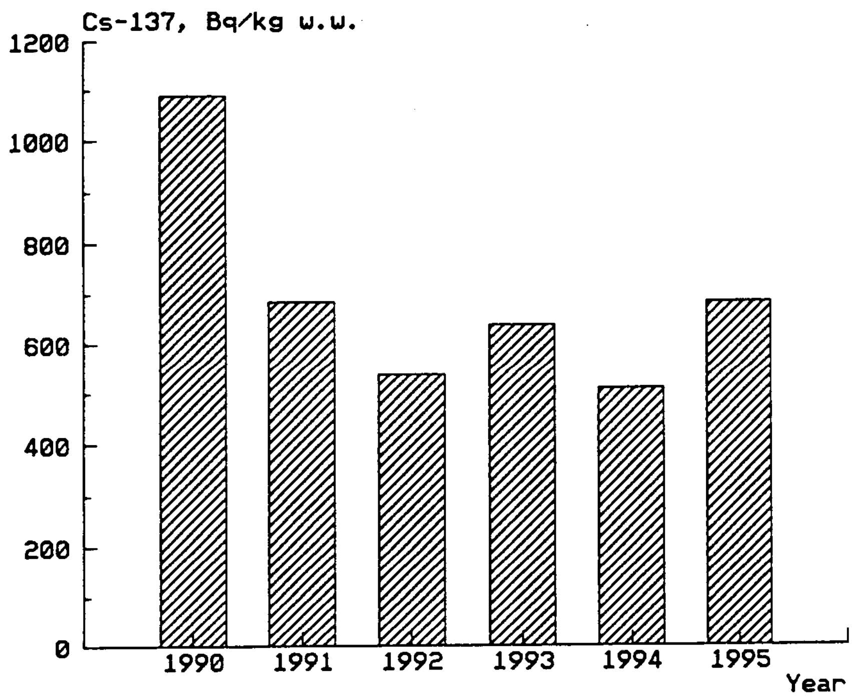

Fig. 5. Cs-137 concentration in abdomen wall muscle samples of lamb carcasses. Means for each year. Values are time-corrected to August 1990.

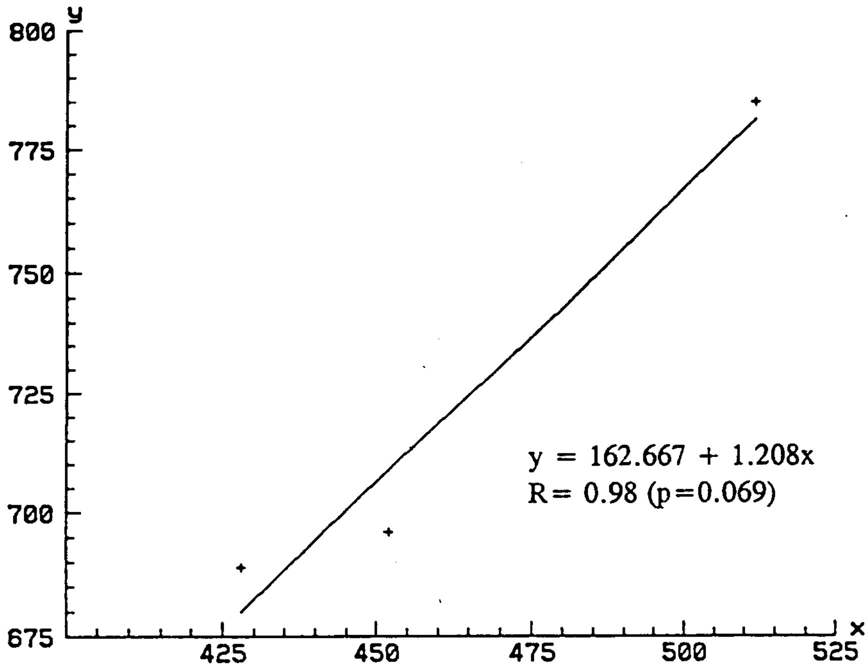

Fig. 6. Relationship between Cs-137 concentration according to live monitoring (y) of the lambs with Canberra Series 10 and Cs-137 concentration in abdomen wall muscle samples of the carcass (x). Three female lambs in 1994.

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Soil Ingestion in Farm Animals - a Review

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Summary

Soil ingestion in farm animals occurs mainly during grazing and as either an inadvertent intake due to soil adhered to vegetation or as an active ingestion suggested due to lack of essential mineral elements such as Cu, Co and Mn. The ingested soil may also act as an antidote to acidosis. Sheep and cattle have been vastly investigated in this field compared to horses and pigs. In horses, soil ingestion has been mostly connected with mass loading of the intestines and digestive disorders, while in pigs, especially piglets, soil ingestion has been associated with Fe supply. However, with the ingested soil, different environmental contaminants like heavy metals, radionuclides, chemicals and pesticides can be consumed. These elements are often found in high concentrations in the upper soil layers and are to a more or less extent transferred to meat and milk depending on e.g. the adhesion of the specific element to soil particles.

Soil content in e.g. feeds and faeces can be determined by the acid insoluble residue of ash (A.I.R.) or by the titanium (Ti) or scandium (Sc) content. The two latter elements can be determined by spectrophotometry and neutron activation analysis, respectively. Using the A.I.R. content, corrections have to be made for plant A.I.R. content. Ti and Sc are not taken up by plants and are not digested by animals and they are therefore usable in determination of soil on plants and in faeces. In Scandinavia, Sc-analysis seems to be most convenient to use as also the detection limit is very low.

Soil adhered to vegetation can be very high (24.7 - 35 % of DM) when grazing animals are present while on non-grazed plots the soil adhered to vegetation is reported to be none or very low. Grazing sheep cause more soil on vegetation than cattle. Soil is generally found in higher amounts on the lower parts of the plants. In many harvested crops, soil concentration is very low (< 0.2 % of DM). However in root crops soil have been accounted for about 7 % of DM.

Soil adhered to plants does not necessarily reflect the real intake of soil as the animals perform selective grazing or ingest soil directly. Faecal soil analysis is therefore more reliable to determine the percentage of soil in the diet where it is needed to estimate the total digestibility of the ration. Soil ingestion will increase with low availability of forage, winter season conditions, high stocking rates, root intake, loose soils and any management that produces soily pasture conditions.

Environmental contaminants in soil may derive from e.g. sludge, atmospheric deposition, metalliferous activities and persistent pesticides. The transfer and excretion of these environmentally dangerous compounds from soil to animal can be of importance in the calculation of reliable biological half-times and exposure risks. The availability of essential mineral elements is also of interest as it may determine the type and composition of salt licks and additional feeding.

Soil ingestion has also been reported to alter mineral element digestion, of e.g. phosphorous, but this phenomenon is highly dependent on the soil type.

Human soil consumption is especially found in children and may be a source of poisonous compounds, parasites and bacteria.

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Soil ingestion by farm animals - a review

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1. Introduction

Soil ingestion by animals is often a neglected phenomenom, but it occurs under natural conditions in both wild and domesticated animals. The main function of a voluntary intake of soil is suggested to be restoring of lacking essential elements but also other motives may be present such as soil being an antedote to acidocis (Connor, 1993; Ammerman et al. 1984; Healy, 1968; Kreulen, 1985). Involuntary or inadvertent soil ingestion may also happen due to contamination of soil adhered to plants.

Whatever the reason, soil ingestion by farm animals may cause a number of negative effects. It can be a source of uptake of radionuclides and chemicals and heavy metals, jeopardise digestive functions, alter mineral uptake and be a source of parasite and bacteria infections. In addition, environmental contaminants like heavy metals, radionuclides, pesticides and other dangerous chemicals are more concentrated in the upper layers of the soil and these will therefore be more readily consumed. In food-chain models for the environmental assessment of nuclear operations and waste-management data on soil-ingestion is needed in order to improve the reliability of the models for the prediction of food safety (Ronneau et al., 1983). Knowledge on the distribution of radionuclides, e.g. caesium, between soil and plant is important as the uptake of radionuclides in soil by the animal is often less than from those in plants (Belli et al., 1993). The dominating pathway on the intake of radionuclides, from soil or plant, is determined by the plant/soil transfer coefficient and the percent soil ingestion of dry matter intake (Zach & Mayoh, 1984).

The aim of this review is to describe the causes for variation in the ingestion of soil in farm animals and additionally give an outline of the effects on animal and food safety. The topic covered in this review is shown in figure 1. The review focus on the factors determining soil ingestion and in more overviewing terms with the relating issues.

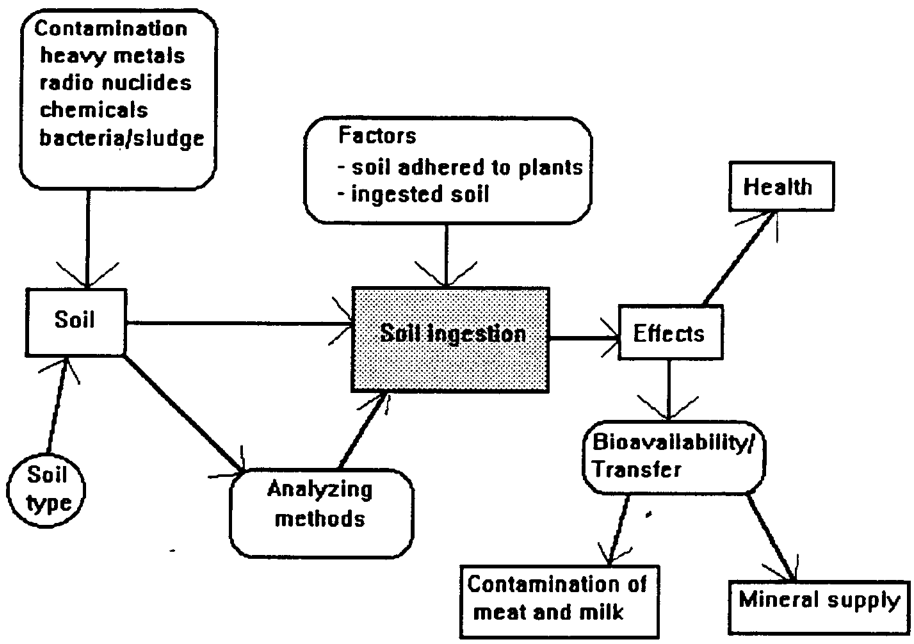

Figure 1. A diagram over the topic soil ingestion by farm animals and the relating issues.

2. Why animals ingest soil

The theory of soil ingestion

As already mentioned, there is often made a distinction between factors that determine voluntary intake and factors that determine inadvertent or involuntary intake. Among the several motives for soil ingestion mentioned in this chapter, it is not always possible to know if these motives trigger voluntary soil ingestion, actively done by the animal or if they only can be seen as a by-product of inadvertent or involuntary soil ingestion.

Voluntary soil ingestion by grazing animals is usually considered to be a nutritional phenomenon. Soils may differ in their ability to supply mineral elements to animals via pasture herbage. The content of e.g. Cu, Co and Se can be found in such low concentrations in pasture herbage that the requirements in these elements for sheep and cattle can not be fulfilled by intake of herbage alone. Thus the animal will then be at risk of developing deficiency symptoms. Thus, soil ingestion by grazing animals can occur in areas where there is an inadequacy of the soils to supply microelements to the vegetation (Healy, 1968; Healy, 1973).

However, many soil types that have been studied do not uniquely explain that they fulfil a supply of mineral elements. Soils may contain other characteristics that make them attractive for ingestion which is presented below (Kreulen, 1985).

Mineral element supply from soil

The concentration of several mineral elements in soil is often higher than in the herbage. A marked increase of the concentration in the diet of several mineral elements like Cu, Mn, Se and Fe when adding a certain amount of soil (14 %) into the diet of sheep was demonstrated by Healy (1973). However, this increase in mineral elements reflects total amounts ingested and not the available fractions of the elements. It should be noted that soil ingestion on pasture is highest when dry matter (DM) intakes are low due to feed limitations. At such times mineral elements available to the animal directly from soil can be a significant contribution to intake (Healy, 1973).

Cobalt (Co) is included in vitamin B_{12}. Very little of Co is taken up by plants and therefore it is mainly by soil ingestion that sheep and cattle can fulfil their needs of this mineral element (Healy, 1973; Thornton 1974).

Opposing the above statements on the function of soil ingestion in cattle and sheep as a source of some essential minerals, Russel et al. (1985) concluded that there is a direct intake of soil including mineral elements e.g. Cu, but the fractional utilisation of a soil element of total intake is very small and the major source is from plants.

It is a well known fact that newborn suckling piglets will be deficient of iron (Fe) and they will very soon develop anaemia if they are not having Fe administered in some way. It is of no use of feeding the sow extra Fe as practically nothing will be transferred to the milk. However, piglets display rooting behaviour from the day of birth which under natural situations which implies soil ingestion and thus a Fe supply from soil (Per Jensen, pers. comm.).

It is pointed out that the mineral element supply is highly dependent on the actual soil ingestion, the concentration of elements in the soil and the availability of the mineral element in the soil. The supply of dietary trace elements is suggested to be a function of both a soil - animal relationship and a soil - plant - animal relationship (Thornton, 1974)

Stabilising digestive function with soil

Soil may have a stabilising effect on the digestive function in ruminants as soil can provide the animal with buffers which stabilises rumen pH and fermentation (Kreulen, 1985). This function can explain voluntary soil ingestion seen in many in wild ruminants in semi-arid areas in Africa. Wild, especially nomadic, ruminants in the Kalahari desert have been observed soil licking during shifts from a dry, nearly straw-like, grass diet to leaf flush and high palatable grass. This change in diet would likely cause digestive disorders like acidosis but according to Kreulen (1985) this has not been reported in those species that have been observed to ingest soil. Practical observations in Sweden (Mats Kullberg, pers. comm.) have noticed soil ingestion in both sheep and cattle after the change from indoors winter feeding to grazing. Kreulen (1985) lists a number of arguments for animal's soil ingestion in order to restore from acidosis:

1. Gastric irritation by an introduction of concentrate provoke soil eating in cattle. The behaviour ceases when bentonite is added to the diet. A clay like bentonite have a high cation exchange capacity and a structure which

enables it to form complexes with organic compounds. Thus rumen fermentation can be stabilized by buffering and by reduction of substrate.

2. It is mostly a seasonal phenomenon, in temperate and tropical areas it is displayed predominantly in spring and early wet season, following on leaf flush and associated dietary change.

3. Timing of soil ingestion is often done in the late afternoon/early evening by ungulates in the Kalahari desert, which coincides with the peak of the sugar content in the plants a few hours earlier. Minimum pH would be expected in the early evening and would be counteracted by the ingested soil.

4. Ash eating has been observed in both wild and domestic animals, which would mean that they seek other buffer salts than the suggested Na because ash contain mainly potassium carbonate (K_2CO_3).

5. Data on the composition of lick soils show that they are usually rich in those salts and/or clays that have been proved to be effective antidotes to acidosis.

3. Methods for measuring soil content in plants and faeces - soil ingestion estimates

There are several methods of measuring the amount of soil adhered to plants or soil content in faeces. The most commonly used are listed below.

The soil found in animal faeces reflects intake from several sources which cannot be separated. It may have been adhered to plants, the plants may have been ripped up with the soil contaminated roots and the whole plant may have been consumed or there might be a direct ingestion of soil.

Soil ingestion can be estimated by using the acid insoluble residue method (A.I.R.) by which the ash content is determined (Healy & Ludwig, 1965). If the daily faeces output is known as well as the soil concentration of the faeces, then the quantity of soil ingested per day can be determined. However, faeces output data is usually only available from experimental animals. In other cases the faeces output can be calculated by estimating the feed DM intakes and digestibility of feed. The amounts of soil ingested can thereafter be calculated approximately (Healy, 1973).

A soil element that is incorporated by plants and not digested by the animal can be determined and thus knowing the concentration of the element in the soil, the soil content of the matter (plant surface contamination or faeces) can be calculated. Several elements have been suggested and evaluated in order to determine soil concentration in plant material and faeces such as titanium (Ti) by using spectrophotometry (Sherman & Kanehiro, 1965), scandium (^{45}Sc) by using neutron activation analysis (Oughton & Day, 1993; Li et al., 1994), the radionuclides caesium (^{133}Cs) and rubidium (^{85}Rb) by using neutron activation analysis (Oughton & Day, 1993) and radiocaesium (^{137}Cs and ^{134}Cs) by using gamma-spectrophotometry (Riise et al., 1990). Aluminium has together with titanium and A.I.R. been used to estimate soil content in faeces by Millar et. al. (1985).

The determination of ash content in plant material or faeces is considered to be a rough method which only gives an approximately estimation of the soil content (Mayland et al., 1975).

The use of a soil element which is neither taken up by the plant nor digested/absorbed by animal has been proved to be most convenient and accurate in soil amount determinations (Mayland et al., 1975; Li et al., 1994). Titanium determinations can be a little uncertain since the Ti content can change with particle size of soil. Soil fractions with > 100 μm particles have a considerable higher Ti concentrations than smaller fractions (Brebner et al., 1985). The determination of ^{46}Sc by neutron activation analysis seems to be a reliable and practical for soil mass loading research (Oughton & Day, 1993; Li et al., 1994). Scandium is poorly absorbed by plant roots and is not mobile in vegetation (O'Toole et al., 1981). A detection limit of 0.5 mg per g dry plant biomass is reached which is adequate.

The calculation of daily intake (in percent of DM intake) of soil can be made by using the equation suggested by Thornton & Abrahams (1983):

$$\% \text{ Soil ingestion} = (1 - D_h)Ti_f / Ti_s - D_h\, Ti_f * 100$$

where D_h is the herbage digestibility, Ti_s the titanium concentration (of DM) in soil and Ti_f the titanium concentration (of DM) in faeces. Scandium content and other elements fulfilling the criteria of not being incorporated by plants or digested by the animal could also be used for the calculation.

Alternatively, Russel et al. (1985) suggested that the fraction of intake of an element (F) coming from ingested soil can be calculated using the equation:

$$F = (Ti_f * E_s) / (E_f * Ti_s)$$

where E_f is the concentration of an element in faeces and E_s the concentration of an element in soil. This second method avoids estimating herbage digestibility.

4. Factors influencing inadvertent soil ingestion

Soil adhered to plants will doubtlessly be ingested and should be considered to be an inadvertent intake of soil. The difference between factors determining adhesion of soil to plants and the real soil ingestion must also be distinguished. There is often inadequate data to assess the importance of many of these factors determining how much soil is deposited on and retained by vegetation and on the real soil ingestion. In many studies the percentage of soil in faeces is measured but as mentioned above this only partly reflects the intake of soil adhered to plants. Other sources may be licking of soily coat and snout and direct soil ingestion. Additionally there are not always data on the total feed dry matter intake or digestibility of the herbage which makes it difficult to exactly calculate daily soil ingestion rate.

Soil adhered to plants

Pasture

Soil may be adhered to plants for various reasons including action of the wind, rain splash, resuspension and soil distribution by ploughing or livestock activities. The soil contamination on the plants can be heavy on pasture. Soil (titanium content) can contribute to as high as 35 % of the DM in clover and to 24.7 % in ryegrass on pastures grazed by sheep while no soil was found on herbage (both ryegrass and clover) in non-grazed plots (Healy, 1973). To which extent soil adhesion occurs will be influenced by a wide range of environmental activities including species of animal, climate, season, soiltype, stocking rate, vegetation species and pasture management (Beresford & Howard, 1991).

Animal species. The influence of cattle and sheep on soil adhered to plants has been investigated by Green & Dodd (1988) by the use of the titanium content. Soil contamination of herbage in a sheep paddock was 6.8 % of DM while it was 3.2 % of DM in a cow paddock.

Season. Beresford & Howard (1991) measured the soil content on plants in sheep pastures by using the titanium content. A clear seasonal variation in soil adhered to vegetation was found to be as high as 40 % of DM in winter and less than 2 % of DM in summer.

The soil content of grass on a cattle pasture was analysed from May to October by the use of the titanium method (Green et al., 1994). At any given time, the soil content varied between samples but in all but one case the content was less than about 3 % on dry matter basis.

Wind erosion, rainsplash and plant species interaction. Li et al. (1994) tried to separate the effects of wind erosion and rainsplash in experimental studies in greenhouse and in unprotected fields. In ryegrass, 53 % of the total soil concentration (total soil content: 5.77 mg / g dry plant) on plant surfaces derived from wind erosion while 47 % derived from rainsplash. In broad bean wind erosion only accounted for 32 % of total plant surface concentration (total soil content: 9.51 mg / g dry plant) while 68 % derived from rainsplash. The differences between the two plant species might be due to differences in plant anatomy and leave structure.

Resuspension. Another risk of soil contamination on the herbage (and thus of radionuclides) is by resuspension which is a type of wind erosion. Resuspension of estuarine surface sediment deposited during flooding has been described by Summerling (1981).

Harvested crops

Swedes and a different root crops can contribute to large amounts of soil in the diet. Ulvesli and Saue (1965) investigated feeding of uncleansed whole swede with dry cleansed whole swede to dairy cows. The soil content on uncleansed swedes was about 7.3 % of wet weight, while after dry cleansing the soil content was 3.4 - 2.2 %.

Soil contamination of forage plants may be higher in the lower part of the plant than in the higher parts of the plant. The effect of green cut forage cut with two stubble heights (50 and 150 mm) on ^{137}Cs activity in the herbage and the transfer to milk was studied by Bertilsson et al. (1988). The ^{137}Cs concentration of the herbage cut with 50 mm stubble height was 17 times higher (6656 Bq / kg DM) than in the 150 mm (385 Bq / kg DM) stubble height. However, the transfer coefficient of ^{137}Cs to milk was 3.5 times higher in the forage cut with high stubble height ($0.67 \cdot 10^{-2}$) than that cut with in the low stubble height ($0.19 \cdot 10^{-2}$).

Assuming that ^{137}Cs in soil has a lower bioavailability (Belli et al., 1993) this may indirectly reflect soil contamination of the lower part of the plants. However, without data on the radioactivity in the soil, no estimation of the soil contamination of the forage can be made.

Soil content, as reflected by titanium content, was found to be very low (< 0.14 % of DM) in concentrates, corn silage, haylage and hay (Fries et al., 1982). In green chopped herbage and in pasture maximum soil concentration were 0.73 % and 2.88 % respectively. The range of concentrations are shown in Table 1.

Table 1. Apparent concentrations of soil in feeds from study farms (Fries et al., 1982).

Feed	Samples (no.)	Range of concentrations (% DM)
Concentrate	8	<.01 – .01
Corn silage	5	<.01 – .20
Haylage	4	<.01 – .17
Hay	6	<.01 – .14[a]
Greenchop	2	.19 – .73
Pasture	4	.34 – 2.88

[a] Does not include one sample of hay obtained from where it was being fed on the ground.

Ingested soil/faecal soil

Pasture

Animal species. No comparable data has yet been found on the influence of animal species on the amount of ingested soil except for the already mentioned data on soil in herbage (Green & Dodd, 1988). Soil ingestion in cattle and sheep and other animals may be different due to grazing behaviour: the way of separating the grazed plant parts from the rest of the plant, how close to the ground grazing is performed and soil contamination of plants by treading due to difference in claw size, weight and amount of locomotion. It might be concluded from the data by Green & Dodd (1988) that sheep ingest greater amounts of soil than cattle. This is supported by data given by Thornton & Abrahams (1983) which shows that soil ingestion in sheep can account for as much as 30 % of daily DM intake while the corresponding figure in cattle was 18 %.

Available forage and root intake. The available amount of forage in pasture primarily vary with the growth rate of the plants and stocking rate. These factors are dealt with in more detail below but as a general conclusion the concentration of soil in faeces has been found to increase when the availability of forage decrease (cattle: Mayland et al., 1975 ; Kirby & Stuth, 1980 ; sheep: Healy, 1968; Healy, 1973; Millar et al., 1985). Mayland et al. (1975) explained the increased soil ingestion that it was primarily included with the roots of *Bromus tectorum* which were often pulled up and consumed together with the aboveground plant parts. Dust on leaves and stems accounted for only a small portion of the ingested soil. Soil ingestion rates (Ti content) in cattle was here found in the range from 0.1 to 1.5 kg with a median of 0.5 kg soil /animal-day.

Season. Seasonal changes in the soil content of ruminant faeces have been made in several places over the world and most often reflects the available amount of forage: In wet winter climates as in Ireland (Raffety et al., 1994) soil ingestion was found high in sheep during winter months as it also have been found in New Zealand (Healy, 1968; Healy, 1973; Millar et al., 1985). The faecal soil content was at least three times higher in the winter than in the summer. Peak values of A.I.R. were as high as 40 - 50 % of the DM of the faeces (Millar et al., 1985). On twelve farms in the south west of England the percentage of soil (titanium method) as total DM intake by cattle was on average 5.6 %, 1.45 %, and 3.0 % in late April, June and August (Abrahams & Thornton, 1994). Soil ingestion rates varied with season in nearly all the farms but was particularly high in April (Table 2).

Table 2. Seasonal variation of soil ingested by cattle at 12 farms investigated (Abrahams & Thornton, 1994)

Sample period	Percentage of soil as total dry matter intake	
	Mean	Range
Late April	5.64	1.47 - 17.9
Late June	1.49	0.18 - 3.91
Late August	3.01	1.36 - 4.66

In arid climates, high soil surface temperature (above 30°C) which is dependent on ambient temperature and wind velocity has been found to be inversely related to soil ingestion (titanium method) in sheep (Vaithiyanathan & Singh, 1994). Sheep being a close grazer, may avoid picking up the plant material which is close to soil surface when soil temperature is high.

Heifers being on a pasture with a good stand of crested wheatgrass (*Agropyron desertorum*) under rather mesic conditions (in Idaho, USA) average soil ingestion rates was 0.73 kg / animal and day in June and 0.99 kg / animal and day in August (Mayland et al., 1977).

Soil type. Low ingestion rates have been found when animals are kept on well drained soils which have a strong structure. In contrast soils with a weak structure and poor drainage are associated with high pasture contamination (Healy, 1968).

Stocking rate. Increasing stocking rate results in a greater amount of soil ingested (Healy, 1968). With 16 ewes / ha compared with ewes stocked 7.5 / ha soil ingestion rates can be more than four fold (8 and 2 % of DM intake respectively; measured by A.I.R. content) during summer. In winter, soil content in faeces was found to peak at nearly 40 % with 16 ewes / ha while with 7.5 ewes / ha soil content was about 25 %. A seasonal variation in the pattern of soil ingestion can be seen with different stocking rates. Soil ingestion rates increases earlier in the autumn and decreases later in the spring with the high stocking rate compared with the low stocking rate. This interaction of season and stocking rate is shown in figure 2.

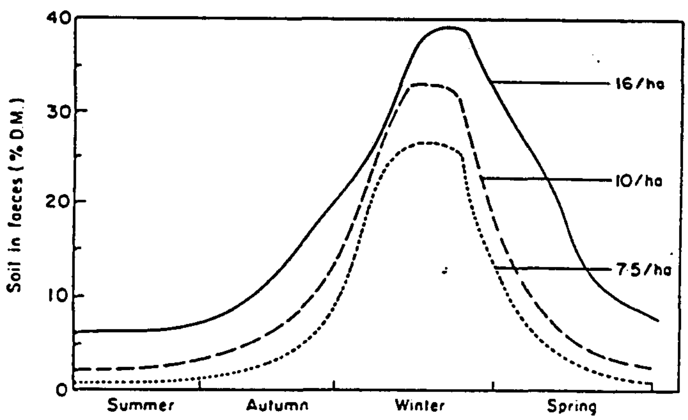

Figure 2. Effect of stocking rate and season on soil content of faeces (Healy, 1973).

Bare ground. A positive relationship between percent open ground and faecal soil (A.I.R.) has been shown by Kirby & Stuth (1980) due to mainly the use of mechanically tilling of pastures.

Management. Dry ewes stocked 37/ha when rotationally grazed on a 28 day basis ingested less soil (10 % soil in faeces) than than did animals rotated on a 7 day basis (37 % soil in faeces) (Healy, 1973).

Animals given supplementary feed during winter months will ingest less soil than animals relying on pastures alone (cattle: Fries et al., 1982; sheep: Healy, 1968).

Hoggets grazing swedes on a break system ingest little or no soil at the start of the break but large amounts of soil is ingested when most crop is eaten down to ground level (Healy and Drew, 1970).

Healy (1973) concludes the close correlation between pasture condition and soil in faeces. Where pasture is short and closely grazed, soiled and associated with abundant earthworm casts, high contents of soil in faeces can be expected. Any management practice producing these conditions in pastures will affect soil ingestion.

Soil ingestion by individuals. There is a considerable individual variation in soil intake by individual animals on pasture. In the same herd it can be more than twofold (Healy, 1973).

Confined management systems

Soil intake is generally very low under confined conditions for cattle (< 1 % of dry matter intake). However, lactating cows that had access to unpaved lots ingested more soil than cows confined to buildings and paved lots (Fries et al., 1982). Cows whose only exposure to soil was bedding of free-stalls ingested intermediate amounts of soil. It seems evident that soil intake in these cases are due to coat and snout licking. Dry cows and heifers kept under similar circumstances had generally a higher percentage (> 1 %) of soil ingestion rates than the lactating cows. But in the case of a group of cattle with no soil exposure factor this might be an artefact due to bedding in the stanchions with wood shavings which had a titanium count equivalent to 0.86 % soil. Ingestion of wood shavings might explain this.

Table 3. Soil ingestion rates in cattle and sheep under different conditions.

Animal category	Kg soil per day	% of DM intake	Conditions	References
Dairy cattle, grazing	0.5 - 1.2	4 - 8	Depending on feeding schedule,	Healy, 1968
	2.2		poor range conditions	
		<2	Lush plant growth	
		14	Poor plant growth	
		3.4		Green & Dodd, 1988
		1.38 - 2.43	Pasture + supplementary feeding	Fries et al., 1982
Dairy cattle, confined		0.14 - 0.53	Confined to concrete	Fries et al., 1982
		0.35 - 0.64	Free-stall barn with soil bedding	
		0.60 - 0.96	Access to unpaved lots, no vegetation	
Range cattle	0.5 (median)	6.2 (median)	Semiarid conditions, Idaho	Maynard et al., 1975
	0.1 - 1.5	1.2 - 18.8		
Heifers	0.73 & 0.99		Crested wheatgrass, June and August	Maynard et al., 1977
Heifers, confined or with supplement feed		0.52 - 0.81	Confined to buildings and or paved lots	Fries et al., 1982
		0.25 - 2.26	Unpaved lots, no vegetation	
		1.56 - 3.77	Unpaved lots, sparse vegetation	
		1.38 - 2.43	Pasture with supplemental feed	
Steers (grazing)	0.41 - 0.84		Mechanically tilled	Kirby & Stuth, 1980
	0.34 - 0.67		Chemically treated	
	0.28 - 0.61		Untreated pasture	

Table 3 continued. Soil ingestion rates in cattle and sheep under different conditions.

Animal category	Kg soil per day	% of DM intake	Conditions	References
Sheep, grazing		up to 14	Range conditions and soil structure	Healy, 1967
Sheep, grazing		6.8		Green & Dodd, 1988
Sheep, grazing		1.64 - 3.16	individual variation	Healy & Drew, 1970
Sheep, grazing	0. 71 - 0.163	3.7 - 10.7	arid climate, temperature, wind velocity	Vaithiyanathan & Singh, 1994

5. Aspects on soil ingestion

Environmental contamination of soil

Zach and Mayoh (1983): Soil ingestion is an important pathway for chemical pollutants and radionuclides

O'Toole et al. (1981): Aerosol contamination from power plant and the enrichment of contaminants in the ecological system

Heavy metals

Thornton & Abrahams (1974)

Thornton (1973)

Radionuclides

Atmospheric deposition from nuclear operations which have suffered radioactive leakage (Sellafield, Chernobyl).

^{137}Cs is mostly concentrated in the upper layers of soil and very little mobility to lower layers of soil is seen (Chamard et al., 1993; Rosén et al., 1995; and others)

Chemicals

Fries (1987) concluded that soil ingestion may be a major pathway for dioxin (TCDD) to animal products and human diet.

Fries (1982) the risks of using PCB (Polyclorinated biphenyls)-contaminated sludge to land - soil ingestion has the greatest potential of producing residues in animal products - Direct and indirect plant contamination.

Transfer of environmental contaminants

Heavy metals

Russel et al., 1984: soil ingestion and absorbtion of lead (Pb) and Cu in dairy cattle, fractional intake from soil by lead was 0.42 - 0.87, higher values with higher contamination, corresponding for copper was 0.30 - 0.10.

Abrahams & Thornton (1994) Major pathway of As is by soil ingestion.

Kadmium - taken up by plants - soil intake? geochemical mapping in Sweden

Radionuclides

Availability and transfer of radionuclides

Zach & Mayoh (1984). The relationship between plant/soil transfer coefficient of different elements and % soil ingestion of dry matter intake.

In vivo: Transfer of soil-Cs to milk and/or meat (Assimakopoulos et al., 1993; Belli et al., 1993; Hansen & Hove, 1991).

In vitro: Salbu et al. (1992) estimated availability by extraction and incubation experiments of vegetation. Soil ^{137}Cs availability in ruminants by extraction using rumen liquor (Cooke et al., 1995).

Belli et al. (1993) found very low transfer coefficients (soil to milk) in soils (clay content 11 and 16 %) contaminated with ^{137}Cs. Assimakopoulos et al. (1993) soil - milk transfer can be depentdent on soil composition.

Wilkins & Green (1988): Rather low transfer coefficients of ^{137}Cs due to intake associated with soil. Less than 8 % of caesium is found in other soil phases (water soluble, exchangable, carbonate, oxide and organic) than in the residual.

Experimental data on the availability of Cu and Mo + the interaction with S in soils and the inhibitory response of Fe on Cu uptake has been provided by Russel et al. (1984).

Raffety et al. (1994) Seasonal variation in th transfer of ^{137}Cs to grass.

In this connection, the ^{137}Cs-binding effects of the clays bentonite and zeolite (Andersson, 1989; Åhman et al., 1990)

Chemicals

Harrison et al. (1970) found DDT residues in sheep due to soil ingestion

Models of the transport of contaminants through agroecosystems

Kirchner & Whicker (1983/84): - PATHWAY - A dynamic model on radionuclide transport to food.

Nielsen (1994): A dynamic model fo the transfer of ^{137}Cs through the soil-grass-lamb-food chain

Other effects of soil ingestion

Health and nutrition:

Excessive toothwear in sheep was found to be correlated with soil ingestion (Millar et al., 1985). In herbage, Ca/P fell below one resluted in no change in plasma calcium and phosphorous levels. Copper (Cu) was low most of the time but physiological data, blood and liver Cu values were adequate at all times.

Sand deposition in the large intestines of horses can cause diaorrea (Ramey & Reinertson, 1984)

Molybdenum (Mo) is a constituent of xantine oxidase, a metalloflavo protein which plays an essential role in purine metabolism. Excessive amounts of Mo is toxic and it also hinders the uptake of copper. This may induce copper deficiency illness (hypocuprosis) even if adequate amounts of Cu is present in the herbage. Adding extra Cu to the diet restores the animals. Mo in high amounts can be obtained by soil ingestion. The geographical area distribution of Mo in United Kingdom can explain regional disorders in sheep which relates to trace-element imbalance (Thornton, 1974).

Phosphorous deficency symptoms have often be seen in tropical areas and has been suggested to be explained by ingestion of soil with high P-binding capacity. The utilisation of phosphorous (P) may be negatively affected by including soil with high P-binding capacity into the diet to sheep (Ammerman et al., 1984;). A Costa Rican soil had a greater effect on P utilisation in sheep than did sand or a Colombian soil. But when feeding a soil (from Florida) with a high P-binding capacity to lambs, P-utilisation was improved. Lambs appeared to be able to adapt to changes of dietary minerals in soil or redistribute body mineral pools. Garcia-Bojalil et al., 1988

Deposits on rumen epithelium of sheep due to ingestion of soil has been reported by Healy & Wilson (1971).

Ingestion of Al (soil) can alter Mg, Ca and P metabolism in lactating beef cows (Allen et al., 1986).

Grace & Healy (1974) studied the effect of soil ingestion on feacal losses and retention on Mg, Ca, P, K and Na. (soils increased the apparent absorbtion ant retention of Mg and Ca in the sheep)

It has been demonstrated that the clay bentonite added to the diet of dairy cows had adverse effects on their mineral balance (Ca, P, Mg) (Rindsig & Schultz, 1970).

Human soil ingestion:

Davis et al., (1990): Soil ingestion - population studies

Bashor & Turri (1986): Determining allowable concentration of mercury in soil

Calabrese & Stanek (1994): Soil ingestion issues and recommendations

Binder et al. (1986) Soil ingestion by young children

6 . Discussion

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