REPORT 1

RADIOCESIUM IN THE FOODCHAIN OF LAMB IN THE FAROE ISLANDS. RESULTS FROM THE RAD-3 AND EKO-2 PROGRAMMES.

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ABSTRACT

The paper summarizes the results from an eight-year investigation of transfer of radiocesium from soil to grass and further to lamb. The investigation is part of RAD-3 (1990-93) and EKO-2 (1994-97), being inter-Nordic radioecology projects under the Nordic Committee for Nuclear Safety research, NKS.

Nine uncultivated pastures have been selected for the Faroese part of the projects. The sample program involves lamb meat lamb, mixed grass and soil from the uppermost 10cm. Lamb faeces have been included since 1995.

The deposition of radiocesium is now around 5 kBq/m^2. About 60 Bq/kg(d.w.) is observed in mixed grass and around 12 Bq/kg(f.w.) in lamb meat. However, despite the limited geographical extent of the Faroe Islands, a significant variation is observed between pastures. Significant inter-annual variation is observed within the pastures as well.

Taking all stations together gives the following estimates of transfer in 1997: Grass/soil concentration ratio around 0.3, meat/soil concentration ratio around 0.05, and meat/grass concentration ratio around 0.5. The aggregated transfer factors are about $15 \cdot 10^{-3}$ m^2/kg and $2.5 \cdot 10^{-3}$ m^2/kg for grass/soil and meat/soil, respectively. These are low compared to other Nordic countries.

The meat/faeces and faeces/grass concentration ratios are found to be 0.20 ± 0.14 and 2.3 ± 2.0, respectively. These are comparable to results found in a feeding experiment.

The effective ecological half-life, $T_{1/2}$, of radiocesium in mixed grass and lamb meat is estimated, assuming an exponential decay model. Data from single pastures give $T_{1/2}$(grass) and $T_{1/2}$(meat) to be in the range 2.0-2.8y and 4.0-12.6y, respectively.

1. Introduction

Fairly high consumption of lamb meat in the Faroe Islands has been a motivation for making radioecology a field of priority at University of the Faroe Islands. The annual per capita consumption of lamb meat is 9.5 kg. There is an additional consumption of imported lamb meat (mainly from Iceland) of 9.6 kg per capita.

The Faroes have been contaminated by radioactive isotopes from the bomb tests in the 50'ies and 60'ies, and from the Chernobyl accident in 1986. Both sources can be registered. Results presented in this paper are from the Faroese part of the RAD-3 (1990-93) and EKO-2 (1994-97) programs under the Nordic Committee for Nuclear Safety Research, NKS.

2. Material and methods

For the eight-year period 1990-1997, soil and grass sampling took place every summer in nine uncultivated pastures in the Faroe Islands. Samples were taken from lamb at time of slaughter, typically in October. The sampling program includes faeces from lamb in the period 1995-97.

2.1 Soil

In the project period, some differences have been with respect to soil sampling technique. In 1990, two or three 1m^2 areas were randomly chosen in each pasture and divided into four 0.25m^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 the pastures Sandur and Sumba, samples were taken from four randomly chosen 0.25m^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. The participating laboratories agreed upon the latter technique in 1990 when only Sandur and Sumba remained to be sampled.

Four 0.25 m^2 microplots were randomly chosen in each pasture for soil and grass sampling in the years 1991-97. A corer with inner diameter of 5.7 cm and length of 10 cm was used for the sampling. The cores were divided into an upper and a lower 5 cm layer except for 1992, when they were split up into 1cm layers down to 5 cm depth and 2.5 cm layers further down to 10 cm depth.

Every core disc was measured in 1990 when typically three cores were taken from each 0.25 m^2 microplot. In other years, three cores were taken from the microplots, and measurement was carried out on mixed samples from each layer.

Soil samples were dried at room temperature before measurement. Some chemical analyses have been carried out on the soil.

2.2 Grass

The grass was cut from the 0.25 m^2 microplots before soil sampling. It was dried at 105°C before measurement, and the samples from each microplot were measured.

2.3 Lamb

The stock of sheep varied from one pasture to another, from 65 to 260. At slaughter, lamb meat (neck muscle) was collected according to an arrangement made with the farmers. Samples were taken from 30-40 lambs every year, typically in October when the lambs were about 6 months of age. The carcass weight was around 12-13 kg. Meat samples were used fresh for measurement, and samples have not been mixed.

2.4 Detector and software

The samples were measured using a lead shielded Germanium-detector, and the software OMNIGAM from EG&G Ortec was used for the spectral analyses.

2.5 Pasture data

Table 1 shows some data for the selected pastures. The pasture Funningur is only included in the RAD-3 project (1990-93). Pasture locations can be seen in Appendix H.

Table 1. The stock of sheep, area and approximate height above sea level of pastures. Local names are included.

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

2.6 Climate conditions

Local phenomena may affect the climate conditions in the pastures. There are no weather stations close to the pastures, but the tables below with data from the

Faroese capital, Tórshavn, may indicate the inter-annual variation in precipitation and temperature.

Table 2.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	1996	1997	1961-81
330	340	393	286	376	262	438	465	426

Table 3. 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	1996	1997	1961-88
9.9	10.2	9.8	8.3	8.8	9.1	9.4	9.6	9.2

3. Results

3.1 Chemical analyses of the soil

Chemical analyses of the top 10cm of the soil show pH to be generally less than 5.3. The observed ignition loss is typically in the range 50-70 %. The content of potassium is mostly in the range 300-600 mg/kg, but values around 1000 mg/kg are also observed. The concentration of sodium is similar to potassium, but higher values are observed in the southern end of the country, particularly in Hvalba where the content of sodium exceeds 1400 mg/kg.

3.2 Radiocesium in soil

Soil sampling took place every year in July except for 1990, when it was carried out in August. In the top 10 cm, typically 50-80 % of the radiocesium deposition is found to be in the uppermost 5 cm, with practically the same relative distribution every year.

There is a lot of inter-annual scattering in the data, and it is obviously not possible to make any simple exponential curve fitting, although a decreasing trend is observed for some pastures. A discernible geographical variation may be noticed, but no simple geographic correlation is found when the time variation is compared between pastures.

Estimates of deposition and concentration of radiocesium in soil for the country as a whole can be found in Figs. 1 and 2 (all samples are considered as one pool).

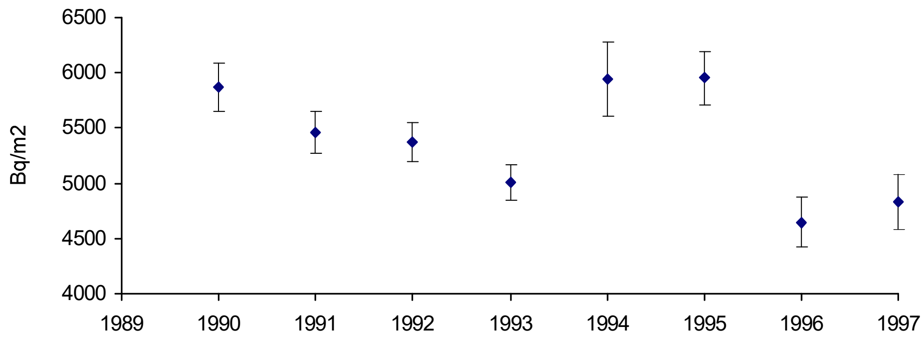

Figure 1. Radiocesium deposition in the 0-10 cm soil layer. Annual average ± 1 standard error.

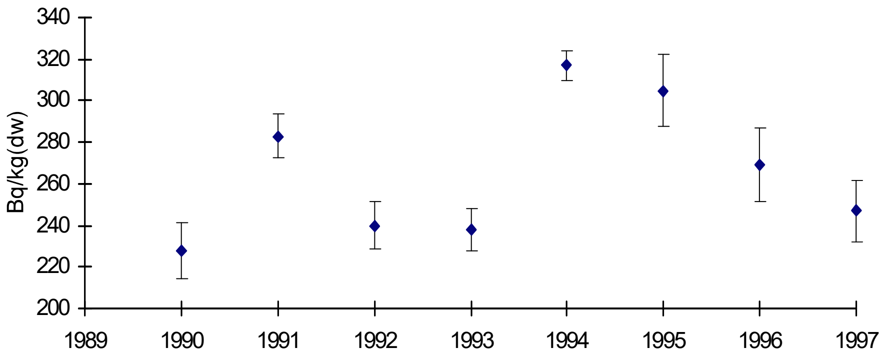

Figure 2. Radiocesium concentration in the 0-10 cm soil layer. Annual average ± 1 standard error.

The $^{134}Cs/^{137}Cs$ ratio in the soil - documenting contamination from Chernobyl - is presented in Table 4 (-no data for Skáli and Sandur in 1991). ^{134}Cs is not detected in 1990 or after 1995.

Table 4. The $^{134}Cs/^{137}Cs$ ratio in the 0-5 cm soil layer. (No data in 1990 and after 1995. N = number of samples). N.D. = Not Detected

	Bøur	Velbastað	Hvalvík	Skáli	Funning	Norðoyri	Sandur	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

3.3 Mixed grass

The concentration of ^{137}Cs (Bq/kg(d.w.)) in grass is presented in Figure 3, pooled for all the pastures. Hvalvík in the northern part of the Faroes has generally higher values than other pastures, while the lowest level is found in Hvalba in the southern end of the country. A decreasing trend is observed for some pastures, while others show an even increasing trend for the last 3 years of the project period.

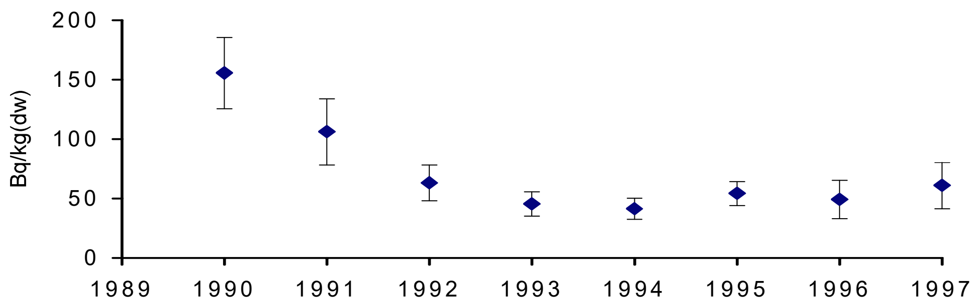

Figure 3. Radiocesium in mixed grass. Annual average ± 1 standard error.

Putting all the data into one pool shows a decrease from 1990 to 1994 followed by a level around 50-60 Bq/kg(d.w.).

The $^{134}Cs/^{137}Cs$ ratio found in 1990 and 1991 is presented in Table 5. ^{134}Cs was not detected in 1992, and in 1993 it was only observed in a sample from Hvalvík, having a $^{134}Cs/^{137}Cs$ ratio of 0.051. ^{134}Cs has not been detected in grass samples since 1993.

Table 5. 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

3.4 Lamb

In the eight-year project period, samples have been taken from 30-40 lambs every year. The time of slaughter is from late September to early November. The radiocesium concentration (Bq/kg(f.w.)) in the pastures and the country as a whole is shown in Fig. 4. The results are based on single lamb measurements.

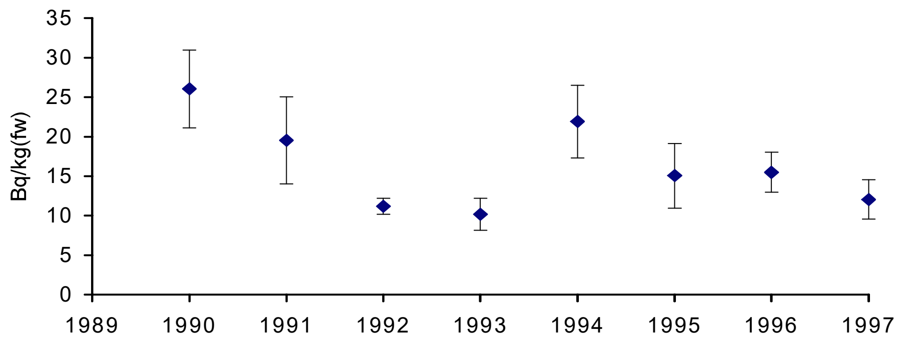

Figure 4. Radiocesium in lamb meat. Annual average ± 1 standard error.

The average $^{134}Cs/^{137}Cs$ ratio in meat, based on single lamb measurements, was 0.117 in 1990 and 0.067 in 1991. The ^{134}Cs isotope could be detected in only 5 lamb samples in 1992 (all from different pastures), giving the mean value 0.065.

4. Concentration ratios and transfer factors

All the results are for radiocesium. The observed concentration ratios are presented in Figs.5-9. The results are arithmetic means of data for the pastures together with minimum and maximum observed ratios.

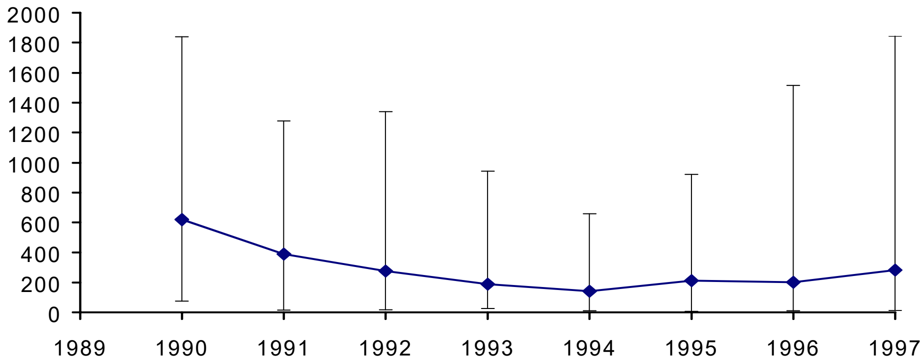

*Figure 5. Grass/soil concentration ratio*1000. Mean, min and max..*

For each 0.25m^2 microplot, grass/soil concentration ratio has been calculated from the concentration (Bq/kg(d.w)) in the 0-10cm soil layer and the concentration in grass. An estimate for the pasture is obtained by averaging these data, and an estimate for the country is obtained by averaging the results for the pastures.

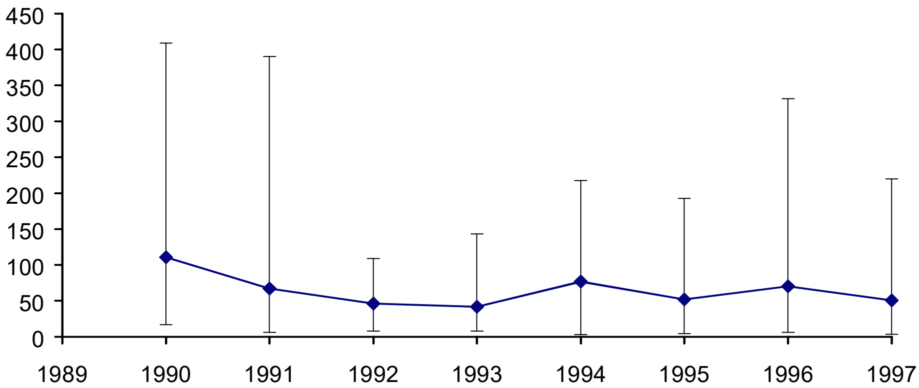

Figure 6. Meat*/soil concentration ratio*1000. Mean, min and max.*

The ratio between the concentration in each lamb and the mean concentration in the 0-10 cm soil layer is calculated for every pasture. This gives an indication of the variation with respect to animal. Averaging these ratios gives an estimate of the meat/soil concentration ratio for the particular pasture. An estimate for the whole country is obtained by averaging the pasture results.

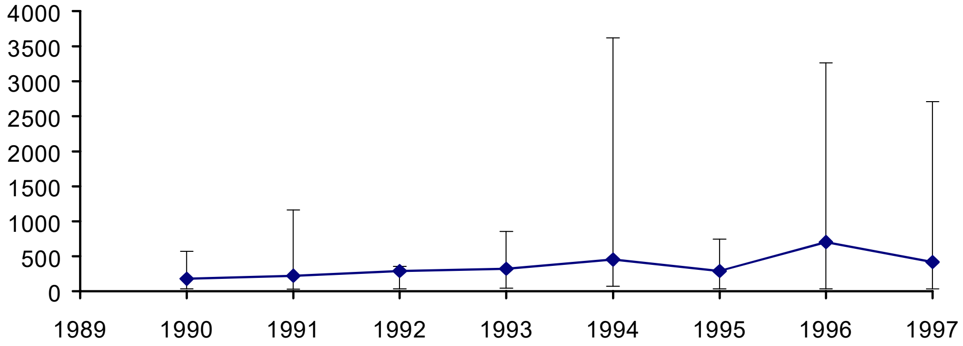

*Figure 7. Meat/grass concentration ratio*1000. Mean, min and max.*

The meat/grass concentration ratio is calculated for each pasture from single-lamb data and average values for concentration in grass. The ratio for the whole country is found as the arithmetic mean of pasture results.

The observed soil-to-grass (m^2/kg(d.w.)) and soil-to-meat transfer factors (m^2/kg(f.w.)) have been calculated in the same way as the concentration ratios, using the deposition (Bq/m^2) in the 0-10cm soil layer.

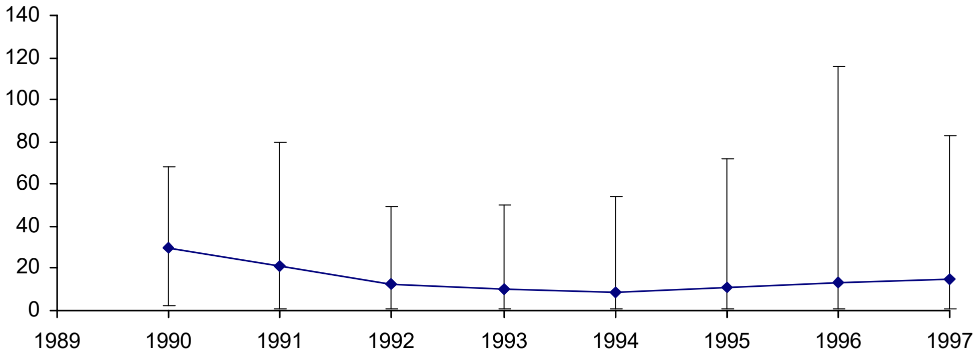

*Figure 8. Grass/soil aggregated transfer factor (m^2/kg)*1000. Mean, min and max..*

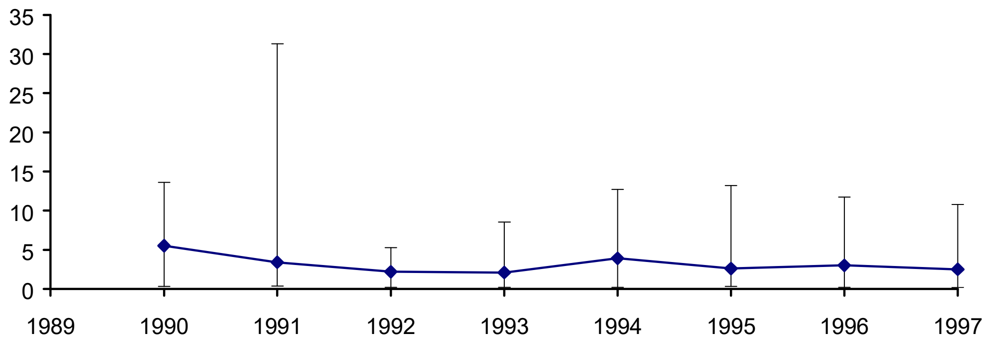

*Figure 9. Meat/soil aggregated transfer factor (m^2/kg)*1000. Mean, min and max*

5. Half-life

Doing a linear regression analysis between time and the logarithm of radiocesium in grass and in lamb meat gives the results in Table 6. It has not been possible to distinguish between the half-life of Chernobyl- and fallout-cesium, since ^{134}Cs content is mainly below the detection limit.

Table 6. Effective ecological half-lives (years) assuming exponential decay. R^2 from the linear regression between time and natural logarithm of activity is shown in parenthesis. No data if $R^2<0.3$.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
Grass 1990-97	- (0.008)	2.1 (0.559)	- (0.297)	- (0.055)	- (0.168)	2.0 (0.597)	- (0.198)	2.8 (0.651)
Meat 1990-97	12.6 (0.425)	7.8 (0.386)	- (0.053)	- (0.032)	- (0.193)	- (0.047)	6.9 (0.847)	4.0 (0.513)

Using annual mean values for the *whole country* and doing a semi-logarithmic fit between time and radiocesium in grass gives the half-life $T_{1/2}$(grass)= 5.3 years (R^2=0.508). Using the same procedure for meat gives R^2=0.168, which is too poor for estimating half-life.

Fig.4 shows that the level of radiocesium in meat is shifted from 1993 to 1994. Doing the same semi-logarithmic fit for the sub-periods 1990-93 and 1994-97 gives $T_{1/2}$(meat)= 2.1y (R^2=0.940) and $T_{1/2}$(meat)= 4.0y (R^2=0.853), respectively. For grass we obtain $T_{1/2}$(grass)= 1.6y (R^2=0.993) for the years 1990-93, while no decreasing trend is observed for 1994-97 (see Fig.3).

The results indicate that the decay model is more complicated than simple exponential.

6. Faeces as an indicator of sampling representability

The most obvious problem in transfer factor calculations is to estimate the activity of the vegetation the sheep have actually eaten. Concentration of ^{137}Cs in faeces can in steady state conditions be used to estimate the concentration in the feed. ^{137}Cs in faeces is not just a left-over from ingested ^{137}Cs, since sheep excrete around 2/3 of ^{137}Cs excreted into the intestines (refs. 8, 12, 13, 15). Table 7 shows ^{137}Cs concentrations in faeces 1995 –1997 from Faroese sampling stations. Annual variation in ^{137}Cs-concentration in faeces is less than in vegetation.

Table 7. Cs-137 (Bq/kg(d.w) in lamb faeces from Faroese pastures 1995-97.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
1995	32.6	59.2	61.5	120.9	98.2	111.0	23.2	69.0
1996	30.1	29.3	64.0	117.6	55.6	76.6	18.4	65.3
1997	49.2	32.8	125.7	113.7	37.2	56.6	18.5	55.3

The average meat/faeces concentration ratio based on data in Table 5.2 is 0.20 ± 0.14 (stdev). This ratio is generally more constant than the corresponding meat/grass ratio. From a feeding experiment the value 0.24 should be expected for the ratio (see section below, Table 9). From the data in Table 8 it seems likely that the lamb samples from Hvalvík are non-representative.

Table 8. Meat/faeces ^{137}Cs-concentration ratio in Faroese pastures 1995-97.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
1995	0.19	0.04	0.58	0.27	0.20	0.14	0.09	0.09
1996	0.26	0.06	0.58	0.38	0.13	0.26	0.11	0.05
1997	0.09	0.12	0.26	0.21	0.19	0.22	0.10	0.16

Table 9 shows faeces/grass concentration ratios for the sampling stations. Five of the eight stations have ratios consistently around the expected value of 2.8 ± 1.0 (see section below Table 9). Two stations, Hvalvík (which also had an unusually high meat/faeces ratio) and Bøur had ratios less than half the others. Sandur had a ratio more than double of what should be expected. The average and standard deviation of the data in Table 9 is 2.3 ± 2.1. Excluding Bøur, Hvalvík and Sandur we obtain 2.0 ± 0.9. From the data in Table 5.3, ^{137}Cs- concentration in feed may probably be overestimated in Hvalvík and Bøur, and underestimated in Sandur.

Table 9. Faeces/grass ^{137}Cs-concentration ratio in Faroese pastures 1995-97.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
1995	1,43	2,32	0,38	1,53	1,54	4,89	1,56	1,68
1996	0,37	3,66	0,40	2,44	1,23	8,06	1,28	2,41
1997	0,66	1,59	0,64	1,17	0,54	7,45	3,25	3,43

A feeding experiment was carried out in order to get some insight into connections between faeces and feed concentrations. Twin male lambs were moved from a meadow with a known ^{137}Cs- activity in grass to another with about 1/3 of the concentration of the former. Two weeks later the lambs were moved to a stable and fed grass from the second field. Amount of feed, faeces and their ^{137}Cs-activity were measured. Digestibility in this period ranged from 70 to 84%, with a mean of 82%. The first fortnight, faeces/grass ^{137}Cs- concentration ratios ranged from 4.5 to 9.5. In this period the lambs excreted more ^{137}Cs through their faeces than they ingested. In the following 3 weeks concentration ratios dropped rapidly to 2.8 ± 1.0. Therefore, the faeces/grass concentration ratio is expected to be around this value under steady state conditions.

Meat/faeces ^{137}Cs- concentration ratio in the feeding experiment was 0.24. Only faeces concentrations from the steady state period were used in the calculation. Standard deviation for concentration in faeces in this period was around 30%.

7. Discussion

The paper summarizes the results from the Faroese part of the RAD-3 and EKO-2 projects. The RAD-3 program involved 9 uncultivated pastures, one of which had to be abandoned for practical reasons in the EKO-2 program.

Chemical soil parameters have been measured in addition to radiocesium. 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 typically in the range 300-600 mg/kg.

The ratio between the deposition in the uppermost 5cm of the soil and in the 0-10 cm soil layer has a range from 0.5 to 0.8 every year. The highest Cs-134/Cs-137 ratios were found in the southern part of the country.

Physical data for the pastures are presented in Table 1. In most cases it was manageable to find the same spots for soil and grass sampling every year, although no fencing was done for the project, mainly because the same people took the samples every year. However, it was necessary to move the sample-taking site in Velbastað about 3km for the years 1994-97 because of cattle grazing, and this change may be an explaining factor for the increasing trend in observed deposition in

Velbastað these years. Such changes have not occurred in other pastures, and it seems difficult to give a satisfactory explanation of the inter-annual variation of radiocesium in soil. The main reason may possibly be related to differences in soil characteristics, but this has not been analysed as yet.

Considering all radiocesium soil data as one pool show unexpected high deposition levels (Bq/m^2) in 1994 and 1995 (Fig.2). A decreasing trend is observed for concentration (Bq/kg) for the years 1994-1997, while more scattering and lower values are observed for 1990-93. There seems to be a shift to higher levels in both deposition and concentration from 1993 to 1994.

The radiocesium content in lamb meat presented in Fig.4 for the whole country do also shift to higher levels from 1993 to 1994. The rise comes mainly from Hvalvík, Skáli, Norðoyri and Sandur. It is well-known that Hvalvík and Norðoyri are places with quite high precipitation rates. A tempting explanation for the shift in content of radiocesium in soil and lamb meat would be that an extra input of ^{137}Cs should have entered the Faroes, but no source for it has been revealed to our knowledge.

For the country as a whole the radiocesium content in grass decreases from 1990 to 1993, where upon it comes to a level around 50-60 Bq/kg(d.w). However, this trend is not observed for all pastures, as an increasing trend in Hvalvík, Skáli, Norðoyri and Bøur can be observed for the years 1994-97.
Radiocesium in grass is observed to vary a lot from one 0.25 m^2 microplot to another. This confirms the difficulty of taking representative samples, but may also reflect difference in botanical composition on the microplots.

The results of a correlation analysis are presented in Table 10. Annual mean values are used for the pastures. Correlating radiocesium in meat and grass for 1990-97 give positive correlation in all pastures, with the highest coefficient for Sumba (0.908) and the lowest for Bøur (0.261). Making the correlation for the years 1994-97 gives lower correlation, and it is found to be negative for Hvalvík, Skáli and Sandur, indicating non-representative sample taking. However, such a correlation analyses is not satisfactory in deciding whether or not the sample taking has been representative.

Table 10. Correlation coefficients for radiocesium in meat (Bq/kg(f.w.)) and grass (Bq/kg(d.w.)) calculated for 1990-97 and 1994-97.

	Bøur	Velbastað	Hvalvík	Skáli	Norðoyri	Sandur	Hvalba	Sumba
Meat & Grass 1990-97	0.261	0.834	0.594	0.296	0.391	0.756	0.471	0.908
Meat & Grass 1994-97	0.252	0.462	-0.934	-0.863	-0.026	-0.273	0.157	-0.023

Faeces have been sampled simultaneously with grass and soil sampling in the years 1995-97. For the years 1995-97 the average (± 1 standard deviation) for the meat/faeces concentration ratio is found be 0.20 ± 0.14, while the analogue faeces/grass concentration ratio is 2.3 ± 2.0. Excluding extreme values for three of the pastures (Bøur, Hvalvík and Sandur) result in a faeces/grass concentration ratio of 2.0 ± 0.9. From a feeding experiment the meat/faeces concentration ratio is estimated to 0.24 ± 0.07, while the faeces/grass concentration ratio was found to be 2.8 ± 1.0. The sampling must therefore be considered as representative for most pastures.

The observed concentration ratios and aggregated transfer factors (m^2/kg) vary significantly both geographically and within the pastures. For the country as a whole the average grass/soil and meat/soil concentration ratios tend to decrease from 1990 to 1994 and from 1990 to 1993, respectively. After this they tend to be a bit higher (Figs.1 and 2), slightly increasing in the first case and having a decreasing trend in the second case. The meat/grass concentration ratio tends to increase slightly from 1990 to 1994, while it is more scattering after 1994. The average ratio between the concentration (Bq/kg) of radiocesium 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 (not discussed in the paper) with two male twin lamb confirmed the observed meat/grass ratios.
The aggregated transfer factor from soil to meat for the country as a whole has a decreasing trend from 1990 to 1993. After 1993 it shifts to a bit higher value, slightly decreasing until 1997 (Fig.5). The observed meat/soil transfer factor is observed to be lower than in Norway by a factor of 15-20.

The aggregated transfer factor from soil to grass for the country as whole decreases from 1990 to a minimum in 1994 followed by a slightly increasing trend until 1997 (Fig.5). It is observed to be a factor 3-10 lower than in Norway.

The variation with respect to animal is found to be high for both meat/soil concentration ratio and meat/soil aggregated transfer factor (Figs.5 and 6), as well as for meat/grass concentration ratio (Fig.4).

The effective ecological half-life, $T_{1/2}$, has been estimated on the assumption of simple exponential decay with time. However, data from most pastures do not fit to this model (Table 7). For grass, $T_{1/2}$ is found to be 2.0-2.8 y for the pastures and 5.3 y when data from all pastures are considered as one pool. For lamb meat, $T_{1/2}$ is between 4.0 y and 12.6 y for single-pastures, but the exponential decay model does not fit to the data when all pastures are considered as one pool. The decay model seems therefore to be more complicated than simple exponential.

8. Acknowledgements

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9. References

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