TRANSFER OF RADIOCAESIUM FROM SOIL TO VEGETATION AND TO GRAZING LAMBS IN A MOUNTAIN AREA IN NORTHERN SWEDEN

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INTRODUCTION

In the northern Arctic and boreal regions many radioecological problems appear in the terrestrial environment. The climate and the soil, and as a consequence also the vegetation types, favour a high transfer of radionuclides to the food chain. Consequently there is a risk for high transfer to domestic animals grazing in these environments. As most of the lamb production in the Nordic countries is carried out on permanent pasture and in semi-natural environments the radioecological and economic effects are evident.

This investigation was initiated and supported by the Nordic Nuclear Safety Research Programme (NKS), working group RAD-3, as a part of an inter Nordic research programme. All the Nordic countries, i.e. Denmark, the Faroe Islands, Finland, Iceland, Norway and Sweden, have participated in the project. The sampling technique for soil, herbage and lamb was to be the same in all countries, in areas where no counter-measures had been applied after the Chernobyl fallout. The main results of these common Nordic studies will be summarized by Hove et al., 1994. The Swedish part of the study has also been financially supported by the Swedish Radiation Protection Institute in Stockholm.

The purpose was to study the transfer of radiocaesium from soil to plants and further to lamb meat in natural or semi-natural areas over the years.

This paper is an extended summary of a work (Rosén et al., 1994) to be published in Journal of Environmental Radioactivity. In the present report only results of soil and transfer from soil to vegtation and lambs are given.

MATERIALS AND METHODS

Description of the farm and the sampling area

The study was carried out in the grazing seasons in 1990-1993 on the mountain farm Blomhöjden, situated at 64.4° N latitude and 14.4° E longitude in the northern part of the county of Jämtland in Sweden. The farm is situated at an altitude of about 600 m and is surrounded by mountain ridges of up to 1200 m altitude above sea level.
The yearly mean for temperature and precipitation during the growing periods, June to September, in 1990-1993 had a range of 8.9-10.7 °C and 315-405 mm respectively (SMHI, 1993). The temperature at Blomhöjden is, due to its altitude supposed to be somewhat lower than those observed at the climate stations. The mean yearly temperature and precipitation (1961-1990) in the area were 1.4 °C and 750 mm, respectively (Alexandersson et al., 1991).

The infields of the farm are almost exclusively permanent grassland for hay production and pasture. The domestic animal stock consists of a number of dairy cows for milk and beef production, together with about 15 ewes and about 10 goats. The grazing area utilised by the sheep flock totals about 10 km^2, including permanent grassland close to the farm, mountain pastures, and the slopes and the top of a mountain ridge called Jemesvarto.

The area where Blomhöjden is situated was hit by the Chernobyl fallout in May 1986. The ground deposition, as determined by inflight measurements from May to October in 1986, was estimated to be in the range of 10 to 30 kBq ^{137}Cs per m^2 (SGAB, 1986). A minor part of ^{137}Cs originates from the world-wide fallout from nuclear weapon tests, about 2.8 kBq per m^2 through 1982 in northern Sweden (United Nations, 1982).

Vegetation and soil were sampled in the last week of August every year at five localities, each representing about 1000-5000 m^2 of the grazing area. Within each locality, representative sampling sites of about 100 m^2 were selected for the soil and herbage sampling.

The vegetation types, altitude above sea level, and the sampling area in the different localities on the mountain of Jemesvarto, were:

1. Moor on the top of the mountain at an altitude of 770 m and with an area of about 2500 m^2
2. 2a, *Betula* forest and 2b, *Carex* bog located on the slope of the mountain at an altitude of 700 m and with an area of about 1500 m^2
3. Thin *Betula* forest on ground with seepage water on slopes of the mountain at an altitude of 620 m and with an area of about 1000 m^2
4. 4a, permanent grassland, 4b, moorland and grassland and 4c, moorland, at an altitude of 580 m and with an area of about 5000 m^2
5. Forest vegetation at an altitude of 570 m and with an area of about 1500 m^2

On each site, the herbage was sampled on four microplots, each of 0.25 m^2, distributed at random within the area. The herbage was cut at a stubble height of about 2 cm and quantitatively put together to a bulk sample, thus representing the yield of 1 m^2. In addition to the bulk sampling of herbage, the most frequent single plant species (altogether 17) were collected. When possible the same species were collected at all localities. A bulk sample of each species, leaves or annual shoots, was collected within the whole area of each locality.

The soil was sampled by taking three or four cores, 57 mm in diameter, to a nominal depth of 10 cm in each microplot and pooled to a bulk sample for the sampling site. The soil cores were cut in two pieces, before being pooled and bulked to represent the 0-5 cm and 5-10 cm layers, respectively.

Description of the soil

The dominating natural soil type in the grazing area is a slightly podsolized gravely and sandy moraine, formed by the Caledonian metamorphic rocks (Seveschists and amphibolites and others) (Eklund, 1953).

Mean data for a number of soil parameters for all the sampling sites were; for loss on ignition 10.0 %, pH_{H_2O} 4.6, the labile fraction of calcium and potasium 9.7 and 4.5 mg per 100 g soil. The results show that the main part of the labile fractions of potassium and other macro elements seem to be associated with the content of organic matter of the soil. Generally most of the soil factors favour a high transfer of radiocaesium from soil to vegetation.

Description of the animals

The animals studied included 13 lambs (1990), 1 lamb (1991), 6 lambs (1992) and 7 lambs (1993) of mixed breeds. The lambs grazed freely on the pastures described above during the period from mid-June until slaughter, when they were 5-8 months old. Their mean carcass weights were 22, 18, 18 and 16 kg in the mentioned years.
Live monitoring of the lambs was done in 1990 and 1993, 2 days and one week before slaughter, respectively. The measurements were made on the backs of the lambs by means of using a portable gamma detector with a NaI-crystal. The relationship between the ^{137}Cs concentration according to live monitoring and the subsequently recorded concentration in carcass meat sample was calculated. (The result of live monitoring are not presented in this summary).
Muscle samples were taken in all years immediately after slaughter of the lambs from the abdomen wall of the carcass (*M. obliquus abdominis externus* and *M. obliquus abdominis internus*) used for the official activity control. The meat samples were analysed for ^{137}Cs by means of a germanium detector or a NaI-detector. All activity concentrations refer to wet weight (w.w.) of the muscle samples.
In 1990 samples were also taken from the neck part of each carcass. The samples were cut at the level of atlas and backwards, mainly ventrally (*M. sterno-cephalicus* and *M. intertransversarius longus*, the former consisting of *M. sterno-mandibularis* and *M. sterno-mastoideus*).

RESULTS AND DISCUSSION

Deposition and distribution of radiocaesium in the soil

The fallout in the region was relatively homogeneously distributed between the sampling sites as well as between years within the grazing area. Yearly mean range for ^{137}Cs was 14.07-17.62 kBq per m^2 (data corrected for decay to August 1990). There were no statistically significant differences ($p>0.05$) between the sites and the years. The results agree well with the ground deposition, as determined by inflight measurements (SGAB, 1986).

The relative caesium distributions in 0-5 cm and 5-10 cm cores are described in mean per cent in the different layers was nearly the same in each year. In the surface soil layer of 0-5 cm, the range was 87.4 - 89.5 % and in the 5-10 cm layer it was 10.2 - 12.6 %. There were no statistically significant differences ($p>0.05$) between years as to activity levels in the 0-5 cm soil layers. This shows that the main part of caesium can still be found in the upper layer of the soil 7 years after the deposition.

The ratios of ^{134}Cs/^{137}Cs in the Chernobyl reactor core have been estimated to be 0.673 (Gudiksen et al., 1989), while the corresponding ratio in the released fractions has been found to be 0.539 (Aarkrog, 1988; Gudiksen et al., 1989). The mean 4-year ratios of ^{134}Cs/^{137}Cs in the upper layer 0-5 cm and in the lower layer 5-10 cm, of the soil of Blomhöjden were almost the same, 0.523 and 0.521, respectively. All data were corrected for decay to 1 May 1986.

Transfer of ^{137}Cs from soil to plant and to single plant species

The transfer factors, TF_g, stands for the caesium concentration in the plant, Bq per kg (d.w.), related to the total ground deposition, Bq per m^2 (IAEA, 1987). TF_g and and the percentage of the deposition recovered in the cut herbage are given in Table 1. The transfer factors varied within the range of 0.012 - 0.192 m^2/kg, or by a factor of about 16. The removal of ^{137}Cs with the harvested herbage varied between 0.21 and 2.79 per cent of that deposited and with a mean for all years of 0.86 per cent. This high variation between sites should be due to the influences on the caesium uptake by the varying composition by the soils and of the plant community. The fraction of caesium recovered in the herbage depended also on the observed mean yield level, which increased somewhat during the mentioned period.

The highest transfer of ^{137}Cs from soil to plant was found at sites 4a and 4b, the permanent grassland (mean 0.150 and 0.059 m^2/kg), where the TF_g was about twice as high as at sites 1, 3 and 5. The high value at site 4a can not be fully explained by the soil data available. However, the grassland at this site was fairly well grazed in 1990 and 1991, and thus the grass sampled was mainly new grass with probably higher mineral content and higher concentration of ^{137}Cs than at the other sites with older grass and herbs "diluted" by growth. Relatively low TF_g-values were recorded at sites 2a and 4c. The mean value for all sites, however, is supposed to be representative for the whole grazing area. From 1990 to 1993 the mean transfer decreased from 0.074 to 0.057 m^2/kg (Table 1), indicating that 4-7 years after the Chernobyl fallout there is still an obvious reduction with time in caesium transfer to the herbage. Analysis of variance with a two-way classification, site and year, on logarithmized data showed significant differences of $p<0.05$ and $p<0.05$, respectively.

Table 1. Transfer of ^{137}Cs from soil to plant in 1990 - 1993, TF_g, $m^2\ kg^{-1} \times 10^{-3}$, calculated by relating activity concentration data in single years to the average deposition at the respective site. Per cent of the ^{137}Cs deposited in the soil taken up in the cut herbage. All data corrected for decay to August, 1990

Site	$TF_g \times 10^{-3}$					Per cent uptake of ^{137}Cs of soil dep.				
No.	1990	1991	1992	1993	Mean	1990	1991	1992	1993	Mean
1	82.7	81.5	46.0	42.3	63.1	0.76	1.41	0.87	0.92	0.99
2a	25.3	37.7	32.3	12.4	29.9	0.32	0.57	0.48	0.21	0.40
2b	105.2	89.3	71.0	93.3	89.7	0.92	0.89	0.76	0.59	0.79
3	75.4	54.0	43.5	53.4	56.6	0.61	0.76	0.62	0.96	0.81
4a	163.3	127.6	192.2	115.6	149.7	1.01	0.99	2.79	2.28	1.76
4b	65.3	63.3	62.0	58.7	58.7	1.12	0.57	1.00	0.96	0.91
4c	37.5	60.8	34.3	29.8	40.6	0.64	0.62	0.51	0.65	0.61
5	39.7	64.3	36.2	52.0	48.0	0.47	0.80	0.46	0.85	0.65
Mean	74.3	72.3	64.7	57.2	67.1	0.77	0.82	0.94	0.99	0.86
SD	44.7	27.4	53.3	33.2	38.1	0.28	0.28	0.77	0.60	0.41

The transfer factors, TF_g, from soil to individual plant species at the different sampling localities are given in Table 2. The mean TF_g values for the whole 4-year period are 0.077 m^2/kg for grasses 0.065 m^2/kg for herbs and 0.028 m^2/kg for woody plants and trees.

By comparing the transfer average values in 1990-1993 for all single plant species of herbage with the transfer average value for the herbage data, a good accordance was found, 0.065 m^2/kg versus 0.067 m^2/kg.

Table 2. Average transfer of ^{137}Cs from soil to sampled plant species, TF_g, $m^2\ kg^{-1}$ 10^{-3}, at different sites. Ecological half-time in years, T_{ec}. Data corrected for decay to August 1990

Plant species	Sampled at site No.	TF_g, x 10^{-3}, average 1990	1991	1992	1993	Mean	T_{ec} 1990-93
Grasses							
Molinia caerulea	2	208.6	167.0	119.5	112.0	151.8	3.2
Carex spp	2	134.8	110.0	94.9	119.7	114.9	13.8
Poa sp	3	85.4	72.2	41.2	-	66.3	1.9
Descampsia caespitosa	1-4	55.8	38.7	68.0	64.7	56.8	(long)
Descampsia flexuosa	1-5	44.6	51.3	59.5	40.1	48.9	(long)
Nardus stricta	4, 5	36.8	34.2	46.4	54.9	43.1	(long)
Agrostis capillaris	4	19.7	40.1	102.9	-	54.2	(long)
Herbs							
Rumex acetosa	1-4	168.1	132.6	86.3	78.8	116.0	2.5
Cornus suecica	1, 4	93.2	110.4	74.3	63.2	85.3	4.4
Solidago virgaurea	1, 2, 5	92.5	69.8	53.0	72.0	71.8	6.8
Filipendula ulmaria	3	51.4	53.8	38.9	38.8	45.7	6.0
Cirsium helenioides	1	3.0	10.5	5.5	0.8	4.0	1.5
Woody plants, shrubs and trees							
Vaccinium myrtillius	1-5	55.2	34.9	34.9	31.9	39.2	4.2
Empetrum nigrum	1, 4	28.6	26.7	24.3	21.4	25.2	7.2
Betula tortuosa	1-5	28.4	22.0	20.2	20.5	22.9	6.5
Salix spp	1-5	27.1	37.5	57.0	34.5	39.0	(long)
Betula nana	1, 3, 4	14.6	21.4	14.5	9.8	15.1	4.3

Transfer of ^{137}Cs from plant and soil to lamb muscle

The ^{137}Cs concentration in muscle samples of abdomen wall related to that in the plant ($TF_{plant \rightarrow muscle}$, Bq/kg w.w. per Bq/kg d.w.) was 0.93, 0.61, 0.56 and 0.71 in the different years, respectively (Table 3, which also summarizes all the main results of the study). The lower values after 1990 indicate a somewhat decreased and possibly stable level of activity transfer from the plants to lamb meat.

Supposing that steady-state conditions were prevailing, an activity transfer coefficient for ^{137}Cs from plant to muscle ($TC_{plant \rightarrow muscle}$, day per kg) can be given. At a daily intake of herbage of 1.0 kg dry matter per lamb, the $TC_{plant \rightarrow muscle}$ values were thus 0.93, 0.61, 0.56 and 0.71 in the different years. If dry matter intake was supposed to be somewhat higher, 1.4 kg, (value based on results of an experiment with lambs in Sweden, see Andersson, 1989), corresponding transfer coefficients were calculated to be 0.66, 0.43, 0.40 and 0.51 (Table 3). These values are higher than the value of 0.24 which was demonstrated in the experiment by Andersson (1989), which was performed in 1986 with lambs fed with hay contaminated by radiocaesium from the Chernobyl fallout. The present values are, however, of the same order of magnitude as that given by Howard et al. (1987), i.e. 0.79 for lambs grazing in high mountain areas.

Calculated values of the transfer of ^{137}Cs from soil to lamb muscle (aggregated transfer factor, T_{ag}, Bq/kg w.w. per kBq/m^2) were 61.9, 47.0, 32.3 and 45.5 in the different years, respectively (Table 3). Similar values were reported from studies in Norway with lambs grazing on a natural pasture in the same 4-year period (Hove et al., 1994).

Table 3. Transfer of ^{137}Cs from plant and soil to abdomen wall muscle of the lambs. Given mean values of ^{137}Cs concentrations are corrected to soil and herbage sampling date in August 1990.

	Year			
	1990	1991	1992	1993
^{137}Cs concentration in				
Soil, kBq/m^2	17.62	14.56	16.66	14.07
Herbage, Bq/kg d.w.	1175	1125	960	900
Muscle, Bq/kg w.w.	1090	684	538	640
Transfer factors (TF)				
$TF_g = TF_{soil \rightarrow plant}$				
Bq/kg d.w. plant per kBq/m^2 soil	74.3	72.3	64.7	57.2
$TF_{plant \rightarrow muscle}$				
Bq/kg w.w. muscle per Bq/kg d.w. plant	0.93	0.61	0.56	0.71
$T_{ag} = TF_{soil \rightarrow muscle}$				
Bq/kg w.w. muscle per kBq/m^2 soil	61.9	47.0	32.3	45.5
Transfer coefficient (TC)				
$TC = TC_{plant \rightarrow muscle}$				
Bq/kg w.w. muscle per Bq intake/day at:				
1.0 kg d.w. daily plant intake	0.93	0.61	0.56	0.71
1.4 kg d.w. daily plant intake	0.66	0.43	0.40	0.51

CONCLUSIONS

This study demonstrates the relationship between radiocaesium deposition in soil and the activity transfer to pasture in a natural or semi-natural ecosystem. Factors that may influence the transfer are described. The study also demonstrates which level of radiocaesium that can be expected in lambs grazing in the mountain area when no counter-measures are taken. Table 3 summarizes all the main results of the study.

The results indicate that agriculture, especially animal production, based on the utilization of the natural and semi-natural environment, is very sensitive in a fallout situation. Problems may persist for many years and counter-measures have to be taken for a long time in order to provide acceptable levels of radiocaesium in animal products for human consumption. Otherwise diet recommendations should be given.

Dose contributions via lamb meat in the diet of people living on the farm can be calculated to 0.07 mSv per year. This value is based on an assumed annual consumption of 7 kg lamb meat with a 4-year mean ^{137}Cs concentration of 716 Bq/kg and a dose factor of 14 nSv/Bq. In addition, the consumption of other animal products (milk and milk products from cows and goats, and beef) produced on the farm, as well as fish, game, fungi and berries from the surrounding area, contribute to a total annual internal dose that probably exceeds the Swedish maximum recommended level of 5 mSv during one year or 1 mSv during each of several years.

This study is going to continue during another four years, 1994-1997 in the research project NKS, EKO-2, in order to demonstrate possible changes in the radiocaesium transfer over a longer period and to give reasonably significant values of ecological half-time of ^{137}Cs in the chain from the soil, through grass, to lamb meat.

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