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Distribution of ^{137}Cs in a Low Arctic Ecosystem in West Greenland

MORTEN STRANDBERG[1]

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ABSTRACT. During the summer of 1992, sampling of soil and vegetation was carried out at five localities in West Greenland to investigate the distribution of ^{137}Cs in soil and in some reindeer fodder plants. Depending on the locality, between 69% and 97% of the total ^{137}Cs deposition resided in the vegetation and upper 5 cm of soil. Between 0% and 15% had penetrated to depths lower than 10 cm. Both in the soil and in the vegetation, the concentration of ^{137}Cs was in agreement with the degree of continentality estimated from the composition of plant communities; this agreement indicates a precipitation-related longitudinal gradient in the deposition of ^{137}Cs along the coast of West Greenland. In leaves of *Salix* spp., the ^{137}Cs concentrations in dry matter varied between 2 and 30 Bq kg^{-1}: the lowest concentrations were in *Salix glauca* growing on mineral soils in the continental inland of Søndre Strømfjord (Kangerlussuaq), and the highest concentrations were in *Salix glauca* growing in bogs at Skarvefjeld on the coast of southwestern Disko Island. In the two species of lichens, the ^{137}Cs concentration pattern was similar to that of *Salix*, with a variation between 65 and 138 Bq kg^{-1} in *Cetraria nivalis* and between 209 and 305 Bq kg^{-1} in *Cladina mitis*. The ratio between the concentration (Bq kg^{-1}) in the plant and the ground deposition (Bq m^{-2}), the Observed Ratio, or OR (m^2 kg^{-1}), was calculated for *Salix*, lichen, and moss species. The OR for *Salix* varied between localities, and ranged from 0.003 to 0.017 m^2 kg^{-1}. The OR of moss and lichen varied between 0.074 and 0.238 m^2 kg^{-1}; it was lowest in *Cetraria nivalis* and highest in *Cladina mitis*. Faecal samples of the wild reindeer, *Rangifer tarandus groenlandicus*, and the muskox, *Ovibos moschatus*, from Kangerlussuaq indicated that the reindeer eats plant species that are richer in ^{137}Cs and poorer in potassium than those eaten by the muskox.

Key words: radiocesium, deposition, distribution, faeces, Greenland, lichen, moss, ^{137}Cs, *Salix*, soil

RÉSUMÉ. Au cours de l'été de 1992, on a procédé à un échantillonnage du sol et de la végétation à cinq localités de l'ouest du Groenland en vue d'étudier la distribution de ^{137}césium dans le sol et dans quelques plantes fourragères consommées par le renne. Selon la localité, entre 69 et 97 p. cent du dépôt total de ^{137}césium se trouvait concentré dans la végétation et dans les 5 cm de surface du sol. Entre 0 et 15 p. cent avait pénétré à des profondeurs supérieures à 10 cm. Dans le sol comme dans la végétation, la concentration en ^{137}césium s'accordait au degré de continentalité estimé d'après la composition des communautés végétales. Cet accord indique un gradient longitudinal relié aux précipitations, dans le dépôt de ^{137}césium le long de la côte du Groenland occidental. Dans les feuilles de *Salix* spp., les concentrations en ^{137}césium dans la matière sèche variaient de 2 à 30 Bq kg^{-1}: les concentrations les plus faibles se trouvaient dans *Salix glauca* qui poussait sur les sols minéraux de la zone intérieure continentale de Søndre Strømfjord (Kangerlussuaq) et les concentrations les plus fortes se trouvaient dans *Salix glauca* qui poussait dans les tourbières de Skarvefjeld sur la côte de l'île Disko située au sud-ouest du Groenland. Dans les deux espèces de lichen, le schéma de concentration en ^{137}césium était similaire à celui dans *Salix*, avec une variation allant de 65 à 138 Bq kg^{-1} dans *Cetraria nivalis* et de 209 à 305 Bq kg^{-1} dans *Cladina mitis*. On a calculé le rapport entre la concentration (Bq kg^{-1}) dans la plante et le dépôt au sol (Bq m^{-2}) — c'est-à-dire le rapport apparent ou RA (m^2 kg^{-1}) — pour *Salix,* le lichen et l'espèce moussue. Le RA pour *Salix* variait selon les localités et allait de 0,003 à 0,017 m^2 kg^{-1}. Le RA de la mousse et du lichen variait de 0,074 à 0,238 m^2 kg^{-1}; il était le plus bas dans *Cetraria nivalis* et le plus élevé dans *Cladina mitis.* Des échantillons coproscopiques du renne sauvage, *Rangifer tarandus groenlandicus,* et du boeuf musqué, *Ovibos moschatus,* de la localité de Kangerlussuaq révélaient que le renne consomme des espèces végétales qui sont plus riches en ^{137}césium et plus pauvres en potassium que celles consommées par le boeuf musqué.

Mots clés: radiocésium, dépôt, distribution, fèces, Groenland, lichen, mousse, ^{137}césium, *Salix,* sol

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INTRODUCTION

Radiocesiums are man-generated radionuclides originating from nuclear fission. Major sources of radiocesiums found in the terrestrial environment have been atmospheric tests of nuclear weapons and the Chernobyl nuclear power plant (CNPP) accident. The Northern Hemisphere has received the main part of the global deposition of radiocesium (UNSCEAR, 1988). All radiocesium released after atmospheric weapon testing was the ^{137}Cs-isotope, while both ^{134}Cs (half-life = 753.145 days) and ^{137}Cs (half-life = 10957.5 days) were deposited after the CNPP accident, in a ratio of approximately 0.55 (Aarkrog et al., 1988a) at the time of the discharge, on 26 April 1986. In the long term, therefore, the radioecological

[1] Nuclear Safety Research and Facilities Department, Risø National Laboratory, DK-4000 Roskilde, Denmark; present address: National Environmental Research Institute, Department of Terrestrial Ecology, Vejlsøvej 25, DK-8600 Silkeborg, Denmark; mts@dmu.dk

importance of ^{137}Cs relative to ^{134}Cs increases. The ratio ^{134}Cs/^{137}Cs can be used to determine the fraction of the total ^{137}Cs deposition that was dispersed as a result of the CNPP accident, as the presence of ^{134}Cs serves as a marker of ^{137}Cs of Chernobyl origin.

In the Arctic, the major part of the deposition originates from ^{137}Cs discharged to the stratosphere during testing of nuclear weapons in the 1950s and 1960s. The deposition of ^{137}Cs in the North American and Greenland Arctic generally decreases as the latitude increases (e.g., Hutchison-Benson et al., 1985; Aarkrog, 1994); however, this pattern may be overshadowed locally because of a topographically determined precipitation increase in certain areas. Because the main part of the deposition following the CNPP accident was subject to dispersion only through the lower part of the troposphere, the contamination was mainly local and regional (Persson et al., 1987). However, minor parts of the release from the accident reached arctic terrestrial environments of Canada and Alaska (Taylor et al., 1988; Baskaran et al., 1991; Thomas et al., 1992; France et al., 1993).

The rate of litter decomposition is slower in arctic ecosystems than in ecosystems of warmer regions. Biogeochemical processes are generally slower, too; hence, a contaminant resides for a longer period in the biota of an arctic ecosystem. This property can be expressed by the ecological half-life ($T_{1/2eco}$) of a given compound in the ecosystem, in this case ^{137}Cs. The half-life expresses the time passed before a given amount is reduced to half its original value. The trend of a longer effective half-life with increasing latitude was demonstrated by Taylor et al. (1985) for lichen, moss, and vascular plant species from the Canadian Arctic.

The food chain *lichen–reindeer–man* has been the main object of research within terrestrial arctic radioecological research, e.g., Lidén and Gustafsson (1967), because of the importance of the transfer of fallout radionuclides to man. Hence, the mechanisms involved in this transfer are among the best known within the radioecology of all natural ecosystems. From the Nordic countries and Great Britain, it is known that mushrooms are also significant contributors of ^{137}Cs to man, either directly or through reindeer and other ruminants (Hove et al., 1990; Rafferty et al., 1994; Strandberg and Knudsen, 1994). Since the Chernobyl accident, Rolf Olsen (pers. comm. 1993) has observed that ^{137}Cs levels in the meat of Norwegian reindeer increased in years rich in mushrooms.

The present study aims to further our understanding of the distribution and behaviour of ^{137}Cs in the low arctic ecosystems of West Greenland.

MATERIAL AND METHODS

Samples of soil and vegetation were gathered for ^{137}Cs analysis from five localities in West Greenland (Fig. 1). These localities represent different vegetation and climatic types of the low arctic zone of West Greenland (Fredskild, 1996). The separation between oceanic and continental locations was estimated from the composition of plant communities at the localities. The local vegetation has been described by Strandberg (1992), Strandberg and Strandberg (1993), while Strandberg (1996) described both soil and vegetation from the three northernmost locations.

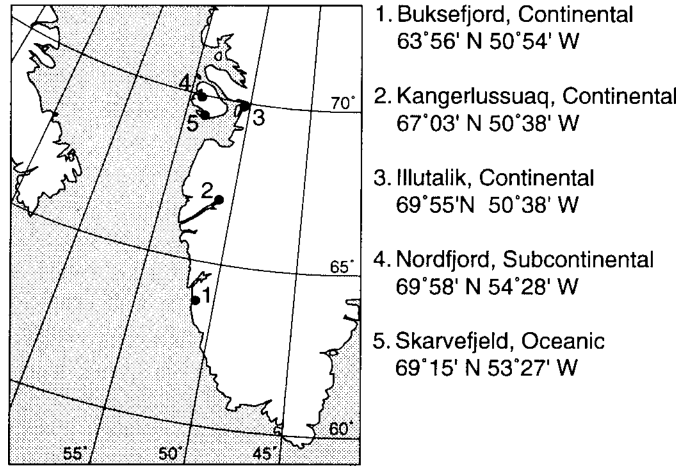

FIG. 1. Position of sampling stations (1 – 5) in West Greenland.

Continental plant species, such as *Antennaria affinis* Fern., *Arctostaphylos uva-ursi* L., *Artemisia borealis* Pall., *Betula nana* L., and *Draba arctica* J. Vahl, were used as indicators of a high degree of continentality (Böcher, 1963), i.e., a continental climate with a relatively low mean annual precipitation, many hours of sunshine during the summer, and, on average, relatively warm summer temperatures. Plant communities such as herb slopes, heaths of *Empetrum hermaphroditum* rich in moss, and snow patch vegetation were used to estimate the degree of oceanity (Böcher, 1963), i.e., an oceanic climate with relatively higher mean annual precipitation rates, fewer hours of sunshine during the summer, and colder average temperatures during the summer.

The aim was to take similar samples on all localities. However, some species were not present at all localities. When possible three replicate samples were taken.

Three different corers were used for soil sampling. In Kangerlussuaq, 8 mm corers were used and in Godthåb (Buksefjord), 6 cm diameter corers were used. At the rest of the localities, the corers were 4.9 cm. Other sample types were sampled by hand. The extent of lichens was measured to estimate the amount of deposition retained in the lichen carpet per unit area. Samples of *Salix* spp. were *Salix glauca* (L. coll.) in all places but Nordfjord, where *Salix arctica* Pall. was sampled. Two species of mushrooms were sampled in Kangerlussuaq: *Leccinum rotundifoliae* (Sing.) Smith, Thiers and Watle and *Calvatia* sp. Muskoxen and reindeer have been observed to ingest both species (B. Strandberg, pers. comm. 1994). The species of algae were sampled at two localities. *Fucus vesiculosus* L. was sampled only at the west coast of Illutalik, while *Fucus distichus* L. em. Powell was also sampled in Nordfjord. No samples of biota were sampled in Buksefjord.

The nomenclature of mammals follows Honarcky et al. (1982) and Meldgaard (1986). For the nomenclature and determination of species of vascular plants, Böcher et al. (1978) was used. The nomenclature of lichen and moss species follows Hallingbäck and Holmåsen (1982) and Moberg and Holmåsen (1982). The algae are named according to Gams (1974). The names of the mushrooms follow Moser (1983).

Samples were measured for ^{134}Cs, ^{137}Cs and ^{40}K using low-background, lead-shielded Ge(Li) detectors with efficiencies ranging from 18% to 37%. Both 604 and 795 keV spectral lines were used for the determination of ^{134}Cs to obtain a weighted mean of the ^{134}Cs determination. Standards for determination of the isotopes of cesium were made from cesium chloride solutions. The correction for variation in density between samples was made after a model presented by Lippert (1983), which describes this problem for the Ge(Li) detector. Samples and standards were measured in 200 ml cylindrical plastic containers. For ^{137}Cs, the counting error was 1% or less; for ^{134}Cs, it was 10% in the lichen carpet and 21% in the reindeer meat. All results concerning ^{137}Cs were decay-corrected to the date of sampling. For the ^{134}Cs and ^{137}Cs isotopes, the results are presented as Bq kg^{-1} dry matter or Bq m^{-2}, while the unity for radiopotassium has been recalculated to g kg^{-1}.

RESULTS

The Inventory of ^{134}Cs and ^{137}Cs

The total deposition of ^{137}Cs per unit area at the five localities, found in the upper soil layers and in the vegetation, varied between 0.6 kBq m^{-2} in Kangerlussuaq and 1.8 kBq m^{-2} at the Skarvefjeld location (Table 1). The Chernobyl deposition was estimated from samples of the lichen, *Cladina mitis*, from Illutalik and Skarvefjeld. The ^{134}Cs concentrations in these samples were 0.7 and 2.1 Bq kg^{-1}, respectively (Table 2). From the area and the mass, the ^{134}Cs deposition per unit area was determined to be 1.7 and 5.5 Bq m^{-2} in August 1992, which equals 14 and 44 Bq m^{-2} at the time of the deposition. Using the ratio ^{134}Cs/^{137}Cs of 0.55 at the time of the CNPP discharge, the ^{137}Cs deposition of Chernobyl origin retained in the lichen carpet can be calculated to be 26 Bq m^{-2} for Illutalik and 81 Bq m^{-2} for Skarvefjeld. These values correspond to an increase of ^{137}Cs concentration in the lichen carpet of 5% and 10%, respectively.

Depth Penetration of ^{137}Cs in the Soil

The penetration of ^{137}Cs through soil layers was minimal, even though the main deposition took place in the first half of the 1960s. Between 69% and 97% resided in the ground vegetation and the upper 5 cm of soil, between 0% and 15% had penetrated to depths lower than 10 cm, depending on the locality. At the northernmost locality, Nordfjord, penetration below 20 cm was observed (Table 1). The calculation of a mean distribution of ^{137}Cs between soil layers was carried out from the results in Table 1. Of the total deposition of ^{137}Cs, 83% resides in the vegetation and the upper 5 cm of the soil column, 10% is in the 5–10 cm layer, and 6% is located in the 10–20 cm layer. Below this depth less than 1% of the total deposition can be found. These values were used to estimate the levels below 5 cm in Buksefjord, where no samples below 5 cm were taken (Table 1).

TABLE 1. The present mean distribution of ^{137}Cs deposition in soil layers (kBq m^{-2}), n = 3 or more.

Material	0–5 cm	5–10 cm	10–20 cm	20–35 cm	Total	Mean annual precipitation (mm)
Kangerlussuaq	0.51	0.09	0		0.60	139
SD	0.35	0.15				
Illutalik	0.64	0.13	0.11		0.88	205[2]
SD	0.34	0.11	0.07			
Nordfjord	0.82	0.19	0.14	0.04	1.19	279[2]
SD	0.44	0.38	0.32	0.04		
Skarvefjeld	1.71	0.05	0.01	0	1.77	413
SD	0.30	0.03	0.02			
Buksefjord	1.40	0.17[1]	0.10[1]	0.01[1]	1.69[1]	394[2]
SD	0.41					

[1] Estimates based on the average penetration from the other locations.
[2] Estimates based on the average ratio of the deposition to the precipitation.

TABLE 2. Chernobyl-derived radiocesium in *Cladina mitis* lichen carpet (Bq m^{-2})

Collection site	^{134}Cs 1992	^{134}Cs 1986	^{137}Cs 1986
Illutalik (n = 1)	0.7	14	26
Skarvefjeld (n = 1)	2.1	44	81

^{137}Cs in the Biota

The concentrations of ^{137}Cs in lichen and moss samples collected from the three northernmost sites are presented in Table 3. The samples of lichen and moss showed that the ^{137}Cs concentration levels were highest in *Racomitrium lanuginosum* (Hedw.) Brid. and *Cladina mitis* (Sandst.) Hustich and lowest in *Cetraria nivalis* (L.) Ach. Bearing in mind the morphology of these three species, it is obvious that this trend will be even more distinct when the deposition per unit area of lichen or moss is compared, because the biomass per unit area is highest in *Racomitrium lanuginosum* and *Cladina mitis*. In two samples of *Cladina mitis* from Illutalik, the top and the bottom layers were analysed separately. The ^{137}Cs concentration was 75 ± 8 Bq kg^{-1} in the top layer, and 300 ± 17 Bq kg^{-1} in the bottom layer.

In the leaves of *Salix*, the ^{137}Cs concentration varied between 1.6 Bq kg^{-1} and 29.8 Bq kg^{-1}, lowest in *Salix glauca* growing on continental mineral soils in Kangerlussuaq, and highest in *Salix glauca* growing in bogs at the oceanic locality, Skarvefjeld (Table 3). In the two species of lichens, the pattern was similar, with a variation between 65.3 Bq kg^{-1} and 138.1 Bq kg^{-1} in *Cetraria nivalis* sampled in continental Illutalik and oceanic Skarvefjeld respectively (Table 3). The ^{137}Cs concentrations in *Fucus* spp. were small, varying

TABLE 3. ^{137}Cs in biota (Bq kg^{-1} D.M.), mean and standard deviation are given. n = 3 where the SD is calculated.

Material	Collection sites[1]			
	Kangerlussuaq	Illutalik	Nordfjord	Skarvefjeld
Salix glauca leaves				
Mean	1.6	15.3	12.3[2]	29.8
SD	2.2	6.3		20.2
Cetraria nivalis				
Mean		65.3	98.5	138.1
SD		9.8		42.7
Cladina mitis				
Mean		209.3		304.9
SD		12.1		33.3
Racomitrium lanuginosum				
Mean			99.0	282.4
SD				54.5

[1] Buksefjord not included because vegetation was not sampled at that location.

[2] In Nordfjord, *Salix arctica* was sampled instead of *Salix glauca*.

between 1.0 and 2.6 Bq kg^{-1}. In *Leccinum rotundifoliae* the level was 50.4 Bq kg^{-1}, while in *Calvatia* sp. the concentration was below the detection limit.

The reindeer and muskox faeces showed a difference in ^{137}Cs and ^{40}K concentration (Fig. 2), with approximately five times higher ^{137}Cs concentrations in the reindeer faeces. In contrast, the ^{40}K concentration in the muskox faeces was almost four times that of the reindeer faeces. Small amounts of ^{134}Cs were detected in reindeer meat; the concentration was 0.25 Bq kg^{-1} with a counting error of 21%, indicating a content of Chernobyl-derived ^{137}Cs of 17% (Fig. 2).

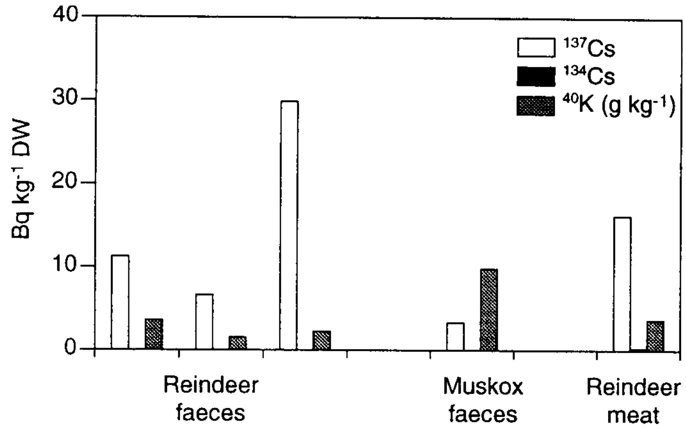

FIG. 2. ^{137}Cs in meat and faeces of individual reindeer and a muskox in West Greenland.

TABLE 4. Observed ratios (OR $m^2 kg^{-1}$) from four West Greenland localities[1].

Material	Kangerlussuaq	Illutalik	Nordfjord	Skarvefjeld
Salix glauca	0.0027	0.0174		0.0169
Salix arctica			0.0103	
Cladina mitis		0.238		0.173
Cetraria nivalis		0.074	0.083	0.078
Racomitrium lanuginosum			0.083	0.159
Leccinum rotundifoliae	0.084			

[1] Buksefjord not included because vegetation was not sampled at that location.

The Observed Ratio

The ratio between the ^{137}Cs concentration (Bq kg^{-1}) in the plant and the ground deposition (Bq m^{-2}), the observed ratio OR (m^2 kg^{-1}), was calculated for species of *Salix*, lichen, moss, and mushroom (Table 4). The OR is identical to the aggregated transfer factor $T_{agg.}$ or TF_g, which has been used by some authors, especially within agricultural ecosystems (e.g., Rosén, 1991). Here the OR is preferred, because it does not implicitly make one believe that a transfer between different compartments of the ecosystem takes place. The OR varied between localities for *Salix*, especially between the samples from the Disko Bay area and the samples from Kangerlussuaq: the range was between 0.0026 m^2 kg^{-1} and 0.0174 m^2 kg^{-1}. The moss and lichen ORs varied between 0.074 m^2 kg^{-1} and 0.238 m^2 kg^{-1}. The lowest was in *Cetraria nivalis* and the highest in *Cladina mitis*.

DISCUSSION

The observed low penetration of ^{137}Cs through soil layers is a feature common to most natural ecosystems. In a pine forest ecosystem on sandy ground, Strandberg (1994) found that all ^{137}Cs from the Chernobyl accident still resided in the upper five cm of organic soil, while 41% of the ^{137}Cs of weapon test origin had penetrated down into the sandy mineral soil to depths below 5 cm. Under spruce and pine in Germany, Schimmack and Bunzl (1992) in 1989 found the main part of the ^{137}Cs from Chernobyl in the organic layer: only a minor fraction had penetrated down into the upper 5 cm of the mineral soil. On permanent grassland, Nielsen and Strandberg (1989, unpubl.) found that all Chernobyl-derived ^{137}Cs was in the vegetation and upper 2 cm of soil.

Results from Bergman (1994) indicate that the penetration decreases as the latitude increases. Other aspects are often more important. For example, Bergman (1994) states that the amount of precipitation at the time of the deposition can influence the penetration: heavy rainfall may lead to a fast penetration of ^{137}Cs to depths below 5 cm. Three other factors that can cause an increased and fast penetration are mixing of layers by the activity of soil animals; edaphic characteristics, such as texture and pore volume; and characteristics of the vegetation, such as density and percentage cover. As the concentration of ^{137}Cs in the soil samples is influenced by the vegetation cover, it is possible that differences between southern and western low arctic sites in Greenland are not due to the differences in deposition alone. Although all soil samples were taken in association with willow shrubs, there are significant morphological differences between the willows of the relatively warm, continental Kangerlussuaq and Buksefjord and those of the colder, more oceanic locations, Skarvefjeld and Nordfjord. The willows from the continental site of Illutalik are more similar to those from Nordfjord and Skarvefjeld than to those at the two southern continental low arctic sites. The main difference is that the willows at the southern continental low arctic sites are taller and have a higher biomass per unit area than the willows of the sites in Disko Bay. The interception of ^{137}Cs by the willow canopy is thereby likely to be higher at the southern sites. The effect of the shade of the denser willows might on the other hand mean that the retention in the shaded ground cover is smaller than at the sites in Disko Bay.

The distributional pattern of the ^{137}Cs concentration in the vegetation was tested by analysis of variance. The analysis showed a significant difference between species and sites when the ^{137}Cs concentration in the samples at the three northernmost sites were compared. The difference between sites can roughly be related to the degree of continentality (Böcher, 1963) of the sites, and thereby also to the precipitation. The mean annual precipitation ranges from 100 mm at the most continental sites in low arctic West Greenland (e.g., 139 mm in Kangerlussuaq, N. Thingvad, pers. comm. 1993), to 400 mm or more at the most oceanic sites (e.g., 413 mm at Skarvefjeld according to Humlum, 1985). In Illutalik and Nordfjord, the annual mean precipitation is unknown, but is likely to be between 200 and 300 mm. Böcher (1963) and Humlum (1985) state that the northern central part of Disko is more continental than the southern part where Skarvefjeld is located. In southern Greenland, the amount of rainfall is higher than in North Greenland, where polar deserts are common. Among the three locations in Disko Bay, the lowest concentrations of ^{137}Cs in the biota were found on Illutalik, the most continental site of the three, and the concentrations were highest on the Skarvefjeld, with the most oceanic climate. The fact that all three localities are between 69° and 70°N (Fig. 1) indicates the existence of a longitudinal gradient in the distribution of the ^{137}Cs deposition along the coast of West Greenland. However, it would be more correct to relate the deposition to the degree of continentality, because the topography and the ice caps determine the direction of the gradient. In a few places in West Greenland, the increase in continentality does not follow a west to east running gradient (Böcher, 1963) because of the "continental influence" (Bliss and Matveyeva, 1992) from minor ice caps such as the Disko ice cap and the Sukkertoppen ice cap. This is not surprising, because the deposition of ^{137}Cs is strongly correlated to the rainfall, e.g., Basher and Matthews (1993). Data from Greenland (Aarkrog and Lippert, 1965) also show a connection between ^{137}Cs deposition and precipitation, indicating a latitudinal trend, with a decrease in the deposition as the latitude increases. Baskaran et al. (1991) reported that the Chernobyl deposition in Alaska decreases as the latitude increases. Thomas et al. (1992) treated arctic terrestrial ecosystem contamination in general, and showed that the depositional pattern of ^{137}Cs in Canada is similar to the latitudinal trend of ^{137}Cs deposition in Alaska.

From the two stations where the mean annual precipitation is known, the ratio between the precipitation (mm) and the deposition (Bq m^{-2}) can be calculated. From these values, 0.23 ± 0.19 in Kangerlussuaq and 0.23 ± 0.05 in Skarvefjeld, a mean ratio of 0.23 ± 0.12 mm $\times$ $Bq^{-1} \times m^2$ can be obtained. By multiplying this ratio by the deposition at the three localities where the rainfall is unknown, it is possible to estimate the mean annual precipitation (Table 1).

The deposition of Chernobyl-derived ^{137}Cs of 26 Bq m^{-2} (decay corrected to May 1986) in Illutalik lichen carpet (Table 2) is almost equal to the deposition of approximately 30 Bq m^{-2} in nearby Ilulissat reported by Aarkrog et al. (1988b). This indicates that where the ground is covered by a dense lichen carpet, the major part of the deposition after the Chernobyl accident is still retained in the lichens. Lidén and Gustafsson (1967) calculated a biological half-life of 17 years for ^{137}Cs in Finnish lichens. It is reasonable to believe that this half-life is longer in the slow-growing lichens of Illutalik, which is why the main part of the Chernobyl cesium is still retained in the lichen carpet. The deposition found in the Illutalik lichen carpet is in the lower end of the range reported for the Chernobyl ^{137}Cs deposition in the whole of Greenland, which is between 27 and 196 Bq m^{-2} (Aarkrog et al., 1988b). This is not surprising, because Illutalik belongs to a region of very little precipitation. In the *Cladina mitis* sample from the Skarvefjeld site where ^{134}Cs was determined, the resulting decay corrected ^{137}Cs deposition was 81 Bq m^{-2} (Table 2). The general pattern of deposition of ^{137}Cs in West Greenland is confirmed in these two cases, although no general statement can be made on the pattern of the deposition from Chernobyl from only two results. The results presented by Aarkrog et al. (1988b) on Chernobyl deposition in Greenland largely show the same pattern.

Faecal samples from reindeer and a muskox taken in Kangerlussuaq indicated that the faeces of the reindeer were richer in ^{137}Cs and poorer in potassium than those of the muskox (Fig. 2). This probably indicates different feeding habits of the two species. Lichens eaten by the reindeer could be an explanation, but lichens are rare in Kangerlussuaq and are eaten mainly during the winter period. The reindeer also eat moss, sometimes in large amounts (Thomas and Edmonds, 1983), and that might be a better explanation of the observed differences. However, this is apparently not the case in Kangerlussuaq. Observations of reindeer and muskoxen in the Kangerlussuaq area and of their rumen contents (Olesen, 1993a) have revealed some differences in the feeding ecology of the two species. According to Olesen (pers. comm. 1993), reindeer are more selective and prefer forbs and mushrooms in the summer season, while the muskoxen are less selective, preferring areas of graminoids. McGee et al. (1994) found a relation between the level of ^{137}Cs in the faeces and in the meat of Irish sheep. Assuming that similar relations exist for other species of ruminants, we can conclude that the ^{137}Cs level is higher in reindeer meat than in muskox meat in the summer period. This is in accordance with Aarkrog (1979), who found significantly lower ^{137}Cs levels in muskox meat from northeastern Greenland than in reindeer meat from West Greenland, even when differences in precipitation between the localities were taken into account. Aarkrog also found that the potassium level in reindeer meat was 1.3 times that in muskox meat. Together with the differences in feeding habits, this explains that the ^{137}Cs concentration in the meat is higher in the reindeer than in the muskox. In Greenland, the wild reindeer *Rangifer tarandus groenlandicus* is now protected, while the importance of the muskox as a game object is increasing because of the rapidly expanding muskox population in West Greenland (Olesen, 1993b). How this change in hunting practice will influence the transfer of ^{137}Cs from terrestrial ecosystems to man in Greenland might be an interesting object for future research.

Chernobyl-derived ^{137}Cs has previously been monitored in lake sediments of southern Greenland (Sandgren and Fredskild, 1991; Fredskild, 1992), precipitation, seawater, and lamb and reindeer meat of East and West Greenland (Aarkrog et al., 1988b).

Records on Chernobyl-derived ^{137}Cs from other parts of the arctic region are frequent. White et al. (1986) compared the ^{137}Cs level in lichens and vascular plants on selected sites in Alaska before and after the Chernobyl accident. In some lichens from these sites, a 75% increase was observed, while in some vascular plants the increase was 120%. Taylor et al. (1988) reported a 19% average increase of ^{137}Cs concentrations in mosses and lichens in Canada as a result of the deposition from Chernobyl. This increase is much lower than that observed in some Alaskan lichens (White et al., 1986), as mentioned above, but slightly higher than those of lichen in Illutalik (5%) and Skarvefjeld (10%) in the present study. If only the top parts of the lichens are compared, the increase due to the Chernobyl deposition is likely to be much higher, because the contribution from weapon fallout is situated in the older basal parts of the lichen thallus. In the arctic part of Scandinavia, the ^{137}Cs concentration increase in biota caused by the Chernobyl-derived deposition was at least one order of magnitude higher than in the arctic part of North America, Greenland included. Rissanen and Rahola (1989) reported increases of about 400% in lichens from permanent plots in Finland after the Chernobyl accident. The average level in Finnish reindeer meat increased from 300 Bq kg^{-1} fresh weight before the accident to 720 Bq kg^{-1} fresh weight after the accident.

CONCLUSION

A latitudinal gradient in the deposition of ^{137}Cs along the west coast of Greenland was described by Aarkrog and Lippert (1965). The results from the investigation presented here show a gradient of the ^{137}Cs deposition along the west coast of Greenland that is related to the degree of continentality. In general, the gradient shows a decrease in the ^{137}Cs deposition from west to east, i.e., the deposition is highest near the coast and lowest inland near the ice cap.

The deposition of Chernobyl-derived ^{134}Cs was still determinable in the lichen carpet six years after the accident. Apparently the deposition was higher near the coast than inland.

The penetration of ^{137}Cs through soil layers was small, on average 83% of the total deposition was still residing in the vegetation and the upper 5 cm of soil.

Levels of ^{137}Cs in willow *Salix* varied between 2 and 30 Bq kg^{-1}, lowest at the inland sites and increasing with proximity to the outer coast. In lichen and moss, the trends were similar, but the levels were higher.

Some faecal samples from reindeer and muskox indicated that the content of ^{137}Cs and ^{40}K and the Cs/K ratio can be used to investigate the feeding ecology of the two species.

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