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Radioactive Food Chains in Arctic Regions

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Investigations of bioenvironmental radioactivity in the arctic regions of Scandinavia and Alaska have revealed high body contents of ^{90}Sr and ^{137}Cs in animals and man. Large quantities of these radionuclides have been produced and spread into the stratosphere by the megaton-range weapon tests. Being "third generation" - fission products these nuclides are "born" from their gaseous parent nuclides mainly in the stratosphere after the fireball has spread and cooled and thus appear in a very finely divided, nearly monoatomic state. This fine dust comes down primarily by so-called stratospheric cold air injections, which are strongest in spring, in April and May, and between 30° and 60° northern latitude.

Air currents from the west usually take the fallout to Lapland after it has got into the troposhere somewhere above the North Atlantic, often within the so-called Icelandic low-pressure area. The bulk of it comes down with rain above the Norwegian mountains. Fallout as well as the amount of rain is much smaller in Sweden and Finland than in the mountainous parts of Norway, and about the same or slightly lower in Lapland than in the southern parts of the countries (Fig.1). In the whole of Finland the fallout is in general about 1/3 to 1/2 of that in the middle Europe, e.g. Berlin-Dahlem [1]. The integrated amount of ^{137}Cs was about 20 ns/m^2 in Swedish soil in 1960 [2]. Thus, the high activities of ^{90}Sr and ^{137}Cs in animals and people in Lapland are not caused by exceptionally large amounts of fallout, but rather by unusual food chains.

For the elucidation of the arctic food chains, a Finnish Atomic Energy Commission-sponsored field investigation called "Project Lapland" was started

in 1960. In that year a dietary survey of the Finnish Lapps was carried out, which involved about one third of the Lapp population in Finland [3]. The seasonal forage consumption by reindeer and cattle was also investigated. On the basis of the results, a program of regular sampling of forage and of milk and tissues of reindeer and cattle was started. The results for the years 1960 and 1961 have been published [4,5].

The highest values of ^{90}Sr and ^{137}Cs were found in reindeer lichens (Cladonia and Cetraria species). These plants, which have no real roots but a simple prothallium, grow very slowly (a four inches tall Cladonia lichen may be fifty years old) and have a high capacity for collecting nutrients from the air and from rain or snow. In Lapland, the forest floor is generally covered by a dense mat of reindeer lichens, which still retain most of the fallout that has come down during the Atomic Age. In dense patches of Cladonia lichen, where 1 kg of dry lichen covered about 1 m^2, we found in 1961 4 nc ^{90}Sr and 30 nc ^{137}Cs per kg dry weight [5]. At the end of the first test moratorium, in 1960-1961, samples of reindeer lichens collected from Inari, Finnish Lapland, contained 3 to 10 (mean=5) nc ^{90}Sr per kg dry wt. and about 8 times more ^{137}Cs, 10 to 60 (mean=40) nc/kg dry wt. [4,5]. Most of the activity is in the green, living "top" part of the plant, which is eagerly eaten by the reindeer from autumn to spring, i.e. during about 8 to 9 months of the year. Since each reindeer eats daily about 6 kgs of lichen (50 % dry wt.), its daily intake was in winter 1960-61 about 15 nc ^{90}Sr and 120 nc ^{137}Cs. More recently the values have greatly increased.

Grasses, horsetails (Equisetum) and sedges (Carex) are important forage in Lapland for cattle throughout the year and for reindeer in the summer. Reindeer also graze Vaccinium plants and leaves of birch and willow in the summer. Results of analyses of some samples of these plants are compared with a typical sample of Cladonia lichen in Table I. As can be seen, in 1961 the annual parts of vascular plants had roughly 1/10th of the radionuclide content of lichens. Slightly lower results for ^{137}Cs in lichens from Sweden have been reported (10-30 nc/kg dry wt., ref.6), and higher ones from Norway, if allowance is made for the earlier date of sampling (36 nc/kg in 1959, ref.7).

In Alaska the situation seems to be rather similar to that in Lapland. In the northern part of Alaska the ^{90}Sr on the ground, in 1959, 10-22 nc/mi^2, (=4-8 nc/m^2), was about the same as in Lapland and low compared with levels found elsewhere in the U.S. (25-99 aver.50 nc/mi^2 (=20 nc/m^2)) [8]. In 1960 lichens from Ogotoruk Creek, Alaska, contained ^{90}Sr 2.0 nc/kg dry wt. and ^{137}Cs 26

nc/kg, the corresponding values for the sedge, Carex aquatilis, being 3.5 and 6.6. In 1961, 8.7 ± 0.75 nc ^{137}Cs/kg was reported as the average for 10 samples of sedges [9]. For lichens the Alaskan values are somewhat lower, for sedges higher than the Finnish ones, but as a whole the picture is quite similar.

Milk and tissues of reindeer and cattle have been analyzed both in Scandinavia and in Alaska since 1959. In summer 1960 cow's milk in Lappland contained about 8 pc, reindeer milk 60 pc ^{90}Sr per g Ca. During the winters 1960 and 1961 cow's milk contained 15 pc ^{90}Sr/g Ca. Some values for meat and bone from Finland are presented in Table II. Both annual and seasonal variations are apparent: This is due to the fact that on Lapp farms lichen is collected for winter and given to the cattle as "additional fodder" in such amounts that it makes up about 1/3 of the forage. Strontium is mainly (at least 99 per cent) located in the bones of the animals, which are not eaten by man, but radiocesium is located in meat, which is the main food of Lapps (reindeer meat) and several Eskimo tribes (caribou meat). Thus, this nuclide is the more important one from the viewpoint of man's diet.

^{137}Cs content of reindeer meat is greatly decreased during the summer, when the animals mainly eat less radioactive vascular plants: grass, sedges, horsetails and leaves of Vaccinium, willow and mountain birch. In summer (May to August) reindeer's diet contains only about 5 to 10 % lichen. The lowest ^{137}Cs-level is reached in July-August and since the biological half-time of ^{137}Cs in reindeer is about 1 month [13], it is only about 1/8th of the winter level (Table II, 1963-samples). A similar decrease takes place in caribou meat in Alaska, where 8.6 nc/kg fresh wt. was reported at Colville in May 1961, but 0.90 nc/kg in August 1961 [14]. The highest values from Alaska, 15 nc in Feb. '61 and 26 nc in Dec. '61 [14] are of the same order as the contemporary values from Sweden [6] and Finland (Table II), but from Norway max.37 nc (evidently winter value) is reported [7], the level there being evidently about double that in Finland. In several studies different tissues of the same reindeer were analysed for ^{90}Sr [4,10,16] or ^{137}Cs [4,14] . Liver, spleen and lung have about 1/3 to 1/2, kidney 2/3 and blood 1/10th of the ^{137}Cs content of meat, on fresh weight basis, The "observed ratio" nc ^{90}Sr/g Ca $\frac{\text{in tissue}}{\text{in diet}}$ was for reindeer meat and liver 0.3, lung and blood 0.1 and for reindeer milk in summer 0.2 [4].

With the knowledge of the high radioactivity of reindeer and high consumption of reindeer meat especially by the Lapps an accurate estimation of ^{90}Sr and ^{137}Cs body burdens in Lapps evidently was of major interest. The quantitative investigation of the Lapps' diet in 1960 [3], and the ^{90}Sr analyses of cow's

milk and reindeer meat made possible an early estimate of the ^{90}Sr body burden in Finnish Lapps. The average content of ^{90}Sr in their diet was about 30 pc/g Ca in 1960, i.e. twice that of the average Finnish diet. Assuming a discrimination coefficient of 4, the maximum ^{90}Sr content of Lapp children could be estimated to about 7.5 pc/g Ca, or twice the value found in Helsinki children. For the adult Lapp in 1960, a ^{90}Sr bone-content of about 1 pc/g Ca could be assumed [17]. Based on bone and urine analysis, Schulert [18] estimated Eskimos, for whom caribou is a staple in the diet, to form new bone with 12 pc ^{90}Sr/g Ca, four times the ^{90}Sr content of the average of the world population of the North Temperate Zone. Thus, although ^{90}Sr is enriched in Lapp and Eskimo bone at a two to four times faster rate than the Northern Hemisphere average, the situation is not quite exceptional regarding his nuclide.

New possibilities for direct determination of body burdens of ^{137}Cs in Lapp were opened in 1961. In spring 1961 Kurt Lidén, Head of the Department of Radiation Physics at the University of Lund, Sweden, determined at Lund the ^{137}Cs body burden of 3 Lapps by whole body counting and obtained values about 40 times higher than for Swedes in general [19]. Spurred by this alarming result, he and his associates developed in summer 1961 a semiportable whole body counter [20] and determined with it the whole body burden of 170 people in Swedish Lappland in Sept.1961 [6]. One month later 180 people were counted at Inari, Finland, with the same equipment as a joint Finnish-Swedish project [9,21]. The latter study also included an individual dietary survey and a quantitative study of the ^{137}Cs content of the diet . With the help of a form specially made for this survey and weighed samples of most important foods and dishes each subject was interviewed about his diet. The results obtained in Sweden and Finland were very similar. In Finland the male reindeer-breeding Lapps contained on the average 245 nc ^{137}Cs, 30 times the corresponding Helsinki average (8.4 nc), while females and children had an average of 122 and 51 nc ^{137}Cs, respectively. Intake of ^{137}Cs from reindeer meat (70 - 90 %), fish (8 (8-16 %) and milk (2-16 %) was found to contribute 98 to 99 % of the total dietary intake of ^{137}Cs. From dietary data and the measured body burden a biological half-time of 65 days for adult Lapps was calculated [9]. In Sweden the body burden of Lapps in autumn 1961 was 30 to 100 % higher, that of non-Lapps 10 to 30 % lower than in Finland [21], mainly due to a better availability of refrigerators in the Swedish Lapp area.

Prompted by the new period of nuclear weapon tests a mobile whole body counter installed in a covered truck was constructed by the laboratory of the

present author during the winter 1961-1962 (Fig.2). With this mobile counter groups of one to two hundred Lapps were counted four times in 1962-1964. 250 Lapps , a representative sample of the whole Finnish Lapp population (Fig.3), were selected from church registers by a random sampling method in spring 1962, and about one half of the same group was taken for the later studies. The results from the Inari region (reindeer breeders and reindeer breeding fishers) are presented in Table III. Dietary [22], medical, and clinical studies [23,24] were also included in the investigation carried out in May, 1962. The full results of this investigation will soon be published.

As can be seen from Table III, the Inari Lapps' body content of ^{137}Cs shows a similar (although not so large) seasonal variation as that of the reindeer. This is mainly due to the fact that the consumption of reindeer meat is very low in the Finnish Lapp areas in summer compared with that in winter (less than 1/10th), and to a lesser extent to the lower ^{137}Cs content of reindeer meat in the summer.

A steady increase of body burdens, too, is noticeable from Table III. The percentage increase compared with May 1962-values is given after the figures for '63 and '64. The increase is greatest in the southern Finns (=control group), who do not consume reindeer meat regularly, and less pronounced with increasing proportion of reindeer meat in the diet. This is understandable as lichens and reindeer remained relatively radioactive throughout the test moratorium. The maximal individual value was in April '64 in males 2.66 μc, in females 1.01 μc. The "maximal permissible concentration" of ^{137}Cs in individual of the general population is 3 μc according to ICRP [35]. None of the individuals studied has yet exceeded this level, but the highest value, 2.66 μc is very close to it. The present average body burden of the adult Finnish Lapps, males, 890 nc, corresponds to an annual total body radiation dose of about 80 mrem, the corresponding figures for adult females being 400 nc and 35 mrem/y with due allowance in both cases to the lower body burden in summer.

Large groups of Swedish Lapps were studied in April 1962 and 1963 [25] by portable whole body counters. The Swedish Lapps, (males, age group 21 to 40 years) contained an average of 490 nc ^{137}Cs in April '63, the corresponding value at Inari being 646. The increase in Sweden from '62 to '63, 26 percent, was very similar to that of Inari Lapps. Only one group of Alaskan Eskimos, those living in Anaktavuk Pass, had a ^{137}Cs body content closely comparable with that of Lapps, the males having 474 nc compared with 498 nc at Inari. At Anaktavuk Pass, caribou meat is reported to constitute a major part of the diet

[26]. The maximum value, 790 nc, was exactly the same as in Inari. Thus, the situation seems to be very similar in Alaska and Lapland.

Although the highly efficient food chain lichen-reindeer-man probably is the most important one in Lapland, it is not the only one. Efficient hydrospheric food chains evidently prevail in the fresh waters, as high activities in the fish of pray have been found in Lapland in the last few years [27]. In summer 1963 pike and perch contained in Lapland 10 to 15 nc ^{137}Cs/kg fresh weight, twice the summer-value of this nuclide in reindeer meat. Highest values have been obtained in fish from lakes with a high humus but low cation concentration . Nearly as high ^{137}Cs contents as in Lapland have been found in fish from similar type of lakes in southern Scandinavia [27,28,29] while about ten times lower avlues have been found in fish from lakes of the "rich" types [29]. The factors causing these great differances in Finnish lakes are not yet known in detail.

Other interesting food chains involve the radon daughters RaD(^{210}Pb, half life 19.4 y.) and RaF(^{210}Po, half life 140 d.). Radium-226 is always present in the soil from where its daughter, radon-222, diffuses into the ground level air. From there the radon daughters are brought back to the soil surface by rain or aerosols as "natural fallout" and are absorbed by lichen and pass further to reindeer and man. Reindeer meat and bone have exceptionally high contens of RaD and RaF, meat about 0.2 pc [30], bone about 5-10 pc/g dry wt. of each [30,31]. Beef contains only about 0.01 pc/g dry wt. RaD [32]. On the basis of known facts about RaD resorption in man [32] and reindeer meat consumption by Lapps [3,9], Lapps' RaD content can be estimated to be about 10 times higher than the Northern Hemisphere average. bones have not been analysed yet but for one single Eskimo bone 2.3 pc/g ash [33], a value about 15 times the American average [32], was reported. Assuming for Lapps a ten times higher RaD+RaF body content than the general population average, the effective dose to their skeleton from these two nuclides alone may be estimated to be of the order of 120 mrem/y. (based on facts in refs 32 and 34).

The present results of our "Project Lapland and the corresponding studies in Sweden and Alaska can be summerised in the following way:

1) They have given interesting information about terrestrial and hydrospheric food chains of fission product nuclides, information which is also applicable to the environmental problems of peaceful atomic energy power programs;

2) they have given precise information about the present radiation dose to Lapps and Eskimos from internal contamination by articifial radionuclides, and

3) they have made possible rapid calculations of future situations, should new nuclear test series or accidents take place.

New nuclear tests which would produce large amounts of fission products should not be started, however, since a considerable number of people may exceed the ICRP level of 3 μc ^{137}Cs alone due to the fallout which already exists but has not yet reached the man. In the next twenty years even larger groups of people living in the reindeer and caribou meat-consuming regions of Alaska, Canada, Scandinavia and USSR may exceed the tighter genetic maximum permissible level for large groups of population, 5 rem, within 30 years, when to total integrated radiation dose from all sources of artificial contamination is reckoned with. The situation is made more grave by the fact that the very same group of people evidently have a considerably higher than normal body content of the natural radionuclides RaD and RaF.

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Table I. ^{90}Sr and ^{137}Cs in typical samples from Inari, Finnish Lapland in summer 1969 (5)

Sample	Habitat	ash % of dry wt	^{90}Sr nc/g Ca	^{90}Sr nc/kg dry wt	^{137}Cs nc/g K	^{137}Cs nc/kg dry wt
Cladonia lichens (80% Cl.alpestris)	regio sub-alpina	2.8	2.3	4.2	30.0	34.0
Wild grass	wet meadow	5.0	0.15	0.26	0,27	3.8
Horsetail (Eq.Fluviatile)	lake	13.7	0.07	0.85	0.05	1.1
Sedge (Carex aquatilis)	river	5.4	0.10	0.26	0.19	2.3
Cowberry (V.vitis idaea)	forest	3,1	0.13	0.73	1.20	4.2
Dwarf birch (Betula nana) leaves	hill top	2.4	0.26	0.84	0.44	1.9

Table II. ^{90}Sr and ^{137}Cs in meat and bone of reindeer and cow in Inari, Finland, since 1959.

year	month	animal	tissue	^{90}Sr		^{137}Cs		Ref.
				pc/gCa	pc/kg fresh wt.	pc/gK	pc/kg fresh wt.	
1959	1-4	reindeer	bone	200	-	-	-	15
"	"	"	meat	-	-	-	20.000	"
1960	2	"	bone	213	18.300	-	-	4
"	"	"	meat	611	22	5.280	35.300	"
"	8	cow	bone	28	-	-	-	"
"	"	"	meat	148	15	194	740	"
1961	3	reindeer	meat	220(x	24(x	4.500	18.000	9,10(x
"	9	"	bone	380	43.000	-	-	10
"	"	"	meat	560(x	73(x	2.670	7.400	9,10(x
1962	4	"	"	190(x	36(x	5.700	17.200	10,11(x
"	9	"	"	-	-	2.400	6.400	"
1963	3-4	"	"	-	-	10.000	40.000	"
"	7	"	"	-	-	1.900	4.800	"
"	11	"	"	-	-	11.400	47.000	"
1964	3-4	"	"	-	-	15.000	60.000	"

Table III. Body burden of ^{137}Cs in Lapps at Inari, and in a control group in Helsinki, Finland, in October 1961-April 1964 (age group 20-50 years)

	nc ^{137}Cs						
Males:	10/61	5/62	9/62	3/63	(+% spr. 62)	4/64	(+% spr. 62)
Lapps, Inari:							
Reindeer breeders	274	498	307	646	(+30)	1105	(+122)
(Number of subjects)	(33)	(20)	(9)	(10)		(10)	
Reindeer breeding fishers	115	322	189	404	(+25)	863	(+168)
	(3)	(16)	(4)	(2)		(11)	
Lapps of other occupations	157	187	132	205	(+10)	591	(+216)
	(4)	(11)	(5)	(13)		(6)	
Boarding school pupils	49	83	68	140	(+68)	-	-
	(11)	(11)	(9)	(8)			
Control group, Helsinki							
Adult males:	8,4	~8	17,9	16,4	(+105)	33	(+312)
	(5)		(5)	(25)			
Females							
Lapps, Inari:							
Reindeer breeders	125	237	205	425	(+79)	580	(+145)
	(21)	(10)	(2)	(4)		(6)	
Reindeer breeding fishers	60	137	83	143	(+4)	414	(+202)
	(1)	(6)	(1)	(2)		(4)	
Lapps ot other occupations	56	71	84	128	(+80)	329	(+363)
	(4)	(6)	(2)	(2)		(2)	
Boarding school pupils	40	64	70	82	(+28)	-	-
	(13)	(9)	(8)	(7)			
Control group, Helsinki :							
Adult females	3,2	~4	9,3	11,5	(+188)	18,6	(+365)
	(6)		(5)	(25)		(24)	