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STRONTIUM-90 IN DECIDUOUS TEETH COLLECTED IN NORTHERN FINLAND FROM CHILDREN BORN IN 1952—1964

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Strontium-90 content was measured by means of Čerenkov radiation in deciduous teeth collected in three areas in northern Finland from children born in 1952—1964.

The ^{90}Sr levels in tooth crowns in areas I and II showed a continuous increase in children born in 1952—1958, no further increase during the years 1959—1961, a sharp increase in 1962—1963, and no further change in 1964. In the northernmost part of Finland (area III) the strontium-90 contents of deciduous teeth when plotted against year of birth showed a slightly different trend with no increase during the years 1952—1957 and a steep rise in 1958 and 1959. These changes occurred in both Lapp and non-Lapp children. These differences in the strontium-90 content of deciduous teeth were presumably related to environmental peculiarities and specific dietary habits in area III. The maximum strontium-90 level, 16.76 pCi/gCa, was found in a sample of tooth roots of four Skolt children born in 1963.

The strontium-90 contents in the crowns of the four types of deciduous teeth were related as follows: second molars > cuspids > first molars > incisors.

The radioactive fallout contaminating the environment is well reflected in the ^{90}Sr content of the deciduous teeth in Helsinki children born in 1956—1963 (*Rytömaa*, 1971). The values observed in Helsinki compare favourably with those observed in the St. Louis area, Czechoslovakia and Denmark (*Rosenthal et al.*, 1966; *Santholzer & Knaifl*, 1966; *Aarkrog*, 1968, 1971) but differ from values observed in Italy (*D'arca Simonetti et al.*, 1969) and in the Faroe Islands (*Aarkrog*, 1968, 1971).

The strontium-90 content of mineralizing tissues, such as teeth, is related to dietary levels. Strontium and calcium have close chemical similarities and thus behave in the organism in a similar manner. Although the main source of calcium (about 85 %) in the average Finnish diet is milk, only half the dietary strontium-90 in adults is ingested with milk; the rest is present in

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cereal products, vegetables and meat (see *Paakkola*, 1970). This apparent discrepancy is due to the much lower strontium-90 content per gram of calcium in milk than in cereals, resulting from the fact that the cow's organism discriminates against about 95 % of the strontium present in fodder plants (*Paakkola et al.*, 1960; *Lakanen & Salo*, 1964; *Paakkola*, 1964b). However, milk dominates the infant's diet and is almost the sole source of strontium-90 in deciduous teeth.

Between southern and northern Finland there are differences in both the environment and the dietary habits of men and animals. The diet of Lapps is characterized by a high consumption of reindeer meat and, especially in the case of the Skolts, a low consumption of milk. It is known that these differences are responsible for the much higher caesium-137 body burden in Lapps and in non-Lapps living in Lapland than in people living elsewhere in Finland: the difference was at one time as great as 30-fold (*Miettinen et al.*, 1963). The main factor causing this is that in Lapland the staple food of reindeer (reindeer meat is very rich in ^{137}Cs) and sometimes even of cattle is lichen, which grows slowly and absorbs most of its nutriments, including ^{137}Cs and ^{90}Sr, from the air (*Paakkola & Miettinen*, 1963; *Salo & Miettinen*, 1964). During the winter reindeer feed almost exclusively on lichen; Lapps also use lichen to feed their cattle while the non-Lapps living in the same area use silage and hay (*Paakkola & Miettinen*, 1963). It is therefore not surprising that in the households of Lapps the strontium-90 content of milk has once been found to be fourfold that of non-Lapps living in Lapland (*Paakkola & Miettinen*, 1963). Similarly, in 1960 in Raittijärvi, Inari, the strontium-90 content of reindeer milk was 60 pCi/gCa, while in cow's milk it was 9 pCi/gCa (*Paakkola & Miettinen*, 1963). All these dietary differences between southern and northern Finland are well reflected in the finding (*Jokelainen et al.*, 1962; *Jaakkola et al.*, 1969) that in 1961 the strontium-90 in the diet of Skolts was 32 pCi/gCa, whereas in the diet of southern Finns it was 8.3 pCi/gCa.

In view of the high strontium-90 content in the diet of Lapps it may be surprising to learn that in 1966 a Lapp group (18 Skolt Lapps) was found to contain 4.8 ± 0.7 pCi ^{90}Sr per kg blood, while at the same time a group of southern Finns contained 4.4 ± 0.7 pCi/kg blood (*Jaakkola et al.*, 1969). This finding may perhaps be explained in terms of a low total intake of calcium in the diet of Skolts: the daily intake of calcium by the Skolt's diet is only 400—500 mg, while it is well over 1 000 mg in other Lapps and in southern Finns (*Jokelainen*, 1965).

The dietary differences between Lapps and the other people living in various parts of Finland make it interesting to compare the body burdens of ^{90}Sr in the different populations. So far, these comparisons have been limited to a few analyses of blood (*Jaakkola et al.*, 1969) and to occasional measurements in bone (*Salo et al.*, 1964; *Salo & Uotila*, 1969). It has been impossible to obtain a sufficient number of blood and bone samples for a large-scale evaluation of the body levels of strontium in Lapps, simply because the total Lapp population is very small (ca. 2 500 in Finland). The only direct way of estimating and comparing the body content of ^{90}Sr in Lapps and non-Lapps is to measure the strontium-90 in teeth.

MATERIAL AND METHODS

The material analysed consisted of 5 364 deciduous teeth obtained from 4 196 children. The teeth were collected in the years 1960—1970 by health sisters, school-teachers and dentists from 21 localities in three areas in northern Finland (Fig. 1).

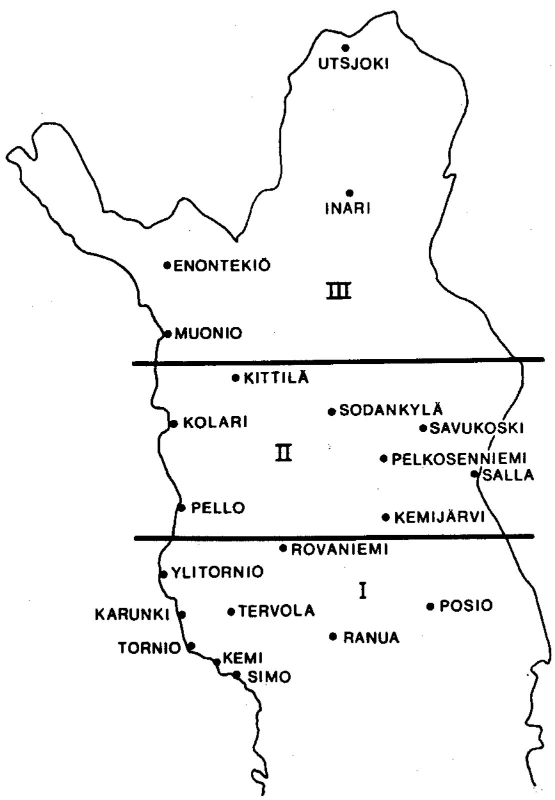

Fig. 1. **Map** of northern **Finland** showing the sampling localities for deciduous teeth.

The teeth were placed in polyethylene bags fixed to cards requesting answers to the following questions: birth year of the child, place of residence during the first year of life, ethnic origin of parents, and length of the breast-feeding period. The replies were occasionally incomplete.

Most of the material was from area I (Fig. 1), altogether 3 550 teeth. These were grouped according to the year of birth of the tooth donor, and to the tooth type (incisors, cuspids, first molars, second molars, and unidentified tooth fragments). When enough material was available, the teeth were further grouped according to the first and second halves of the birth year.

A total of 978 teeth were obtained from area II (Fig. 1). The teeth were grouped according to the birth year and, when possible, to the tooth type and to the first and second halves of the birth year.

836 teeth were obtained from the northernmost area, area III (Fig. 1). The teeth were grouped according to the birth year, type of the tooth, and race of the parents (Skolts, reindeer-breeding Lapps, non-Lapps, and various mixtures).

Caries and fillings were removed from all teeth and the crowns were separated from the roots. The material prepared in this way was dried overnight at 105°C and weighed. All samples were then ashed at 600°C for 2—3 days, and the ash was ground to a fine powder (Retsch Mühle) and weighed. From most samples 6 g of ash was taken for analysis; if more ash was available, replicate samples were analysed. In some tooth groups the samples were smaller in size, owing to shortage of material; a few samples from children born in 1963 contained only 0.8—2 g of ash. Less ash than average was available from children born in 1960s, but smaller samples could be used because the ^{90}Sr levels were expected to be higher.

The ash was dissolved in concentrated hydrochloric acid by heating and the volume of the final sample was made up to about 24 ml with distilled water. If the sample was yellow in colour (colloidal carbon) — this colour interferes strongly with the radioactivity measurement, owing to quenching — the solution was evaporated to dryness under infrared light, and the sample was re-combusted at 600°C and dissolved in hydrochloric acid as before. Re-combustion of a coloured sample increased the net count rate considerably, but produced no change in colourless samples. A total of 50 samples out of 207 were re-combusted.

The radioactivities of the samples were measured in a liquid scintillation counter, which makes use of the Čerenkov radiation produced by ^{90}Y (*Rytömaa & Paakkola*, 1971; *Rytömaa*, 1971). Despite re-combustion, a few samples caused significant colour quenching and their count rates were corrected with the aid of the channels ratio and the count rate of the external standard of the scintillation counter. After radioactivity had been determined, the calcium content of the samples was analysed by atomic absorption spectrophotometry. For further details of the techniques used and for a discussion of the errors involved, see *Rytömaa* and *Paakkola* (1971) and *Rytömaa* (1971).

The material studied comprised a total of 207 samples obtained from areas I—III and 22 background samples prepared from human teeth collected before 1940. All vials (every 10th was a background sample) were counted successively in at least 30 cycles until a total of 600 minutes or more was reached for each sample.

Because the samples analysed were counted 7—19 years after the ^{90}Sr was incorporated in the tooth tissue, all samples were corrected for the decay of strontium-90 (half-life 28 years) back to the year of birth of the child.

The mean background count rate was 12.8 cpm, with a relative standard error of $\pm$ 0.8 %. As observed before (*Rytömaa*, 1971), the variation between the different background samples was a little greater than was to be expected from the statistical counting error. This increase was apparently caused by small differences in sample quenching.

The relative error of the net sample counts was determined from the equation (*Haberer*, 1965)

$$f_r \sqrt{t} = \frac{\sqrt{n_N + 2\, n_0}}{n_N}$$

where f_r is the relative error, t the counting time ($\geqslant$ 600 minutes), n_N the observed net sample count rate, and n_0 the background count rate. According to this equation, the sample with the lowest count rate was counted with a relative error of $\pm$ 33 % and the sample with the highest count rate with a relative error of $\pm$ 1.3 %. In 4/5ths of the samples the relative counting error was less than $\pm$ 10 %.

RESULTS

The average weights of the different types of deciduous teeth (3 199 certainly identified teeth collected from area I) were as follows: incisors (1 140 teeth) 130 mg, cuspids (1 091 teeth) 226 mg, first molars (565 teeth) 290 mg, and second molars (403 teeth) 525 mg. The average ash weight was 77.2 % of the tooth weight, and the average calcium content was 35.7 % of the ash weight (all tooth groups pooled).

The strontium-90 contents obtained for incisors, cuspids, first molars, and second molars in area I are presented in Fig. 2 and Table I. It is seen that in all deciduous tooth types the ^{90}Sr content continuously increased throughout the years 1952—1958. No further increase seems to have occurred during 1959, 1960 and 1961, but during the next two years, 1962 and 1963, the strontium-90 content of deciduous teeth rose to values which were about twice as high as the level observed in 1958—1961. According to the three samples analysed from children born in 1964, the strontium-90 content of incisors, first molars and second molars remained at the same level as in children born in 1963.

It is seen from Fig. 2 and Table I that the strontium-90 contents were higher in second molars than in the other types of deciduous teeth. If the relative pCi ^{90}Sr/gCa level in second molars in children born in 1952—1964 is 100, then the average levels in the other groups of deciduous teeth are as follows: incisors 67.9, cuspids 80.6 and first molars 71.0.

The results obtained for deciduous teeth of children living in area II are presented in Fig. 3 and Table I. The mean strontium-90 contents of deciduous teeth plotted against year of birth followed a similar course in areas I and II: a continuous increase throughout the period 1952—1958, no further increase during 1959, 1960 and 1961, and a strong increase in 1962 and 1963 (cf. Figs 2 and 3).

The strontium-90 contents in the deciduous teeth of children living in area III (Fig. 4 and Table I) appear to follow a slightly different pattern. During the years 1952—1958 the strontium-90 values tend to be lower in area III than in areas I and II, but during the years 1959—1963 the situation is reversed.

The strontium-90 content in deciduous teeth of Lapp children born in 1959—1963 may be somewhat higher than in deciduous teeth of non-Lapp

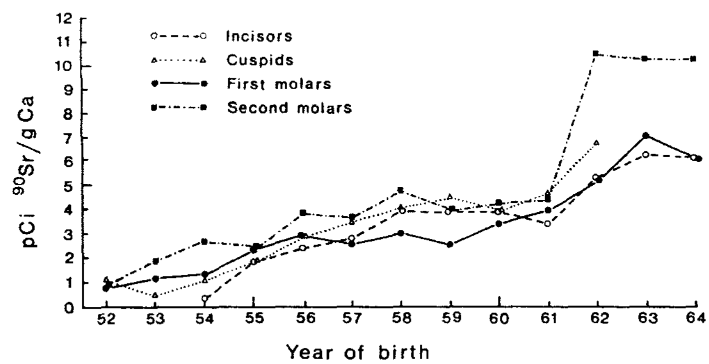

Fig. 2. Mean ^{90}Sr content (pCi/gCa) of different deciduous tooth types in area I plotted versus year of birth.

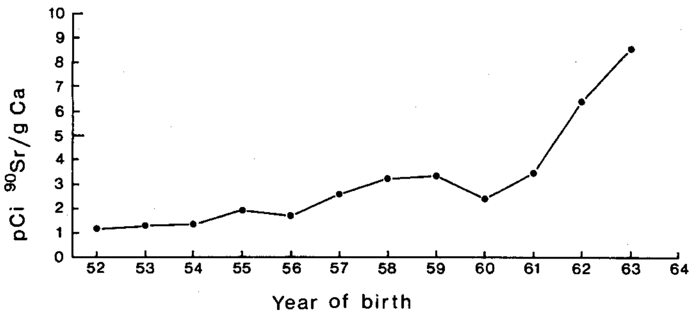

Fig. 3. Mean ^{90}Sr content (pCi/gCa) of deciduous teeth in area II plotted versus year of birth.

children living in the same area: if the relative pCi $^{90}Sr/gCa$ level in the former group is 100, it is 91.8 in the latter group (statistically this difference is not significant). For deciduous teeth of children born in 1963 the number of samples analysed is relatively high; therefore the results obtained for the different races are given separately in Table II. On the basis of these results differences in the strontium-90 contents between the various races appear questionable. It should be noted, however, that the value obtained for the tooth roots of the four Skolt children was the highest ^{90}Sr content measured in the present study.

Table III lists the individual strontium-90 contents in deciduous teeth of eight Lapp children born in 1963 (reindeer-breeding Lapps). These results show that individual variations are large, ranging in the present group from 5.90 pCi/gCa to 13.69 pCi/gCa. The two extreme values were obtained for children living in the same village, which demonstrates that the fallout rate

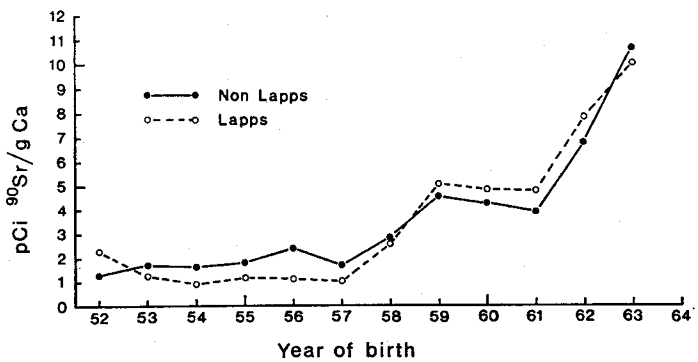

Fig. 4. Mean ^{90}Sr content (pCi/gCa) of deciduous teeth in area III in Lapp and non-Lapp children versus year of birth.

Table I.

Strontium-90 content (pCi/gCa) of deciduous teeth collected in three different areas in northern Finland from children born in 1952—1964. When replicate samples from the same

Area of residence Ethnic origin of parents	Type of tooth	Year of birth				
		1952	1953	1954	1955	1956
	Incisors			0.36	1.86±0.08	2.42±0.10
	Cuspids	1.07±0.37	0.44±0.18	1.10±0.28	1.89±0.12	2.84±0.20
I	First molars	0.82±0.22	1.17	1.36±0.01	2.34±0.26	2.95±0.03
	Second molars	0.87±0.12	1.93±0.14	2.68±0.01	2.46±0.05	3.84±0.01
	Unidentified fragments	1.56±0.20	1.67	2.14±0.16	2.20±0.16	
	Incisors				2.00±0.18	
II	Cuspids	1.22	1.27	1.18	2.29	
	Diff. types combined	1.11±0.10	1.34±0.28	1.50±0.12	1.54±0.01	1.42* 1.94†
III non-Lapps	Crowns	1.26	1.68	1.61	1.81±0.11	2.38±0.28
	Roots	←——1.44——→		←——2.07——→		2.46±0.36
III Lapps	Crowns	2.26	1.25	0.93	1.16	1.12
	Roots					

need not be the main factor determining the body burden of strontium-90. Thus, owing to differences e.g. in dietary habits the strontium-90 content of the body may vary by a factor of at least two. In view of this, it is somewhat surprising that in this material there was no correlation between the length of the breast-feeding period and the strontium-90 content of the deciduous teeth (see Table III).

DISCUSSION

The strontium-90 content of deciduous teeth is a good measure of the ^{90}Sr body burden (*Reiss*, 1961; *Rosenthal et al.*, 1966; *Aarkrog*, 1968, 1971;

*pool of tooth ash were analysed, the mean ± SE is given. Strontium-90 contents of teeth collected from children born during the first half of the year are indicated by * and during the second half of the year by †*

Year of birth							
1957	1958	1959	1960	1961	1962	1963	1964
3.62*	3.94*	3.90	3.94*	3.09*	5.16*	7.74*	6.14
1.93†	4.01†		3.81†	3.69†	5.49†	5.68†	
						5.29	
3.10±0.02*	4.02±0.44*	4.22±0.05*	4.30*	4.68	6.74		
3.85±0.41†	4.27†	4.98†	3.56†				
2.71*	2.89*	2.49*	3.60*	3.43*	5.15*	8.26*	6.12
2.54†	3.20†	2.61†	3.28†	4.52†	7.30†	4.67†	
						8.28	
3.66	4.79	3.57*	3.99*	4.01*	10.10*	10.12*	10.34
		4.38†	4.48†	4.90†	10.92†	10.99†	
						9.97±0.18	
2.26*	3.42*	3.38	2.37	3.48	6.37	8.56	
2.93†	3.10†						
1.65	2.82	4.54	4.24	3.84	5.60	9.34	
					7.93±0.25	11.93±0.29	
←2.36→		1.19	4.43	5.67	9.05±0.11	9.88±0.78	
0.98	2.56	5.06	4.81±0.07	4.74	7.77±0.13	10.09[1]	
	0.37	4.99	6.90	6.64	9.82±0.18	9.97[1]	

1) Details presented in Tables II and III

Rytömaa, 1971). Thus samples collected in northern Finland from children born in 1952—1964 closely follow changes in the fallout rate of strontium-90, except perhaps in the northernmost part of Finland (Lapland). The increase in deposited artificial radioactivity resulting from the nuclear tests in 1952—1958 is reflected in the continuous increase of the strontium-90 content of deciduous teeth in children born in 1952—1958. Because no further nuclear devices were exploded above ground before 1961, the ^{90}Sr content of deciduous teeth did not increase during the years 1959, 1960 and 1961; in fact, there seems to have been a decrease in teeth collected from children born in 1960. These trends are identical with those observed in deciduous teeth by *Aarkrog*

Table II.

Strontium-90 content (pCi/gCa) of deciduous teeth collected in area III from Lapp and non-Lapp children born in 1963

Ethnic origin	Area of residence	Number of children	Number of teeth	Type of teeth	pCi $^{90}Sr/gCa$ Crowns	pCi $^{90}Sr/gCa$ Roots
Skolts	Inari	4	10	First & second molars	13.40	16.76
Reindeer-breeding Lapps	Inari, Enontekiö, Utsjoki	9	15	First & second molars	11.43	8.17
	Inari, Utsjoki	8	37	First & second molars	9.93[1]	9.34[1]
Mixed marriages	Inari	2	6	Incisors & molars	7.10	
	Enontekiö, Inari, Utsjoki	11	25	Incisors & molars	9.76	7.53
Non-Lapps	Enontekiö, Inari	14	20	Incisors, cuspids & first molars	9.34	9.88 (for both rows)
	Enontekiö, Inari, Muonio	20	38	Second molars	11.93	

[1]) Average values: details presented in Table III

Table III.

Strontium-90 content (pCi/gCa) of deciduous teeth collected in area III from eight reindeer-breeding Lapp children born in 1963

Place of residence	Duration of breast feeding (months)	Numbers of teeth		Weights (grams)			pCi ^{90}Sr/gCa	
		First molars	Second molars	Crowns	Ash	Calcium	Crowns	Roots
Utsjoki, Outakoski	12	2	2	1.53	1.20	0.432	13.69	
Utsjoki, Outakoski	9	3	1	1.21	0.93	0.341	11.77	7.25
Utsjoki, Outakoski	8	3	1	1.06	0.83	0.287	5.90	
Utsjoki, Polvilampi	7	1	2	1.47	1.17	0.421	10.78	
Utsjoki, Kaamasmukka	1.5	2	4	2.24	1.75	0.647	7.93	10.87
Utsjoki, Akukoski	6	3	4	2.57	2.04	0.766	11.13	
Inari, Ivalo	6	2	2	1.63	1.26	0.468	6.68	7.83
Inari, Menesjärvi	3	3	3	2.03	1.58	0.594	11.54	11.40

(1971) in Denmark, Greenland, and the Faroes, and it also corresponds well to the strontium-90 content in human bone samples collected in the north temperate zone from 0 to 4-year-old children (UNSCEAR report, 1969).

After the resumption of nuclear tests in 1961, the strontium-90 contents rose sharply in deciduous teeth collected in northern Finland from children born in 1962 and 1963. These results are in accordance with observations made in other localities (see *Rytömaa*, 1971; *Aarkrog*, 1971), and they also compare well with the strontium-90 levels in human bone in Finland (*Salo et al.*, 1964; *Salo & Uotila*, 1969), Norway (*Hvinden*, 1967) and elsewhere (UNSCEAR report, 1969; *Aarkrog*, 1971). As was expected from the decreased annual fallout rate of strontium-90 in 1964, and from the ^{90}Sr levels detected in human bone, the strontium-90 content in deciduous teeth did not increase further in children born in 1964.

When the strontium-90 levels in deciduous teeth in the three different areas in northern Finland are compared with each other and with the levels observed in other localities (see *Rytömaa*, 1971; *Aarkrog*, 1971), it is seen that the values are well within the expected range. But there are a few minor peculiarities, some of which may be worth noting in this context. For instance, the average level of strontium-90 in deciduous teeth is higher in area I than in area II, although no such difference would be expected from the fallout rates of ^{90}Sr, the strontium-90 content in milk, or the dietary habits of the people living in these areas (see *Paakkola*, 1966). The explanation of the difference detected is apparently due to dissimilarities in the material analysed: in area II the material consisted of small numbers of second molars and large numbers of incisors (the tooth type in which the relative pCi $^{90}Sr/gCa$ level is lowest).

As shown in the results, the relative ^{90}Sr contents in the four types of deciduous teeth are related as follows: second molars > cuspids > first molars > incisors. This is in fact the order expected, because discrimination against ^{90}Sr is greater prenatally than postnatally (UNSCEAR report, 1969), because postnatal calcium deposition in the crowns is 95 % for second molars, 94 % cuspids, 83 % for first molars, and 68 % for incisors (*Reiss*, 1961), because postnatal period of calcification is 11 months for second molars, 9 months for cuspids, 6 months for first molars, and 5 months for incisors (see *Reiss*, 1961), and because the Sr/Ca ratio is higher in cow's milk than in breast milk (see *Wasserman*, 1963). Similar differences in the relative contents of strontium-90 between the tooth types have been reported by *Aarkrog* (1968). Lower strontium-90 levels in incisors than in other tooth types have also been observed elsewhere (*Rosenthal et al.*, 1966; *Rytömaa*, 1971; *Aarkrog*, 1971).

The results show that the variation in strontium-90 contents between the three different areas is not very marked. Areas I and II are probably identical in respect to both the curve form (strontium-90 content of deciduous teeth versus year of birth) and the average pCi $^{90}Sr/gCa$ level, but the northernmost area is somewhat different. For children born during the years 1952—1957 the strontium-90 contents of deciduous teeth did not increase in area III as they did in areas I and II; another obvious difference was the steep increase occurring in area III in teeth of children born during the years 1958 and 1959. This unique curve form observed in the northernmost part of Finland is apparently not artificial, because these changes in the strontium-90 contents of deciduous teeth occurred in both Lapp and non-Lapp children. In children born during the years 1959—1963 the average strontium-90 level in deciduous teeth was also higher in area III than in areas I and II. This is in accordance with the strontium-90 content in milk in the corresponding areas (*Miettinen et al.*, 1961; *Paakkola & Miettinen*, 1963; *Paakkola*, 1964a).

Differences in the strontium-90 contents of deciduous teeth between the three areas are presumably related to environmental peculiarities and specific dietary habits in area III. At the first glance, race does not seem to be involved either directly or indirectly, because there is no significant difference in the strontium-90 content of teeth between Lapp and non-Lapp children. This may be surprising, because the strontium-90 content in the milk — and in the diet in general — has been found to be fourfold in the households of Lapps as compared with non-Lapps living in the same area (*Jokelainen et al.*, 1962; *Paakkola & Miettinen*, 1963). Perhaps the effect of this difference is cancelled out by the lower total intake of calcium, and hence also of ^{90}Sr, in the diet of Lapps (at least of Skolts) than of non-Lapps (*Jokelainen*, 1965). In any case the absence of a marked difference in the ^{90}Sr content of deciduous teeth between Lapp and non-Lapp children is substantiated by the similar ^{90}Sr values in the blood of Skolts and southern Finns (*Jaakkola et al.*, 1969).

However, the observation that body burdens of ^{90}Sr are similar in spite of different dietary habits does not mean that dietary habits play a minor role in the accumulation of strontium-90 in the body. This is clear from the large variation in the strontium-90 content of deciduous teeth observed among the eight reindeer-breeding Lapp children. In particular, two children living in the same village, and hence under identical environmental conditions, showed ^{90}Sr content in their deciduous teeth which differed by a factor of about two (5.90 and 13.69 pCi/gCa). It is likely that the great variation between the eight children is due to differences in the farming practices and the dietary habits of individual families.

In addition to the strontium-90 contents of deciduous teeth, the present study also gave other information of interest. Thus the average weight found for the four different tooth types can be compared with the values reported by *Reiss* (1961). The average weights of deciduous incisors (132 and 130 mg) and cuspids (222 and 226 mg) in the two materials are almost identical, but the values for the molars are a little lower in the present material (307 and 290 mg in the case of first molars, and 592 and 525 mg in the case of second molars). These differences are evidently caused by the severe caries observed in the present material.

The average ash weight (77.2 %) compares well with values reported in the literature (see *Miles*, 1967). This also applies to the calcium content (35.7 % of ash weight). The average calcium content was a little higher in the sample of deciduous teeth collected in Helsinki (*Rytömaa*, 1971) than in the present study, but the difference is probably not biologically significant.

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