consumed in large quantities by caribou and reindeer.[2,4] In addition to ^{90}Sr and ^{137}Cs, ^{210}Pb and ^{210}Po have also been observed to be in high concentrations in lichens and in bones and some soft tissues of caribou, while in the muscle of the latter, high levels of ^{210}Po have been observed.[6–9] For this reason, it has been suggested that populations who consume a regular diet of caribou or reindeer meat may also have high body burdens of ^{210}Pb and ^{210}Po. The latter, being an alpha emitter, is particularly hazardous in high concentrations with respect to internal radiation exposure.[10]

The body burden of ^{137}Cs has been measured extensively throughout the caribou eating populations of Alaksa by whole-body counting techniques employing gamma-spectrometry.[3–5,11]

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has reported the ^{210}Po concentrations in 18 samples of human placenta,[12] and the ^{210}Pb content of 3 bone samples from northern Canada.[8] In addition, HOLTZMAN has reported concentrations of ^{210}Pb and ^{210}Po in 3 placenta and 1 blood sample from subjects residing near Barrow, Alaska.[7]

As a result of the absence of ^{210}Po and ^{210}Pb measurements in tissues from the Alaskan Eskimo, it has been possible only to compute an approximate body burden of these nuclides from either the analyses of caribou meat with an estimated intake or from urine analyses. From the latter, BEASLEY and PALMER have estimated that the average ^{210}Po body burden of people living at Anaktuvuk Pass, Alaska is 3.5 nCi.[9]

It has been generally accepted that the source of the ^{210}Pb in the arctic ecosystem, as in other regions, is from the decay of atmospheric ^{222}Rn.[6–9] Lead atoms so formed return to the

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8	77	M	Koyuk	A steady diet of reindeer meat, but ate none during terminal illness of 3 months

3	0.24 ± 0.04	1.2 ± 0.2	0.20 ± 0.05
4	0.32 ± 0.05	0.8 ± 0.1	0.40 ± 0.09
6	1.8 ± 0.1	2.1 ± 0.3	0.9 ± 0.1

C—Carcinoma present; O—ovary; T—testis.
Errors are one standard deviation counting error.

The order of listing is the same as that used in Table 1; lower to higher caribou consumption. The concentrations are based upon fresh weight for the soft tissue and defat weight for the rib samples. The uncertainties shown are for a one standard deviation counting error.

The values observed in the samples from the Alaskan subjects, #1 and #2, who had eaten no caribou meat are within the normal range of values reported for unexposed populations.[8,20,21] The lower lung and rib levels reported for #1 are probably due to her young age, 6 yr. Hence, if these two sets of tissues may be assumed typical, then the ^{210}Pb-^{210}Po body burden of an Alaskan whose diet does not include caribou or reindeer meat is similar to that of individuals residing in the conterminous United States.

The ^{210}Pb and ^{210}Po tissue concentrations of subject #3, who ate caribou meat while in Barrow but none during the last 3 yr while living in Anchorage, are somewhat less but not significantly different from those of unexposed U.S. residents.[20,21] As HILL has reported high ^{210}Pb levels in 3 human bone samples from northern Canada,[8] and considering the 2400-day half-life of ^{210}Pb in the skeleton,[13] it was somewhat surprising, if the dietary information is correct, that the bone level in this case is not higher than that observed. Subjects #4 and #5, who occasionally included caribou meat in their diet, contained significantly higher concentrations of ^{210}Po in the kidney and liver samples and possibly in the testes of the latter. The concentration of ^{210}Pb in the rib sample of #5 is high with respect to the other rib samples measured; however, it does fall within the concentration range reported by HOLTZMAN for an unexposed population.[21]

The results showed significantly higher levels of ^{210}Po in the soft tissues of subjects considered to be caribou or reindeer meat eaters. The concentration of ^{210}Po in tissues of subjects #6, #7 and #8 were about 4, 14 and 18 times, respectively, the values reported for tissues of an unexposed population.[8,20,21] Smoking data are not available for these Alaskans; however, their ^{210}Po lung concentrations are significantly higher than observed even in the lung of cigarette smokers.[20,22] The results in Table 2 also show, except for bone, a general increase in the ^{210}Po concentration with consumption of caribou or reindeer meat.

Subject #7 ate caribou regularly in winter, and, as he died on December 19, had included caribou meat in his diet for 3–4 months prior to death. Subject #6 included caribou meat in her diet a few times each month, while #8 ate reindeer regularly until 3 months prior to his death, during which time he had eaten none. It is quite interesting that although these three subjects had elevated ^{210}Po soft tissue levels, their ^{210}Pb bone concentrations do not show a proportional increase, and fall within the range reported by HOLTZMAN for concentrations observed in human bone samples of residents of the conterminous United States.[21] It has been reported that although caribou bones, liver and kidney contain high concentrations of ^{210}Pb,[8] the concentration in the meat is low, 5–16 pCi/kg,[6] and not much different from that observed for beef in the conterminous United States.[21] Consequently, unless the subject had consumed an extract of the caribou bone or a soft tissue which concentrates ^{210}Pb, as liver or kidney, the ^{210}Pb skeletal burden would probably not be expected to be much higher than for individuals who consumed no caribou meat.

The ^{210}Po/^{210}Pb activity ratio exceeds one and is generally much greater in soft tissues of the subjects who ate caribou or reindeer meat. Similar results were recently reported by KAURANEN and MIETTINEN for reindeer breeders living in Lapland.[23] These high activity ratios are especially significant in the case of the lung for which activity ratios of less than one are usually observed.[20] Since the ground-level air concentration of ^{210}Pb is about 10 times greater than ^{210}Po,[24] these results suggest exposure by a route other than inhalation and by a source containing ^{210}Po in excess of ^{210}Pb. These observations support the conclusion that caribou or reindeer meat is the principal source of ^{210}Po for this population.

When large quantities of ^{210}Pb are ingested, it is concentrated in the skeleton with an effective half-life of about 2400 days.[23] During this time, the ^{210}Po grows into near radioactive equilibrium with the ^{210}Pb and serves as a reservoir for other body compartments.[25] That is, some ^{210}Po is translocated from the skeleton to other body tissues which sustains the

for subject #3 who ate caribou regularly while residing at Barrow, but not while residing in Anchorage during the three years preceding death. Except for the concentrations in the kidney and liver which appear to be significantly higher than normal, the same reasoning can explain the apparent "normal" ^{210}Po concentrations in tissues of subjects #4 and #5. In addition, the ^{210}Po tissue concentration of subject #8 who ate reindeer regularly until three months before his death was undoubtedly much higher while eating caribou than was observed at the time of his death.

The body burden of ^{210}Po was estimated for subject #8 by summing the products of the concentration observed in each tissue multiplied by the tissue mass, based on the 70 kg "standard man".[13] On this basis, approximately 60% of the total body mass was analyzed. The concentration in the remaining 40% was assumed equal to that in muscle. The ^{210}Po body burden of this subject, so calculated, was estimated at death to be 1.7 nCi. Taking $\frac{1}{10}$ the ICRP recommended value for an occupational exposed population as the maximum permissible body burden for the general population, the estimated body burden at death, 1.7 nCi, is about one-half the maximum burden if the spleen is assumed the critical organ.[13]

If it is assumed that the ^{210}Po is distributed uniformly within the organ and if 10 is used as the RBE for ^{210}Po alpha particles, then the dose rate in mrem/year is numerically equivalent to the concentration of ^{210}Po in the units of pCi/kg of tissue. Consequently, the dose rates delivered by ^{210}Po to these tissues may be read directly from Table 2. The soft tissues which contain the higher levels, kidney and liver, are exposed respectively. This corresponds to a dose rate of about two and 1 rem/yr, respectively, if the assumptions mentioned above are correct.

In making the above extrapolation to estimate the tissue concentration 3 months prior to death, it was assumed that the metabolism during the terminal 3 months of illness was normal, the diet during this interval contained no food with abnormally high levels of ^{210}Po, and that the biological parameters given by ICRP for ^{210}Po are accurate. The first assumption may not be true and the ^{210}Po excretion rate may have been different than that of a healthy person. It is, however, unlikely that this individual consumed food during hospitalization which contained high concentrations of ^{210}Po, and the ICRP values, although possibly requiring some revision, are the best presently available. Consequently, the person who consumes caribou meat daily will probably receive larger dose rates from the ^{210}Po during the time of ingestion than is indicated by the results shown in Table 2. Tissue levels for such individuals would be extremely valuable; however, autopsies are rarely performed on subjects of this population, and to obtain autopsy tissue samples will be extremely difficult.

Lichens and caribou

In order to determine if thermonuclear explosions in the arctic contributed significantly to the ^{210}Pb levels in the arctic ecosystem, samples of lichen and caribou (*Rangifer tarandus*) bones which had been collected before the advent of nuclear testing in the arctic (1951), were analyzed for ^{210}Pb and ^{226}Ra. The collection data and analytical results for the lichen

samples and caribou bones are given in Tables 3 and 4, respectively. The ^{210}Pb results have been corrected for radioactive decay to reflect the concentrations at the time of collection and the ^{210}Pb, contributed by the ^{226}Ra since the time of collection, has been subtracted.

The ^{210}Pb levels in 14 Alaskan lichen samples collected over the last 8 yr have been reported.[7,9,26] These varied from 3.44 to 69 pCi/g dry weight with an average of 13 ± 8 pCi/g (S.D.). The data in Table 4 indicate that lichens collected prior to 1951 had ^{210}Pb concentrations ranging from 3.41 to 34.5 pCi/g dry weight with an average of 16 ± 12 pCi/g (S.D.). Thus, there was no apparent increase in ^{210}Pb concentration due to nuclear testing activities. Further, the range of values (9.68–39.5 pCi/g) for lichen samples collected at Anaktuvuk Pass in 1949 bracket the 14.9 pCi/g recently reported from the same area.[9]

Table 3. Concentrations of ^{210}Pb *and* ^{226}Ra *in Alaskan lichen samples collected before* 1951

Sample	Location	Date collected	^{210}Pb, *pCi/g†	^{226}Ra, pCi/g†
Cetraria islandica	Point Barrow 71°19′N, 56°40′W	1948	17.3 ± 0.2	0.050 ± 0.011
Cetraria richardsonii	Point Barrow 71°19′N, 56°40′W	1948	12.2 ± 0.1	0.045 ± 0.010
Alectoria nitidula +*Cladinia* sp.	Anaktuvuk Pass 68°10′N, 51°54′W	1949	35.0 ± 0.2	0.043 ± 0.010
Sphaerophorus globosus	Anaktuvuk Pass 68°10′N, 51°54′W	1949	9.68 ± 0.12	0.125 ± 0.009
Parmelia omphalodes	Anaktuvuk Pass 68°10′N, 51°54′W	1949	39.5 ± 0.2	0.028 ± 0.004
Cetraria delisei	Wainwright 70°39′N, 160°W	1949	12.2 ± 0.1	0.034 ± 0.011
Cladonia subulata	Cape Nome 64°28′N, 165°W	1923	7.30 ± 0.10	0.122 ± 0.008
Cladonia uncialis	Noorvik-on Kobuk River 66°49′N, 161°6′W	1923	3.41 ± 0.06	0.032 ± 0.006
Cladonia cenotea	Cape Nome 64°28′N, 165°W	1923	6.2 ± 0.10	0.031 ± 0.006

* Activity corrected to date of collection and the ^{226}Ra contribution subtracted.
† Dry weight (dried at 90°C for 24 hr).

Table 4. Concentrations of ^{210}Pb *and* ^{226}Ra *in caribou bone collected before* 1951

Sample number	Location collected	Date collected	Age	Bone type	^{210}Pb(pCi/g)*	^{226}Ra(pCi/g)
OC-01	Longhead Island 77°20′N, 105°W	8–16	Adult	Metatarsal	15.4 ± 0.2	0.21 ± 0.01
OC-02	Ellesmere Island 78°3′N, 85°W	3–35	Adult	Occipital	8.08 ± 0.13	0.25 ± 0.01
OC-03	Teslin Dist., Yukon Terr. 60°2′N, 132°50′W	11–12	Adult	Manible	5.4 ± 0.17	0.24 ± 0.01
OC-04	Nettilling Lake, Baffinland 66°26′N, 71°W	8–25	Fawn	Ulna	1.51 ± 0.08	0.065 ± 0.006
OC-05	Near George R., Quebec 53°30′N, 66°12′W	9–49	Fawn	Scapula	2.08 ± 0.12	0.11 ± 0.01

* Activity corrected to date of collection and the ^{226}Ra contribution subtracted.

Table 5. A comparison of the ^{210}Pb *content in old and recent caribou bones*

Latitude	Concentration in recent (1965–1966) caribou bones (pCi ^{210}Pb/g)[6]	Concentration in pre-1951 caribou bones from Table 4 (pCi ^{210}Pb/g)
<60°N	Range: 2.1–5.6 (14) Mean: 3.1 ± 0.4	2.1 (fawn)
60°–65°N	Range: 2.4–7.5 (26) Mean: 4.5 ± 0.4	5.4
>65°N	Range: 4.9–13.1 (15) Mean: 7.6 ± 0.6	15.4, 8.1 1.5 (fawn)

Note: (a) The number of caribou are given in parentheses
(b) The uncertainties are the standard deviations of the mean.

The next step in the arctic food chain is caribou, which should also reflect higher levels of ^{210}Pb after 1951 if nuclear testing contributed substantially to the ^{210}Pb levels in the arctic environment. The ^{210}Pb results for the pre-1951 caribou bone samples given in Table 4 are compared in Table 5 to adult caribou bone samples which were collected during 1965–1966.[6] Due to a possible increase in the ^{210}Pb bone concentration with increasing latitude,[6] the results in Table 5 are arranged in three groups according to latitude. Except for sample OC-05, a fawn, the results of the pre-1951 samples are within the range of values reported for the recent samples.

As it has been reported that the ^{210}Pb skeletal burden of fawns is only about one-half that found in the skeleton of the adult,[6] the two samples from fawns, OC-04 and OC-05, are undoubtedly low relative to adult caribou from the same areas. As in the case for lichen samples, there does not appear to be any substantial increase in the ^{210}Pb skeletal burden of caribou following the advent of nuclear testing in the arctic. Consequently, it seems unlikely that arctic testing of nuclear weapons has had any significant effect on the amount of ^{210}Pb in the arctic ecosystem.

SUMMARY

Although there were relatively few tissue samples available for study, the results indicate that caribou or reindeer meat is the principal source of ^{210}Po for Alaskan residents, and that, in general, the intake of ^{210}Pb and ^{210}Po by inhalation is about the same as in the conterminous United States. In addition, it was illustrated in the case of these subjects that consumers of caribou meat may ingest large quantities of ^{210}Po unsupported by its parent, ^{210}Pb. This produces high ^{210}Po body burdens only as long as the subject continues to eat caribou or reindeer meat, and when the meat is eliminated from the diet the ^{210}Po will be excreted within a relatively short period and the body burden will approach that of an unexposed person.

The ^{210}Pb concentrations in lichen and caribou bone samples collected before 1951 were comparable to concentrations in similar samples recently collected. The data tend to discount the importance of nuclear testing in the arctic as a significant source of ^{210}Pb.

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