Transfer of the Uranium Decay Products, Polonium-210 and Lead-210, Through the Lichen-Caribou-Wolf Food Chain in Northern Canada

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ABSTRACT (May 1991)

A STUDY OF POLONIUM-210 AND LEAD-210 IN THE LICHEN-CARIBOU-WOLF FOOD CHAIN

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The main purpose of this study is to investigate the accumulation and transfer of polonium-210 and lead-210 in the arctic food chain, lichen-caribou-wolf, in the Northwest Territories. Polonium-210 arises from lead-210 decay and is a widespread alpha-emitting radionuclide. It seeks soft tissue and has the potential to accumulate in the food chain. Caribou, wolves and other wildlife may become exposed to enhanced levels of these two uranium-series radionuclides if the proposed uranium mine near Baker Lake, Northwest Territories, proceeds.

Baker Lake lies at the crossroads of the ranges of the Beverly, the Kaminuriak and the Wager Bay caribou herds. Therefore, it is important to establish baseline concentrations and natural food chain transfer of uranium series radionuclides,in this study. This information can be used for baseline data before any further mining development takes place. This study will also provide data regarding the statistical uncertainty attached to transfer coefficients. This can help ensure reliable and appropriate future monitoring of environmental change.

With the participation of the hunters of Baker Lake, caribou and wolf samples were collected and analyzed for polonium. Results indicate that polonium-210 activity in caribou tissues were somewhat higher than previous data reported from Alaska. Transfer coefficients for polonium-210 from caribou to wolf were near unity for many tissues. However, polonium-210 does not appear to cross the placenta in caribou.

Further study includes lichen collections and collection of further caribou samples from the Beverly herd in order to determine transfer from lichens to caribou in both the Baker Lake and Snowdrift areas in the Northwest Territories.

CONTENTS

LIST OF ABBREVIATIONS

Bq	Becquerel (unit of radioactivity corresponding to one disintegration per second).
Cs-137	Cesium-137
kg	kilogram
LET	Linear Energy Transfer
mSv	millisievert (1/1000 Sievert)
Pb-210	Lead-210
Po-210	Polonium-210
Sv	Sievert (absorbed biological dose unit; 1 Sievert = 100 rem)
TC	Transfer coefficient

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EXECUTIVE SUMMARY

The main purpose of this study is to investigate the accumulation and transfer of polonium-210 and lead-210 in the lichen-caribou-wolf arctic food chain in the Northwest Territories. Polonium-210 arises from lead-210 decay and is a widespread alpha-emitting radionuclide. It seeks soft tissue and has the potential to accumulate in the food chain. Caribou, wolves and other wildlife may become exposed to enhanced levels of these two uranium-series radionuclides if the proposed uranium mine near Baker Lake, Northwest Territories, proceeds.

Baker Lake lies at the crossroads of the ranges of the Beverly, the Kaminuriak and the Wager Bay caribou herds. Therefore, it is important to establish baseline concentrations and natural food chain transfer of uranium series radionuclides. This information can be used for baseline data before any further mining development takes place. This study will also provide data regarding the statistical uncertainty attached to transfer coefficients. This can help ensure reliable and appropriate future monitoring of environmental change.

With the participation of the hunters of Baker Lake, caribou and wolf samples were collected and analyzed. This report covers the analyses of polonium-210 (Po-210) and lead-210 (Pb-210) activity in tissues from 24 caribou and 21 wolves, collected from Baker Lake in the Northwest Territories during the winter of 1991. This is Phase I of a more extensive Ph. D. study.

Baseline Po-210 activities in caribou tissues were somewhat higher than previously reported from Alaska in the 1960's. Liver and kidney mean activities were 308 and 200 Becquerels (Bq)/kg, respectively. Muscle mean activities (16 Bq/kg) were at the high end of the range of previously reported values (1-19 Bq/kg, Blanchard and Kearney 1967).

Baseline Po-210 activity in wolf tissues were similar to caribou tissues, with two exceptions. Wolf bone (31 Bq/kg) was an order of magnitude less than caribou bone (474 Bq/kg). Wolf kidney (264 Bq/kg) was slightly higher than caribou kidney (200 Bq/kg).

Lead-210 activities were less than 200 Bq/kg in all analyzed tissues except caribou bone (1023 Bq/kg). High Po-210/Pb-210 ratios (35:1) were found in wolf liver and kidney. Ratios less than unity were found in bone from both species

All organisms concentrate substances into their body from their environment, including some polonium. This is called **bioconcentration**. However, if concentration in the tissues of a consumer species are greater than concentration in their food

source, this is called **biomagnification.** Biomagnification is measured by the means of **transfer coefficients.** Transfer coefficients greater than unity indicate biomagnification in that particular food chain.

Transfer coefficients (TCs) were calculated for caribou tissues in relation to their food source by utilizing rumen content analyses. Polonium-210 TCs from rumen contents to caribou tissues were above unity for bone, liver and kidney and less than unity for muscle and fetal tissues. Lead-210 TCs varied, depending on the tissue.

Transfer coefficients for Po-210 from caribou to wolf, using wolf stomach content analyses were variable, due to the inhomogeneous nature of wolf stomach contents. Therefore, transfer was analyzed by comparing a given caribou tissue with the same tissue in the wolf. Transfer coefficients were determined for cortical bone (TC = 0.065), kidney (TC = 1.32), liver (TC = 0.77) and muscle (TC = 0.63). Lead-210 TCs were much lower.

The data also indicate Po-210 does not cross the placenta in caribou, while Pb-210 appears to cross the placenta. This is evident since Po-210 concentrations are higher in muscle and placental tissue than they are in fetal or fetal liver samples. The opposite is true in the case of Pb-210.

For Phase II of the study, lichen collections are planned from the following areas: hunting grounds, used by Baker Lake, Snowdrift and Wollaston Lake (Saskatchewan) hunters; calving grounds near Baker Lake; and the Kiggavik mine site near Baker Lake. Lichen samples will be collected with reference to radiation maps, indicating uranium surface outcrops by bismuth-214 aerial radiometric surveys. With the help of the communities of Snowdrift, Northwest Territories, and, possibly, Wollaston Lake, Saskatchewan, collection of samples from 24 caribou from the Beverly herd are planned for next winter.

INTRODUCTION

One of the greatest areas of uncertainty in environmental impact assessment of uranium mining is the lack of baseline data on the distribution of radionuclides in the terrestrial environment and subsequent movement in food chains leading to man. This is of particular concern in the Arctic where deposition of contaminants can be widespread and the concentration in food chains significant.

Arctic ecosystems are prone to accumulation of aerial contaminants. Lichens are important components of arctic ecosystems and efficiently accumulate airborne contaminants because of their large surface area and longevity. They are the base of simple food chains. Contaminants cannot become "diluted" among a diversity of consumers in these simple food chains (Whicker and Schultz 1982). Since lichens form a substantial part of the winter diet of caribou, radionuclides can accumulate in caribou tissue. A diet of caribou can impart higher radiation burdens to northerners than the diets of other populations.

When mining activities bring ore to the surface and mill it to fine tailings, there is opportunity for uranium decay products, especially the gas radon, to be released more widely to the environment. Baseline data on the distribution of these decay products in the terrestrial environment and their subsequent food chain transfer to man must be measured in order to assess the impact of uranium mines. One such development is the proposed Kiggavik uranium mine near Baker Lake, N.W.T., which lies on the migration routes of three caribou herds.

The Kiggavik mine site is near the calving grounds of the Beverly caribou herd, forms part of the winter range of the Wager Bay herd, and is also home to a herd of resident caribou. Areas near the northern Saskatchewan border are part of the winter range of the Beverly herd and are near of inactive and currently active uranium mines. The Snowdrift area, on the east arm of Great Slave Lake, is just north of a natural radioactive belt. These areas contain caribou hunting grounds for local residents and, as such, are the concern of this study.

Increased radiation burdens in northerners consuming reindeer or caribou has been shown for cesium-137 (Cs-137) from atmospheric nuclear tests in the 1960's (Hanson et al. 1964; Blanchard and Kearney 1967) and the 1986 Chernobyl accident (MacKenzie 1986; Skoglund 1987). Accumulation of natural uranium decay products in food chains is also important to examine because, unlike Cs-137, some of the radon daughters emit alpha radiation.

Blanchard (1967) was one of the first to recognize the potential toxicity of polonium-210, as one of the naturally occurring radon daughters. This is because Po-210 is widespread from uranium decay in rocks and soils around the world, emits alpha radiation, has a short half-life (138 days) and seeks soft tissue where it can be consumed by animals at the next trophic level in the food chain. Polonium-210 is derived from lead-210, which is long-lived (half-life 22 years) and concentrates in bone. Lead-210 is, in turn, a daughter of the widely dispersed radon gas.

Baseline concentrations of these radionuclides in the food chain will help ensure reliable and appropriate future monitoring of environmental changes. From these data, transfer coefficients and estimates of natural background dose can also be determined. Transfer coefficients, as well as their standard deviations, are needed for use in subsequent food chain modelling and risk assessment. As a result, more comprehensive environmental impact assessment of uranium decay products will be possible.

Transfer coefficients are calculated by dividing the concentration of polonium-210 in the consumer's tissue by the concentration in the food source or corresponding prey tissue. Any transfer coefficient greater than unity indicates the ability of the substance to biomagnify in the food chain. This has been shown for Cs-137, where transfer coefficients are 2-3 between trophic levels. There is some evidence (Holtzman 1968) that Po-210 may also biomagnify slightly in muscle tissue.

Purpose

The main purpose of this study is to investigate the role of the food chain, lichen-caribou-wolf, as a pathway for the transfer of uranium series radionuclides. Polonium-210 (Po-210) is of particular importance because of its radiotoxicity and ability to concentrate in edible soft tissues. The longer lived lead-210 (Pb-210) is also of interest because it concentrates in bone and can serve as a body reservoir for Po-210,.

The objectives of the study are: (1) to determine the level of Po-210 in lichen, several caribou tissues and several wolf tissues; (2) to derive transfer coefficients for Po-210 between trophic levels in the food chain, and (3) to determine Po-210:Pb-210 ratios for lichens and selected tissues in caribou and wolf.

The study will model Po-210 transfer from one trophic level to the next. Standard deviations for transfer coefficients will provide uncertainty parameters, which are needed to estimate dose from food chain models more accurately. Greater accuracy will make it easier to set appropriate limits for acceptable radionuclide release into the environment and gain more perspective on radiation risk in the north.

For environmental impact assessment, the relationship between Pb-210 and Po-210 will also be examined in some tissues. If this relationship is consistent, data for the one radionuclide can be used to predict levels of the other. This can help facilitate environmental monitoring for radon daughters.

Literature Review

Naturally occurring polonium-210 (Po-210) is widely dispersed, emits alpha particles with high linear energy transfer (LET) and seeks soft tissue. Its presence in soft tissues means Po-210 is able to pass through food chains to man. Polonium-210 can account for a significant fraction of the alpha emitting radionuclides in marine organisms and humans (Holtzman 1966, McDonald et al. 1986).

Polonium-210 came to the attention of radioecologists in the early 1960s during their investigations of nuclear weapons fallout. They found that lichens, as the base of the arctic food chain, were efficient accumulators of aerial contaminants, such as the fission product, cesium-137, and naturally occurring Pb-210. Lichens, as the primary winter forage for reindeer and caribou, serve as radionuclide reservoirs and thus can transfer contaminants to caribou and on to man.

The decay of uranium in rocks and soils releases radon-222 (Rn-222) to the atmosphere, with concentrations four times higher near the ground (Hamilton 1967). Radon-222's rapid decay to lead-210 occurs in the air, with Pb-210 being deposited to soil by rainfall (Haar et al. 1967). Long-term accumulation by lichens results in the slow decay of Pb-210 (half-life = 22 years) to polonium-210 (Po-210).

The early research on Po-210 yielded several general conclusions. Researchers agreed that: 1) Po-210 and Pb-210 were not released from bombs; 2) Pb-210 levels were correlated to Cs-137 and strontium-90 (Sr-90) in their mode of deposition; 3) diet and not air, water or internal decay of radium-226 or Rn-222 was the primary route of exposure; 4) an arctic diet of caribou doubles Pb-210 concentrations and increases Po-210 by one or two orders of magnitude in human tissues; and, 5) high latitude and the winter season increases Po-210 and Pb-210 in caribou because of increased consumption of lichens by caribou. Blanchard and Kearney (1967) showed that spring-killed caribou contained four times more Po-210 than autumn-killed animals, due to a winter diet restricted to lichens.

In lichens, Po-210 and Pb-210 activity levels are similar. Lichens show Po-210 levels of 296-740 Bq/kg dry weight, Pb-210 levels of 111-2,553 and Po-210/Pb-210 ratios near one (Blanchard and Kearney 1967, Blanchard and Moore 1970, Holtzman 1968, Sheard et al. 1988). Although Pb-210 accumulation is considered constant, local variation has been noted near uranium outcroppings and mine sites (Benson et al. 1983, Sheard et al. 1988). For Po-210 and Pb-210, species variation, rainfall, wind and habitat also have an effect.

There have been no studies on Po-210 deposition onto lichens near uranium (U) outcrops. Svoboda et al. (1985) measured U, Radium-226 (Ra-226) and Cs-137 in substrates and vegetation along transects up to 16 km out from the Lone Gull and Nogassh uranium outcrops near Baker Lake, N.W.T. They found elevated levels 100 m from the outcrops and higher levels of U and Ra-226 600 m to the south in a drainage basin. However, both U and Ra-226 are water transported, whereas Po-210 and Pb-210 must be studied with regard to wind direction and rainfall patterns because they are also deposited aerially.

Polonium-210, ingested directly from food or redistributed from bone stores, goes to many soft tissues. Hill (1966) found ratios of concentration in human tissues, relative to placental concentration, of 8:5:5:1:1 for bone, kidney, liver, muscle, and placenta, respectively. Unlike bone or lichen, the Po-210/Pb-210 ratio can be as high as 7 in human liver (Blanchard 1967) or 20 in caribou spleen (Beasley and Palmer 1966). Hill (1965) suggested Po-210 may bind to insulin in the pancreas. Smoking can triple concentrations in the lung but is thought to turn over rapidly without going to other tissues.

When consumed by caribou or man, Hill (1967) about 8% of ingested Pb-210 is absorbed. It seeks bone, where it is stored and subsequently decays to Po-210. There is debate about: 1) the redistribution of Po-210 to other soft tissues from Pb-210 decay in bone; 2) the biological half-life of Po-210 in soft tissues and; 3) the rate of direct absorption of Po-210 from the intestine, assumed to be about 6% (Kauranen and Miettinen 1969, McDonald et al. 1986).

Caribou muscle has 10-100 times more Po-210 activity than meats from southern areas (Beasley and Palmer 1967). High consumption of caribou and reindeer can transfer the Po-210 and Pb-210 from edible soft tissues to man (Hill 1966). In the north, ingestion rates were estimated at 300-900 g/day/person with the average Po-210 concentration in meat being 4-8.5 Bq/kg (Blanchard 1967, Blanchard and Kearney 1967, Hill 1965, Kauranen and Miettinen 1967).

Polonium-210 levels in blood have been shown to be 17 times higher in Lapps than in southern Finns. Soft tissues in Lapps and Inuit people show Po-210 concentrations generally 12 times higher than in their southern counterparts (Kauranen and Miettinen 1969, Blanchard and Moore 1970). In 32 human placentae from the northern Canada, Hill (1966) found average values three times and one value 80 times the average placental values from other populations. Hill's data, indicate Po-210 activity levels of 4.2 Bq/kg wet weight from the northwest coast of Hudson Bay; 1.26 Bq/kg from inland rural areas along the MacKenzie River; 0.89 Bq/kg from Yellowknife among those subjects eating caribou several times per week. Subjects from England showed placental Po-210 activities of 0.12 Bq/kg.

The only attempt to measure transfer coefficients for Po-210 was Holtzman's (1968) study on 10 caribou and two wolves. He reasoned that wolves were at the same trophic level as people and thus concentrations in wolf tissue might be similar. However, the type of tissue consumed and metabolic differences must be considered. His measured values yield a transfer coefficient of 1.16 (wolf:caribou) for Po-210 for muscle tissue. These transfer coefficients are particularly important in testing Hill's (1967) hypothesis that Po-210, when bound organically to protein in caribou tissue, may transfer more efficiently than Po-210 from other food sources. In other words, organically bound Po-210 may be assimilated at rates greater than 8%.

If such transfer coefficients were known with greater accuracy and site-specific data were obtained for areas of concern, dose estimates and the prediction of consequences from uranium mining for food chains would be more realistic. The need for more specific measurements has been noted by many authors (Turner 1963; McDowell-Boyer et al. 1980; Swanson and Richert 1987).

METHODS

The study will measure background levels of lead-210 and polonium-210 for: 1) three trophic levels in the food chain near Baker Lake, Northwest Territories; 2) lichens and caribou near Snowdrift, Northwest Territories and 3) lichens from hunting grounds north of Wollaston Lake in northern Saskatchewan. Lichen samples will consist of 24 samples of Cladina mitis from Baker Lake and 12 samples of C. mitis from Snowdrift and 12 samples from Kasba Lake in the Northwest Territories. The Kasba Lake area is utilized by hunters from Wollaston Lake in Saskatchewan. Quadrat samples will also be collected to assess the forage diversity found in the different sampling areas. For the second trophic level, samples from 24 caribou were analyzed from Baker Lake. Analyses of samples from 24 caribou from Snowdrift is planned. For the third trophic level, 21 wolves were analyzed from Baker Lake.

The study is divided into two phases. Phase I covers the collection and analysis of caribou and wolves from Baker Lake. Phase II covers: 1) the collection of lichens from hunting grounds used by all three communities; 2) caribou samples from Snowdrift and Wollaston Lake; and 3) return trips to all communities to report the study's results.

Community involvement is fundamental to the study design. For Phase I, an initial trip to Baker Lake in January 1991 provided opportunity to explain the study and to discuss procedures with hunters regarding the collection of samples. From late February through April 1991, hunters collected seven samples from each caribou or wolf killed: a femur; a portion of the rumen; embryos with placentae, if present; both kidneys; one kilogram of liver; one kilogram of muscle tissue; and a tooth for ageing the animal. These samples were shipped to Saskatoon for analyses by a hired local coordinator. All samples were analyzed for Po-210. The femur, rumen contents, placentae and fetuses were analyzed for Pb-210. For fetal analyses, the entire fetus was homogenized, except for the head and legs.

Similar procedures are planned for Phase II caribou samples from Snowdrift. In the summer of 1991, lichen samples will be collected from all three community hunting grounds with the aid of radiometric maps. Strata for sample sites to be chosen which should reflect surficial radioactivity from uranium deposits by Bi-214 activity (Grasty et al. 1984). A total of six strata, showing both high and low surface activity, will be chosen. Four random samples will be chosen within each stratum. This study design allows possible correlation of local variation of Po-210 activity in lichens with uranium surface deposits.

Analysis of samples for Po-210 and Pb-210 will be performed using the standard methods of the Saskatchewan Research Council's analytical lab (Energy Research Program, CANMET, 1979). Detection limits are 0.005 Bq for polonium-210 and 0.02 Bq for lead-210.

All samples for Po-210 analysis were wet ashed by nitric-perchloric acid dissolution under low heat until all organics are gone. This is a difficult procedure due to the explosive reaction between perchloric acid and organic material. Since Po-210 is volatile, temperature must be carefully controlled to avoid boiling off the polonium. The ashed sample was then dissolved in hydrochloric acid (HCl) and diluted. It is also possible to lose Po-210 from recovery by its adhesion to glassware when it is diluted from strong acid. The sample was then plated on to silver disks for 100 minutes, placed next to a zinc sulfide film and measured by alpha spectrometry.

Lead-210 samples are also wet ashed. After repeated extraction with 0.1% DDTC extractant in 2M HCl, the precipitate plus bismuth carrier (bismuth oxychloride) were precipitated, redissolved, filtered and measured for bismuth-210 activity. Using percent bismuth-210 (Bi-210) recovery and equilibrium between Bi-210 and Pb-210, Pb-210 activity is calculated.

Quality control for analysis included blind duplicates for 20% of the samples, blanks and a spiked standard. Questionable results were re-analyzed. The published methods require the use of the tracer, Po-208, in order to determine polonium recovery after analysis. This was not done in the early data analyses from the 1960s and was not done by the Saskatchewan Research Council. The Saskatchewan Research Council lab are now updating their methods as a result of this study. These problems in recovery may reduce the values for Po-210 reported.

Because Po-210 has a short half-life (138 days), a correction factor was applied to account for Po-210 decay occurring between the time the animal was killed and the analysis. It was calculated for each measured Po-210 concentration as follows:

$$N_t = N_0 \, (e^{-\lambda \, t})$$

In this equation, N_t equals measured Po-210 concentration, lambda (λ) equals 0.693/ $T_{1/2}$, which equals 0.00502 for Po-210, and t equals time (in days) between kill and analysis. By rearrangement and substitution, $N_0 = N_t \, / \, e^{-(0.00502) \, t}$. Therefore, values for N_0 were subsequently used in the analysis.

Analyses were reported in Becquerels/gram, using two significant figures; twenty gram samples were measured for all soft tissue; ten gram samples were measured for bone. Duplicate analyses of 20% of the samples show a percent deviation from the average value range from 4% for Pb-210 in caribou bone to 33% for

Po-210 in fetal liver. One must remember that this error also accounts for inhomogeneity in these biological samples and the inherent difficulty in the wet ashing technique. Particular attention must be paid to possible volatilization of Po-210 when being digested under low heat.

RESULTS

Polonium-210 concentrations in caribou were highest in bone (474 Bq/kg), followed by liver (308 Bq/kg) and kidney (200 Bq/kg). High levels in bone were expected in cortical bone, since bone is known to sequester Pb-210, which produces Po-210 by radioactive decay. As expected from literature values, levels were much lower in muscle and placenta. They were still lower in fetal tissues. Mean activities for Po-210 and Pb-210 are shown in Table 1.

Placental activity levels (21 Bq/kg) and muscle activity (16 Bq/kg) than in the homogenized fetal sample (5 Bq/kg). This indicates Po-210 may be inhibited from crossing the placenta in caribou. Fetal liver contained more Po-210 (13 Bq/kg) than the homogenized fetal organs (5 Bq/kg). This would indicate that when Po-210 does cross the placenta, it concentrates in fetal liver. This is also the case in adult caribou.

Bone stores of Po-210 in wolves were an order of magnitude less (31 Bq/kg) than in caribou bone (474 Bq/kg). This may be due to the fact that many wolves shot in the Keewatin are young wolves with lower bone stores of Pb-210. The highest levels of Po-210 were found in kidney (264 Bq/kg) and liver (237 Bq/kg). Polonium-210 activity in wolf kidney was slightly higher than in caribou kidney.

Table 1
Mean Polonium-210 (Becquerels/kg), Lead-210 (Becquerels/kg) and Po-210/Pb-210 ratios in Baker Lake Caribou and Wolves

Organism/ tissue	N	Po-210	s.d.	Pb-210	s.d.	Po-210/Pb-210
Caribou						
Bone	24	474	154	1023	393	0.49
Rumen	24	164	29	103	25	1.65
Kidney	24	200	71	84	32	2.91
Liver	24	308	64	158	40	1.93
Muscle	24	16	7			
Placenta	15	21	5	3	1	9.14
Fetus	13	5	3	11	6	0.49
Fetal liver	5	13	6	25	13	0.52
Wolves						
Bone	21	31	13	179	104	0.23
Stomach contents	13	115	109	359	446	2.97
Kidney	21	264	88	7	2	35.06
Liver	21	237	89	6	4	34.88
Muscle	20	10				

Mean lead-210 concentrations in caribou were an order of magnitude higher in bone (1023 Bq/kg) than in liver (158 Bq/kg) and kidney (84 Bq/kg). Lead-210 measurements were low (3 Bq/kg) for placenta. Levels were higher for fetal tissues (11 Bq/kg) and higher still for fetal liver (25 Bq/kg).

With a Po-210/Pb-210 ratio of 9:1 in caribou placenta, it is interesting to find ratios less than one in caribou fetal tissues. This suggests that Pb-210 crosses the placenta much more readily than Po-210. High Pb-210 levels and lower Po-210 levels result in the observed low Po-210/Pb-210 ratio in fetal tissues.

Mean lead-210 activity in wolves was two orders of magnitude higher in bone (179 Bq/kg) than in liver (6 Bq/kg) or kidney (7 Bq/kg). These Pb-210 levels in bone, liver and kidney were an order of magnitude lower than they were in the comparable caribou tissues.

In both caribou and wolf, high Pb-210 levels in bone indicate that Pb-210 is stored preferentially in bone. This is very different from the situation with Po-210, where soft tissue activity levels are similar to bone levels. Unfortunately, no Pb-210 analysis was planned for muscle tissue. It may be possible to do so, using future Phase II caribou samples.

Mean Pb-210 content in wolf stomach contents (359 Bq/kg) were higher than in caribou (103 Bq/kg). However, standard deviations for wolf stomach contents were very high (see Table 1). Although caribou rumen contents are primarily homogeneous lichen material, wolf stomach contents are extremely heterogeneous. This caused great variability in the analyses, since stomach contents may consist of bone fragments, meat, masses of fat and hair or mixtures of these. (Fat cannot be wet ashed with nitric acid without exploding. This was evident when a bone marrow sample was attempted). The presence of bone in wolf stomach contents caused the increases in Pb-210 in these samples. In addition, the feast and famine eating habits of wolves resulted in many wolf stomachs being empty.

Polonium-210/Pb-210 ratios for bone were less than unity, indicating that long-term storage of Pb-210 in bone has driven the ratio down. Ratios in all other tissues were above unity, indicating excess Po-210 was present and not in equilibrium with its parent, Pb-210. The highest ratios (35:1) were found in wolf kidney and liver; these ratios are an order of magnitude greater than in the comparable caribou tissues.

It has been suggested that high Po-210 stores in liver and kidney are a result of Po-210 redistribution from bone. High Po-210/Pb-210 ratios (35:1) in wolf liver and kidney suggest this, which are not found in caribou kidney or liver. Alternatively, it may be that Po-210, when organically bound in caribou tissue, is taken up directly by the wolf liver and kidney from the diet, as Hill (1967) suggested. Since Pb-210 in wolf bone is much lower than in caribou bone, it is likely Po-210 in wolf liver or kidney is from dietary intake than from bone redistribution.

Transfer coefficients (TCs) for Po-210 and Pb-210 from rumen contents to caribou tissues were calculated for each animal by dividing the tissue activity by the stomach content activity. The mean values for these TCs are shown in Table 2. Rumen contents were mostly lichen material and so this is indicative of transfer from lichen trophic level to herbivore trophic level.

Polonium-210 TCs from rumen to caribou were greater than one for bone, kidney and liver, on the order of 10^{-1} for placenta and muscle and 10^{-2} for fetal tissues. This indicates that: 1) Po-210 increases slightly in concentration from the food source (rumen contents) to bone, kidney and liver; 2) does not sequester in muscle and 3) is prevented from crossing the placenta to a large extent.

Transfer coefficients from Table 2 indicate that Pb-210 in caribou is preferentially sequestered in bone (TC=10.43). Biomagnification is slight in liver (TC=1.725) and TCs are near unity for kidney (TC=0.911). Transfer coeffients are an order of magnitude higher for the fetus than it is for the placenta, once again indicating the ability of Pb-210 to cross the placenta.

Table 2
Transfer Coefficients from Rumen Contents to Caribou Tissue

Tissue	[Caribou]/[Rumen Contents]					
	N	Po-210	s.d.	N	Pb-210	s.d.
Bone	24	2.937	1.015	24	10.433	4.786
Kidney	24	1.275	0.560	24	0.911	0.285
Liver	24	1.920	0.476	24	1.725	0.376
Muscle	24	0.097	0.044		-	
Placenta	15	0.132	0.040	15	0.025	0.007
Fetus	13	0.034	0.020	13	0.111	0.062
Fetal liver	5	0.089	0.045	5	0.264	0.109
*FL/liver	5	0.045	0.025	3	0.140	0.034

*Transfer from maternal liver to fetal liver (FL).

Transfer coefficients, calculated from wolf stomach contents to wolf tissues, were highly variable. The general trend in these data do indicate, however, Po-210 TCs of 5 between gut contents and liver or kidney and 10^{-1} for bone and muscle. In contrast, Pb-210 TCs are 15 for bone and 10^{-1} for liver and kidney.

Comparisons can also be made by calculating TCs from the tissue means of both species. When this is done, it appears that Po-210 biomagnifies in only one tissue transfer from caribou to wolf. This is the caribou kidney to wolf kidney (TC= 1.32), shown in Table 3. Transfer coefficients are slightly less than unity for liver and muscle. Bone TCs are much less at 10^{-2}. This would indicate that Po-210 in bone arises more from Pb-210 stores than from direct intake whereas Po-210 in soft tissues may result from direct intake from the diet.

For Pb-210 tissue to tissue comparisons, transfer coefficients are 10^{-1} for bone and 10^{-2} for liver and kidney. These low TC's are likely due to the estimated 10% absorption of Pb-210 across the gut wall. While this prevents biomagnification, it is still high, relative to the absorption of other heavy metals.

Table 3
Transfer Coefficients from a Given Caribou Tissue to the Same Tissue in Wolf.

Tissue	[Wolf Tissue]/[Caribou Tissue]			
	Po-210	s.d.	Pb-210	s.d.
Bone	0.065	0.035	0.175	0.123
Kidney	1.320	0.643	0.083	0.043
Liver	0.769	0.330	0.035	0.025
Muscle	0.625	0.370	-	-

In calculating the TCs from caribou to wolf, it should be noted that <u>mean</u> concentrations for each tissue were used, i.e., mean concentration of wolf bone divided by mean concentration in caribou bone. This is necessary since no individual caribou is related to any individual wolf, except through stomach content analysis. Thus, the data in Table 3 reports TCs as a ratio of two means. The standard deviation for a ratio of two means, x and y, was calculated using the following formula:

$$S_{\frac{\bar{y}}{\bar{x}}} = \sqrt{\left(\frac{\bar{y}}{\bar{x}}\right)^{2}\left[\frac{S^{2}\bar{x}}{\bar{x}^{2}} + \frac{S^{2}\bar{y}}{\bar{y}^{2}}\right]}$$

DISCUSSION

When activity measurements for Po-210 from this study are compared with previous data from the 1960's, it is evident that Po-210 concentrations in Baker Lake caribou are somewhat higher than those measured previously in Alaska. Beasley and Palmer's (1966) data show 171 Bq/kg in liver versus 308 in this study; 150 Bq/kg for kidney versus 200 in this study; 140 Bq/kg for bone versus 474 in this study; and 11 Bq/kg for muscle versus 16 in this study. Blanchard and Kearney's (1967) data on 95 caribou showed a range of Po-210 values for muscle from 1-19 Bq/kg. Thus, this study's data are at the high end of the range for muscle.

There are three reasons for these differences. Firstly, Beasley and Palmer's (1966) data was based on small sample sizes. Secondly, most of the 1960s' data was measured on Alaskan caribou from a higher latitude and possibly from an area with fewer surface outcroppings of uranium than the Keewatin-Baker Lake area. However, the general assumption has been that Po-210 is globally dispersed and does not show local variation. This assumption may prove debatable and will be examined through Phase II lichen analyses.

The second possibility is that early methods for analyzing Po-210 may have differed somewhat from methods in this study. It is certainly possible to lose Po-210 during digestion or due to the length of plating time onto the silver disks. Neither the 1960's methods nor this study's methods used a Po-208 tracer to estimate Po-210 recovery. Because of this, results from this study should be comparable to earlier work.

The results of this study do provide some evidence for high absorption of Po-210 from a caribou diet in the wolf. Polonium-210 does not appear to biomagnify since transfer coefficients were near unity in wolf kidney and liver. However, high Po-210/Pb-210 ratios of 35 for wolf kidney and wolf liver suggest significant absorption or redistribution in the body. Since bone stores of Pb-210 in the wolf are not lower than in caribou, direct intake of Po-210 from the diet may explain the presence of excess Po-210 in wolf liver and kidney.

The use of the wolf in environmental impact assessment is of value because the wolf is at the same trophic level as people in this food chain. Wolves and people consume different amounts and types of caribou tissue and thus may consume different amounts of Po-210 from this source in their diets. Metabolic differences must also be considered. However, the wolf data does allow an estimate of the transfer from Po-210 from caribou tissue to body tissues at the next trophic level in this food chain.

These results may suggest that current environmental impact assessment processes require more routine monitoring of Po-210 in environmental samples. Such analyses are, indeed, expensive and hazardous. However, if local variation in Po-210 in lichens or caribou exists, then mining companies may possibly be adding to this source of exposure by grinding up large volumes of ore and releasing radon gas.

CONCLUSIONS

The results of this study lend support to the hypotheses that Po-210, organically bound to animal tissue, may be absorbed to a greater extent than Po-210 in lichens. This is suggested by the differences in transfer coefficients; transfer from rumen contents (i.e., lichen) to caribou muscle is 0.097 while transfer from caribou muscle to wolf muscle is 0.63. High Po-210/Pb-210 ratios of 35 in wolf liver and wolf kidney also suggest high absorption of Po-210 from diet, particularly since wolf bone stores of Pb-210 are low relative to caribou.

Transfer of Po-210 from rumen contents to caribou liver and kidney are above unity. This suggests slight biomagnification. However, higher levels of Po-210 in kidney and liver may result from redistribution of Po-210 from Pb-210 decay in bone, since Pb-210 stores in caribou bone are so high.

Transfer of Po-210 from caribou tissues to similar wolf tissues show slight biomagnification for kidney (TC=1.32) but not for other tissues. However, TCs for liver (TC=0.769) and muscle (TC=0.625) indicate that wolf tissues still absorb a significant fraction of the Po-210 in their food source, caribou.

Transfer of Pb-210 from caribou to wolf clearly shows no biomagnification. Lead-210 levels in wolf bone, kidney and liver are an order of magnitude less than in the comparable caribou tissues. However, Pb-210 levels in caribou placentae, fetus and fetal liver indicate that Pb-210 crosses the placenta. In contrast, Po-210 levels indicate Po-210 is inhibited from crossing the placenta.

Baseline activities of Po-210 in Baker Lake caribou indicate somewhat higher levels than Alaskan data from the 1960s. This may be due to sample variation, local variation in natural uranium surface outcrops in the two regions or a difference in methods for Po-210 analyses. If local variation is the cause, then radon dispersion, and subsequent Pb-210 and Po-210 dispersion, from uranium mines may have an environmental impact on this food chain.

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