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Radionuclide Levels in Caribou of Northern Alaska in 1995–96

TODD M. O'HARA,[1] DOUG DASHER,[2] JOHN C. GEORGE[1] and VICTORIA WOSHNER[3]

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ABSTRACT. Caribou (*Rangifer tarandus*) were sampled (1995–96) from a mortality event near the Project Chariot site (the location of a radiotracer experiment in northwestern Alaska during the 1960s) and reference sites. Radionuclide levels in muscle and bone and the cause(s) of the mortality were determined because of local residents' concerns. Bone gross alpha mean activity (n = 65) was 130.0 Bq/kg, and varied significantly ($p < 0.01$) from 73.3 to 168.0 Bq/kg among locations. Bone gross beta mean activity was 510.4, and muscle gross beta mean activity was 9.78 Bq/kg. Bone strontium-90 mean activity (n = 58) was 137.8 Bq/kg. Muscle potassium-40 mean activity (n = 65) was 83.0 Bq/kg, and varied significantly from 76.0 to 104.4 Bq/kg among locations. Muscle cesium-137 mean activity (n = 65) was 6.67 Bq/kg, ranged significantly from 0.74 to 15.6 Bq/kg by location, and increased with increasing body condition score. Bone potassium-40 mean activity ranged from 18.9 to 47.4 Bq/kg, and muscle strontium-90 ranged from 8.89 to 20.0 Bq/kg. Radionuclide concentrations were at expected levels. In some cases, they were low compared to those in Canadian caribou studies.

Key words: caribou, *Rangifer*, radionuclides, Alaska, Project Chariot

RÉSUMÉ. En 1995 et 1996, on a prélevé des échantillons de caribou (*Rangifer tarandus*) morts accidentellement près de l'emplacement du projet Chariot (N.-O. de l'Alaska), sur les lieux d'une expérience menée avec des radiotraceurs dans les années 1960 et sur des lieux de référence. On a déterminé les niveaux de radionucléides dans les muscles et les os ainsi que la ou les causes de mortalité afin de répondre aux questions que se posaient les résidents de la région. La radioactivité moyenne brute alpha dans les tissus osseux (n = 65) était de 130,0 Bq/kg, et variait largement ($p < 0,01$), de 73,3 à 168,0 Bq/kg selon les emplacements. La radioactivité moyenne brute bêta dans les tissus osseux était de 510,4 et celle dans les tissus musculaires était de 9,78 Bq/kg. La radioactivité moyenne du strontium 90 (n = 58) était de 137,8 Bq/kg. La radioactivité moyenne du potassium 40 (n = 65) dans les tissus musculaires était de 83,0 Bq/kg, et elle variait largement, de 76,0 à 104,4 Bq/kg selon les emplacements. La radioactivité moyenne du césium 137 (n = 65) dans les tissus musculaires était de 6,67 Bq/kg et variait largement, de 0,74 à 15,6 Bq/kg selon l'emplacement; son augmentation suivait celle de la cote de l'état du corps. La radioactivité moyenne du potassium 40 dans les tissus osseux allait de 18,9 à 47,4 Bq/kg, et celle du strontium 90 dans les tissus musculaires allait de 8,89 à 20,0 Bq/kg. Les niveaux de concentration en radionucléides étaient ceux auxquels on s'attendait. Dans certains cas, ils étaient bas, par rapport à ceux d'études canadiennes sur le caribou.

Mots clés: caribou, *Rangifer*, radionucléides, Alaska, projet Chariot

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INTRODUCTION

An investigation of weak and dead caribou near Point Hope (PH), Alaska and dead carcasses on and near Cape Thompson (CT), Alaska in 1995 included aerial surveys, necropsy of many carcasses, chemical analyses (radionuclides), aging, and a similar examination and analyses of caribou from reference or control sites (Barrow, Teshekpuk Lake, and Red Dog Mine).

This study explored potential causes of caribou mortality, specifically the roles of radionuclide exposure and emaciation due to malnutrition. This monitoring effort was conducted to compare caribou from the 1995 mortality event at Point Hope and Cape Thompson to caribou sampled from other locations. We compared the recent (1995) radionuclide exposure levels to historically reported levels and to levels reported from Canada, and studied the effects of body condition (BC score) and age of the animal on measured levels.

Point Hope, Alaska is one of the oldest continually occupied Iñupiaq villages in North America (Burch, 1981) and is near the Project Chariot site. Burch (1981) estimated the pre-contact population (ca. 1850) of the Point Hope "region" at about 1300, which is greater than the present occupation. Caribou were the most important nonmarine mammal species harvested at Point Hope in

[1] Department of Wildlife Management, North Slope Borough, Box 69, Barrow, Alaska 99723, U.S.A.; tohara@co.north-slope.ak.us
[2] Alaska Department of Environmental Conservation, 610 University Ave., Fairbanks, Alaska 99709, U.S.A.
[3] Department of Veterinary Biosciences, College of Veterinary Medicine, University of Illinois, 2001 S. Lincoln Ave., Champaign, Illinois 61802, U.S.A.

terms of amount (mass). During the 1992 calendar year, the village took approximately 225 animals (Fuller and George, 1997).

Caribou are seasonally available but tend to move toward the eastern boundary of the Point Hope area in July, following the post-calving aggregations in the northern foothills of the De Long Mountains of the western Brooks Range (Jim Dau, pers. comm. 1995). Burch (1981) reported accounts of dozens to hundreds of animals moving towards the village from the northeast, from the Kukpowruk Basin. During the early and middle portion of the 19th century, when the Western Arctic Herd (WAH) was apparently quite large, small groups of caribou moved out towards Point Hope. However, this movement was highly variable then, as it is now (Burch, 1981). During winter 1995, some of the authors and local residents observed the animals moving onto the Point Hope spit and adjacent sea ice, and this movement was considered unusual.

In March 1995, local residents observed weak and dead caribou of the Western Arctic Herd (Fig. 1) near the village of Point Hope, Alaska. We responded and examined six freshly found dead or killed (euthanatized) caribou. We concluded, on the basis of lack of fat (subcutaneous, visceral, marrow cavity), histology (serous atrophy, hepatic hemosiderosis), and minimal muscle mass, that malnutrition/emaciation was the major cause of death and severe weakness.

Documentation of malnutrition/emaciation events is essential for understanding mortality factors during critical periods of severe weather, increased population numbers, degraded range, decreased forage availability, or disease. Also, responding to public concerns about why a large number of animals died is considered part of the management team's responsibility. Documenting these events calls for a thorough examination of many carcasses and the local environmental conditions temporally and spatially associated with the mortality event.

A unique aspect of this situation at Cape Thompson, Alaska is the presence of the Project Chariot site, a locally infamous area where a radionuclide tracer experiment (intentional contamination of soil, water, and other matrices) was conducted in the early 1960s. This site was implicated as a possible source of contamination, and we expanded our efforts to include radionuclide analyses. We compared radionuclide levels in the bone (femur) and associated muscle from three reference populations to levels at the locations of concern (Point Hope and Cape Thompson) near the Project Chariot site.

Project Chariot Site

Studies were conducted at Cape Thompson in northwestern Alaska in preparation for Project Chariot (1958–63) (North Slope Borough Science Advisory Committee, 1993). Project Chariot, part of the United States Atomic Energy Commission's Plowshare Program (Watson et al., 1965), was an experimental program to test the use of nuclear explosives for peaceful purposes, in this instance for harbor excavation. Most of the studies were related to a geological and ecological assessment of the region (i.e., tundra soil and water radionuclide movements).

One test in 1963 involved the use of radioactive tracer materials, including soil from the Project Sedan nuclear excavation project, which occurred at the Nevada test site. It was this material that was buried, capped with clean soil, and frozen in place. O'Neill (1994) discovered that the reported amount of radioisotopes apparently exceeded the amounts permitted under federal regulations for burial. The actual (exact) amount of radioactive material buried is not clear.

In 1993, local residents became concerned when planning documents revealed that researchers had considered using up to 5 curies (Ci) of material. These documents produced confusion about the actual amount of radioactive material used, i.e., 26 mCi versus 5 Ci (North Slope Borough Science Advisory Committee, 1993). The confusion heightened public concern, even though excavated material was found to contain an estimated 3 mCi of ^{137}Cs (Dasher et al., 1994), which was near the expected level for radioactive decay of the original 26 mCi. An assessment of caribou from the 1995 mortality event was requested to address continuing, heightened public concern about radionuclide contamination in the Cape Thompson area.

MATERIALS AND METHODS

Caribou were sampled from many areas on or near the North Slope of Alaska. Animals found dead or euthanatized (Cape Thompson and Point Hope) and hunter-killed (Barrow, Point Hope, Teshekpuk Lake, and Red Dog Mine) were examined and sampled for this study. The numbers of caribou examined and/or sampled are 6 in Point Hope in March 1995; 6 from Barrow in March–April 1995; 101 from Cape Thompson in 1995 (65 of these sampled and 30 analyzed); 9 from Teshekpuk Lake in July 1995; and 15 from Red Dog Mine in March 1996. In all, 137 were examined, 100 were sampled, and 65 were analyzed.

Radioanalyses

A contract laboratory (Lockheed Martin Lockheed Analytical Services, Las Vegas, Nevada) measured gross alpha and beta emissions (method LAL0060), ^{137}Cs and ^{40}K by gamma spectroscopy (method LAL0064), and ^{90}Sr (method LAL0196) in muscle and bone. Specimens (femur and associated muscle) were collected in the field, placed in sealed plastic bags, labeled, and frozen. All specimens were returned to the North Slope Borough – Department of Wildlife Management freezer in Barrow, Alaska to be logged and prepared for shipment to the processing laboratory (Diagnostic Services, College of Veterinary Medicine, Mississippi State University, Mississippi State, Mississippi, U.S.A.). Upon arrival at the processing laboratory, the muscle was trimmed from the

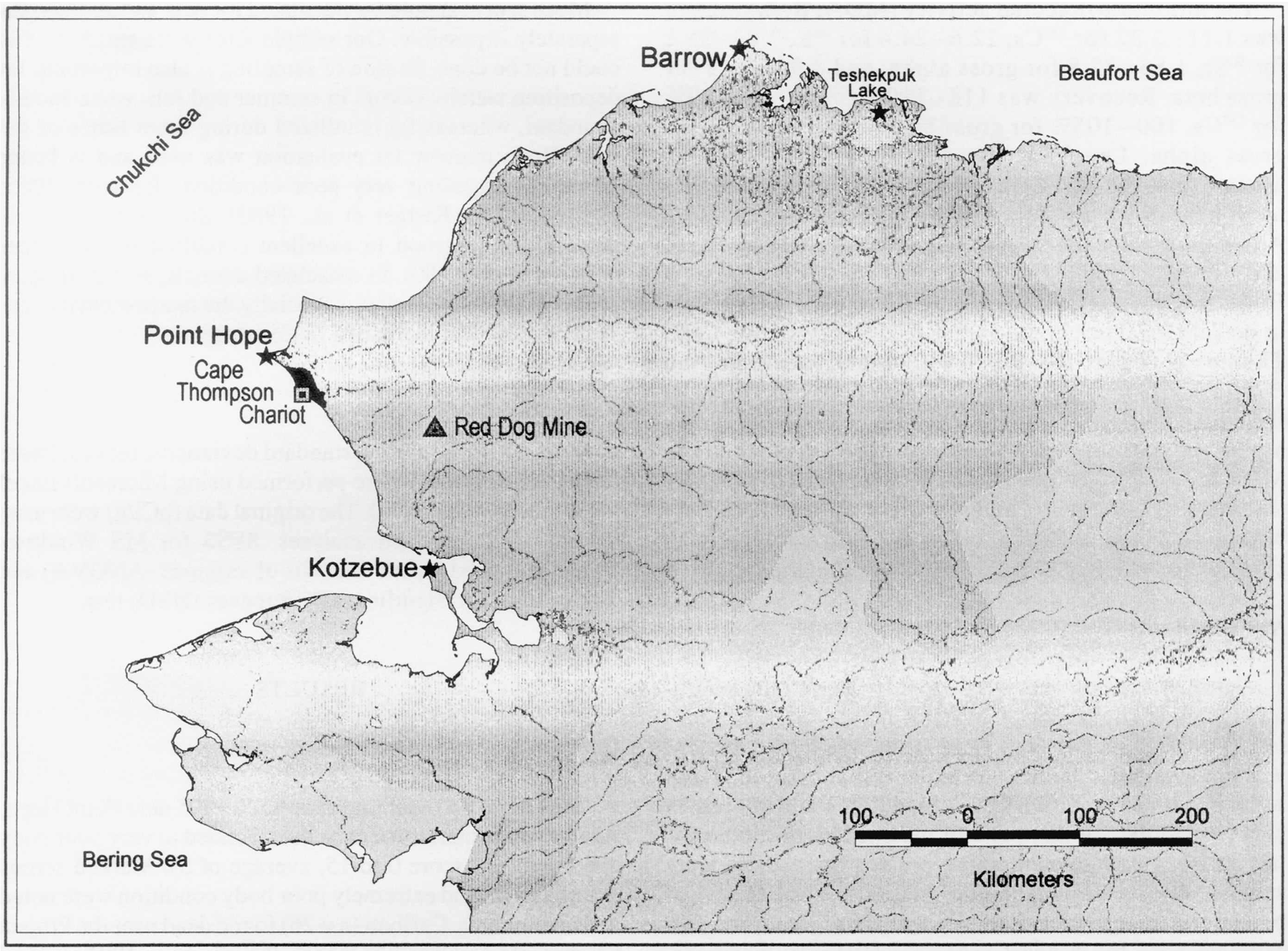

FIG. 1. The study area in northwestern Alaska, showing the range of the Western Arctic Herd of caribou (shaded region) and radionuclide study sites (square = Project Chariot site; triangle = Red Dog Mine; black region surrounding the Chariot site = Cape Thompson area; and stars = Point Hope, Barrow, and Teshekpuk Lake).

bone. Muscle was homogenized using a food processor and placed in polypropylene containers provided by the contract laboratory. A band saw was used to prepare cross-sections of femur, which were placed in the container provided by the contractor.

For all radiochemical analyses, calibration and quality control (QC) included instrument calibration, initial and continuing calibration verification, quench monitoring standards, instrument background analysis, method blanks, yield tracer, laboratory control samples, and duplicate samples. All samples were analyzed as wet weight. Gamma spectrum analysis was all within QC criteria using High-Resolution Gamma Spectroscopy and activity reported as pCi/g. For gross alpha and beta, all criteria were met except that sample weight reductions were needed in some cases.

Strontium-90 analyses were within criteria limits except for two samples that had yttrium recoveries slightly above the limits. Stable strontium carrier was added to the sample. Samples were dissolved using microwave digestion and the cations were concentrated using a strong cation exchange column from dilute acid. The cations were then eluted using 8 M nitric acid and evaporated to dryness. The residue was dissolved in Sr Spec column feed solution and passed through the Sr Spec column. The strontium was eluted with 0.05 M nitric acid and evaporated to dryness in a planchet. The strontium yield was determined by the weight of strontium nitrate on the planchet. The radiostrontium was counted several times over 2 weeks using a low background beta counting system (< 1.0 cpm beta). The ingrowth of ^{90}Y allowed the activity of ^{89}Sr and ^{90}Sr to be determined by regression analysis of the resulting counts. The counting efficiency was obtained using standard ^{89}Sr, ^{90}Sr, and ^{90}Y activities. These data must be used to make corrections, since the beta particle energies are different for ^{89}Sr, ^{90}Sr, and ^{90}Y.

Alpha and beta counting was conducted using a low background alpha/beta proportional counting system, and counting efficiencies were determined from a plot of the counting efficiencies as a fraction of sample mass. The calibration standard used for gross beta was ^{90}Sr in equilibrium with Yttrium-90, and that used for gross alpha was Americium-241.

The minimum detected activity (MDA, Bq/kg) range was 1.11 – 2.22 for ^{137}Cs, 22.6 – 24.4 for ^{40}K, 7.04 – 35.2 for ^{90}Sr, 1.85 – 37.8 for gross alpha, and 2.96 – 75.9 for gross beta. Recovery was 118 – 119% for ^{90}Sr, 92 – 99% for ^{137}Cs, 100 – 105% for gross beta, and 107 – 114% for gross alpha. Levels at or near the MDA and those greater than the MDA were reported as measured. Detection limits were reported for each sample and nuclide. A few animals were reported as exhibiting - (negative) activity (well below the MDA) and were recorded as 0 Bq/g. Negative activity occurred mostly for ^{137}Cs levels in muscle for those areas with low levels (Barrow, Cape Thompson, Point Hope). For all other locations, the ^{137}Cs activity was above the MDA and was recorded as the measured level for all caribou tested. For gross alpha, the detected levels and averages are close to the MDA for muscle samples. Units were reported in pCi/g by the contract laboratory, and summary statistics (means) will be reported as Bq/kg, using the following conversion: pCi/g $\times$ 1 Bq/27 pCi $\times$ 1000 g/kg = Bq/kg.

Age Estimates

Aging of caribou was conducted by a contract laboratory (Matson's Laboratory, Milltown, Montana). The central (primary) incisor was used when available; when it was not available, the first premolar was submitted. Teeth were extracted from collected mandibles and placed in paper envelopes. When pairs of matched teeth (both central incisors from one animal) were available, these were submitted for comparison and quality control (a test of precision). If ages for matched teeth disagreed, the age estimate with the highest score of reliability was used. Each age estimate was accompanied by a letter suffix (A = nearly certain age, B = some error possible, C = error likely) that indicated reliability of the estimate based on the annulus pattern. Of 45 matched pairs of caribou teeth, 28 (62%) agreed; 12 (27%) disagreed by 1 year, 4 (9%) by 2 years, and 1 (2%) by 4 years.

Body Condition Score

Body condition (BC) scores were determined as outlined by Kistner et al. (1980), who developed a field technique for evaluating physical condition of deer based on muscle mass and carcass fat at indicator depot sites (cardiac, omental, and perirenal regions, and subcutaneous regions at the base of the tail and brisket). Fat indices were rated by multiples of 5 from 0 to 15, and muscle was scored as 0 or 5. BC scores were set as emaciated (0 – 10), poor (11 – 40), fair (41 – 70), good (71 – 80), and excellent (81 – 95). Obtaining a complete BC score was not always possible because of time restrictions. Six fat depot sites were given scores of 0 (no visible fat), 5 (slight quantities of fat), 10 (moderate fat), and 15 (heavy fat), and muscle mass was ranked as 0 (if carcass was "bony") or 5 (full). Scores can range from 0 to 95.

Mean scores should be calculated for sex- and age-classes separately if possible. Our sample sizes were small, so this could not be done. Season of sampling is also important: fat deposition usually occurs in summer and fall, when food is abundant, whereas fat is utilized during other times of the year. Bone marrow fat evaluation was used and is better suited for assessing very poor condition (Ransom, 1965; Neiland, 1970; Kistner et al., 1980). Subcutaneous fat is present only in good to excellent condition of most deer (Kistner et al., 1980). In emaciated animals, serous atrophy occurs at these depot sites, especially the marrow cavity, and such atrophy was examined in this study.

Statistical Analyses

Most statistics (means, standard deviations, ranges, linear regression analyses) were performed using Microsoft Excel for Windows version 7.0. The original data (pCi/g) were used for all calculation and analyses. SPSS for MS Windows (7.5.2) was used for the analysis of variance (ANOVA) and Tukey's Highly Significant Differences (HSD) test.

RESULTS

Caribou Sampling and Examination

Caribou (n = 6) examined in March 1995 near Point Hope, Alaska were determined to be in emaciated to very poor body condition (BC score 0 to 15, average of 5). Marked serous atrophy of fat and extremely poor body condition were noted in these animals. Caribou (n = 26) found dead near the Project Chariot site on Cape Thompson in early June 1995 showed evidence of malnourishment, as indicated by rocks in the abomasum, no visceral or body fat, and serous atrophy of bone marrow fat or no fat present.

In early July 1995, 75 additional animals in varying postmortem condition were examined and determined to have serous atrophy or an empty marrow cavity and no body fat, except for 4 (4%) out of 95 of those thoroughly examined. Those four were apparently hunter-killed, as evidenced by removal of the head in the traditional manner.

In total, 101 caribou carcasses were examined at Cape Thompson. On the basis of lack of marrow fat and body fat, emaciation was diagnosed for 91 (96%) of 95 animals suitable for evaluation. Of the 101 animals examined, 35 were males, 58 were females, and 8 were of unknown gender. There were significantly more females ($p = 0.02$); however, adjusting for multiple comparisons (Bonferonni, $p = 0.016$), the difference is not significant. Most animals examined were adults (66), while the remaining consist of 22 yearlings (approx. 1 year old), and 11 calves (born the previous summer). Of 12 females examined for a fetus, 3 (25%) were pregnant. Age ranged from 0 (calves) to 12 years with an average of 5.6 years (Table 1). Small rocks (estimated average diameter of 5 – 8 mm) were found in the abomasum of 26 (84%) of 31 stomachs.

TABLE 1. Body condition assessment (BC score, bone marrow fat, visceral fat), gender, and pregnancy rate for all caribou and by region sampled (found dead or harvested).

Area	Mean Age (years)	Mean BC Score (range)	Male[1] # (%)	Female[1] # (%)	Bone Marrow Fat # (%)	Visceral Fat # (%)	Female[2] Pregnant
All	6.0	10 (0–85)	56 (43)	73 (57)	34/131 (26)	28/74 (38)	
Barrow	ND[3]	24[B] (5–45)	2 (33)	4 (67)	5/6 (83)	5/6 (83)	0/1
Cape Thompson	5.6	0[C]	35 (38)	58 (62)	4/95 (4)	0/38 (0)	3/12 (25)
Point Hope	ND	5[C] (0–15)	3 (50)	3 (50)	1/6 (17)	0/6 (0)	1/3 (33)
Teshekpuk Lake	7.9	50[A] (35–65)	8 (89)	1 (11)	9/9 (100)	9/9 (100)	0/1
Red Dog Mine	5.4	42[A,B] (10–85)	8 (53)	7 (47)	15/15 (100)	14/15 (93)	4/7 (57)

[1] 8 of unknown sex.

[2] Not all females were examined for pregnancy. # pregnant/# examined for fetus.

[3] ND means not determined.

[A,B,C] Means with the same superscript letter for a specific location are not significantly different (Tukey's HSD, $p < 0.05$).

TABLE 2. Gross alpha and beta activity (Bq/kg w.w.) mean, range, and sample size for caribou bone and muscle for all caribou and by region of northern Alaska.

Area	Statistic	Muscle Gross Alpha	Bone Gross Alpha	Muscle Gross Beta	Bone Gross Beta[1]
All Sites	Mean (SD)	0.74 (0.30)	130.0 (69.3)	9.78 (82.2)	510.4 (140.4)
N = 65	Range	0–0.22.2	33.3–307.4	48.1–725.9	300.0–970.4
Point Hope	Mean (SD)	1.48 (0.37)[A]	73.3 (8.15)[B]	85.6 (14.4)[A]	407.4 (58.9)[A]
N = 6	Range	0.74–2.22	59.3–77.8	58.9–103.3	329.6–477.8
Cape Thompson	Mean (SD)	1.48 (4.07)[A]	168.0 (75.6)[A]	97.0 (125.2)[A]	538.9 (120.0)[A]
N = 30	Range	0–22.2	63.0–307.4	48.1–725.9	348.1–766.7
Teshekpuk Lake	Mean (SD)	0.15 (0.37)[A]	82.2 (33.3)[B]	91.9 (11.9)[A]	515.9 (195.6)[A]
N = 9	Range	0–1.11	36.7–125.9	67.0–107.0	363.0–970.4
Barrow	Mean (SD)	0.15 (0.30)[A]	96.3 (48.5)[A,B]	84.8 (15.9)[A]	414.1 (69.6)[A]
N = 5	Range	0–0.74	48.5–151.9	58.9–103.3	329.6–511.1
Red Dog Mine	Mean (SD)	0.22 (0.74)[A]	110.7 (50.4)[B]	113.0 (12.2)[A]	516.7 (159.3)[A]
N = 15	Range	0–2.22	51.9–233.3	95.6–133.3	300.0–807.4[1]

[1] N = one less than total sampled for this analysis.

[A, B, C] Means with the same superscript letter for a specific radionuclide and tissue are not significantly different (Tukey's HSD, $p < 0.05$).

During March and April 1995, six hunter-killed caribou were sampled in Barrow, Alaska. Four of these were examined (BC score range 5 to 45): three were determined to be in moderate body condition, and one animal was in very poor body condition (BC score 5). All were adults: 3 males, 1 female, and 2 unknowns (intact carcass not available). The female was not pregnant (Table 1).

During July 1995, nine apparently healthy adult caribou (4.0–12.0 yr, mean = 7.9) shot for meat near Teshekpuk Lake were sampled and found to be in average-to-good body condition (BC score 35 to 65, mean = 50). During March 1996, 15 apparently healthy caribou, 7 females (4, or 57%, were pregnant) and 8 males, were harvested by local residents just southwest of the Red Dog Mine. These animals were in average-to-good body condition (BC score 10 to 85, mean = 42) and were all adults (average age of 5.4 yr; see Table 1).

Radioanalyses

Radioanalyses for bone and muscle are presented in Tables 2, 3, and 4.

Gross alpha and beta activity in bone: For gross alpha activity in bone, there was a significant difference (ANOVA, $p < 0.01$) between locations. Gross alpha mean activity (Tukey's HSD) was significantly higher in bone samples from Cape Thompson than in caribou from Teshekpuk Lake, Red Dog Mine, and Point Hope, but not Barrow (Table 2). Regression analysis indicated that body condition had no significant effect on bone gross alpha activity. For gross beta activity in bone, ANOVA ($p = 0.35$) showed no significant difference between locations, and regression analysis indicated no difference for body condition.

Gross alpha and beta activity in muscle: For gross alpha activity in muscle, there was no significant difference between locations (ANOVA, $p = 0.58$) and regression analysis showed no difference for body condition. For gross beta activity in muscle, there was no significant difference between locations (ANOVA, $p = 0.97$) and regression analysis showed no difference for body condition.

Strontium-90: For ^{90}Sr levels in bone, there was no significant difference (ANOVA, $p = 0.17$) by location, and regression analysis showed no difference with varying BC score.

TABLE 3. Mean, standard deviation (SD), range, and sample size (N) for activity (Bq/kg w.w.) of cesium-137, strontium-90, and potassium-40 for muscle.

Area	Statistic	^{137}Cs	^{90}Sr	^{40}K
All Sites	Mean (SD)	6.67 (7.78)	13.7 (27.0)	83.0 (20.4)
	Range, N	0–25.6, 65	0–108.1, 18	45.2–127.0, 65
Point Hope	Mean (SD)	1.11^{B} (1.11)	–	76.7^{B} (28.1)
	Range, N	0.37–2.22, 6	–	51.1–117.4, 6
Cape Thompson	Mean (SD)	2.22^{B}(3.70)	13.0 (67.4)	76.0^{B} (18.5)
	Range, N	0–14.1, 30	0–211.5, 12	45.2–127.0, 31
Teshekpuk Lake	Mean (SD)	15.6^{A} (2.96)	8.89 (4.81)	104.4^{A} (18.5)
	Range, N	11.1–19.6, 9	5.19–14.4, 3	74.4–125.9, 9
Barrow	Mean (SD)	0.74^{B} (0.74)	–	77.8^{A,B} (19.3)
	Range, N	0–2.22, 5	–	54.1–107.4, 5
Red Dog Mine	Mean (SD)	13.7^{A} (8.15)	20.0 (27.8)	88.2^{A,B} (9.63)
	Range, N	2.96–25.6, 15	0–51.9, 3	75.2–107.8, 15

^{A,B,C} Means with the same superscript letter for a specific radionuclide are not significantly different (Tukey's HSD, $p < 0.05$).

TABLE 4. Mean, standard deviation (SD), range, and sample size (N) for activity (Bq/kg w.w.) of cesium-137, strontium-90, and potassium-40 for bone.

Area	Statistic	^{137}Cs	^{90}Sr	^{40}K
All Sites	Mean (SD)	1.48 (1.85)	137.8 (46.7)	32.6 (20.4)
	Range, N	0–8.15, 21	5.93–244.8, 58	0–81.5, 20
Point Hope	Mean (SD)	1.85 (0.74)	148.5 (47.4)	29.3 (4.81)
	Range, N	1.11–2.22, 4	118.5–232.2, 5	24.1–33.7, 3
Cape Thompson	Mean (SD)	0.74 (0.03)	140.7 (56.3)	47.4 (18.5)
	Range, N	0–2.22, 8	5.93–244.8, 24	18.5–81.5, 8
Teshekpuk Lake	Mean (SD)	1.11 (1.11)	114.8 (31.9)	18.9 (17.8)
	Range, N	0–2.22, 3	40.4–145.2, 9	0–34.8, 3
Barrow	Mean (SD)	0.37 (0.37)	188.5 (29.2)	24.8 (21.9)
	Range, N	0–1.11, 3	37.0–232.2, 5	0–40.7, 3
Red Dog Mine	Mean (SD)	3.33 (4.07)	126.7 (27.0)	20.4 (15.2)
	Range, N	0.37–8.15, 3	88.5–173.3, 15	7.04–36.7, 3

Cesium-137: There was a significant difference (ANOVA, $p < 0.01$) in muscle ^{137}Cs by location. Mean levels in caribou were significantly greater at Red Dog Mine and Teshekpuk Lake than at Cape Thompson, Point Hope, and Barrow. In addition, cesium-137 in muscle increased with increasing body condition score (linear regression analysis, ($r^2 = 0.534$, $p < 0.001$). The rate of increase (coefficient) is 2.22 Bq/kg of tissue per 10 points of BC score.

Potassium-40: There was a significant difference (ANOVA, $p = 0.01$) in potassium-40 in muscle by location, but regression analysis showed no significant difference by BC score. The highest mean level was for Teshekpuk Lake, and the lowest for Cape Thompson and Point Hope (Table 3).

Mean Body Condition: Mean BC scores for Teshekpuk Lake caribou were significantly higher than scores for Point Hope, Cape Thompson, and Barrow caribou; and higher for Red Dog Mine than for Point Hope and Cape Thompson (Table 1).

Age: Linear regression indicated there was no significant relationship with age for gross alpha and beta, ^{40}K, ^{137}Cs, and ^{90}Sr for bone and muscle.

DISCUSSION

Cape Thompson Caribou Mortality Event

The caribou examined in Point Hope (March 1995) and Cape Thompson (June–July 1995) were suffering from or had succumbed to malnutrition; and the levels of radionuclides were within expected levels for the caribou sampled from this region. In the process of this evaluation, we made many observations concerning radionuclide levels including differences based on geographic location of sampling, bone versus muscle, and body condition (BC) score.

An assessment of body condition was essential, considering that the very broad range of condition (emaciated to very good) could possibly affect levels of radionuclides and is critical for diagnosing emaciation. Long-term dietary restrictions are characterized by a decreasing body mass (reduction of muscles) and low values of bone marrow fat indices, indicators of extreme undernourishment (Suttie, 1983; Torbit et al., 1988). Such a condition was well documented for the caribou examined near Point

Hope and Cape Thompson. Severe weather (cold, wind, precipitation) combined with malnutrition may cause death before total exhaustion of fat reserves (Cheatum, 1952; deCalesta et al., 1975) because of high metabolic demands (Kistner et al., 1980). A combination of poor body condition, harsh climatic conditions (cold, strong wind, and freezing rain), and unavailable (beneath frozen snow) or poor forage may have resulted in this mortality event at Cape Thompson, Alaska. Winds averaged 37 mph on 31 October 1994 with precipitation and an average temperature of 14˚F (-18˚C) at Kotzebue, Alaska, as reported by the U.S. Weather Service.

A reduction in muscle protein, lack of food intake, and decreasing muscle mass may explain the lower level of ^{137}Cs in muscle, as it was excreted, but not regained through consumption of forage. Radiocesium levels in caribou follow grazing habits (season): they are low following the summer (when caribou consume primarily vascular plants and sedges) and higher in the winter (when diet is mostly lichen). Caribou excrete more ^{137}Cs during summer than in the winter (Holleman et al., 1971). When winter forage (lichen) is abundant, muscle residues of ^{137}Cs are known to increase significantly. This was clearly not the case with the emaciated caribou of Point Hope and Cape Thompson in 1995, which showed low levels of ^{137}Cs in muscle. Cesium-137 was used to monitor foraging and is related to body condition (Alldredge et al., 1974). A lack of exposure (decreased intake) and/or limited winter forage (lichen) likely explains the low residue levels seen in caribou sampled at Point Hope and Cape Thompson.

Arctic Radionuclide Ecology and Sources

Lichens obtain nutritional elements from atmospheric deposition of particles on their upper surfaces, and radioactive fallout collects on the surface. Thus, ^{137}Cs and ^{90}Sr, the principal long-lived fallout radionuclides of concern, are transferred from lichen to caribou in fall and winter. Potassium (K) can be considered an analog for ^{137}Cs adsorption and distribution in the body. A potassium-poor diet, like that encountered by caribou during winter foraging, allows the ^{137}Cs to be readily absorbed and distributed through the body, with highest concentrations found in muscle and kidney tissue.

Knowledge that the uptake of ^{137}Cs as a potassium analog was used to reduce ^{137}Cs levels after the Chernobyl nuclear accident by providing potassium to reindeer (Guillitte et al., 1994). In spring, when emergent shrubs low in ^{137}Cs and high in potassium (compared to lichens) become available for forage, excretion of ^{137}Cs occurs, reducing muscle and kidney levels of this substance. A similar process occurs for ^{90}Sr, in this case a calcium analog, as ^{90}Sr accumulates in bone tissue. Annual variation is less for ^{90}Sr because of its distribution in the body.

Contaminated lichens begin a process of exposure through the food chain that involves herbivores and ultimately carnivores (wolves, humans). In the early 1960s, Watson et al. (1965) reported strontium-90 levels (Bq/kg d.w.) to be 24.4 in willow (*Salix*), 74.1 in carex sedge (*Carex*), 66.7 in cotton sedge (*Eriophorum*), and 122.2 in lichens. They also measured cesium-137 levels (Bq/kg d.w.) of 207.4 in willow, 166.7 in carex sedge, 259.3 in cotton sedge, and 1111.1 in lichens. Caribou muscle was reported to have 985.2 Bq/kg d.w. of ^{137}Cs (Watson et al., 1965). In 1993, levels of ^{137}Cs from the Project Chariot assessment were willow (*Salix*) < 5.52 Bq/kg d.w., carex sedge (*Carex*) 1.33 Bq/kg, cotton sedge (*Eriophorum*) 4.15 Bq/kg, lichens 77.8 Bq/kg d.w., and caribou muscle 12.4 Bq/kg; and ^{90}Sr levels were 18.5 for lichens and 74.1 Bq/kg for caribou muscle (Dasher et al., 1994). These data and others indicate levels of ^{137}Cs and ^{90}Sr are gradually decreasing over time.

The common and largest source of anthropogenic radioactivity (i.e., ^{137}Cs) of the polar regions has been global fallout from atmospheric testing of nuclear weapons initiated in 1952 and banned in 1963 (Aarkrog, 1994). Other significant sources of anthropogenic radionuclides include discharges into the Techa River (a part of the Ob River system) from the Cheliabinsk-40 (MAJAK) plutonium plant in 1949–51; nuclear reprocessing in western Europe at a plant in Sellafield, United Kingdom, where maximum releases occurred around 1975; the Chernobyl accident in 1986; and dumping of liquid and solid radioactive wastes in bays of Novaya Zemlya and in the Kara Sea (Aarkrog, 1994). Arctic regions appeared to receive about one-quarter of the fallout of temperate regions (Hanson and Dasher, 1998).

Fallout reached North America from the 26 April 1986 accident at a nuclear power plant at Chernobyl, near Kiev (Taylor et al., 1988) with long-lived ^{137}Cs (half-life of 30.17 years) accompanied by ^{134}Cs, which is shorter lived (half-life of 2.062 years). The ^{134}Cs from nuclear testing over three decades ago is now well below detection level, whereas the ^{134}Cs from Chernobyl can be easily detected to determine the relative amount of radiocesium that is "new" or fresh (Taylor et al., 1988). In Alaska, the deposition rate has been estimated to be 0.5 Bq/m^2 (White et al., 1986). Lichens from the central Arctic showed a ^{137}Cs increase of 14% (Chernobyl contribution) above the persistent burden from past atmospheric nuclear weapons testing (Taylor et al., 1988). Moss and lichens from Wood Buffalo National Park (Canada) showed an average ^{137}Cs increase of 19% due to Chernobyl fallout. In absolute terms, the contribution of Chernobyl fallout is not significant for North America compared to nuclear testing fallout.

Radiocesium Levels in Caribou

Radiocesium levels in muscle of Canadian caribou ranged from 20 to 160 Bq/kg in muscle, and levels in bone were very low at 0.4 Bq/kg (Taylor et al., 1988). Health Canada (1995) reported ^{137}Cs levels from 3.5 to 179.0 Bq/kg in muscle in Canadian herds. Thomas (1995) reported ^{137}Cs levels of 300 to 500 Bq/kg in muscle and 40 to 80 Bq/kg in bone of caribou from Saskatchewan. Caribou muscle ^{137}Cs concentrations ranged from 1.10 to 60.0 Bq/kg for animals taken in 1985–87 in arctic Alaska (Baskaran et al., 1991), and we measured similar levels. Levels detected in this study on the North Slope of Alaska averaged 6.7 Bq/kg of ^{137}Cs in muscle and 1.5 Bq/kg in bone. However, for other northern regions (i.e., Scandinavia) the levels are much higher (by a factor of 1000 to 10 000 for ^{137}Cs).

The Chernobyl accident resulted in an uneven distribution of radiocesium on the lichen carpet of Norway. Most wild reindeer meat contained high levels of radiocesium (> 6000 Bq/kg), and in some areas the level exceeded 10 000 Bq/kg (Gaare, 1987). Following the Chernobyl accident, radiocesium levels in the hind leg muscle of wild reindeer at Dovreefjell, Norway varied from 8000 Bq/kg in August to 46 000 Bq/kg in March, indicating seasonal variation.

Alpha and Beta Emitters

Lead-210 (^{210}Pb) and polonium-210 (^{210}Po) are naturally occurring radionuclides that are products of the decay of uranium in the earth's crust. In the radioactive decay process, these radionuclides are introduced into the atmosphere and later reach the earth's surface as wet and dry fallout. ^{90}Sr, ^{210}Pb, and ^{210}Po are known to concentrate in the bone rather than in soft tissues (liver, kidney, and muscle) with maximum mean absorbed doses of 18.2–18.5 mGy/yr (Macdonald et al., 1996) in caribou. However, ^{210}Po is a decay product of ^{210}Pb that has already entered bone, and dietary ^{210}Po will preferentially enter soft tissues (Thomas, 1995).

Strontium-90 (beta emitter) concentrations were determined in foods of Alaska Native peoples using caribou taken in 1961 from Shungnak, which had 2.5–3.0 Bq/g ash for bone and 0.02–0.06 Bq/g ash for meat. Caribou antlers from Alaska (1.64 Bq/g ash) had ^{90}Sr levels ten times higher than those of deer sampled in California (0.11 Bq/g ash). Hanson (1966) described an increase in caribou bone ^{90}Sr levels from 370.4 – 740.8 Bq/kg in 1960 – 61 to 1851.9 Bq/kg d.w. in 1964. This increased tissue burden in caribou occurred despite a lower deposition of ^{90}Sr on the tundra than in temperate areas (Schulert, 1962).

Mean ^{90}Sr levels in our study were 13.7 Bq/kg in muscle and 137.8 Bq/kg in bone. The naturally occurring radionuclides ^{210}Pb (beta emitter) and ^{210}Po (alpha emitter, decay product of ^{210}Pb) have been detected in bone from caribou sampled in Canada at mean levels of 3800 and 3070 Bq/kg (Macdonald et al., 1996); in Saskatchewan and the Northwest Territories at a range of means of 274 to 531 Bq/kg (^{210}Pb) and 562 to 1022 Bq/kg (^{210}Po) (Thomas et al., 1994); and in Alaskan reindeer bone at approximately 300 Bq/kg (Beasley and Palmer, 1966).

^{210}Pb and ^{210}Po have been shown to vary considerably by geographical region (Thomas, 1995), and some of the highest values have been reported in northern Canada (Macdonald et al., 1996). Lead-210 in caribou bone was shown to not change with age (Macdonald et al., 1996). Polonium-210 was shown to be the major contributor to absorbed dose for caribou studied in Canada (Macdonald et al., 1996). For caribou bone in our study, gross mean alpha activity was 130.0 Bq/kg, and gross mean beta activity was 510.4 Bq/kg, and both showed no relationship with age or body condition. We did detect a difference for alpha activity by location, which has been described in other studies (Macdonald et al., 1996).

Potassium-40 (^{40}K)

Potassium-40 averaged approximately 100 Bq/kg for caribou muscle, liver, and kidney sampled in northern Canada in 1992 – 94 and showed no difference between herds (Macdonald et al., 1996). ^{40}K ranged from 81.1 to 149.1 Bq/kg in Canadian caribou (Health Canada, 1995) and averaged 78 to 89 Bq/kg in Saskatchewan caribou (Thomas, 1995). Our study agreed with these findings, as the mean ^{40}K level in muscle was 83 Bq/kg; however, a difference by location was detected.

Exposure and Risk to People

The maximum recommended intake of ^{137}Cs for a human adult is approximately 100 000 Bq/year. This value is calculated from the radiation dose limit for the whole population of 1.7 mSv/year and the radiation dose equivalent of 0.000017 mSv per Bq of ^{137}Cs intake (NCRP, 1977; Baskaran et al., 1991). Thus concentrations in human foods should not exceed 300 Bq/kg for milk and meat and 1500 Bq/kg for berries and mushrooms (Taylor et al., 1988; Baskaran et al., 1991). Scandinavian and European countries have established similar permissible levels (Jones, 1989) and will allow consumption of reindeer meat at levels up to 1500 Bq/kg (Taylor et al., 1988).

The ^{137}Cs levels found in these studies and in the 1995 data are substantially lower than the acceptable limits, indicating little health risk associated with the consumption of caribou meat. On the basis of the mean ^{137}Cs level of 7.0 Bq/kg in caribou muscle, our study indicates a predator or human would need to consume 39 kg/day every day for a year to reach the maximum permissible intake of 100 000 Bq/yr. Similar results occurred in northern Canada (Taylor et al., 1988).

Macdonald et al. (1996) sampled caribou muscle in 1992 – 94 in the Canadian North and found levels of ^{137}Cs that ranged from below detection limits on Banks Island to 231 Bq/kg in the Beverly herd in the central Arctic. Comparing those ^{137}Cs levels with published values from the 1960s and 1980s, the authors concluded that the levels were declining, with an effective half-life (T_{eff}) of 9.9 years (Macdonald et al., 1996). This effective half-life is in the range of the T_{eff} for lichen, which is double that of other plants. This slow rate of elimination has been attributed to the lower biomass, slow rate of growth, and low turnover of biomass (Macdonald et al., 1996). Even though the absorbed doses (mGy per year) calculated by these authors were relatively high, no observable effects have been reported: the herds are thriving and increasing in size.

The relatively high doses observed in Canadian caribou are the result of natural radiation (Macdonald et al., 1996). The major contributor to the effective dose in caribou is ^{210}Po, which is found in lichen in the diet and also as a decay product of ^{210}Pb from bone. Thomas (1994:688) states: "^{210}Po contributes substantially to internal radiation dose in caribou (13–20 mSv y^{-1}), wolves (7–18 mSv y^{-1}) and human residents consuming caribou meat (0.3–0.4 mSv y^{-1})." The annual dose rate to Canadian Arctic Native residents was estimated to be 2.0 to 8.6 mSv, and the major contributor is ^{210}Po (Health Canada, 1995). ^{210}Po contributes substantially to internal doses in caribou (13–20 mSv/y), wolves (7–18 mSv/y) and humans consuming caribou (0.3 to 0.4 mSv/y). Cesium-137 levels in muscle reached 4000 Bq/kg in Alaskan caribou in 1964 (Hanson, 1982) and 2000 Bq/kg in caribou of Canada (Thomas et al., 1992). These values are much lower than levels measured after the Chernobyl accident in reindeer of northern Europe: values in reindeer muscle of 45 000 Bq/kg in Sweden (Ahman and Ahman, 1994) and 56 000 Bq/kg in Norway (Eikelmann et al., 1990) have been detected. Over the 30+ years, levels in North America have decreased from 2000–4000 Bq/kg in 1962 (Hanson, 1982) to approximately 7–230 Bq/kg in the 1990s (Baskaran et al., 1991; Macdonald et al., 1996; this paper). Macdonald et al. (1996:70) concluded that "the high doses observed in Canadian caribou are the result of natural radiation, and hence the animals have probably adapted mechanisms to compensate for the elevated radiation levels." By comparison, our findings show lower levels in Alaska caribou, and we reach the same basic conclusion: the levels detected do not significantly affect caribou, and no significant human health risk exists at present. Available information does not indicate any radiological health risk from consuming Alaska caribou containing the present levels of ^{137}Cs or ^{90}Sr. These levels will continue to decrease unless nuclear war or nuclear accidents occur.

In conclusion, gross carcass assessments indicated that malnourishment/emaciation was the cause of mortality for caribou in the Cape Thompson and Point Hope areas in late 1994 and early 1995. More details related to histology, element levels, and necropsy data will be reported elsewhere to support this diagnosis. Much of the evidence indicates that radionuclides played no role. We also conclude that these caribou are unaffected by radionuclides and safe for consumption.

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