ARCTIC
VOL. 52, NO. 3 (SEPTEMBER 1999) P. 279–288

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]

(*Received 7 July 1998; accepted in revised form 16 February 1999*)

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

Traduit pour la revue *Arctic* par Nésida Loyer.

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.

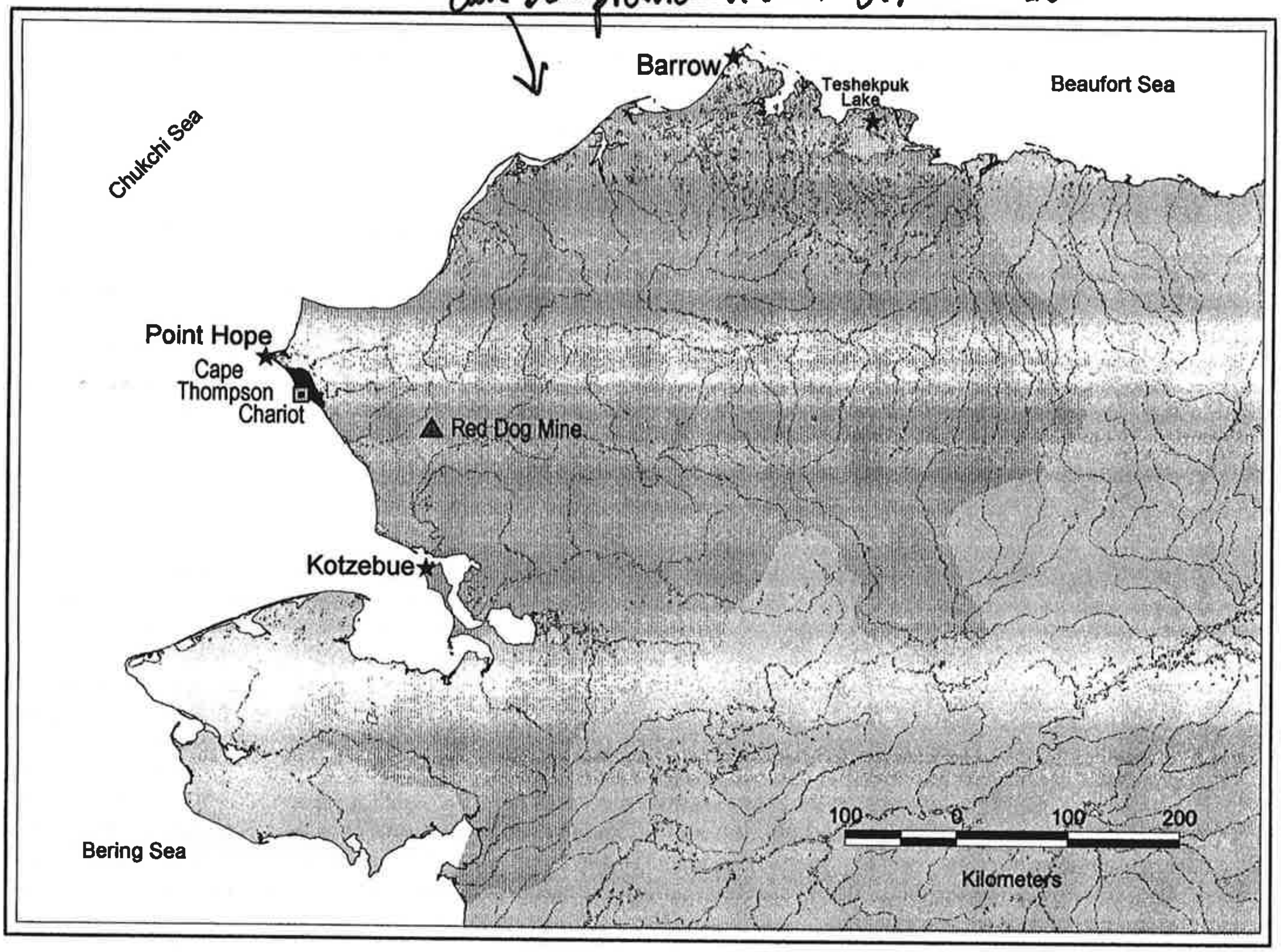

FIG. 1. The study area in northwestern Alaska, showing the range of the Western Arctic Herd of caribou (shaded region) and radionuclide study sites (square = Project Chariot site; triangle = Red Dog Mine; black region surrounding the Chariot site = Cape Thompson area; and stars = Point Hope, Barrow,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

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.

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 Se (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 caribo ranged from 20 to 160 Bq/kg in muscle, and levels in bon 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 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.

ACKNOWLEDGEMENTS

We thank Dr. Lloyd Bennett and Dr. Pat McCoy (Diagnostic Services, College of Veterinary Medicine, Mississippi State University) for help with tissue processing; Geoff Carroll and Jim Dau (Alaska Department of Fish and Game), and Harry Brower, Jr. (North Slope Borough) for assistance with sampling; Dr. John Blake for his assistance with the post mortem examination of caribou at Cape Thompson; and residents of Point Hope, Earl Kingik and Russell and Aggie Lane, for assistance with collection of samples. Dan Bevington, North Slope Borough, produced Figure 1.

REFERENCES

AARKROG, A. 1994. Radioactivity in polar regions: Main sources. Journal of Environmental Radioactivity 25:21–35.

AHMAN, B., and AHMAN, G. 1994. Radiocesium in Swedish reindeer after the Chernobyl fallout: Seasonal variations and long-term decline. Health Physics 66:503–512.

ALLDREDGE, A.W., LIPSCOMB, J.F., and WHICKER, F.W. 1974. Forage intake rates of mule deer estimated with fallout cesium-137. Journal of Wildlife Management 38:508–516.

BASKARAN, M., KELLEY, J.J., NAIDU, A.S., and HOLLEMAN, D.F. 1991. Environmental radiocesium in subarctic and arctic Alaska following Chernobyl. Arctic 44:346–350.

BEASLEY, T.M., and PALMER, H.E. 1966. Lead-210 and polonium-210 in biological samples from Alaska. Science 152:1062–1063.

BURCH, E., Jr. 1981. The traditional Eskimo hunters of Point Hope, Alaska: 1800–1875. Departmental Report to the North Slope Borough. Available from the North Slope Borough, Box 69, Barrow, Alaska 99723. 89 p.

CHEATUM, E.L. 1952. Disease and parasite investigations. Final Report, Pittman-Robertson Project 1-R, Supplement E. Federal Aid Wildlife Restoration. 75 p. (Microfilm: Ithaca, New York: Cornell University Libraries, 1970).

DASHER, D.H., ALBERG, D., KASSEL, J., READ, R., and GIBLER, D. 1994. Report on Project Chariot removal and assessment actions in August 1993. Available from the Alaska Department of Environmental Conservation, 610 University Avenue, Fairbanks, Alaska 99709. 125 p.

DECALESTA, D.S., NAGY, J.G., and BAILEY, J.A.. 1975. Starving and refeeding mule deer. Journal of Wildlife Management 39:663–669.

EIKELMANN, I.M.H., BYE, K., and SLETTEN, H.D. 1990. Seasonal variation of cesium-134 and cesium-137 in semidomestic reindeer in Norway after the Chernobyl accident. Rangifer Special Issue 3:5–38.

FULLER, A., and GEORGE, J.C. 1997. Evaluation of subsistence harvest data from the North Slope Borough 1993 Census for eight North Slope villages: For the calendar year 1992. Available from the North Slope Borough, Department of Wildlife Management, Box 69, Barrow, Alaska 99723.

GAARE, E. 1987. The Chernobyl accident: Can lichens be used to characterize a radiocesium contaminated range? Rangifer 7(2):46–50.

GUILLITTE, O., TIKHOMIROV, F.A., SHAW, G., and VETROV, V. 1994. Principles and practices of countermeasures to be carried out following radioactive contamination of forest areas. The Science of the Total Environment 157:399–406.

HANSON, W.C. 1966. Fallout radionuclides in Alaska food chains. American Journal of Veterinary Research 27:359–366.