Seasonal concentrations of cesium-137 in rumen content, skeletal muscles and feces of caribou from the Porcupine herd: lichen ingestion rates and implications for human consumption

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Abstract. The Porcupine caribou herd was monitored for cesium-137 during 1987 to address human health concerns over potential meat contamination by radioactive fallout from the Chernobyl accident, and to determine lichen intake rates based on body burdens of radiocesium. A total of 36 caribou were collected from northwestern Alaska and the Yukon Territories in March, June, September, and November. Mean radiocesium concentrations in skeletal muscle peaked in March at 133 Bq/kg fresh weight. This value should not prove hazardous to human health. Radiocesium concentrations in skeletal muscle (wet weight) ranged from approximately 22 to 50% of radiocesium concentrations in rumen contents (dry weight), and from approximately 15 to 37% of radiocesium concentrations in feces (dry weight).
Radioactivity in feces was significantly correlated with radioactivity in rumen contents. Computer simulations relating lichen intake rates to radiocesium body burdens are presented for 3 scenarios: (1) when seasonal intakes were adjusted to provide the optimum fit between simulated and observed radiocesium body burdens (2) when seasonal intakes were based on empirical data, and (3) when seasonal intakes were adjusted to yield a "conventional" radiocesium curve of a slow fall build-up prior to a late winter plateau.

Key words: Caribou, intake, cesium, lichens, Alaska

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Introduction

Barren-ground caribou *(Rangifer tarandus granti)* from the Porcupine herd were monitored for Cesium-137 during 1987 to address human health concerns over potential meat contamination by radioactive fallout from the Chernobyl accident. Radioassay of forage plants from the Fairbanks vicinity in August 1986 revealed only modestly elevated levels of radiocesium activity (White *et al.* 1986). However, similar data were not available for vegetation from the range of the Porcupine caribou herd in arctic Alaska and arctic Yukon Territories. Moreover, data were lacking for radiocesium levels in caribou muscle.

Radiocesium burdens measured for caribou in this study were also used to estimate seasonal lichen ingestion rates. Lichen intake rates have previously been estimated with the fallout radiocesium method (Holleman *et el.* 1971, Hanson *et al.* 1975, Holleman *et al.* 1979,). However, application of this method was restricted to the winter period when animals were assumed to have an equilibrium body burden of radiocesium.

This paper presents seasonal radiocesium levels in skeletal muscles, rumen content, and feces of caribou collected from northwestern Alaska and the Yukon Territories. Comparisons are made ofi radioactivity levels among muscles from the neck, shoulder, backstrap, and hindquarter. A two-compartment Kinetic model (Holleman et al. 1989) programmed with a simulation, analysis, and modeling routine (SAAM27) (Berman and Weiss 1978) was used to estimate seasonal lichen intake rates needed to produce observed body burdens.

Methods

Adult female caribou were collected from the Porcupine herd in March, June, September, and November 1987. Collection sites followed migration routes from Alaska in March and June to the Yukon Territories in September and November (Figure 1). One kilogram of muscle was removed from the shoulder, backstrap, and hindquarter of each carcass. The muscle samples were then radioassayed for cesium-137 using a Nuclear Data 1100 pulse height analyzer coupled with a shielded detection system (two opposing 5" NaI(TL) crystals). Rumen contents were oven-dried and counted using the same technique. Neck samples were radioassayed in triplicate in 13.5 ml sample tubes using the Searle Analytic 1195 automatic gamma counter with a 3" NaI (TL) well detector. Fecal samples were prepared by freeze-drying and pulverization, then assayed using the Searle Analytic 1195 gamma counter. Paired t-tests were used to test for differences among muscle samples. Analysis of variance

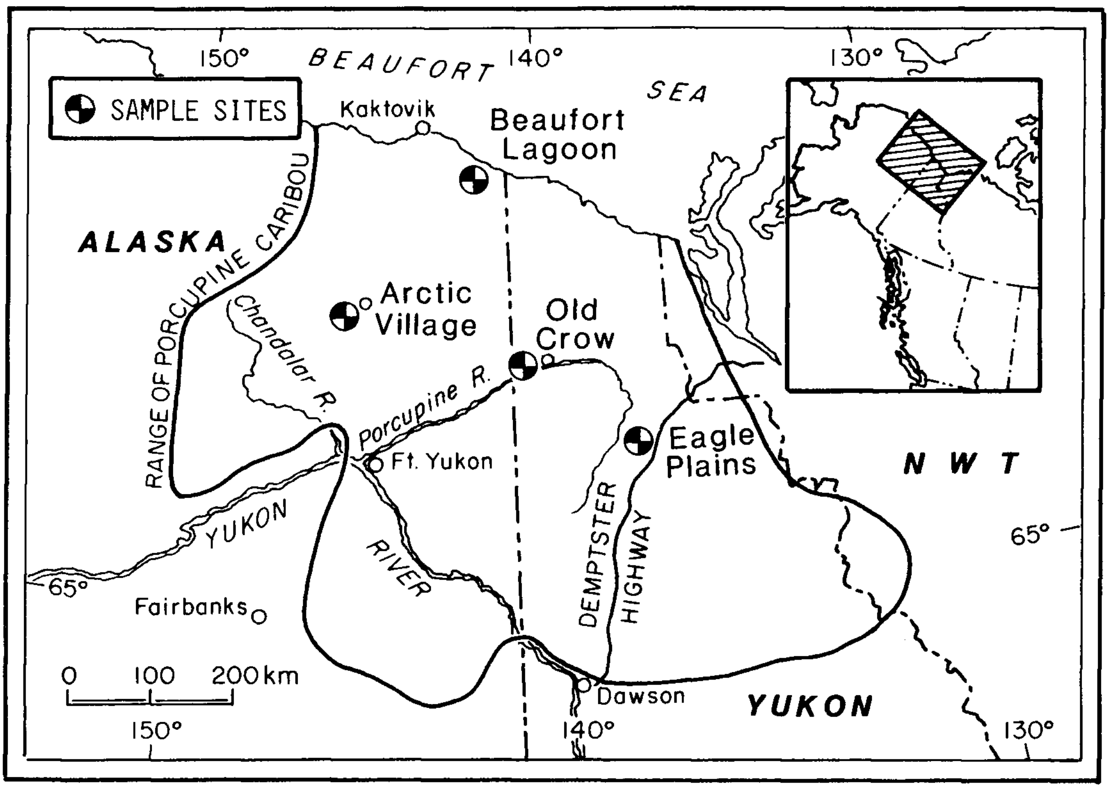
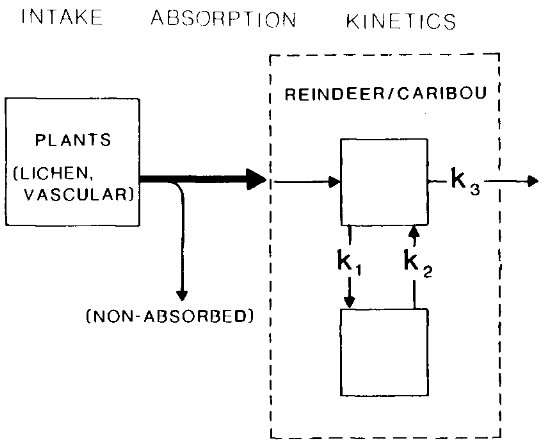


Fig. 1. Seasonal collection sites of caribou radioassayed for cesium-137. Collection dates were March 24 (Arctic Village), June 5 (Beaufort Lagoon), September 5 (Old Crow), and November 30 (Eagle Plains).

was used to test for differences among collection dates.

Lichen ingestion rates were simulated using the Kinetic model described by Holleman et al. (1989). In the model, the total body burden of an animal is represented by the sum of the two compartments (Figure 2), with the size of each



.2. A model showing the movements of radiocesium from plants through the two-compartmentalized reindeer/caribou.

compartment depending on the rates of cesium inflow and outflow. Radiocesium concentrations in food is multiplied by food intake rate to generate radiocesium intake. The radiocesium intake is then multiplied by a radiocesium absorption factor of 0.7 (Åhman 1988) to give the cesium inflow into compartment 1. The flow of cesium from each compartment (the K frational rate parameters, Figure 2) is computed as a function of potassium intake (Figure 3) and then corrected for animal body weight (Holleman *et al.* 1971). Seasonal body weights used in all simulations are based on data for the Porcupine caribou herd (White *et al.* 1988).

Skeletal muscle, wnich accounts for 40% of animal body weight, was assumed to contain 80% of the radiocesium body burden (Holleman *et al.* 1971). The effective biological halftime of radiocesium was established at 8.2 years for lichens (Holleman 1974) and 2.0 years for vascular plants.

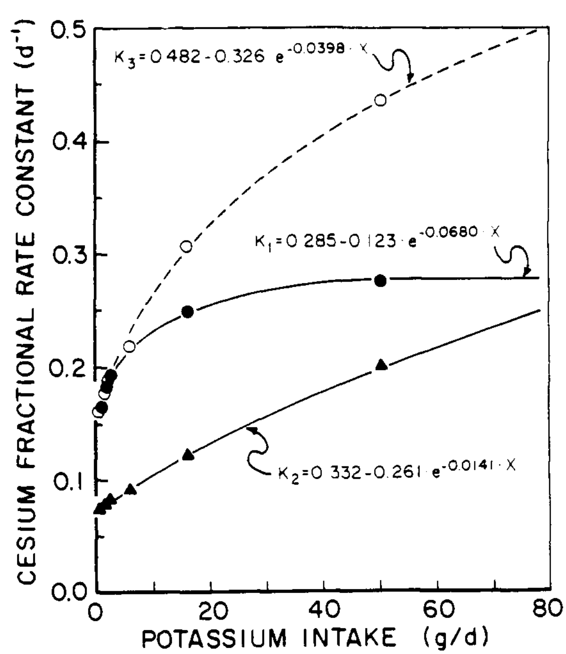


Fig.3. Modeled effects of potassium intake on the cesium fractional rate constants.

Results

Seasonal cesium-137 concentrations.

Cesium-137 concentrations in skeletal muscle ranged from a low of 26 Bq/kg in a neck sample collected in June, to a high of 232 Bq/kg in another neck sample collected in September (Table 1). When data were pooled from the four collection periods, radiocesium concentrations in shoulder and hindquarter samples were statistically comparable, and averaged 1 to 12 Bq/kg higher than radiocesium concentrations in neck and back muscles. When the data were analyzed by collection period, however, intermuscular differences in radiocesium concentration were not consistent between months. Cesium-137 concentrations were therefore averaged for the 4 muscle groups from each animal to yield estimates of mean cesium concentration in skeletal muscle for each collection period (Table 2). These mean values were used in the simulation of lichen ingestion rates.

Mean cesium-137 concentrations in skeletal muscle were significantly higher in March and September than in June and November (Table

Table 1. Seasonal radiocesium concentrations in 4 muscle groups.

	Cecium-137 (Bq/kg)				
	n	mean	SD	min	max
March					
Neck	11	122.6	24.1	80.0	158.0
Shoulder	11	139.8	18.4	121.7	176.2
Back	11	131.0	19.0	102.5	166.5
Hindquarter	11	138.0	19.6	110.6	169.1
June					
Neck	5	58.2	20.8	26.0	84.0
Shoulder	5	72.4	26.7	46.2	114.4
Back	5	85.7	28.7	55.8	129.6
Hindquarter	5	87.5	30.7	57.4	137.9
September					
Neck	8	114.4	54.3	72.0	232.0
Shoulder	8	137.2	39.1	87.2	201.1
Back	8	101.6	34.5	61.6	160.1
Hindquarter	6	118.3	27.7	77.2	161.7
November					
Neck	12	81.2	29.5	33.0	140.0
Shoulder	12	81.4	29.1	28.4	132.7
Back	10	70.5	22.8	30.2	106.9
Hindquarter	12	75.0	24.3	29.6	107.4

Table 2. Seasonal radiocesium concentratios in skeletal muscle (average of neck, shoulder, backstrap, hindquarter), rumen contents, and feces. Sample size in parentheses.

	Cesium-137 (Bq/kg)			
	March	June	Sept.	Nov.
Skeletal muscle* (wet weight)	133[a**]	76[b]	118[a]	77[b]
Rumen contents (dry weight)	287[b] (11)	149[c] (5)	538[a] (8)	242[b] (9)
Feces (dry weight)	455[b] (11)	203[c] (5)	802[a] (1)	516[b] (8)

* Average of neck, shoulder, backstrap, and hindquarter.

** Means with the same letter are not significandy different ($p < 0.05$) in comparisons across time.

2). Rumen contents and feces exhibited similar seasonal trends; however, September activity was significantly higher than March activity in both instances (Table 2).

Radiocesium concentrations in skeletal muscle (wet weight) ranged from approximately 22 to 50% of radiocesium concentrations in rumen contents (dry weight), and from approximately 15 to 37% of radiocesium concentrations in feces (dry weight). Radiocesium concentrations in feces correlated significantly with radiocesium concentrations in rumen contents (Figure 4) since both reflect the effect of immediate-term lichen consumption.

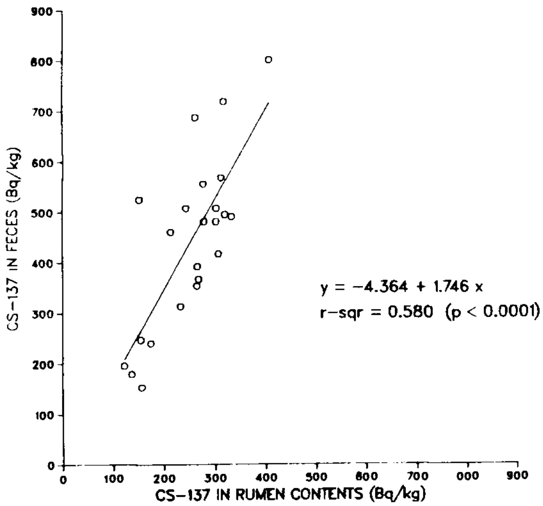


Fig.4. The regression between radiocesium concentrations in feces and radiocesium concentrations in rumem contents.

Simulation of lichen ingestion rates

Data on seasonal radiocesium concentrations in forage were not available for computation of cesium intake. Consequently, seasonal radiocesium concentrations in vascular plants were assumed to be 1/20 of lichen values. Seasonal radiocesium concentrations in lichens were estimated by solving the relationship between lichen radioactivity, proportion of lichens in the diet (Martell *et al.* 1986, Martell and Russell in prep.), and radioactivity in rumen contents. Radiocesium concentrations in lichens thus derived equalled 401 Bq/kg for March, 389 Bq/kg for June, 664 Bq/kg for September, and 353 Bq/kg for November. The agreement between March, September, and November estimates is even closer when the effective half-time of 8.2 years has been accounted for: lichens measuring 400 Bq/kg in January should measure 393 Bq/kg in March, 385 Bq/kg in June, and 370 Bq/kg in November. However, significantly higher radiocesium concentrations in September suggest either the occurrence of a radioactive hotspot, or the ingestion of a food source with a radiocesium concentration higher than that of lichen. The occurrence of a local hotspot is tenable because the caribou typically spend 2 to 4 weeks in the Old Crow-Porcupine River drainage in September-October during the course of fall migration. Alternatively, the ingestion of a highly contaminated food source is also plausible because of altered food habits during fall migration. For example, mushrooms are only present in the diet during the fall migration (Martell and Russell *in prep.*) and represent a likely source of high radiocesium contamination. Because we have no data to support or refute this hypothesis, however, this scenario has not been included in the present simulations. For simulation purposes, therefore, radiocesium concentrations in lichens (befor correction for effective half-time) were set at 400 Bq/kg throughout the year, with the exception of the first week in September when concentrations were elevated to 650 Bq/kg to simulate the occurence of a local hotspot. A transitional week before and after this period was also allowed so that radiocesium concentrations could slide to and from hotspot values.

When seasonal intakes were adjusted to provide the best fit between observed and simulated radiocesium concentrations (Figure 5), lichen intake declined only modestly between winter and summer. Following a seasonal low in mid-June, lichen intake increased to an annual high of 2.1 Kg/day in late August to generate a second peak in the cesium profile. Lichen intake declined sharply thereafter and remained

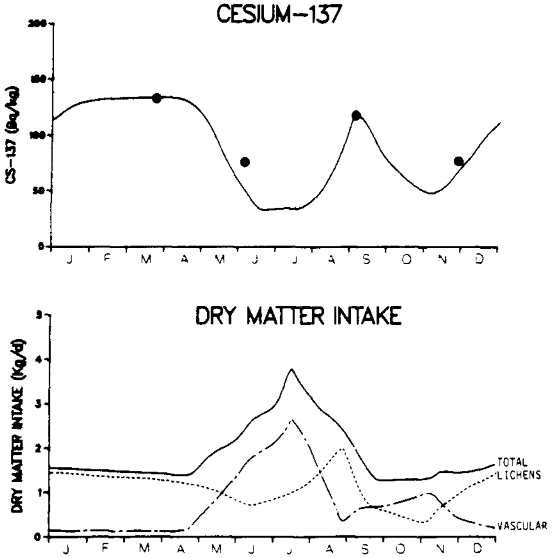


Fig.5. Simulated and observed radiocesium concentrations in skeletal muscle, and simulated ingestion rates when seasonal intakes were adjusted to best fit the observed radiocesium data.

low until November when it started to regain its winter value.

The simulation was repeated using seasonal intake values derived from empirical data (Figure 6). Dry matter intake was adapted from White and Trudell (1980) while dietary proportions of lichens and vascular plants were based on studies of the Porcupine caribou (Martell et al. 1986, Russell and Nixon 1988, Martell and Russell *in prep.*). In contrast to the first simulation, the dietary shift from lichens to vascular plants between winter and summer was pronounced. Additionally, lichen intake was elevated throughout the fall. Simulated cesium concentrations compared favorably with measured values for March, June, and September, but deviated by 80 Bq/kg in November because of sustained high lichen intakes. This resulted in a winter plateau extending from October to April.

In a third simulation, seasonal intakes were adjusted to yield a "conventional" profile depicting a gradual radiocesium incline in the fall prior to the winter plateau between February and April (Figure 7) . Simulated lichen intakes in this scenario are characterized by slow transitions between winter and summer values, constant rates throughout both winter and summers, and the absence of a fall peak.

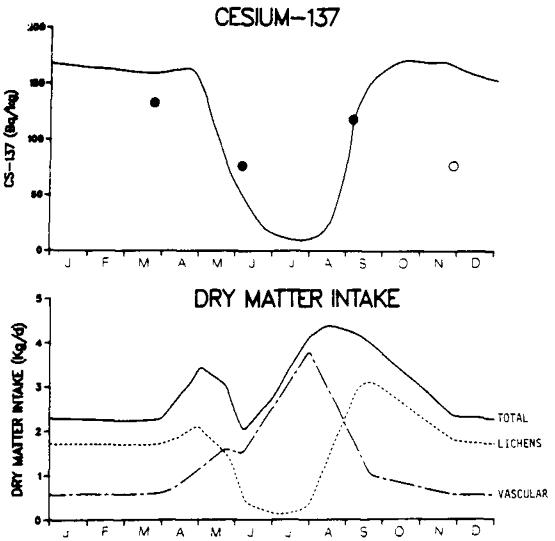


Fig.6. Simulated and observed radiocesium concentrations in skeletal muscle, and simulated ingestion rates when seasonal intakes were based on empirical data.

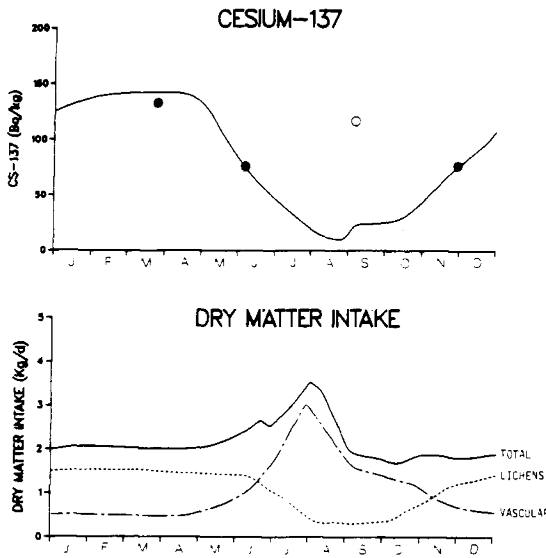


Fig.7. Simulated and observed radiocesium concentrations in skeletal muscle, and simulated ingestion rates when seasonal intakes were adjusted to yield a "conventional" cesium curve.

Discussion

Seasonal radiocesium concentrations measured in this study in caribou muscle from the Porcupine herd do not suggest any reason for health concerns. According to the National Council on Radiaton Protection and Measurements (1977), a radiocesium intake of 300,666 Bq/year results in the maximum permissable nonoccupational exposure for an adult human. In this study, mean radiocesium concentration in skeletal muscle peaked in September at 133 Bq/kg. At this concentration, an annual consumption of 2,260 kg of meat would be needed to reach the allowable intake limit. Even at 232 Bq/kg, the maximum radiocesium concentration found for any sample assayed in 1987, an annual consumption of 1296 kg of meat would be allowed. The radiation dose to an adult human with a daily consumption of 220 g of meat measuring 133 Bq/kg would, at the end of the year equal only 3.6% of the annual permissable maximum.

Simulated lichen intakes declined only modestly between winter and summer, and showed a distinct but transitory peak in late August when seasonal intakes were adjusted to provide the best agreement between simulated and observed radiocesium concentrations. Simulated intake patterns generated in this manner are therefore supported by measured cesium profiles; nonetheless, they should not be accepted as unequivocal in the absence of further validaton. The assumed timing and extent of elevated radiocesium levels directly contribute to the shape and chronology of the fall radiocesium peak. More importantly still, the assumption that animals from different collection dates share common radiocesium histories is both unverified and unverifiable. Results from the second simulation, in which empirical data were used to derive input values for seasonal intakes, suggest that this assumption may in fact be untrue. At present, however, the correctness of simulated scenarios can only be speculated on. Given the unvalidated assumptions of the model, simulation results are meant to be more thought provoking than predictive.

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