Radiocesium concentrations in the lichen-reindeer/caribou food chain: Before and after Chernobyl

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This paper reviews historical concentrations of radiocesium (Cs-137) in the reindeer/caribou food chain in Alaska. These data, along with available kinetic models which describe the movement of radiocesium through the food chain, are used to predict consequences of radioactive fallout from the Chernobyl accident which occurred in late April 1986. During the present discussion, efforts are made to directly relate the Alaskan data to the Scandinavian situation as it exists following the Chernobyl accident.

Radiocesium levels in the ecosystem

Although atmospheric testing of high yield nuclear weapons began in the early to mid 1950's (Carter and Moghissi, 1977), the accumulation of fallout radionuclides in arctic food chains, predominately cesium - 137 and strontium -90, was not recognized and/or monitored until the early 1960's (Baarli et al. 1961). However, following 1961, radiocesium levels in the lichen-reindeer/caribou-wolf/man food chain have been periodically monitored in Alaska (Hanson 1982), Scandinavia (Miettinen, 1967) and U.S.S.R. (Neustrueva et al. 1967).

In Alaska, radiocesium levels increased during the late 1950's and early 1960's. Levels were highest in the mid to late 1960's and have been decreasing ever since. During the mid-1960's, the highest radiocesium concentrations in lichen ranged from 900 to 1150 Bq/kg dry matter (Figure 1). Concentrations decreased gradually through the 1970's and by the end of the decade probably ranged from 440 to 800 Bq/kg dry matter. Presumably, radiocesium concentrations did not decline more rapidly during this 15 year period because of additional fallout from atmospheric testing by the Chinese and French during the late 1960's through the late 1970's (Carter and Moghissi 1977, Carter 1980). From the late 1970's to the present, radiocesium levels in lichen have decreased to 60 to 180 Bq/kg dry matter.

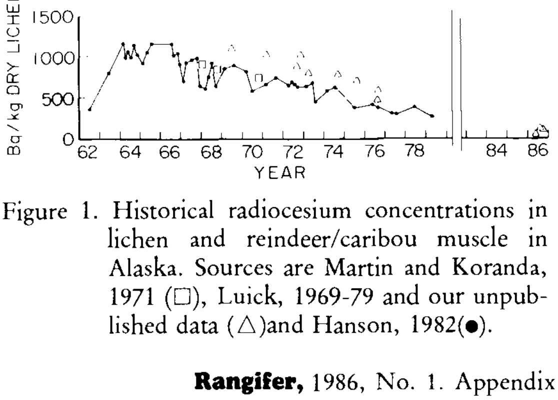

Figure 1. Historical radiocesium concentrations in lichen and reindeer/caribou muscle in Alaska. Sources are Martin and Koranda, 1971 (□), Luick, 1969-79 and our unpublished data (△)and Hanson, 1982(●).

Table 1. Radiocesium concentrations in lichen and vascular plants before and after the Chernobyl accident.

	Cs-137 Conc. Bq/kg DM *mean ± S.D.*	% *increase*
Lichens		
Before (April 86)	57 ± 5	
After (August 86)	100 ± 9	75
Vascular Plants		
Before (April 86)	11 ± 3	
After (August 86)	24 ± 5	120

Plants were collected from established plots in the Ester Dome area, near Fairbanks, Alaska. «Before» samples were collected prior to the arrival in Alaska of fallout debris from the Chernobyl accident.

Following the Chernobyl accident, the radiocesium concentration in lichen in the Fairbanks area increased by 75%, from 57 Bq/kg DM to 100 Bq/kg DM. (Table 1). Radiocesium concentrations in vascular plants increased by approximately 120%. Although the percentage increase is significant, the absolute fallout deposition of radiocesium is small compared with fallout depositions in the mid 1960's. The amount of radiocesium deposition is estimated at approximately 0.5 Bq/m^2 for the period April, 1986 (before Chernobyl) to Aug 1, 1986 (after Chernobyl). This compares to estimated annual deposition rates in Alaska during the mid 1960's of 480 Bq/m^2 (Hanson 1982). Reported deposition quantities in Sweden during the period May 9 to June 3, 1986 were as high as 150 k Bq/m^2 (Snihs, 1986).

Factors affecting radiocesium concentrations in reindeer/caribou are more thoroughly discussed in a later section; however, it is mentioned at this time that radiocesium intake is the predominate factor. The radiocesium concentration in the food supply determines the radiocesium intake, which in turn, determines radiocesium concentrations in reindeer/caribou. With the exception of periods of active fallout, the non-lichen food sources of reindeer/caribou have insignificant radiocesium concentrations compared to the slow growing lichens. Therefore, radiocesium intake will be primarily dependent upon the radiocesium concentration in lichen, and the degree to which the reindeer/caribou consume lichens. Both of these factors are apparent in Figure 1.

In Alaska, the highest radiocesium concentrations in reindeer/caribou muscle were measured during winter in the mid-1960's and ranged from 1200 to 1800 Bq/kg wet muscle following a change in the diet of the caribou from predominately lichens in winter to vascular plants in late spring through early autumn. This seasonal cycling of radiocesium concentration has been documented in Scandinavia (Svensson and Liden, 1965) as well as Alaska (Hanson 1982). By mid-1970 radiocesium concentrations in winter killed caribou had decreased to 200 to 400 Bq/kg wet muscle. A single caribou taken in January 1986 had a radiocesium concentration in muscle of less than 50 Bq/kg wet weight. It should be noted that in recent years, there appears to be considerable variability in radiocesium concentrations in lichen and in reindeer/caribou muscle between Alaska and northwestern Canada. For example, concentrations in lichen in interior Alaska are 1/3 to 1/2 concentrations on the west coast. Radiocesium concentrations in caribou from northwestern Canada are consistently higher than in those from the Brooks Range of Alaska. Presumably this variability is due to differences in the biological turnover of radiocesium in lichens in the various areas and/or differences in historical depositions of radiocesium.

Since most of the radiocesium body burden of reindeer/caribou is derived from the intake of contaminated lichen, a ratio of the radiocesium concentration in muscle to the radiocesium concentration in lichen should reflect the reindeer/caribou dependence upon lichen. The problem with the ratio is that it is affected by factors other than lichen intake, and this has lead past authors to describe the ratio as «not a very useful figure» (Miettinen 1965). For example, during periods of active fallout, significant amounts of radiocesium may be obtained from non-lichen plants. Perhaps of greater importance is the fact that radiocesium concentration in reindeer/caribou strongly depends upon the kinetics of radiocesium in the animal. Therefore, the ratio is also influenced by potassium intake and other dietary factors. Another possible complication is that over time, the absorbability of ingested fallout radiocesium may change, thus directly affecting the ratio. The chemical form of

Table 2. Ratio of radiocesium concentration in reindeer/caribou muscle (Bq/kg wet muscle) to radiocesium concentration in lichen (Bq/kg dry lichen) during winter.

Site (year)	*Ratio*
Alaska (1964-68)[1]	1.5
Alaska (1972-73)[1]	1.2
Alaska (1975-78)[1]	0.6
Alaska (1976)[2]	0.5
Canada (1980)[4]	0.7
Finland (1961-65)[3]	0.8-1.3

[1]Hanson 1982
[2]Luick 1969-79
[3]Miettinen and Hasanen 1967
[4]Unpublished data

radiocesium from fresh fallout may be considerably different from that of radiocesium that has been associated with the lichen for many years. Also, radiocesium may not be uniformly distributed on lichens, thus the measured concentration on lichen, and ultimately the ratio, will be influenced by the method of collecting lichens for radioassay. e.g. some collect only the top part or the newer growth for analysis. With these limitations in mind, a few estimates of the ratio of radiocesium concentrations in muscle to lichen are given in Table 2.

In addition to caribou, wolves predating on caribou also become contaminated and the body burden of wolves may be 4 to 10 times that of caribou. However, a radiocesium body burden much lower than that of caribou is common when the principal food is not caribou. Holleman and Stephenson (1981) have used estimates of the radiocesium body burden of wolves to indicate their predation rate on caribou. Therefore, unless precautions are taken to prevent the absorption of radiocesium, the body burden of animals fed contaminated reindeer/caribou flesh and offal could reach levels up to 10 times that in the food.

The level of radiocesium in reindeer meat in Kautokeino (Norway) has declined exponentially from 3-4.000 Bq/kg in 1968 to approximately 300 Bq/kg in 1981, with a pre-Chernobyl level predicted at 150-180 Bq/kg. This level is similar to that for caribou muscle in Alaska. However, the influence of season on these estimates should be emphasized, and the Alaskan studies suggest that seasonally low levels in summer would be expected where the intake of lichens is low.

Predicting radiocesium concentration in reindeer/caribou

Factors that affect and ultimately determine the radiocesium body burden of reindeer/caribou are (1) the radiocesium intake, (2) the absorption of ingested radiocesium and (3) the in-vivo kinetics of radiocesium in the animal (Holleman and Luick 1975a, b). The radiocesium intake is the product of food intake and the radiocesium concentration in the food. The degree to which ingested radiocesium is absorbed depends upon its chemical form. Earlier measurements have indicated that fallout radiocesium from atmospheric detonated nuclear weapons was not readily absorbed in reindeer (Holleman et al. 1971a). The in-vivo kinetics in reindeer are influenced by diet and physical factors. Possibly the most important aspect of diet is the potassium intake, since potassium intake strongly influence radiocesium kinetics (Holleman and Luick 1975b). Physical factors that may influence radiocesium kinetics include body weight, sex, age and physical condition.

A simple model was constructed to account for all factors affecting radiocesium concentration in reindeer/caribou (Figure 2). Radiocesium concentrations in food resources were multiplied by food intake rate to generate radiocesium intake.

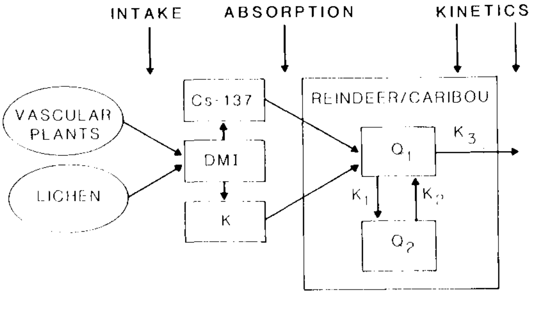

Figure 2. A model showing the movement of radiocesium from plants through reindeer/caribou. The factors that affect and ultimately determine the radiocesium concentration in reindeer/caribou muscle are indicated at their point of occurrence in the model. Factors are intake, absorption and kinetics.

A radiocesium absorption factor of 0.26 was used. This factor was determined for fallout radiocesium in reindeer grazing lichen/shrub pastures in Central Alaska (Holleman et al. 1971a). An absorption factor of 0.97 was used for potassium in the diet. A two pool model was used to describe the accumulation and elimination of absorbed radiocesium in reindeer and caribou (ibid), with total body burden of each animal equalling the sum of the two pools. The radiocesium concentration in skeletal muscle was calculated by assuming that 80% of the radiocesium body burden is in skeletal muscle, and that skeletal muscle accounts for 40% of the animal body weight (ibid).

The influence of potassium intake and body weight on radiocesium concentration in reindeer/caribou was modeled by manipulating the kinetic rate constants (k_1, k_2, k_3 - Figure 2). The effects of potassium (Holleman and Luick 1975b) and body weight (Holleman et al. 1971a) have been described earlier. In this paper, we have updated the original model by using realistic seasonal changes in body weight for the North Ottadalen reindeer herd (Reimers et al. 1983),

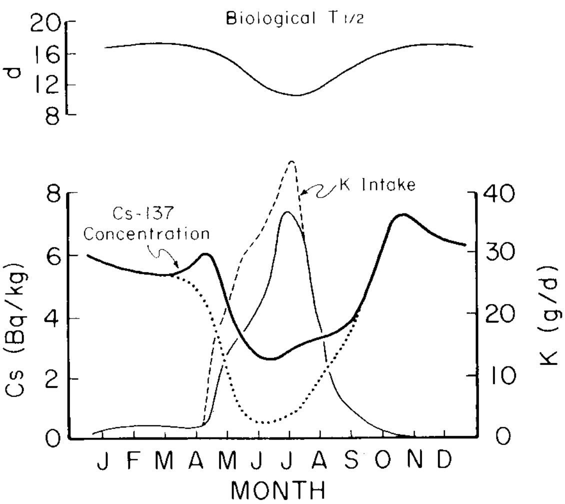

Figure 3. Simulated radiocesium body burdens (Bq/kg) and K intake for reindeer/caribou consuming contaminated forage (600 Bq/kg. lichen; 300 Bq/kg vascular plants) under 2 diet regimes: (1) year-long consumption of lichen, (—) (Gaare and Skogland 1971) and (2) no lichen intake between June 1 and August 15 (---). Potassium intakes, shown for the two diets, illustrate higher summer values apparent for animals not consuming lichens at this time.

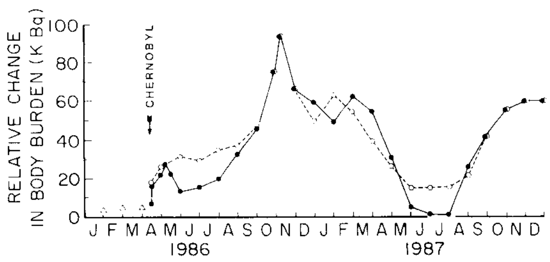

Figure 4. Simulated radiocesium body burden for reindeer/caribou consuming forage contaminated by radionuclide fallout on April 25. Simulated radiocesium concentration in contaminated lichen equals 600 Bq/kg for both 1986 and 1987; simulated radiocesium concentration in vascular plants equal 200 for 1986 and 20 Bq/kg for 1987. Results are shown for animals under 2 diet regimes: (1) year-long consumption of lichen (o - o) (Gaare and Skogland 1971) and (2), no lichen intake between June 1 and April 15 (● - ●).

food intakes (White 1983), diet composition of Hardangervidda (Gaare and Skogland, 1971) and Alaska, and potassium intake based on seasonal changes in potassium concentration of dietary components.

This model was used to estimate the two exponential components that comprise the whole body build-up and elimination curves which are integrated to produce an annual pattern of radiocesium body burden in reindeer/caribou. The results of this exercise were in good agreement with trends found empirically. In addition, it was found that the simulated body burden in summer may be less than 10% of peak winter values if the animal does not ingest lichens during the summer period (Figure 3).

Using the same model, the effect of fallout from Chernobyl was simulated assuming that both vascular plants and lichens were contaminated. Since we did not have access to actual fallout levels the response should be taken as strictly relative (Figure 4).

The model predicts that the radiocesium concentration in reindeer/caribou will increase rapidly following the occurrence of Chernobyl fallout in the environment. However, concentrations in reindeer/caribou muscle will level off during late summer with a further doubling by late autumn. The concentration in reindeer/caribou muscle is predicted to remain high until May when it should decline to 1/4 and perhaps to as low as 1/10th of peak winter concentrations. Concentrations during the summer of 1987 would depend upon radiocesium concentrations in vascular plants, potassium intake of the animal, as well as other factors discussed earlier. Calves may have higher levels in June and July due to radiocesium transfer from the cow to the calf via milk (Holleman et al. 1971b).

Conclusions

Based on a review of the literature and early estimates of radiocesium levels in lichens, we suggest that for much of northern lappland the contamination of reindeer meat is no higher than that experienced when fallout was high during the mid 1960's due to upper atmospheric testing. In addition, a seasonal change in body burden can be expected and low summer levels should provide a window for game harvest or domestic reindeer slaughter and therefore provide some optimism for the continued supply of reindeer meat for human consumption. Since the form of radiocesium is not known, this prediction would only hold provided ecosystems react in the same way in handling radiocesium from the current fallout as from that in the 1960's. Because of the problems associated with high radiocesium concentrations in the lichen food base of the mid to southern areas of Norway and Sweden it would be prudent to extend the data base for working predictions and possibly for altering the management of both domestic and wild reindeer for human consumption. Some research requirements necessary to validate the use of the present model in the Scandinavian situation are as follows: 1) a determination of the absorption factor for Chernobyl fallout, 2) determination of the radiocesium concentrations and residence time in various areas in both lichen and vascular plants, 3) determination the effects of increased potassium intake on radiocesium kinetics (elimination) in yearlings and males as the kinetic data of Holleman and Luick (1975) refer to the female cohort, and 4) determination of the seasonal radiocesium concentrations in reindeer.

Acknowledgements

This work is supported by funds from the Institute of Arctic Biology and the authors are greatful for travel funds from the Nordic Council on Reindeer Research to present this paper at the Conference in Rovaniemi.

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