# Effect of sodium and potassium supplementation on accumulation and excretion of radiocaesium in reindeer

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*Abstract:* We tested the effect of sodium and potassium supplementation on radiocaesium excretion and accumulation in reindeer eating lichens (winter diet). Nine reindeer were divided into 3 groups of 3 animals. One group was daily given 0.35 M KCl, one was given 0.35 M NaCl (both dissolved in 1 l water), and one group was kept as a control with no mineral supplement. The animals were contaminated with $^{137}Cs$ from radioactive pasture. During 3 weeks before the experiment the $^{137}Cs$ concentrations were maintained by daily supplementation of $^{137}Cs$ sprayed on lichens. From the start of the experimental period the animals received identical large daily doses of $^{134}CsCl$. Animals which were given KCl supplementation showed a lower accumulation of $^{134}Cs$ in red blood cells (RBC) and a faster decrease of $^{137}Cs$ in RBC than control animals. Sodiumchloride supplementation had no clear effects on radiocaesium concentrations in RBC. Mineral supplements did not affect excretion of radiocaesium via faeces. Supplement of KCl or NaCl increased urine production and the amount of radiocaesium excreted via the urine. It is concluded that increased K intake decreases the radiocaesium concentration in the animals more than is explained by increased urine production alone. This supports the theory that increased K concentration in the diet may contribute to a fast elimination of radiocaesium in reindeer during spring.

Key words: reindeer, radiocaesium, potassium, sodium

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## Introduction

The concentration of radiocaesium in reindeer grazing pastures contaminated with $^{137}Cs$ from the Chernobyl accident in Ukraine in 1986, has shown considerable variation through the seasons. The concentration decreases rapidly during spring to levels which in summer were 20-25% of the winter concentrations (Skogland, 1987; Eikelmann *et al.*, 1990; Pedersen *et al.*, 1993; Åhman & Åhman, 1994).

Different plant species accumulate radiocaesium in different ways and to different extends. After the Chernobyl accident high radiocaesium concentration ($^{134}Cs$ + $^{137}Cs$) were measured in lichens (30-50 kBq $kg^{-1}$ DM), while concentrations in vascular plants were much lower (0,15-5,0 kBq $kg^{-1}$ DM) in e.g. plant samples collected in the Jotunheimen mountain region of Southern Norway in the period 1986-1989 (Garmo *et al.*, 1990; Hove et *al.*, 1990). Lichens take up all nutrients through the surface, and are therefore highly affected by airborne pollution (Tuominen & Jaakkola, 1973). Plants that depend on root uptake of nutrients are therefore less contaminated by radioactive fall-out. During winter the diet can contain up to 80-90% lichen.

Shrubs, sedges and grasses are important in the summer diet (Skjenneberg *et al.*, 1972; Gaare & Skogland, 1975; Boertje, 1984; Gaare & Staaland, 1994).

The summer diet of reindeer has a higher mineral content than the winter diet. Particularly the content of K differs between diets (Staaland & Sæbø, 1993). In vascular plants the K concentration is 200-400 mM $kg^{-1}$ dry material (DM) compared to 30 mM $kg^{-1}$ DM in lichens. Potassium is presumed to affect Cs retention in animals. Holleman & Luick (1975a,b) found that the turnover rate of radiocaesium in reindeer was two to three times higher during summer than during winter. They also showed that increasing the K intake 20 times, doubled the excretion of radiocaesium (Holleman & Luick, 1975b).

The present experiment was designed to separate the effects of increased K intake from those related to osmotic loads by comparing Cs metabolism in animals receiving supplementation of either Na or K in isosmotic amounts. The effects were studied when reindeer were eating lichen (winter diet) supplemented with K to a level which simulated the content of one kg DM of freshly growing grass in the spring. To simulate possible osmotic effects the same amounts of Na and K were given .

## Materials and methods

Nine semi-domestic male reindeer calves (11 months old) were used. The animals had been grazing in the Vågå reindeer herd in the south central mountain range of Norway. The reindeer were at the time of collection contaminated to a varying degree (900-1630 Bq $l^{-1}$ red blood cells (RBC)) with $^{137}Cs$. Before the experiment started the animals were accustomed to handling and feeding and kept for 3 weeks in the metabolic cages. At the start of the experiment the 9 animals were divided into groups of 3 animals. The K group was given a daily supplement of 0.35 M of KCl dissolved in 1 l of water. The Na group was given a daily supplement of 0.35 M of NaCl in 1 l of water. The control group received no supplement of minerals. The KCl and NaCl solutions were given by a tube passed through the mouth and half way down the oesophagus. Lichen (*Cladinia* spp.) and water was given *ad. libitum.* The lichen had a low concentration of radiocaesium (270 Bq $kg^{-1}$ DM). The K concentration in the food was about 30 mM $kg^{-1}$ DM and the Na concentration about 10 mM $kg^{-1}$ DM.

To keep the animals at a stable level of radiocaesium contamination during the adaptation period they were given a fixed daily amount of radiocaesium. $^{137}CsCl$ was sprayed on small batches of lichen and given to the animals before feeding every morning. The daily dose of radiocaesium was calculated for each individual based on RBC $^{137}Cs$ concentration at arrival to the laboratory (Table 1). We assumed a transfer coefficient of 1.0 from forage to muscle tissue for ionised radiocaesium and a muscle radiocaesium activity 6 times the RBC values (Hove

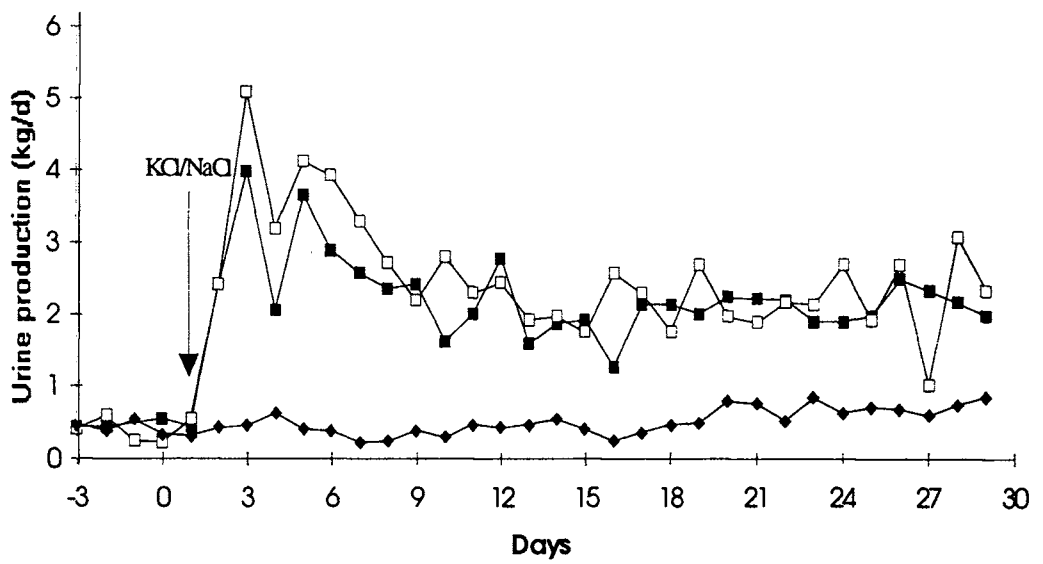


Fig. 1. Daily urine production. The arrows marks the start of the mineral supply. ■ Potassium group, □ Sodium group, ◆ Control group.

Table 1. Experimental animals daily mineral supplement and intake of radiocaesium and food. Equal doses of $^{137}Cs$ were given before the experiment started and $^{134}Cs$ during the experiment.

| Exp. group | Animal no. | Dose (Bq) | Mineral supplement (M $d^{-1}$) | Lichen intake (g DM $d^{-1}$) |
|---|---|---|---|---|
| Potassium | 1 | 6400 | 0.35 KCl | 921±126 |
| | 2 | 5500 | 0.35 KCl | 712±162 |
| | 3 | 7000 | 0.35 KCl | 937±136 |
| Sodium | 4 | 9500 | 0.35 NaCl | 669±162 |
| | 5 | 6400 | 0.35 NaCl | 682±168 |
| | 6 | 8300 | 0.35 NaCl | 782±185 |
| Control | 7 | 6400 | 0 | 667±175 |
| | 8 | 6400 | 0 | 930±208 |
| | 9 | 7000 | 0 | 782±187 |

*et al.*, 1987). In the experimental period (29 days) the $^{137}Cs$ isotope was replaced by the same amount of $^{134}Cs$.

The rate of water turnover was measured in two periods (each 2 weeks) during the experiment. Each animal was given an intravenous injection of tritiated water (THO) in 1 ml aliquots at the start of the experiment and 2 weeks later. Dilution of THO in plasma was used to estimate body pools of water and water fluxes.

The animals were kept in metabolic cages for total collection of faeces and urine and measurement of food intake. Faeces and urine were collected and weighed every day. A sample of 150 g faeces was collected from each animal and dried at 100°C for 48h. Dried material was analysed with respect to K, Na, $^{134}Cs$ and $^{137}Cs$ concentration. Individual samples of 20 ml urine were collected daily for measurement of K, Na, $^{134}Cs$ and $^{137}Cs$ concentrations. Blood samples were collected from the jugular vein two times a week. Plasma and RBC were separated by centrifugation (20 min at 3000 r.p.m). Potassium and Na concentration were analysed in plasma. The concentration of $^{134}Cs$ and $^{137}Cs$ were measured in RBC.

Analyses of radiocaesium and THO were done at the Isotope laboratory, Laboratory of Analytical Chemistry, Agricultural University of Norway. The radiocaesium analyses were done on a Minaxi Autogamma scintillation counter, 5000 series, Packard instrument Co., USA. The THO activity in 1 ml aliquots of sublimated water was determined by liquid scintillation counting on a Tri-CARB 4530, Packard Instrument Co., U.S.A Atomic absorption spectrophotometer GBC 906AA was used for K and Na analyses.

Analyses of variance with Tukey-Kramer tests were used to calculate significant differences between the groups. Significance levels were set to $p<0.05$. Semilogarithmic regression lines (slope=k) were calculated to find the half times of radiocaesium and water dilution ($T_{1/2}=\ln 2/k$).

## Results

Average lichen intake ranged between 667 and 937 g DM $d^{-1}$ (Table 1). There were no changes in body weight of the animals during the experiment (Table 2). Faeces production was not affected by treatments. Supplementation with KCl or NaCl increased the total urine production about four times compared to the control group (Table 2). After 3 days the supplemented animals reached a peak of 4–5 l $d^{-1}$ urine production (Fig. 1), whereafter the urine production decreased and stabilised after 10 days at 2-3 l $d^{-1}$. The water flux was about two times higher in the mineral supplemented animals than in the control animals. The animals of the K and Na groups appeared to have larger body water pool than the controls but the observations were not significant (Table 3).

Supplementation of KCl or NaCl increased the excretion of the respective cations in faeces and urine. At the end of the experiment the K concentration in faeces was 2.7 times higher in the K group than in the control group (Table 4). Increased sup-

Table 2. Body mass at start and end of the experiment and faeces and total urine production during the experimental period (27* days).

| Exp. group | | Body mass (kg) start of exp. | Body mass (kg) end of exp. | Tot. faeces prod. during exp. (kg DM) | Tot. urine prod. during exp. (l) |
|---|---|---|---|---|---|
| Potassium | (n=3) | 50±7 | 50±6 | 6.87±1.21 | 60±11a |
| Sodium | (n=3) | 50±6 | 49±5 | 5.47±1.05 | 66±8a |
| Control | (n=3) | 51±2 | 50±3 | 6.16±0.40 | 14±4b |

Figures followed by different letters are significantly different, $p<0.05$.

* Samples from the two last days of the experiment were omitted because the animals were given other radioisotopes to measure absorption from the alimentary tract.

Table 3. Estimated body pools of water, half-time and flux of water in the different experimental groups. Values used are the average of two experiments on each animal.

| Exp. group | Body pool (% of BM) | $T_{1/2}$ (d) | Flux (l $d^{-1}$) |
|---|---|---|---|
| Potassium (n=3) | 77.9±5.1a | 7.1±1.7a | 3.9±0.8a |
| Sodium (n=3) | 75.6±5.1a | 5.9±0.5a | 4.4±0.3a |
| Control (n=3) | 70.0±8.8a | 11.3±1.3b | 2.2±0.4b |

Figures followed by the same letters are not significantly different, $p>0.05$.

ply of NaCl lead to about 12 times higher concentrations of Na in faeces in the Na group, compared to the control group. Potassium supplementation lead to a significant increase in concentrations of both K and Na in the urine ($p<0.001$). Sodium supplementation lead to increased concentration of Na in the urine, but did not change the concentration of K (Table 4). Because of increased urine production, the total excretion of K in the Na group was nevertheless significantly higher than in the control group ($p<0.05$). At the time of slaughter the concentrations of K and Na in plasma were equal in all groups (Table 4).

There were no significant differences in total faecal $^{137}Cs$ excretion between the groups (Table 5). During the first three days of mineral supplementation the animals reached maximum excretion of $^{137}Cs$ via the urine, then the excretion decreased until slaughter (Fig. 2). The K and Na supplemented animals had a higher total excretion of $^{137}Cs$ in the urine than the control animals ($p<0.01$). There was a decrease in $^{137}Cs$ concentration in RBC during the experiment in all groups. The effective half-time of $^{137}Cs$ in RBC was 18±4 days in the K group and 31±5 days in the control group ($p<0.05$). The Na group was not significantly different from either of the other groups (Table 5). Estimated reduction of $^{137}Cs$ in muscle was found to be significantly greater in the K group than the other groups ($p<0.01$) (Table 5).

During the experiment about 30% of the total $^{134}Cs$ intake was excreted via faeces, and there was no differences between the three groups (Table 6).

Table 4 . Average potassium and sodium concentrations in faeces, urine and plasma at the end of the experiment in each group.

| Exp. group | Faeces mM $kg^{-1}$ DM | | Urine mM $l^{-1}$ | | Plasma mM $l^{-1}$ | |
|---|---|---|---|---|---|---|
| | K | Na | K | Na | K | Na |
| Potassium (n=3) | 369±139a | 11±7a | 116±17a | 13±4.5a | 3.98±0.15a | 136±2a |
| Sodium (n=3) | 105±28b | 149±15b | 1.18±0.71b | 136±11b | 3.85±0.07a | 138±4a |
| Control (n=3) | 139±12b | 12±1a | 1.42±0.60b | 0.60±0.20c | 3.71±0.25a | 139±2a |

Figures followed by the same letters are not significantly different, $p>0.05$.

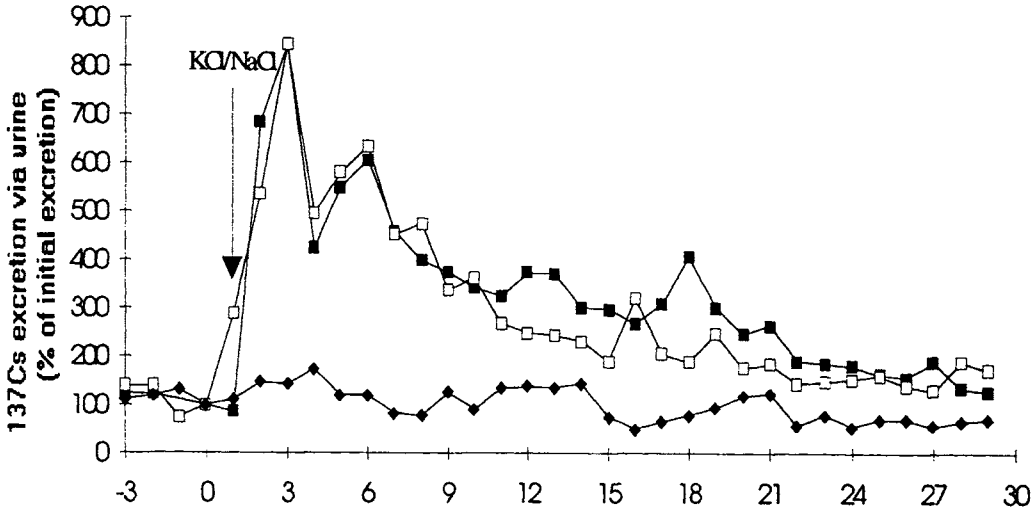


Fig. 2. Relative excretion of $^{137}Cs$ via urine in the different groups. Excretion at start of the experiment is defined as 100%. The arrow marks the start of mineral supplementation. ■ Potassium group, □ Sodium group, ◆ Control group.

Potassium chloride and NaCl treatment increased the excretion of $^{134}Cs$ in urine compared to the control animals ($p<0.05$). In the K and Na supplemented animals 12 and 16 % of the total $^{134}Cs$ intake was excreted via the urine compared to 5% in the control group (Table 6). At the time of slaughtet the transfer factor (i.e. the ratio of the daily dose of $^{134}Cs$ and the RBC concentrations, Bq $l^{-1}$ RBC/Bq $d^{-1}$ in feed) was significantly lower in the K group than in the Na and control groups (Table 6). The average concentration of $^{134}Cs$ in meat of the different groups was 30% lower in the KCl group than in the two other groups, but the difference was not significant.

## Discussion

The amount of K given to the animals was estimated to be similar to the concentration of K in natural pasture during spring (May-June). Although Cl would not be the accompanying ion to the same degree in natural food, chloride dose was expected to be well within the amounts that the animals would tolerate. Since animals treated both with K and Na received the same amounts of Cl it is assumed that differences observed between these two groups would be an effect of Na or K intake. Maintained body mass (BM) of all animals during the experiment support the assumption that the experimental conditions were tolerated well. Also plasma concentrations of K and Na were within normal values (Bjarghov *et al.*, 1976) and was not affected by the mineral supplement.

Potassium chloride and NaCl intake raised the urine production and water flux since the increased osmotic load forced the animals to increase their water intake. Increased urine production contributed to an increased excretion of K and Na in both

Table 5. Total excretion of $^{137}Cs$ via faecs and urine, and k values and half-time of $^{137}Cs$ in RBC during the experimental period (27* days). Estimated reduction of $^{137}Cs$ concentrations in muscle was calculated from estimated muscle concentrations at the start of the experiment based on RBC concentrations and the measured concentrations in meat at slaughter.

| Exp. group. | Tot. $^{137}Cs$ excr faeces (kBq) | Tot. $^{137}Cs$ excr. urine (kBq) | k $^{137}Cs$ | $T_{1/2}$ $^{137}Cs$ RBC(d) | Red.$^{137}Cs$ in muscle (%) |
|---|---|---|---|---|---|
| Potassium (n=3) | 47.2±8.1a | 53.90±12.14a | -0.039±0.009a | 18±4a | 55±3a |
| Sodium (n=3) | 47.8±19.7a | 36.67±18.72a | -0.029±0.005ab | 25±5ab | 42±5b |
| Control (n=3) | 42.4±2.8a | 14.19±2.05b | -0.023±0.003b | 31±5b | 38±6b |

Figures followed by the same letters are not significantly different, $p>0.05$.
* See table 2.

Table 6. Percent of total $^{134}Cs$ dose excreted via faeces and urine during the experimental period. Accumulated $^{134}Cs$ in RBC and muscle at the end of the experiment as % of daily dose for each group.

| Exp. group | (tot. Bq faeces/ tot. Bq intake)*100 | (tot. Bq urine/ tot. Bq intake)*100 | (Bq $l^{-1}$ RBC/ Bq $d^{-1}$)*100 | (Bq $kg^{-1}$ muscle/ Bq $d^{-1}$)*100 |
|---|---|---|---|---|
| Potassium (n=3) | 30±3a | 12±6a | 9±1a | 47±6a |
| Sodium (n=3) | 29±4a | 16±1a | 13±2b | 57±3a |
| Control (n=3) | 29±2a | 5±0.3b | 13±1b | 61±10a |

Figures followed by the same letters are not significantly different, $p>0.05$.

mineral supplemented groups. The total amount of $^{137}Cs$ which daily was excreted via urine seemed to follow the same pattern as the urine production (Figs. 1 and 2). The total amount of both $^{137}Cs$ and $^{134}Cs$ excreted via urine was higher in the mineral supplemented than in the control group. There were no significant differences in urinary and faecal excretion of radiocaesium between the two mineral treated groups. Part of the explanation can be that the animals of the Na group had higher levels of $^{137}Cs$ at the start of the experiment and received higher doses of $^{134}Cs$ during the experiment (Table 1). Even with a slower turnover rate of Cs for the Na treated animals than for the K the group this would minimise expected differences in urinary loss of Cs isotopes as observed by Åhmann (1988 a,b). Although any differences in the effect of K and Na treatment on urinary and faecal excretion of water and Cs isotopes appeared non significant K treatment reduced the activity of $^{137}Cs$ in RBC and meat more efficiently than in Na treated and control animals (Table 5). Similarly the accumulation of $^{134}Cs$ was lower in RBC and meat (NS) in the K treated than in the Na and control animals.

High concentrations of K in spring pasture of grasses and herbs (Staaland & Sæbø, 1987) may therefore contribute to decreased concentrations of radiocaesium in RBC and muscle tissue for reindeer on spring and summer pasture (Pedersen *et al.*, 1993). These findings correspond to observed reduced radiocaesium activity in reindeer during spring (Holleman & Luick 1971), and could at least partly be an effect of increased water turnover at that time of the year (Cameron & Luick 1972).

Also in the present study potassium supplement increased urine concentrations of Na compared to control animals, but had no apparent effect on faecal concentrations (Table 4). Several studies have shown that K has an effect on Na distribution and transfer within the body of reindeer and other animals (Staaland & Garmo 1987; Staaland & Sæbø 1987; Warner & Stacy, 1972).

The present study support the theory that K has an effect on excretion and distribution of the two alkali elements Na and Cs in reindeer. Increased intake of K either from green summer vegetation or given as a direct supplement to the diet therefore reduce retention and accumulation of radiocaesium and Na in reindeer.

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