Radiostrontium, radiocesium and stable mineral composition of bones of domestic reindeer from Vågå, Norway

Hans Staaland [1]**, Helge Bjørnstad**[2]**, Øyvind Pedersen**[3] and **Knut Hove**[3]

1) Department of Biology and Nature Conservation 2) The Isotope Laboratory and 3) Department of Animal Science, Agricultural University of Norway, 1432 NLH-ÅS, Norway.

Abstract: Radiostrontium, radiocesium and macromineral concentrations were measured in metatarsal or metacarpal bones from 78 reindeer (59 calves and 19 adults) in the Vågå reindeer herding district in Southern Norway. Samples were collected in the period August 1988 to May 1989.

Radiocesium concentrations increased from August through the winter. Radiostrontium varied slightly around an average value 1810 Bq/kg DM. Mg concentrations decreased through the winter, the concentrations of other minerals and bone density showed only small variations. No signs of mineral deficiencies were observed. It is concluded that radiostrontium mainly originated from the Chernobyl nuclear accident.

Key words: Reindeer, bone minerals, radiostrontium, radiocesium, Ca, Mg, P, Na, K, Norway.

Rangifer, 11 (1): 17—22

Hans Staaland, H. Bjørnstad, Ø. Pedersen og **K. Hove.** 1991. Radiostrontium, radiocesium og stabile mineraler in reinknokler fra Vågå, Norge.

Sammendrag: Innhold av radiostrontium, radiocesium og makromineraler ble målt i reinsdyrknokler *(metatarsus* og *metacarpus)* innsamlet fra 78 dyr (59 kalver og 19 voksne) tilhørende Vågå tamreinlag. Prøvene ble samlet i perioden august 1988 til mai 1989. Innholdet av radiocesium økte fra august og gjennom vinteren, mens innholdet av radiostrontium var temmelig konstant (1810 Bq/ kg tørrstoff). Magnesium innholdet avtok gjennom vinteren, mens innholdet av andre mineraler samt knoklenes tetthet varierte lite. Det ble ikke observert noen tegn på mineralmangel. Mesteparten av det radioaktive strontium kom fra atomkraftulykken i Tsjernobyl.

Rangifer, 11 (1): 17–22

Introduction

After the Chernobyl accident the contamination of mountain pasture and subsequent accumulation of the radioisotopes ^{134}Cs and ^{137}Cs in reindeer have been highlighted (Skogland 1987; Jones *et al.* 1989; Pedersen *et al.* 1990). In addition to radiocesium the fallout also contained radiostrontium (^{90}Sr) with an activity in Fennoscandia amounting to about 2% of radiocesium activity (Antilla 1986; Aarkrog 1988). The concentration of this isotope in products from farm animals has been below the action limit of ^{90}Sr and has therefore not been emphasized by health authorities to the same extent as radiocesium. Analyses of soils from high mountain areas in Valdres, Norway indicate that the ^{90}Sr

deposition after the Chernobyl was comparable in size to the fallout after the atmospheric nuclear weapon tests (Bjørnstad *et al.* 1990).

The Cs isotopes are rapidly recycled within the body (Staaland *et al.* 1990) and rapidly excreted. Contrary ^{90}Sr follow Ca in biological systems and is firmly bound to the bone matrix and may remain in the bones throughout the lifetime of animals. ^{90}Sr decays to ^{90}Y, a β-emitter at a much higher energy level than ^{90}Sr, 0.546 and 2.28 MeV respectively. ^{90}Y has been related to damage of the bone marrow and to development of leukemia in man. It should also be mentioned that ^{90}Y not like Sr follow calcium in biological systems and therefore more easily can be circulated within the body.

In the arctic maximum concentrations of most fallout radionuclides are associated with the lichen-reindeer-man food chain (Hanson 1967). Most Sr is found in the reindeer bones whereas Cs accumulate in the soft tissues. The levels of both ^{90}Sr and ^{137}Cs in reindeer breeders consuming large amount of reindeer meat were only about twice that of other people living in the same areas both in Russia (Nevstrueva *et al.* 1967) and in Norway (Westerlund 1985). Apparently radiostrontium is more mobile in arctic lichen dominated ecosystems than radiocesium (Hanson *et al.* 1967). Studies from Norway (Hove and Strand 1990) and from the Faroe Islands and Greenland (Hansen and Aarkrog 1990) indicate that radiostrontium and radiocesium can persist for long periods in alpine ecosystems. This long retention has raised concern about possible genetic damage to reindeer and other parts of alpine ecosystems (Skogland 1990).

The purpose of the present study was therefore to measure bone radiostrontium and radiocesium contents and to examine possible seasonal variations in their concentrations in reindeer in an area heavily contaminated with radioactivity from the Chernobyl accident. Comparison is made to the values observed after the global fallout in the 1960'ies. Results obtained are furthermore compared to variations in concentrations of major bone minerals.

Material and methods

Metacarpal or metatarsal bones were collected from 59 reindeer calves aged 3 months to one year through the season from August 1988 to May 1989. In addition samples were taken from 19 adult reindeer of different ages. The animals were from the herd of The Vågå domestic reindeer company in Southern Norway.

About 8–10 cm of the middle part of the bone was used for analyses (Fig. 1). Soft tissues were removed and the bone marrow expelled. Cleaned bone samples were dried at 105°C to

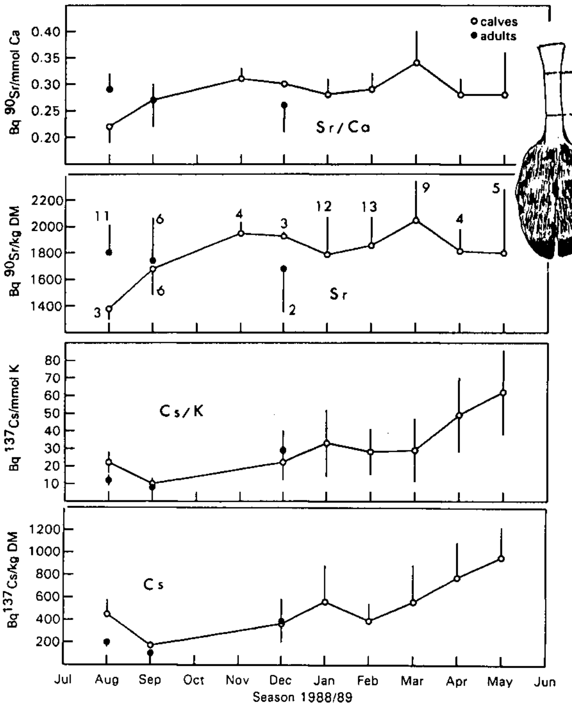

Fig. 1. Radiocesium (^{137}Cs) and radiostrontium (^{90}Sr) in metacarpal or metatarsal bones from reindeer in the Vågå reindeer herding district in southern Norway. Fully drawn lines between open rings calves born in May 1988, black dots adult animals of different ages. Vertical lines one S. D., figures beside S. D. in second diagram from above number of animals. These figures apply to all diagrams in Figs. 1 and 2.

Fig. 1. Radiocesium (^{137}Cs) og radiostrontium (^{90}Sr) i metacarpus eller metatarsus fra rein tilhørende Vågå tamreinlag i Sør-Norge. Heltrukket linje mellom åpne ringer er fra kalver født i mai 1988, fylte ringer stammer fra dyr med forskjellig alder. Vertikale linjer tilsvarer ett standard avvik. Tall ved siden av de vertikale linjer i det andre diagrammet ovenfra er antall dyr undersøkt. Disse tallene gjelder for alle diagrammene i Figurene 1 og 2.

constant weight. The density was measured by submersion of bone specimens in glycerol of known density.

After cleaning and drying the bones were crushed in a steel mortar. One subsample was used for measurement of the two isotopes ^{137}Cs and ^{90}Sr and another for measurement of the minerals P, Ca, Mg, Na and K.

Radiometry

^{137}Cs was analyzed in approximately 10 g of crushed bone, using either a Canberra Ge-detector (20% efficiency and 2kev resolution at 1332 kev) or a Packard 3'' NaI Gamma counter 5000 series.

The concentration of ^{90}Sr in the samples were determined from analysis of ^{90}Y concentration, assuming radiological equilibration between ^{90}Sr and ^{90}Y (Bjørnstad *et al.* 1990). Following gammaspectrometry the samples were dry-ashed overnight at 600°C and dissolved in HCl. After addition of carrier, ^{90}Y was isolated by liquid extraction (Peppard *et al.* 1957). The extracted ^{90}Y was back-extracted into 6 M NHO_3. The Cerenkov spectra from ^{90}Y were couted using a low-level liquid scintillation counter (Quantulus 1220 LKB Wallac, Finland). Chemical yields were determined by compleximetric titration.

Chemical analyses of P, Ca, Mg, Na and K were performed at the Chemical Research Laboratory of our University. Bones were ground and ashed at 500°C and the ash dissolved in *aqua regia.* The concentrations of the elements were determined by Inductively Coupled Plasma Spectrometry (ICP).

Statistical analyses of the data include calculation of the standard deviation of the means and the Duncan multiple range test (Ray 1982).

Result

In 5 animals chemical composition and content of the radioisotopes were measured in the two metatarsal and the two metacarpal bones. No significant differences in either chemical composition or isotope content was detected ($P > 0.05$, Duncan test). Therefore either the metacarpal or metatarsal bone was used for the rest of the animals.

The average bone ^{90}Sr activity through the year was 1814 ± 270 Bq/kg dry matter (DM) with no apparent seasonal trend. Also relatively to Ca ^{90}Sr levels (Bq ^{90}Sr/mmol Ca) remained stable between 0.28 and 0.31 from November to May (Fig. 2, Table 1). The concentrations of ^{137}Cs increased from August–September to May. Since K concentrations remained almost constant through the year, also the ^{137}Cs relatively to K increased through the winter (Fig. 1).

Density of the bones increased from 1.77 g/cm^3 in calves sacrificed in August to about 1.85 g/cm^3 in the winter. Also total ash content showed a similar increase from autumn to winter and spring. There were no significant differences between calves and adult animals in bone ash content (Fig. 2).

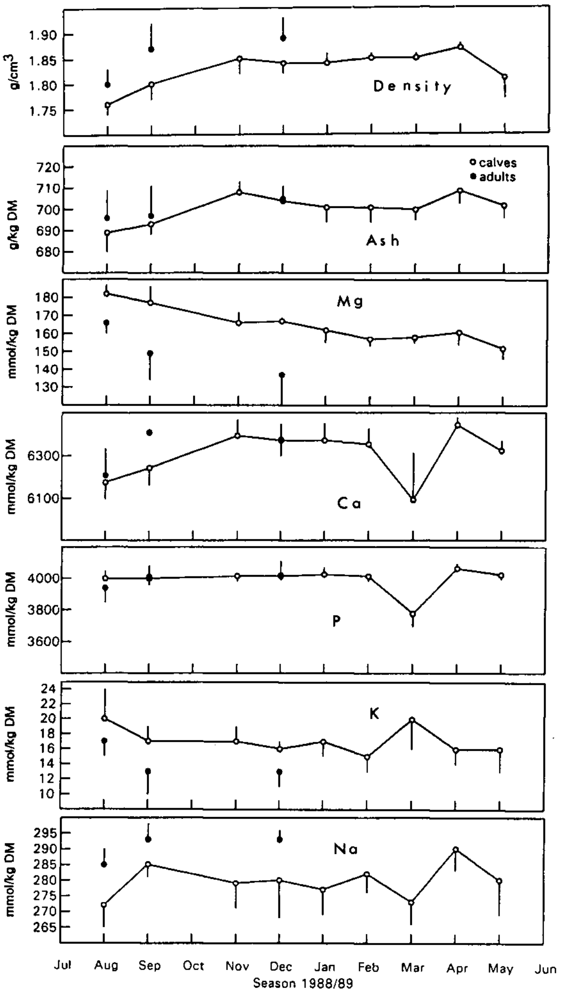

Fig. 2. Mineral concentrations (± S.D.) in metatarsal or metacarpal bones from reindeer in the Vågå reindeer herding district in southern Norway. For further explanations see Fig. 1.

Fig. 2. Mineralkonsentrasjoner i metacarpus eller metatarsus fra rein tilhørende Vågå tamreinlag i Sør-Norge. For nærmere forklaring se Fig. 1.

Table 1. Mean bone composition ± S.D. (n=78). (All data pooled).

Tabell 1. Gjennomsnittlig sammensetning av reinknokler ± S.D. (n=78). (Alle data samlet).

Density g/cm³	1.83 ± 0.04
^{137}Cs Bq/kg DM	474 ± 346
^{90}Sr Bq/kg DM	1814 ± 270
Ash g/kg DM	700 ± 9
P mmol/kg DM	3977 ± 109
Ca mmol/kg DM	6291 ± 154
Mg mmol/kg DM	161 ± 11
Na mmol/kg DM	282 ± 9
K mmol/kg DM	16 ± 3
Sr/Ca Bq/mmol	0.29 ± 0.04
Cs/K Bq/mmol	29 ± 22

The most consistent seasonal variation in bone mineral concentrations was found for Mg where a pronounced downward trend was observed from August to May in the calves. Values for adult animals were significantly lower ($P<0.05$), and the data indicated the same downward trend through the winter (Fig. 2). For Ca an apparent opposite trend was observed with the lowest concentrations in the autumn and higher values through the winter from December to May. Phosphorous and K were apparently only subjected to minor and usually insignificant variations in concentrations, but K was significantly higher in calves slaughtered in August and March ($p<0.05$, Duncan test). Also for Na no apparent seasonal trend in concentrations could be found, but values obtained from adult animals were slightly higher than for calves ($p<0.05$ in August and December). Concentrations of Ca, P and Na in March were unexpectedly low and K high compared to values obtained from February and April.

Discussion

Reindeer bones collected in northern Norway in 1956 and 1958 contained about 0.15 and 0.22 Bq/mmol Ca of ^{90}Sr (Hvinden and Lillegraven 1961), whereas values from the early 1970'ies were about 0.50 Bq/mmol (Westerlund 1985). Our value, about 0.29 Bq/mmol (*i.e.* 1800 Bq/kg dry weight) is between these values from reindeer bones in northern Norway. The radiostrontium in these bones came from atmospheric nuclear weapon tests in the 1960'ies (Fig. 3). The physical half life of ^{90}Sr is 28 years and the estimated biological half life in reindeer bones between 7 and 9 years based on data from Westerlund (1985, Fig. 3). Data on the deposition of radiostrontium in Vågå during the nuclear weapons tests do not exist. However beeing a relatively dry inland area levels may have been comparable to those in Finnmark. Extrapolation of radiostrontium data from Finnmark in the 1970'ies and early 1980'ies give rise to present day concentrations in reindeer bones of about 500 Bq/kg of ^{90}Sr (Westerlund 1985). With measured values of about 1800 Bq dry bones the conclusion is that the Chernobyl accident contributed significant quantities of ^{90}Sr to alpine ecosystems in addition to the well recognized radiocesium contamination. From a physiological point of view ^{90}Sr closely follow the seasonal trend of Ca.

In White-tailed deer Rabon (1968) observed that radiostrontium levels in bones decreased with age. Fawns aged 0–11 months had twice as

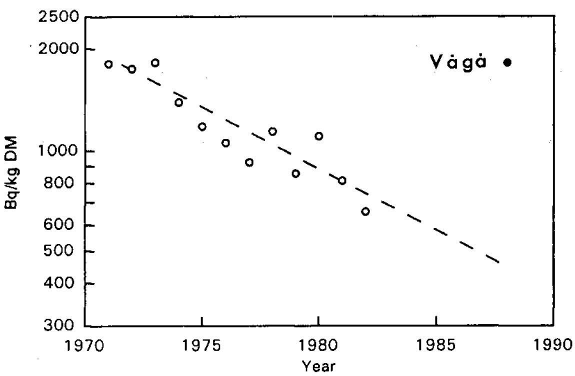

Fig. 3. Comparison of radiostrontium in reindeer bones from Finnmark in the seventies, open rings (Westerlund 1985) and present data from the Vågå reindeer herd, black dot (Table 1). Fully drawn line indicate the loglinear regression of Finnmark data: Ln(Bq/kg DM) = −0.0845*(year) + 174.06; r = −0.92.

Fig. 3. Sammenlikning av radiostrontium nivået i reinknokler samlet i Finnmark i syttiåra, åpner ringer (Westerlund 1985) med dagens gjennomsnittsnivå fra Vågå, fylt ring (Tabell 1). Den heltrukne linjen indikerer loglineær regresjon av Finnmarksdata: Ln(Bq/kg DM) = −0.0845(år) + 174.06; r = −0.92.*

much ^{89}Sr and ^{90}Sr in long bones as had animals older than 3 years. Our data suggest about equal levels in young and old animals which is also to be expected if Ca and Sr behave similarly in biological systems. In Rabon's study, which was performed on deer at the Savannah River plant in South Carolina radiostrontium ranged between 10pCi/g weight (*i.e.* 370 Bq/kg) in old animals to about 20 pCi/g wet weight (740 Bq/kg) in young animals.

The radiocesium levels in the bones reflect dietary radiocesium intake, *i.e.* being high due to lichens in winter and much lower due to green vegetation in summer. Contrary to blood values from the same herd which remained constant and decreased slightly, bone values for ^{137}Cs apparently increased through the winter (Garmo *et al.* 1990).

This may indicate that accumulation into bones occurs at a slow rate compared to the rest of the body pools, accordingly that bone Cs is less readily exchanged with the environment than soft tissue radiocesium. The lower values found for radiocesium in bones from adult animals than for calves correspond to a body size effect observed by Rabon (1968) for white tailed deer. The bone content of radiocesium do not follow the K values and it is well known that K is a bad tracer for radiocesium (Oughton *et al.* 1991).

Very few data on bone mineral composition are available for reindeer. Mineral concentration in femurs from reindeer calves collected in the Elgå herding district in the eastern part of southern Norway showed similar seasonal trends as in the present study (Staaland and Sæbø 1987). In particular a decrease in Mg concentration and an increase in K concentration was observed from fall to spring. Bjarghov *et al.* (1977), which examined metatarsal bones from coastal areas found no change in bone Mg from fall to spring. In an experimental study, however, Bjarghov *et al.* (1976) reported slightly increased K levels in plasma of reindeer calves fed a pure lichen diet through the winter and decreased Mg levels. In the Elgå material Na levels in femur bones apparently increased from fall to spring, but average values varied between only 220 and 240 mmol/kg dry bone against a mean value of about 280 mmol/kg dry matter in the present study (Table 1). In the Elgå area there is a presumed low availability of Mg and Na (Staaland and Sæbø 1987). Higher values found in the Vågå reindeer could result from the use of salt licks or be an effect of higher levels of these minerals in lichens from the Vågå area (Garmo 1986; Staaland and Sæbø 1987). Also in sheep (McDougall *et al.* 1974) Na depletion reduce bone Na levels. No signs of P or Ca deficiency were detected, the Ca values were almost identical in Vågå and Elgå and bone density values indicated adequate Ca intake because inadequate Ca in diet decrease bone density in sheep (Field *et al.* 1975).

References

Aarskog, A. 1988. The radiological impact of Chernobyl debries compared with that from nuclear weapon fallout. – *J. Envir. Radioac.* 6: 151 - 162.

Antilla, M. 1986. The activity inventory of the fuel in a RBMK-type reactor. – *Technical Report Tsecherno 2-86. Espoo: Nuclear Enginering Laboratory, Technical Research Center of Finland, pp?*

Bjarghov, R., S., Fjellheim, P., Hove, K., Jacobsen, E., Skjenneberg, S. and **Try, K.** 1976. Nutritional effects on serum enzymes and other blood constituents in reindeer calves. *(Rangifer tarandus tarandus).* – *Comp. Biochem. Physiol.* 55A: 187 - 193.

Bjarghov, R. S., Jacobsen, E., and **Skjenneberg, S.** 1977. Composition of liver, bone and bone-marrow of reindeer *(Rangifer tarandus tarandus)* measured at two different seasons of the year. – *Comp. Biochem. Physiol.* 56A: 337 - 341.

Bjørnstad, H. E., Lien, H. and **Salbu, B.** 1990. Bestemmelse av strontium -90 i jord og vegetasjon. NLVF's forskningsprogram om radioaktivt nedfall. – *Informasjon fra Statens fagtjeneste for landbruket.* 1: 35 - 50.

Field, A. C., Suttle, N. F., and **Nisbet, D. I.** 1975. Effects of diets low in calcium and phosphorus on the development of growing lambs. – *J. Agric. Sci., Camb.* 85: 435 - 442.

Garmo, T. H. 1986. Chemical composition and *in vitro* dry matter digestibility of lichens. – *Rangifer.* 6: 8 - 13.

Garmo, T. H., Pedersen, Ø., Staaland, H., and **Hove, K.** 1990. Radiocesium i plantemateriale og beitedyr på fjellbeite. – *Informasjon fra Statens fagtjeneste i Landbruk.* 1: 87 - 96.

Hansen, H. J. M., and **Aarkrog, A.** 1990. A different surface geology in Denmark, the Faroe Islands and Greenland influences the radiological contamination of drinking water. – *Wat. Res.* 24: 1137 - 1141.

Hanson, W. C. 1967. Radioecological concentration processes charaterizing arctic ecosystems. *In:* **Åberg, B.**, and **Hungate, F. P.** (eds.). Radioecological concentration processes. - *Proc. Internat. Symp. Stockholm 25 - 29 April, 1966:* 183 - 191.

Hanson, W. C., Watson, D. G. and **Perkins, R. W.** 1967. Concentration and retention of fallout radionuclides in Alaskan arctic ecosystems. *In:* Åberg, **B.**, and **Hungate, F. P.** (eds.). Radioecological concentration processes. - *Proc. Internat. Symp. Stockholm 25 - 29 April, 1966:* 233 - 245.

Hove, K., and **Strand, P.** 1990. Pridiction of the duration of the Chernobyl radiocesium problem in non-cultivated areas based on a reassessment of the behaviour of fallout from nuclear weapon tests. - *Proc. Internat. Symp. Environm. Contamination Following a major nuclear accident. Atomic Energy Agency, Vienna, 1990.* 1: 215 - 223.

Hvinden, T., and **Lillegraven, A.** 1961. Cesium-137 and strontium-90 in precipitation, soil and animals in Norway. - *Nature.* 192: 1144 - 1146.

Jones, B. E. V., Eriksson, O. and **Nordkvist, M.** 1989. Radiocesium uptake in reindeer on natural pasture. - *Sci. Tot. Environm.* 85: 207 - 212.

McDougall, J. G., Coghlan, J. P., Scoggins, B. A. and **Wright, R. D.** 1974. Effect of sodium depletion on bone sodium and total exchangeable sodium in sheep. - *Am. J. Vet. Res.* 35: 923 - 929.

Nevstrueva, M. A., Ramzaev, P. V., Moiseer, A. A., Ibatullin, M. S. and **Teplykh, L. A.** 1967. The nature of ^{137}Cs and ^{90}Sr transport over the lichen-reindeer-man food chain. *In:* **Åberg, B.**, and **Hungate, F. P.** (eds.). Radioecological concentration processes. - *Proc. Internat. Symp. Stockholm 25 - 29 April, 1966:* 209 - 215.

Oughton, D. H., Day, J. P., Beresford, N. A. and **Howard, B. J.** 1991. The distribution and uptake of alakali metals by sheeps tissues in comparison with radiocesium. Health Physics. Submitted.

Pedersen, Ø., Staaland, H., Hove, K. and **Garmo, T. H.** 1990. Årsvariasjoner i radiocesium-innhold i rein fra et sterkt forurenset område (Vågå) 1987 - 89. Husdyrforsøksmøtet 1990. - *Aktuelt fra Statens fagtjeneste for landbruket.* 4: 213 - 217.

Peppar, D. F. Masom, G. W., and **Moloin, S. W.** 1957. The use of Dioctyl phosphoric Acid Extraction in Isolation of carrier face ^{90}Y, ^{140}La, ^{144}Ce, ^{143}Pr and ^{144}Pr. - *J. Inorg. Nucl. Chem.* 5: 141 — 146.

Rabon, E. W. 1968. Some seasonal and physiological effects on ^{137}Cs and ^{89,90}Sr content of the white-tailed deer, *Odocoileus virginianus.* - Health Physics 15: 37 - 42.

Ray, A. A. 1982. SAS user's Guide: Statistics. SAS Inst. Inc., Cary, North Carolina. 584 pp.

Skogland, T. 1987. Radiocesium concentrations in wild reindeer at Dovrefjell, Norway. - *Rangifer* 7: 42 - 45.

Skogland, T. 1990. Reinen. *In:* **Semb-Johansson, A.**, and **Frislid, R.** (eds.). *Norges Dyr. Pattedyrene 2.* J. W. Cappelens Forlag a.s. Oslo: 148 - 170.

Staaland, H., and **Sæbø, S.** 1987. Seasonal variations in mineral status of reindeer calves from Elgaa reindeer herding district, Norway. - *Rangifer* 7: 22 - 28.

Staaland, H., Hove, K., and **Pedersen, Ø.** 1990. Transport and recycling of radiocesium in the alimentary tract of reindeer. - *Rangifer.* Special Issue No 3: 63 - 72.

Westerlund, E.A. 1985. ^{137}Cs i norske samer. - *National Institute of Radiation Hygiene, Østerdalen 25, 1345 Østerås, Norway.* 1: 1 - 31. Mimeographed.

Manuscript accepted 26 April, 1991