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Spatial and temporal variations of ^{137}Cs in moose *Alces alces* and transfer to man in northern Sweden

R. Thomas Palo, Neil White & Kjell Danell

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The radioactive fallout from the Chernobyl accident in 1986 contaminated parts of the boreal forest ecosystems in Sweden, and we report on the activity concentration of radiocaesium ^{137}Cs in the meat of moose *Alces alces* caught in the county of Västerbotten in north-Sweden during 1986-1996. Countywide, the geographic distribution patterns of ^{137}Cs activity in moose muscle were similar in 1986 and 1993. The underlying relationship between ^{137}Cs concentration in moose muscle and ground deposition remained significant for all years, but the proportion of variation explained by this relationship was variable and low in most years. The transfer rate of ^{137}Cs to moose underwent marked annual fluctuations that appear to be synchronous over large areas. The fluctuations in the uptake of ^{137}Cs by moose most probably result from variations in food selection or shifts in habitats. The transfer rate of ^{137}Cs to moose seems to be higher in coastal areas than in inland areas. The ^{137}Cs activity in moose was considerably higher in 1993 than should be expected from a simple decay model based on original deposition data and the ^{137}Cs levels in moose meat from 1986. The large temporal variations in transfer rate make future predictions of transfer to moose and man unreliable. We found that the annual hunting of moose is a major source of ^{137}Cs transfer to man in this region.

Key words: ^{137} Cs, herbivores, hunters, moose, regional variation, temporal change, transfer

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Wild animals are threatened by airborne pollution in many parts of the world. Various types of contaminants, such as organic compounds, heavy metals and radionuclides, are spread over large distances and incorporated into remote food webs (AMAP 1997). This was especially evident after the Chernobyl nuclear accident in Ukraine in April 1986 which led to subsequent contamination of forest products in many parts of Europe (Savchenko 1995).

Northeastern Sweden was among the areas in Europe

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that received large amounts of nuclear fallout after the explosion of the reactor at Chernobyl. Subsequent contamination of plants and wildlife, such as moose *Alces alces* became of public concern, and a program to measure the spatial distribution of the fallout and to follow changes in contamination over time in animal populations was established. The forest ecosystem was severely contaminated by radiocaesium ^{137}Cs fallout, and the activity concentrations in moose follow that pattern (Danell, Nelin & Wickman 1989, Bergman, Palo, Nylén & Nelin 1994). This radioactive isotope has a physical half-life of 30 years, and its turnover in the Scandinavian boreal forest is slow and largely determined by the radioactive decay (Edvardsson 1991, Moberg, Hubbard, Avila, Wallberg, Feoli, Scimone, Milesi, Mayes, Iason, Rantavaara, Vetikko, Bergman, Nylén, Palo, White, Ratio, Aro, Kaunisto & Guillitte 1999).

The moose is an important species for hunters in Sweden. In 1986, about 135,000 animals were shot making moose meat a potential major source of radionuclide transfer to man (Johansson, Bergström, Eriksson & Erixon 1994). About 40% of the moose in Sweden were shot in areas contaminated by fallout from Chernobyl (Swedish Association for Hunting, Uppsala).

Annual surveys of moose muscle samples have revealed large temporal variations in the activity concentration of ^{137}Cs in moose (Palo, Nelin, Nylén & Wickman 1991, Nelin 1995, Palo & Wallin 1996). This variation is puzzling since activity concentrations in major food plants declined during the same period, and the physical half-life of the isotope would be expected to reduce levels by approximately 2.5% per year (Nelin 1994).

More than a decade after the Chernobyl accident, the amount of ^{137}Cs which leaves the forest ecosystem by runoff is negligible (Nylén 1996). A major decline of 70% in the activity concentration was observed in boreal plants from 1986 to 1997, except in pine *Pinus sylvestris*, and mineral soils showed a slight increase over time (Moberg et al. 1999, Rosén, Öborn & Lönsjö 1999). If ^{137}Cs is transferred to the moose in a simple direct manner and does not accumulate in the muscle, the ^{137}Cs activity concentration in moose meat should decline with time at a similar rate as physical decay. From this relationship we assume that the aggregated transfer factor (AGTF) of ^{137}Cs to moose would remain fairly constant over time. However, several other factors related to the foraging behaviour at larger scales, e.g. as habitat use, may cause significant temporal and spatial variations in the ^{137}Cs intake by moose to a point at which a simple correlation with deposition and decay is masked (Palo & Wallin 1996).

We present data on the temporal variation in the ^{137}Cs content in moose populations in Västerbotten over 11 years as related to variations in ground deposition and hunting. The magnitude of transfer to the hunters guild is discussed, as this is an important pathway for the transfer of ^{137}Cs to man.

Material and methods

Moose muscle samples

Our study is based on the following three data sets that were combined in spatial and temporal analyses: 1) samples of moose muscle collected annually by hunters in September, 2) ground deposition of ^{137}Cs recorded in 1986 following the Chernobyl accident (SGAB 1987) and 3) numbers of moose taken each year by the hunters.

Table 1. Numbers of sampled moose and moose shot, meat yield and transfer of radiocaesium ^{137}Cs to man in the county of Västerbotten during 1986-1990 and 1991-1996. Data on the number of moose shot were provided by the Swedish Association for Hunting (SJF).

Year	Numbers sampled	Number of districts (parishes)	Numbers shot	Meat yield (tonnes)	Transfer of ^{137}Cs to man (MBq)
1986	3987	15 (41)	13731	926	242
1987	496	15	14392	971	207
1988	807	11	17105	1154	633
1989	259	14	17157	1158	229
1990	331	12	18260	1232	565
Total 1986-1990	5880		80645	5441	2013
1991	151	10	17299	1167	346
1992	86	6	13150	887	204
1993	1223	15 (50)	11044	745	354
1994	95	8	9525	642	154
1995	48	1 (1)	9891	667	172
1996	57	1 (1)	11121	750	200
Total 1991-1996	1660		72030	4858	1430
Mean 1986-1990 (SD)	1176 (1585)		16129 (1957)	1088 (132)	375 (206)
Mean 1991-1996 (SD)	276 (465)		12005 (2886)	809 (195)	238 (89)
Total all	7540		152675	10299	3443
Mean and (SD)	685 (1155)		13879 (3215)	936 (217)	301 (161)

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During 1986-1996, a total of 7,540 moose muscle samples were collected in 6-15 districts of the county of Västerbotten. In 1995 and 1996, however, samples were obtained from only one district (Robertfors; Table 1). Sweden is divided into counties (län), which are subdivided into districts (kommun) and parishes (församling), respectively.

In 1986 and 1993, a higher spatial resolution of samples enabled analyses for most parishes within the county (see Table 1). The samples from these years were obtained from 41 and 50 out of the 54 parishes, respectively. The sample collection in 1986 included 1,899 males, 1,822 females and 266 animals of unknown sex. In 1993, 590 males, 612 females and 21 of unknown sex were sampled. In other years, animals could only be located to districts. A complete time series for 1986-1994 was obtained for three districts only, Wilhelmina, Lycksele and Robertsfors. All muscle samples (100 g) were measured for ^{137}Cs for 1-10 minutes in a Na-I-detector, giving a measurement error margin of less than 10% (Danell et al. 1989, Palo et al. 1991).

In 1986, the location from which a sample was taken was referenced to a 25 x 25 km grid covering the county of Västerbotten; in the later years samples were attributed to the nearest town or landmark. All grids in a parish were used for calculation of the mean and standard deviation of the activity concentration for 1986 and 1993 using Arcview (Version 3.2, Spatial Analyst 2.0, ESRI Inc. Redlands, Ca., USA).

Ground deposition

Ground deposition of ^{137}Cs following the Chernobyl accident, $A_g(86)$ is the integrated gamma emission of ^{137}Cs per m^2, for each grid location was estimated from a deposition map (SGAB 1987). The mean values for each district and parish were obtained in the same way as the moose muscle activity. For each year (i) an expected ground deposition, $A_g(i)$ was derived from $A_g(86)$ assuming physical decay and corrected AGTF (m^2kg^{-1}) calculated for each year according to $A_g(i) = A_g \exp^{-0{,}023 * T}$, where T is time in years since 1986. The aggregated transfer factor (AGTF), which reflects the rate of transfer of ^{137}Cs to moose, was also derived for each district and parish. AGTF is the quotient

$$\frac{A_m}{A_g}$$

where A_m is the activity in moose muscle (Bq. kg^{-1}) and A_g is the ground deposition (kBq m^{-2}; Bréchignac, Moberg & Soumela 2000).

Numbers of moose taken

Numbers of moose shot were supplied for each parish by the Swedish Association for Hunting (Svenska Jägareförbundet, SJF). Hunting success was calculated as the proportion of animals shot in relation to the number of animals allowed on the individual hunting permits. Transfer of ^{137}Cs to man was calculated based on average meat mass available for consumption in the county of Västerbotten and was taken to be 120 kg per adult male moose, 90 kg per female and 30 kg per calf.

All statistical analyses were undertaken using Minitab 13.31. Heteroscedacity was reduced by logarithmic transformation.

Results

Concentrations of ^{137}Cs in moose muscle, $A_m(i)$, showed a distinct geographic variation among parishes and districts, being highest in the southeastern region in both 1986 and 1993 (Fig. 1). Notably, the ^{137}Cs values in moose muscle were lower just after the accident in 1986 than in 1993. The geographic correspondance of

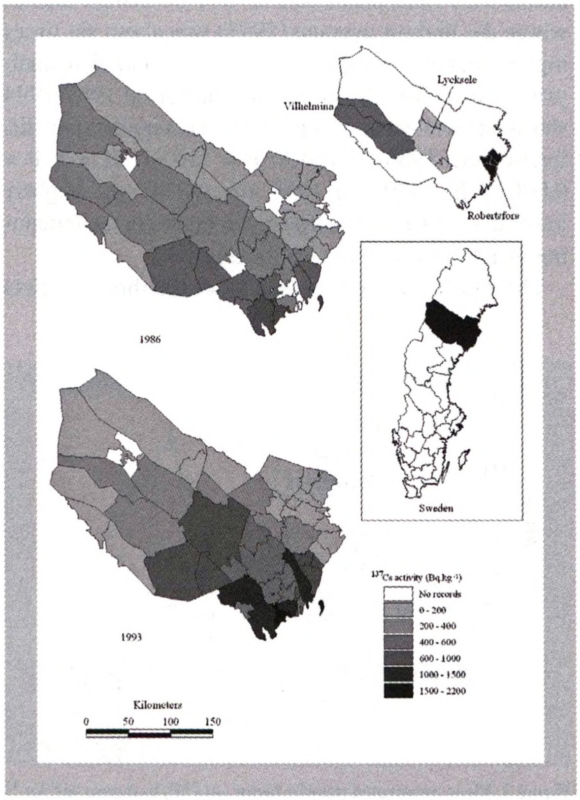

Figure 1. Radiocaesium ^{137}Cs concentrations (in Bq. kg^{-1}) in moose muscle from parishes in the county of Västerbotten in 1986 and 1993 with the districts Wilhelmina, Lycksele and Robertsfors indicated.

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Table 2. Regressions of radiocaesium ^{137}Cs vs ground deposition for the years 1986-1994.

Year	Equation	P	R^2
1986	Y = 11.18X + 105.15	0.0001	0.127
1987	Y = 11.57X - 2.68	0.0001	0.574
1988	Y = 19.45X + 363.05	0.0001	0.102
1989	Y = 11.79X + 29.33	0.0001	0.284
1990	Y = 19.73X + 236.2	0.0001	0.10
1991	Y = 15.27X + 94.62	0.0001	0.288
1992	Y = 6.68X + 218.96	0.008	0.074
1993	Y = 21.0X + 202.43	0.0001	0.126
1994	Y = 8.76X + 21.37	0.005	0.217

^{137}Cs concentration in moose muscle with the ground deposition was significant, but weak in most years. The slopes of the regressions of ^{137}Cs ($A_m(i)$) against ground deposition ($A_g(i)$) were significant for all years. However, except for one year, the regressions explained less than 30% of the variation in ^{137}Cs (Table 2). A clear geographic pattern was also seen in the aggregated transfer factor with higher transfer rates at coastal areas than in western and central districts (ANOVA: F = 8.297, df = 2, P < 0.002, $r^2 = 0.601$; see Figs. 1 and 2).

The mean aggregated transfer factor (AGTF) for the three selected districts of the county of Västerbotten fluctuated markedly over time (see Fig. 2), and the fluctuations were most prominent in the Robertsfors district where the highest average (1993) was about six times higher than the lowest average (1987). Statistical analysis of AGTF for all districts for the period 1987-1994 showed that all years except 1987 were significantly different from 1986 (ANOVA: F = 110.91, df = 7, P = 0.0001). In 1989 and 1994, the AGTF was slightly lower than in 1986, whereas it was higher in the remaining years (Tukey's *post hoc* tests).

The AGTF time series data from the three districts appear to show synchronous fluctuations (see Fig. 2). We tested this by correlation analyses of mean annual AGTF levels for the period 1986-1994, but found that only the Wilhelmina and Lycksele districts gave significant correlations. Although fluctuations tended to mask time trends, we found a slight overall increase in the AGTF with time (Log AGTF = 0.077X-150.8, P < 0.0001, df = 1, $r^2 = 0.055$.

We specifically tested if the distribution of AGTF values within the county of Västerbotten in 1986 would serve as a predictor of the observed distribution in 1993 when corrected for physical decay of ^{137}Cs. The predicted frequency distribution using 1986 data corrected for decay and the observed distribution in 1993 was significantly different (Test for goodness of fit: $\chi^2 = 206$, df = 21, P < 0.0001). Although the distribution of AGTF in 1986 and 1993 correlated significantly (F = 7.17, df = 13, $R^2 = 0.37$, P < 0.02) the latter year showed a considerably higher AGTF than predicted from the AGTF in 1986 (Fig. 3).

We combined data for the amount of ^{137}Cs transferred from moose to the hunter guild in the periods 1986-1990 and 1991-1996, and found no statistical difference between them (t-test: t = 1.48, df = 9, P = 0.172). We estimated that the transfer to man from one single source, i.e. the moose, is slightly higher (1,180 $Bq.person^{-1}.year^{-1}$; SD = 633) than intake from commercial food products (estimated to be 811 $Bq.person^{-1}.year^{-1}$ in Västerbotten; L. Moberg, Swedish Radiation Protection Institute, Stockholm, pers. comm.). We estimated that 3.3 x 10^9 Bq has been transferred to the hunters guild since 1986, giving an average intake of 12,660 $Bq.hunter^{-1}.year^{-1}$ (SD = 7,119) which corresponds to a concentration of 181 $Bq.kg^{-1}$.

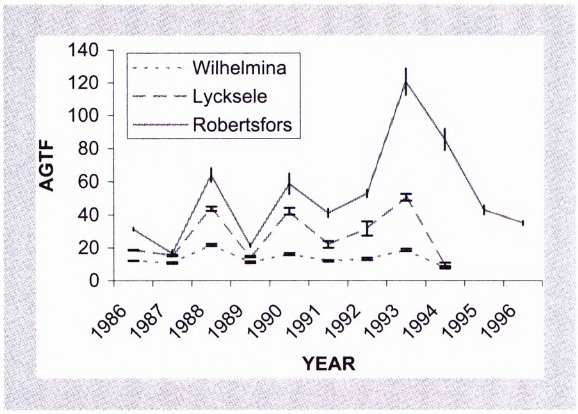

Figure 2. Mean aggregated transfer factor (AGTF) to moose ($m^2.kg^{-1}$) corrected for physical decay in the districts Wilhelmina, Lycksele and Robertsfors in the county of Västerbotten during 1986-1996. Bars denote standard error (SE).

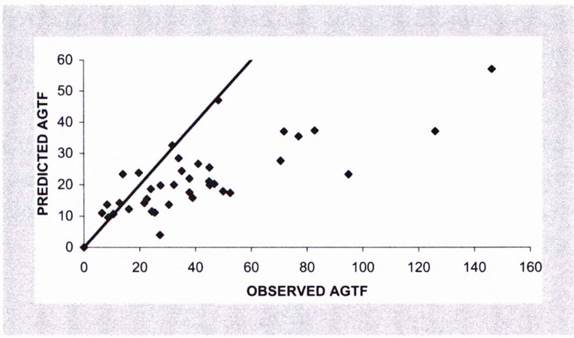

Figure 3. Observed and predicted AGTF in moose muscle in 1993 for the 38 parishes in the county of Västerbotten. The predicted values generated from the relation between 1986 ^{137}Cs, $A_m(86)$, in moose muscle and ground deposition $A_g(86)$ corrected to $A_g(93)$. AGTF for 1993 is $A_m(93)$ devided by ground deposition in 1993 $A_g(93)$ corrected for exponential decay from 1986 to 1993. The line shows predicted = observed AGTF.

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Discussion

On a large geographical scale, the ^{137}Cs activity in moose muscle correlated with ground deposition, a pattern that is largely retained seven years after the fallout. Although significant, the explanatory power of this relationship was low. Looked at in more detail, the ^{137}Cs activity in moose muscle did not follow a simple decay pattern through time nor can it be fully explained from the amount of deposition from Chernobyl over the landscape.

Discrepancies from the above expectations are most likely to be found in the variable rates of uptake and this is why we preferred to analyse the AGTF. These analyses revealed interesting patterns. First, the AGTF was higher in the eastern coastal areas than in the western and central districts. Second, the AGTF underwent marked annual fluctuations that to some extent were synchronous in three districs. Third, the AGTF showed a slightly increasing trend with time.

The reason for lower transfer rates of inland districts is unclear. It might be a result of the earlier onset of winter in this region and thus an earlier shift to winter diet, but such a shift would lead to lower levels and lower variability of AGTF in these locations than in the eastern coastal regions. Moose have lower ^{137}Cs activity in winter than in other seasons (Nelin 1994). The AGTF appears to fluctuate synchronously in the three districts which suggests that the same influencing factor(s) may operate over large areas. However, longer time series are needed to elucidate whether these shifts are extended over large geographical areas. On the scale of single parishes or districts, the annual fluctuations in AGTF may be caused by various ecological factors. Most probably, this relates to differences in moose foraging behaviour, e.g. differences in food selection or habitat use. Major shifts in habitat use by moose have been reported from Norwegian studies (Bo & Hjeljord 1991) and were discussed theoretically by Palo & Wallin (1996). Given the fact that forest habitats generally show higher contamination than open habitats (Palo 1994), it can be envisaged how temporal changes in ^{137}Cs uptake by moose could result from habitat shifts: in some years the moose may prefer foraging in forests whereas in other years they would shift to more open habitats (Bo & Hjeljord 1991). That we found a general relationship between body burden of ^{137}Cs and ground deposition with different means in AGTF among years, may be in favour of the habitat shift hypothesis. Another factor that could theoretically induce annual variations in the transfer of ^{137}Cs to moose is the changing availability of fungi between years. If consumed by moose in significant quantities, fungi can increase both transfer rate and activity concentration (Avila 1998, Moberg et al. 1999). Such an intake is unpredictable in time and space. However, mushrooms have not been found to be common in the diet of moose from analysis of rumen contents during 1986-1989 (Palo et al. 1991, Palo & Wallin 1996). It is clear that the simple assumption of constant AGTF does not hold for the time period studied. Given that the decay of ^{137}Cs is a very deterministic process, the fluctuations seen in AGTF can only be explained by varied annual uptake of ^{137}Cs by the moose. This variation makes it very difficult to predict with any accuracy near future levels of ^{137}Cs in the moose population.

We can only speculate about the reason for the slight but significant increase in available AGTF in the study period, but possible explanations are: i) uptake through roots may have increased the levels of ^{137}Cs in plants with time, and ii) in 1986 a major part of the deposition was large particles that were not immediately available in the food webs. This particle-bound deposition has with time released more ^{137}Cs into circulation. The first explanation seems less probable since no increase in activity concentration in major food plants of moose has been detected (Nylén 1996, Moberg et al. 1999). Even though the increase in AGTF with time is not detected in some selected food plants, it is possible that the foraging pattern of moose integrate and magnify such small changes over a larger area. In order to understand variation of radiocaesium transfer in food webs and subsequent transfer to man, both animal behaviour in relation to food resources and human behaviour in relation to hunting and meat consumption must be studied in more detail than hitherto.

Although the data presented here cover more than a decade after the Chernobyl accident, a high transfer to man from a natural ecosystem is still possible through the consumption of meat from game. The average Swedish population is estimated to receive about 4,000 Bq. $person^{-1}.year^{-1}$ from forest products, i.e. berries, fungi, reindeer meat (excluding meat from game) and fish (Strand, Balanov, Aakrog, Bewers, Howard, Salo & Tsatsov 1997). The absorbed dose equivalent is measured in Sievert (Sv) and gives the radiation dose weighted by coefficients that reflect the capacity to harm biological tissues. The dose conversion factor is 2.5 $\mu Sv\ y^{-1}\ Bq.kg^{-1}$ which gives the effective annual dose in man by consuming moose meat to be 0.45 mSv (UNSCEAR 1988). It is estimated, that an extra dose of 10 mSv of radiation will increase the risk of dying from cancer by 0.05% (UNSCEAR 1988). In this perspective, the contribution from moose is negligible. However, ^{137}Cs transfer from moose is considerably higher than from

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any other single source previously estimated from forest products, and moose hunters receive doses of the same magnitude as reindeer herders and fishermen in Scandinavian fallout areas (Strand et al. 1997, Mehli, Skuterud, Mosdöl & Tönnessen 2000).

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References

AMAP 1997: AMAP Assessment Report. Arctic Pollution Issues: A state of the Arctic Environment Report. - AMAP, Oslo, Norway, pp. 121-123.

Avila, R. 1998: Radiocaesium transfer to roe deer and moose. Modelling and experimental studies. - PhD thesis, Swedish University of Agricultural Sciences, Uppsala, 37 pp.

Bergman, R., Palo, R.T., Nylén, T. & Nelin, P. 1994: Influence of herbivory on caesium turnover in a forest ecosystem. - The Science of Total Environment 157: 301-307.

Bo, S. & Hjeljord, O. 1991: Do continental moose ranges improve during cloudy summers? - Canadian Journal of Zoology 69: 1875-1879.

Bréchignac, F., Moberg, L. & Soumela, M. 2000: Long-term environmental behaviour of radionuclides. - Institut de protection et de sureté nucleaire. Mission communication 2000, Fontenay-aux-Roses, France, 65 pp.

Danell, K., Nelin, P. & Wickman, G. 1989: ^{137}Caesium in northern Swedish moose: The first year after the Chernobyl accident. - Ambio 18: 108-111.

Edvardsson, K. 1991: Fallout over Sweden from the Chernobyl accident. - In: Moberg, L. (Ed.); The Chernobyl fallout in Sweden. The Swedish Radiation Protection Institute, Stockholm, pp. 47-66.

Johansson, K.J., Bergström, R., Eriksson, O. & Erixon, A: 1994: Activity concentration of ^{137}Cs in moose and their forage plants in Mid-Sweden. - Journal of Environmental Radioactivity 22: 251-267.

Mehli, H., Skuterud, L., Mosdöl, A. & Tönnessen, A. 2000: The impact of Chernobyl fallout on the southern Saami reindeer herders of Norway in 1996. - Health Physics 79: 682-690.

Moberg, L., Hubbard, L., Avila, R., Wallberg, L., Feoli, E., Scimone, M., Milesi, C., Mayes, R., Iason, G., Rantavaara, A., Vetikko, V., Bergman, R., Nylén, T., Palo, R.T., White, N., Ratio, H., Aro, L., Kaunisto, S. & Guillitte, O. 1999: An integrated approach to radionuclide flow in semi-natural ecosystems underlaying exposure pathways to man. - SSI report, ISSN 0282-4434, 100 pp.

Nelin, P. 1994: Chernobyl Caesium in the Swedish moose population: Effects of age, diet and habitat selection. - PhD thesis, Department of Animal Ecology, Swedish University of Agricultural Sciences, Umeå, 41 pp.

Nelin, P. 1995: Radiocaesium uptake in moose in relation to home range and habitat composition. - Journal of Environmental Radioactiviy 26: 189-203.

Nylén, T. 1996: Uptake, turnover and transport of radiocaesium in boreal forest ecosystem. - PhD thesis, Swedish University of Agricultural Sciences, Uppsala, 41 pp.

Palo, R.T. 1994: Ecological concepts in radioecology. An alternative to Newtonianism. - In: Holm, E. (Ed.); Radioecology. Lectures in environmental radioactivity. World Scientific, Singapore, pp. 127-135.

Palo, R.T., Nelin, P., Nylén, T. & Wickman, G. 1991: Radiocaesium levels in Swedish moose in relation to deposition, diet and age. - Journal of Environmental Quality 20: 690-695.

Palo, R.T. & Wallin, K. 1996: Variability in diet composition and dynamics of radiocaesium in moose. - Journal of Applied Ecology 33: 1077-1084.

Rosén, K., Öborn, I. & Lönsjö, H. 1999: Migration of radiocaesium in Swedish soil profiles after the Chernobyl accident, 1987-1995. - Journal of Environmental Radioactivity 46: 45-66.

Savchenko, V.K. 1995: The ecology of the Chernobyl catastrophe. Scientific outlines of an international programme of collaborative research. - Man and Biosphere Series. Vol 16. Unesco, Paris, 200 pp.

SGAB 1987: Swedish Geological Company 1987: Map over deposition of ^{137}Cs in Sweden. - Statens Lantmäteriverk, Sweden.

Strand, P., Balanov, M., Aarkrog, A., Bewers, M., Howard, B., Salo, A. & Tsatsov, Y. 1997: Radioactive contamination in the Arctic. - Proceedings of the AMAP International Symposium on Environmental Pollution in the Arctic. Tromsö, Norway, June 1-5, 1997, pp. 5-9.

UNSCEAR 1988: United Nations Scientific Committee on the Effects of Atomic Radiation Sources, effects and risks of ionizing radiation. - Report to the General Assembly, with annexes. New York: United Nations, 647 pp.

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