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Contaminants in food chains of arctic ungulates: what have we learned from the Chernobyl accident?

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Abstract: The Chernobyl accidenr of 1986 caused radioactive contamination of widespread areas of reindeer pasture in Scandinavia. Reindeer (*Rangifer tarandus*) are especially exposed to radioactive fallout due to theit wintet diet, of which lichens are an important part. Much knowledge about the transfer of radiocaesium to reindeer, and via reindeer meat to man, was accumulated by intense scientific investigations, undertaken during the 1960's and 1970's, following nuclear weapons testing. Various ways to reduce the transfer of radiocaesium to animals and humans were also developed during this time. Much of the older knowledge proved to be of great value in the attempts to determine potential consequences of the Chernobyl accident and to suggest possible ways to ameliorate the effects of contamination. After Chernobyl, not only did reindeer prove ro be a problem; many other food products originating from natural and seminatural ecosystems were found to accumulate significant amounts of radiocaesium. Intense scientific work has produced new knowledge about the role of ungulates in the transfer of nutrients and contaminants within these systems. Diffetent measures, like providing uncontaminated feed, use of caesium binders, altering the time of slaughter have been used with good results to minimize the transfer of radiocaesium to animals grazing natural pastures. The high cost of countermeasures has enforced consideration of cost against risk, which may also be of general interest with respect to other forms of pollution. Information, introduction of countermeasures and so forth would be more efficient in case a similar accident were to happen again. The Chernobyl accident is an obvious example of how human failures when dealing with a modern technical system can have global consequences and also be a potential threat to what we like to think of as the unspoiled wilderness of the Arctic.

Key words: radioactive contamination, fallout, radiocaesium, reindeer, *Rangifer tarandus*.

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Introduction

In the morning of April 28, 1986, an alarm caused the immediate evacuation of one of the Swedish nuclear power plants, Forsmark, north of Stockholm. Local contamination detectors had registered greatly increased levels of radioactive material in the air. At this time, no reports of radioactive release had been received from elsewhere.

In the evening of the same day, news of a serious accident at the Chernobyl nuclear power plant in the Ukraine, about 2000 km distant from Forsmark, was released on Moscow television. As a result of a technical experiment, on 26 April, two explosions in quick succession had blown the toof off one of the reactors at the power plant. The explosion and fire had caused the release of considerable amounts of radioactive material, consisting of both transuranic elements and fission products (IAEA, 1991). Smoke and fumes had risen almost 2000 m into the atmosphere.

Much of the radioactive material was precipitated close to the reactor site, especially the heavier particles, but a substantial part was also carried away by the wind and deposited ovet other parts of Europe. Clouds carrying radioactive material reached the Nordic countries, causing major radioactive fallout on two occasions, Aptil 27-30 and May 8 (Persson *et al.,* 1987). The maximum deposition of ^{137}Cs recorded in Sweden was about 200 kBq m^{-2} (Edvarson, 1991). High deposition densities were recorded also in Norway (Henriksen & Saxebøl, 1988), southern Finland (Saxén *et al.,* 1990) and at many locations in eastern and southern Europe (Graziani *et al.,* 1991).

The fallout from Chernobyl created serious problems in many countries, as it was necessary to predict the potential human exposure to radiation and to decide what actions to take, to minimize the radiation doses to humans. The widespread, uneven distribution of the fallout and the consequent transfer of radiocaesium to food products, required a regional approach to the problem (UNSCEAR, 1988). It was obvious early on that problems were especially serious in areas where food was obtained from natural or semi-natural systems (Bennet & Bouville, 1988). This is the case in regions where natural pasture is used for animal production (as in reindeer husbandry) or where hunting and fishing provide much of the food for the local population.

The efforts to contain the problem that arose as an effect of the radioactive fallout, have generated important experience and knowledge. In this paper I shall highlight a few examples of new knowledge that has been acquired regarding radioactive contaminants in arctic and subarctic environments.

Before Chernobyl

The Chernobyl accident was not the first event to cause widespread radioactive fallout. Atmospheric testing of nuclear weapons, made by several nations from 1945 until 1962, caused a global fallout of radioactive material. Occasional tests carried out later, the most recent in 1980 (UNSCEAR, 1993), produced additional fallout. The largest amounts of radioactive material were deposited in a belt between latitudes 30° and 60°N (UNSCEAR, 1982). Variations between different areas at the same latitude were mainly attributable to differing amounts of precipitation (Langham, 1961).

The fallout from the nuclear bomb tests initiated scientific work in radioecology in many countries. Much interest focused on radiocaesium and radiostrontium in the food chain: lichen - reindeer/caribou (*Rangifer tarandus*) - man (or predator) (e.g. Hvinden & Lillegraven, 1961; Salo & Miettinen, 1964; Svensson & Lidén, 1965; Hanson, 1967). The reason why reindeer are especially susceptible to fallout is their diet, where lichens play an important part, particularly during the winter. Lichens absorb nutrients and contaminants directly from both air and precipitation (Tuominen &

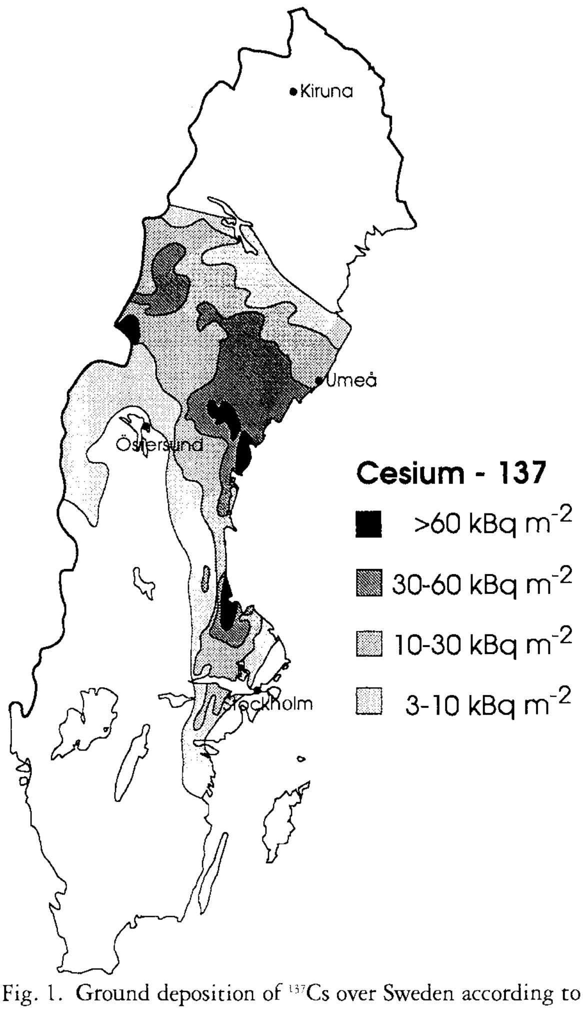

Fig. 1. Ground deposition of ^{137}Cs over Sweden according to aerial measurements May - October 1986 (redrawn from map by Swedish Geological Co. 1986).

Jaakkola, 1973), resulting in an effective uptake of radionuclides from fallout. Activity concentrations of ^{137}Cs in reindeer after the nuclear bomb tests were at their maximum, at around 3000 Bq kg^{-1} in 1966 (Westerlund *et al.,* 1987). Thereafter the levels declined with an effective half-life of 5 to 7 years (Westerlund *et al.,* 1987; Rissanen & Rahola, 1990).

Most work in radioecology, apart from that dealing with reindeer, was concentrated on agricultural systems (Coughtrey & Thorne, 1983). Levels of radiocaesium and factors affecting its uptake were, however, studied in some wild species of Cervidae (*e.g.* Whicker *et al ,* 1965; Longhurst *et al.,* 1967; Plummet *et al.,* 1969). Johnson & Nayfield (1970) also reported the role of fungi for the intake of tadiocaesium by white-tailed deer.

Contamination of pasture and animals after the Chernobyl accident

As a result of the Chernobyl fallout, most of the central and southern parts of the Swedish reindeer pasture land became contaminated with radiocaesium (Fig. 1), as were the Norwegian reindeer pastures (Henriksen & Saxebøl, 1988). Finland sustained fallout mainly in areas outside reindeer pasture land (Saxén *et al.,* 1990). Most of the deposition from Chernobyl was washed out from radioactive clouds with precipitation in the form of rain or snow showers, resulting in a scattered fallout pattern.

The radionuclides considered to be of primary interest for human health and for the environment, were two caesium isotopes (^{134}Cs and ^{137}Cs), iodine (^{131}I) and strontium (^{90}Sr). The iodine is short-lived (8 days' physical half-life) and consequently there was only an initial interest in this nuclide. The ratio of ^{90}Sr to ^{137}Cs in the Chernobyl fallout was low (1 to 100, as measuted over central Europe, UNSCEAR, 1988). Interest was therefore concentrated mainly on radiocaesium. It was anticipated, from the fallout pattern and previous knowledge (e.g. Hvinden & Lillegraven, 1961; Svensson & Lidén, 1965; Hanson, 1967), that reindeer and reindeer husbandry would be severely affected in the areas that had been contaminated.

The Chernobyl fallout contaminated the reindeer ranges at the start of the growing season when vascular plants (grass, herbs and leaves) gradually become more important in the diet. It was just before calving and reindeer calves may have received significant amounts of radioactive iodine via the milk. Monitoring of radiocaesium in Swedish reindeer in June 1986 showed that some animals had up to 7000 Bq ^{137}Cs per kg in the muscles (Åhman, 1986). Even higher levels were found in wild reindeer in Norway (Skogland, 1986). It was predicted that the levels would rise considerably in the autumn when the reindeer srarted to feed on lichens (Skogland, 1986; Åhman, 1986). This was confirmed the following winter, when the highest activity concentrations of ^{137}Cs in Swedish reindeer reached almost 100 000 Bq kg^{-1} (Åhman & Åhman, 1994). Maximum levels of up to 150 000 Bq kg^{-1} were recorded in Norway (Strand *et al.,* 1990).

The contamination of reindeer was not the only problem after the Chernobyl accident. Meat from wild herbivores, mainly moose and roedeer, was also found to be important in the transfer of radiocaesium to humans (Johanson & Bergström, 1994). Activity concentrations of ^{137}Cs around 1000–2000 Bq kg^{-1} in moose meat were found in highly contaminated areas of Sweden (Johanson, 1994). Roedeer from the same areas had somewhat higher activity concentrations, with peak values around 5000 Bq kg^{-1} in August and September, when edible fungi are an important dietary component. Meat from game animals is an important part of the diet of many people in all Nordic countries. The total consumption of all game meat in Sweden amounts to around 20 million kg y^{-1}, compared with about 2 million kg y^{-1} of reindeer meat (SCB, 1996).

Dealing with the contamination problem

The deposition of radiocaesium raised several problems for the authorities in many European countries. How should humans be protected from potentially dangerous radiation via contaminated food and how should people involved in food production be protected from economical loss? Furthermore, could radiation from the Chernobyl fallout be harmful to ecosystems or to certain species?

The problem of protecting the public was generally tackled by introducing control procedures for food produced in contaminated areas and by setting upper limits of radiocaesium contamination for food that was sold on the market (Salo & Daglish, 1988). In Sweden, the threshold for intervention was first set for ^{137}Cs at 300 Bq kg^{-1} for all food products (Bruce & Slorach, 1987). A year later, in May 1987, the Swedish National Food Administration agreed to raise this limit for wild berries, freshwater fish, game and reindeer meat to 1500 Bq kg^{-1}. The products mentioned had been found to retain far more radiocaesium than others, but were considered to form only a small part of the diet of the general Swedish population. People eating these foods regularly were, however, recommended to apply the lower limit of 300 Bqkg^{-1} for themselves. The general aim was that the radiation dose due to food (excluding radiation from naturally occurring radioisotopes like ^{40}K) should not exceed 1 mSvy^{-1}. According to dose convetsion factors (ICRP, 1990) this corresponds to an intake of 77 kBq of ^{137}Cs or 53 kBq of ^{134}Cs. Other countries made somewhat different judgments than Sweden when setting threshold levels for food products. In Norway, the threshold for radiocaesium (^{134}Cs + ^{137}Cs) in all types of food except milk and baby food was fitst set at 600 Bqkg^{-1} (Strand *et al ,* 1990). This threshold was raised to 6000 Bqkg^{-1} for reindeer meat in November 1986, but again changed to a lower level, 3000 Bqkg^{-1}, in August 1994.

Refunding systems were established in Sweden (Lantbruksstyrelsen, 1986) as well as in other countries, e.g. Norway (Strand *et al.,* 1990), to reduce the economic loss sustained by food producers, and to compensate for costs or loss of income caused by radioactive contamination. An early interest was raised after the Chernobyl accident in different ways of avoiding contamination ot to decontaminate animals and food products (Howard *et al.,* 1991; Gaare & Staaland, 1994).

The biological half-life of caesium in the body of mammals seems to vary from 7 to 100 days, with a generally longer half-life in larger animals (Stara *et al.,* 1971). Since the excretion of caesium by reindeer is relatively rapid, with a biological half-life of 2-4 weeks in winter (Holleman *et al.,* 1971; Åhman, 1996), contaminated reindeer could be decontaminated in a relatively short period of time if they are prevented from eating contaminated food. One possible measure is thus to move the animals away from contaminated areas. Reindeer were moved on two occasions after the Chernobyl accident in one area of Sweden (Jones *et al.,* 1990). However, the method is restricted by the limited access to uncontaminated pastute land. Moving semi-domestic reindeer also involves moving the reindeer herders, which is also a serious drawback. Another effective method that is frequently used, also for other animals than reindeer, is to keep the animals in enclosures and provide non-conraminated feed for a sufficient period of time (Howard *et al.,* 1991). From 1993 to 1997, around 16% of the slaughtered reindeer in Sweden were fed before slaughter to reduce the levels of radiocaesium. The costs for feeding are relatively high but in many cases this is the most practical method available.

If uncontaminated food cannot be provided, it may be possible to give the animals various compounds that can bind the contaminant and prevent it from being absorbed from the gut. Some techniques in this field were devised alteady after nuclear weapon testing (e.g. Mraz & Patrick, 1957; Giese, 1971; van den Hoek, 1976). Two types of compound are available fot binding caesium: clay minerals (bentonite or certain zeolites) and hexacyanoferrates (Prussian blue, Giese-salt). Bentonite and hexacyanoferrates have been fed to reindeer with good results (Gaare & Staaland, 1994; Åhman, 1996). Clay minerals are needed in relatively large amounts and are added to the feed, whilst hexacyanoferrates, which are effective in vety small amounts, can be added to salt licks ot be incotporated in slow-releasing boli placed in the rumen of the animal. Boli used for reindeer (Hove *et al.,* 1990) last for about two month and reduced the activity concentrations of radiocaesium in the muscles of the reindeer with 60%. The method requires that the animals are gathered and handled at some occasion, up to two month before the planned slaughtet, and that the same individuals are regained again at slaughter. This limits the application of the method on freely grazing species as reindeer and game animals. Salt licks containing hexacyanoferrares have been used to wild ungulates, mainly moose, and have been shown to reduce the activity concentrations of radiocaesium in muscle with 20-25% (Johanson, 1994).

One practice that has been widely used for e.g. reindeer and roedeer is to shift the slaughter (or hunting) season according to the seasonal variations in radiocaesium levels (Fig. 2). This is often an effective and relatively simple method (Åhman & Åhman, 1990; Johanson, 1994).

The problem of the potential harm of ionizing radiation to wild animals or ecosystems has been the subject of many earlier investigations (IAEA, 1992) but has received less attention after the Chernobyl accident. However, there is some evidence of genetic disorders in small rodents inhabiting the highly contaminated area close to Chernobyl (Shevchenko *et al.,* 1992). Studies in Norway (Røed *et al ,* 1991) suggest a possible genetic effect of radiation on reindeer calves from one highly contaminated atea. These calves had received total doses ranging from

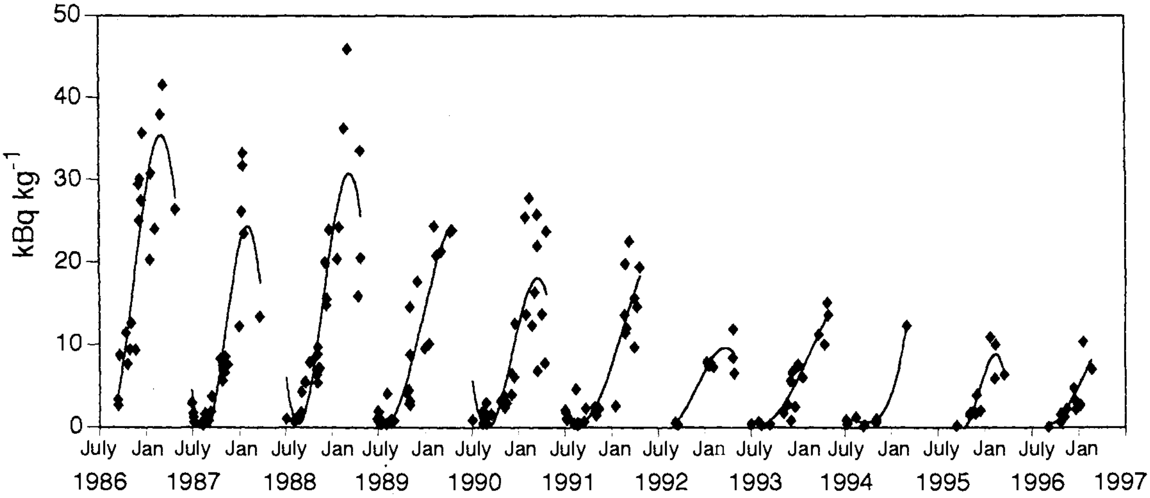

Fig. 2. Seasonal variations of ^{137}Cs in reindeet (Bq kg^{-1} in muscle) in the district of «Vilhelmina Norra» from July 1986 to February 1997 (mean values from reindeer slaughter and live reindeer moniroring).

40 to 80 mSv. Howevet, the International Atomic Energy Agency (IAEA, 1992) states that higher doses, over 1 mSv day^{-1} for a longer period of time (years), are needed to cause observable effects at the population level in terrestrial animals. It has therefore not been consideted necessary to apply any countermeasures, as a result of the Chernobyl accident, to protect animal populations from radiation.

Protecting humans from the effects of Chetnobyl fallout has been expensive. The total cost for the Swedish state during the first year after the accident was over 300 million SEK (40 million USD). This sum includes cost for administration, information and radiocaesium control, as well as compensation to producers for loss of income and expenses for countermeasures. During the first year, much of the money (63% of the total cost) was spent in connection with agricultural production and fishery. Later, most of the cost was related to reindeer mear production - a total sum, from 1986 to 1996, of nearly 500 million SEK (65 million USD).

Justification for these costs can be assessed by comparing the reduction in risk to the human population with the cost of countermeasures. In a rich developed country it might be worth about 100 000 USD to save the population from a collective radiation dose of 1 manSv (ICRP, 1991). Bengtsson & Moberg (1993) argues that a justified cost for radiation protection should be between 0.4 and 2 million SEK (50 000-260 000 USD) $manSv^{-1}$.

The countermeasures used in Sweden during the period July 1995 to June 1996 have been estimated to have reduced the collective radiation dose via reindeer meat to humans by 11 manSv (from 18 manSv to 7 manSv) at a total cost of 17 million SEK (B. Åhman, unpubl.), that is 1.54 million SEK (200 000 USD) $manSv^{-1}$. One feasible way to reduce the costs is to make cost-benefit comparisons of the individual countermeasures to select the most cost-effective. A tempting way to reduce costs for the state would be to raise the limit for ^{137}Cs in food products (1500 Bq kg^{-1} for reindeer meat in Sweden). However, this would cause problems for the reindeer meat market, which has only recently tecoveted from customer resistance due to public fear of radiation after the Chernobyl accident. Another obvious risk with raising the threshold, unless not absolutely justified, is that it might diminish public trust in the authorities concerning these matters.

The future

The rate of decline of radiocaesium in reindeer after the Chernobyl accident has been relatively rapid, corresponding to 3–4 yeats' effective half-life for reindeer grazing on natural pasture (Åhman & Åhman, 1994). This is faster than the approximately 7 years observed for weapons test fallout (Westerlund *et al.*, 1987; Rissanen & Rahola, 1990). The highest activity concentration recorded in

Swedish reindeer during 1996 was 24 000 Bq kg^{-1}. However, even though the effective half-life is relatively short, problems with tadiocaesium in reindeer are expected to persist for at least 15 more years in Sweden.

It would seem that the rapid decline reported above applies only to reindeer, suggesting that the decline is mainly an effect of the disappearance of tadiocaesium from lichens. In the forest ecosystems in general, most of the tadiocaesium remains and is available for plant uptake. Accotding to Swedish investigations (Johanson, 1994; Palo & Wallin, 1996) the decline in radiocaesium in moose and roedeer has not been significantly faster than the radioactive decay (30 yeats physical half-life for ^{137}Cs), which also seem to agree with the decline in radiocaesium in moose aftet the weapons test fallout (Johanson & Bergsttöm, 1994). The decline in radiocaesium in sheep also seems to be considetably slower than in teindeer (Hove *et al.,* 1994).

The apparent slow decline in tadiocaesium in vasculat plants (which comprise the diet of moose, toedeet and sheep) is of importance fot ptedictions of radiocaesium levels in reindeer. As the lichen content of radiocaesium declines, vascular plants will contribute relatively more to the radiocaesium intake of reindeer, thus effectively prolonging its ecological half-life. A tendency in this direction has alteady been observed (Åhman & Åhman, 1994).

Concluding remarks

At the time of the Chernobyl accident, much of the previous knowledge proved to be essential for those trying to cope with the effects of the tadioactive fall-out. One conclusion from this is that, as long as hazardous matetials are produced and handled, there has to be adequate and practical knowledge of how to protect people and other living otganisms if such materials are released into the environment, whether accidentally or intentionally.

The majot route of transfer of radiocaesium to man following the Chernobyl accident has been in the fotm of meat from reindeer, game animals, sheep on natural pastutes and freshwater fish. This demonstrates the crucial role of natural and seminatutal systems in the transfer of contaminants to man.

As a result of the Chernobyl accident, scientists and public authorities have gained more experience in dealing with contamination affecting large human populations. The production and release of information, adjusting food producrion, introduction of countetmeasures and so forth would be mote efficient in case a similat accident were to happen again.

The Chernobyl accident is a glaring example of how single human failures made in modern, highly technical systems can have large global consequences and also be of potential harm to what we like to think of as the unspoiled wildernesses of the arctic regions.

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