Journal of Environmental Radioactivity 177 (2017) 241–249

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Estimated lifetime effective dose to hunters and their families in the three most contaminated counties in Sweden after the Chernobyl nuclear power plant accident in 1986 – A pilot study

Martin Tondel [a,*], Christopher Rääf [b], Robert Wålinder [a], Afrah Mamour [c], Mats Isaksson [c]

[a] Occupational and Environmental Medicine, Department of Medical Sciences, Uppsala University, Sweden
[b] Medical Radiation Physics, Department of Translational Medicine, Malmö, Lund University, Sweden
[c] Department of Radiation Physics, Institute of Clinical Sciences, Sahlgrenska Academy, University of Gothenburg, Sweden

ARTICLE INFO

Article history:
Received 19 February 2017
Received in revised form
16 June 2017
Accepted 20 June 2017

ABSTRACT

Hunters and their families were one of the most exposed subpopulations in Sweden after the Chernobyl nuclear power plant accident in 1986. In this pilot study we used existing registries and whole-body measurements to develop algorithms to calculate lifetime effective doses and collective doses to some hunters in Sweden.

Ten hunters and their family members were randomly selected from each of the three most contaminated counties in Sweden (Västernorrland, Uppsala, Gävleborg) using the register for hunting weapons from the Police Authority in 1985. Hence, this design can be regarded as a closed cohort only including hunters and their family members living in these three counties at the time of the accident. Statistics Sweden matched these individuals (n = 85) with their dwelling coordinates onto the digital map produced by the Swedish Radiation Safety Authority after aerial measurements of ^{137}Cs (kBq m^{-2}). Internal effective doses were estimated using aggregated transfer factors from ground deposition to in-vivo body concentration for ^{134}Cs and ^{137}Cs in hunters (Bq kg^{-1}). External effective doses were also calculated on the dwelling coordinate for ^{134}Cs, ^{137}Cs and short-lived nuclides in these three counties. Annual effective doses for external and internal doses were then cumulated up to a life expectancy of 80 years for men and 84 years for women, respectively.

The total lifetime effective doses to the members of the hunter families in this cohort were on average 8.3 mSv in Västernorrland, 4.7 mSv in Uppsala and 4.1 mSv in Gävleborg. The effective dose to men were about 40% higher than in women. In all counties the internal dose was about 75% of the total lifetime effective dose. The collective dose for all hunters with family members, in total about 44,000 individuals, in these three counties could be approximated at about 256 manSv.

This study shows it is possible to use register data to develop algorithms for calculating lifetime effective dose commitments for hunters with relatively accuracy.

1. Introduction

On 26 April, 1986 an accident occurred at the Chernobyl nuclear power plant in Ukraine with a release of 5300 PBq of radioactive material (excluding noble gases). In total 85 PBq ^{137}Cs was released from the reactor core (UNSCEAR, 2000). Five percent (4.25 PBq) of this ^{137}Cs was deposited in Sweden in the ensuing days, especially during a heavy rainfall on 28–29 April, with an unequal distribution in the eastern coastal regions from Stockholm in the south to Umeå in the north (Mattsson and Moberg, 1991). The counties of Västernorrland, Uppsala and Gävleborg were among the most contaminated counties in Sweden compared to several counties without any deposition after the Chernobyl accident, but with remaining ^{137}Cs of 2–3 kBq m^{-2} from atmospheric nuclear weapons tests (Andersson, 2007). The Swedish authorities issued recommendations on food intake for the population, including a food regulation program with a maximum allowed activity in food sold to the public of 300 Bq kg^{-1} ^{137}Cs (Persson and Prethun, 2002). This intervention level was set to keep the dose from food intake

* Corresponding author. Occupational and Environmental Medicine, Department of Medical Sciences, Uppsala University, SE-751 85 Uppsala, Sweden.
E-mail address: Martin.Tondel@medsci.uu.se (M. Tondel).

http://dx.doi.org/10.1016/j.jenvrad.2017.06.017
0265-931X/

below 1 mSv y^{-1}. In 1987 a recommended level at 1500 Bq kg^{-1} was introduced for game and reindeer meat, wild berries, mushrooms, freshwater fish and nuts sold to the public (Livsmedelsverket, 1987).

Although given specific information how to monitor and reduce their exposure, hunters and their families are of particular concern as they subsist on products from the forest ecosystem to a high degree. Therefore, several studies have been performed to estimate not only their internal doses, but also the transfer factor and effective ecological halftime (Agren, 1999, Agren, 2001, Rääf et al., 2006a, 2006b). In the first study 183 households and 261 measured individuals (participation rate 82%) were selected in 1994 from five locations in Sweden with an average ^{137}Cs deposition of 7, 10, 40, 45 and 80 kBq m^{-2}, respectively (Agren, 1999). The transfer factor varied between 0.4 and 1.1 (Bq kg^{-1})/(kBq m^{-2}) and was dependent on the ground deposition and sex. At the follow-up of these hunter families during the years 1994–1998 the ecological half time was calculated to be 6 y (Agren, 2001). Further studies on hunters in the most contaminated locations in Sweden 1994–2001 have shown a slightly lower ecological half time of 5.6 (±0.7) y (Rääf et al., 2006a).

An algorithm for effective dose over a period of 70 years was derived based on the ground deposition of ^{137}Cs with a conversion coefficient of 100 μSv per kBq m^{-2} for hunters (Rääf et al., 2006b). Hence, it was possible to calculate the time-integrated effective dose in mSv from internal contamination based on the average of ^{137}Cs concentrations in the hunters. The time-integrated internal effective dose (given with 95th percentile) was calculated in hunters from Uppsala County to be 1.4 (2.8) mSv and in hunters from Gävleborg County 2.4 (5.7) mSv 1986–2036 (Rääf et al., 2006a).

In view of these past exposure assessments of hunters in regions affected by the Chernobyl fallout there has hitherto not been a systematic assessment of the total exposure from both the internal contamination and from external exposure for this group. Dose contribution from short-lived fission products have hitherto been ignored. The aim of the present study was therefore to calculate the total lifetime effective dose to hunters and hunter family members linking registry data on licenses for hunting weapons with dwelling coordinates. The aim was also to include both short- and long-lived nuclides in calculating the contribution to the internal and the external effective dose. Finally, the aim was to evaluate if this method could be used to estimate the collective effective dose for hunter families.

The study was approved by the regional ethics committee in Uppsala (Reg. No. 2014/184).

2. Methods

2.1. Aerial measurements

At the request of the Swedish Radiation Safety Authority, the Geological Survey of Sweden (SGU) has performed annual aerial measurements of ^{137}Cs over Sweden, with a flight line spacing of 200 to 5000 m depending on deposition density, since 1986 (e.g. (Byström, 2000)). This database now includes about 9.9 million measurements of ^{137}Cs, given in kBq m^{-2}. A digital map, showing the surface equivalent deposition (Finck, 1992) of ^{137}Cs, A_{esd} (kBq m^{-2}), has been created from this database in a 200 × 200 m grid backdated to 1 May, 1986 accounting for the physical decay of ^{137}Cs (Fig. 1).

2.2. Description of the hunter cohort

In Sweden all hunters need a licence, issued and registered by the Police Authority on the hunter's civic registration number, to keep their hunting weapons. The register is updated annually and to identify active hunters in 1986 we used the register from 1985. The number of hunters living in the three most contaminated counties of Västernorrland, Uppsala and Gävleborg amounted to a total of 15,698 licensed hunters (counties indicated in Fig. 1). The Swedish National Land Survey has appointed each inhabitant in Sweden a dwelling coordinate based on the coordinate of the real estate. Using the civic registration number as a unique matching variable, Statistics Sweden superimposed the hunters dwelling coordinates on the digital map of A_{esd}, achieving a match in 15,689 hunters (99.9%) in the three counties. Statistics Sweden included the persons living at the same address as the hunters in 1985, defining a cohort of hunters with their family members. Ten hunter households were randomly selected from each county, in total 85 individuals (Table 1). From Statistics Sweden anonymous data on all inhabitants in these three counties was retrieved, giving the A_{esd} of ^{137}Cs at their dwelling coordinate (Table 2), sex, year of birth, county, municipality and parish, respectively, on 31 December, 1985. The average size of the household in the total sample was 85/30 = 2.8 individuals.

2.3. Description of the model for external radiation

The model used for the calculation of external effective dose rate from the deposited ^{137}Cs and ^{134}Cs from the Chernobyl accident for the hunters in the North of Sweden is described below. The external exposure rate has been divided into two components, $\dot{E}(t)_{outdoor}$ and $\dot{E}(t)_{indoor}$, respectively, where

$$\dot{E}(t)_{outdoor} = \left(\dot{K}(t)_{Cs-137} + \dot{K}(t)_{Cs-134}\right) \cdot F_{snow} \cdot F_{rot} \cdot F_{out} \quad (1)$$

is the external effective dose rate outdoors [mSv y^{-1}], and

$$\dot{E}(t)_{indoor} = \left(\dot{K}(t)_{Cs-137} + \dot{K}(t)_{Cs-134}\right) \cdot F_{snow} \cdot F_{rot} \cdot F_{sh} \cdot (1 - F_{out}) \quad (2)$$

is the external effective dose rate indoors (mSv y^{-1}). F_{out} is the fraction of the time spent outdoors (occupancy factor), and typical values for Northern European populations are reported to be 0.1–0.2 (Almgren et al., 2008a, Almgren et al., 2008b, Andersson, 2007, Brown, 1983, WHO, 1999). F_{sh} is the shielding factor of the building, and typical values for one- or two-storey detached houses of wood and brick in Sweden range between 0.4 and 0.5 (Finck, 1992). F_{snow} is a factor describing the attenuation by the snow cover depending on thickness and length of the winter period, typically ranging from 0.81 to 0.97, depending on the latitude in Sweden (Andersson, 2007, Finck, 1992). F_{rot} is the dose conversion factor from air kerma, K_{air} (Gy), to effective dose at rotational geometry (Sv Gy^{-1}) (adult (ICRP, 2010), 0–15 y (Chou et al., 2001)). This factor is not only age, but also gamma-energy dependent and therefore needs to be considered. Here, individuals below 16 y of age are regarded as children, and F_{rot} is then adjusted accordingly. The factors F_{snow}, F_{rot} and F_{sh} all have inherent photon-energy dependence. However, since the mean photon energies per decay of ^{134}Cs and ^{137}Cs are similar, 698 keV vs. 661 keV (JAEA, 2016) we applied the same value, for these F-factors independent of caesium isotopes.

There are no available time-series of *in situ* gamma spectrometry allowing deduction of the particular contributions to the air kerma or absorbed dose rate in air from the two Cs-isotopes. However, total ambient dose equivalent rates have been monitored at several places in the affected municipalities in Sweden by means of a regular monitoring program in the Swedish