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Increased cancer risk in male hunters compared to the general male population in Northern Sweden after the Chernobyl Nuclear Power Plant accident?

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Background: Male hunters in Swedish counties with high fallout of ^{137}Cs after the Chernobyl Nuclear Power Plant (NPP) accident have higher radiation exposure due to higher consumption of game compared with the general population.

Methods: Cancer incidence in Sweden was studied in 9 counties with different ^{137}Cs fallout after the Chernobyl NPP accident in 1986. In total, 9,267 cancer cases occurred in hunters and 138,909 cancer cases in non-hunters to 31 December 2015. Incidence rate ratios (IRR) with 95% confidence intervals (CI) were calculated using unexposed hunters, or non-hunters, as reference to study internal radiation exposure or hunter life style, respectively.

Results: Directly age standardized total cancer incidence showed an increasing trend in non-hunters. For hunters, the total cancer incidence was significantly lower up to 2001 when the total cancer incidence crossed over the weaker non-hunter trend and remained higher for the following 15 years. IRRs for total cancer in hunters versus non-hunters for each county did not show any clear exposure response pattern. IRRs for hunters versus non-hunters were higher regardless of rural/non-rural status with slightly higher risk estimates for the rural settings. The IRR for hunters was 1.06 (95% CI 1.04–1.08) 1986–2015, representing an excess of 531 cancer cases in hunters.

Conclusion: An increased total incidence of cancer was identified for male hunters compared with male non-hunters. No obvious association between cancer and ^{137}Cs from the Chernobyl NPP accident could be identified, although the exposure classification was too crude to exclude such an association.

Key Words: hunter, ^{137}Cs, Chernobyl, cancer, rural

Background

On 26 April 1986 at 1.24 am, a steam explosion occurred at the Chernobyl Nuclear Power Plant (NPP) in Ukraine with a release of 5,300 PBq of radioactive material (excluding noble gases) into the atmosphere. The radionuclide release from the damaged reactor continued mainly over a 10-day period, but with varying release rates. A gamma monitoring station at the southern tip of the island of Öland southeast of Sweden recorded an increased dose rate at 7 pm on 27 April.[1] Five percent (4.25 PBq) of the 85 PBq ^{137}Cs released from the Chernobyl NPP accident was deposited in Sweden in the ensuing days, especially during a heavy rainfall on 28–29 April.[2,3] The deposition of ^{137}Cs was unequally distributed in the eastern coastal regions from Stockholm in the South to Umeå in the North. In 1986, there was remaining ^{137}Cs from the atmospheric nuclear weapons tests of 2–3 kBq/m^2, and after the Chernobyl NPP accident the ground deposition could exceed 100 kBq/m^2 in Sweden.[4] After the Chernobyl NPP accident, the Swedish authorities issued recommendations to the public on the intake of certain foods, and a food regulation program was introduced restricting the activity in food sold to the public to 300 Bq/kg.[5] This limit was set to ensure that the dose from food intake was below 1 mSv/year. An additional recommendation of a maximum of 1,500 Bq/kg was introduced in 1987 for game, venison (mainly reindeer meat), wild berries, mushrooms, freshwater fish, and nuts sold to the public.[6]

Due to the elevated ^{137}Cs concentration in game, the Swedish Radiation Safety Authority, together with the Swedish Defence Research Agency (FOI) launched a measurement program in 1996. Several hunting communities in Sweden were regularly

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What this study adds

This is the first study on cancer incidence in male hunters. The nine northern counties of Sweden had a high contrast of ^{137}Cs deposition after the Chernobyl Nuclear Power Plant accident resulting in higher internal radiation dose to hunters because a higher proportion of game meat in their diet than the general population in those counties. Incidence rate ratios (IRRs) for various cancer sites could therefore be calculated *between* hunters, using low deposition counties as reference, and *within* counties using non-hunters as reference. This method allows to examine risk for cancer of internal radiation exposure and the hunting life style, respectively.

surveyed by whole-body counting.[7,8] In a general assessment of the Chernobyl-associated internal doses from the time-integrated radioecological transfer of ^{134,137}Cs, it was estimated that hunters, on average, had a three-fold higher internal contamination of ^{137}Cs than non-hunters living in the same county.[9]

Following the Chernobyl NPP accident, the effective dose to the Swedish population consisted of an external and an internal dose contribution, and both can be considered as life-style dependent. Simulated model estimates of the life-time effective dose has shown that the most important factor for the external dose contribution is fallout at the dwelling coordinate and shielding from buildings and snow. For the internal dose, the most important factor is the amount of consumption of radioactive contaminated foodstuff and male sex, assuming a higher food intake than women.[10] Based on whole-body measurements of ^{137}Cs in the body the transfer factor from ground contamination to effective dose is almost three times higher for hunters compared with the general population.[10] In an earlier pilot-study, we have shown that there was a difference in lifetime effective doses to the members of hunter families, with county averages of 8.3 mSv in Västernorrland, 4.7 mSv in Uppsala, and 4.1 mSv in Gävleborg, respectively. An inverse relationship between age in 1986 and the lifetime dose was seen with a maximum dose of 11.9 mSv in the county of Västernorrland, the county in Sweden with the highest average deposition of ^{137}Cs.[11] In these three counties, the internal dose for the hunter households was about 75% of the total lifetime effective dose, which can be translated into almost 30% in the general population in these three counties.[11] The hypothesis for this study was that hunters from more contaminated counties would have an increased incidence of cancer due to higher internal dose from ^{137}Cs after the Chernobyl NPP accident.

Materials and methods

Population

The study design is a closed cohort consisting of all persons living in the nine northern-most counties in Sweden (Table 1). From Statics Sweden (SCB), we retrieved information on all individuals living in these nine counties by 31 December 1986. In the population registry at SCB, all individuals have a unique social identity number and information on the county where they lived. SCB also keeps registries on date of emigration and date of death that can be linked to the data set. The Swedish National Land Survey has assigned each inhabitant in Sweden an annually updated dwelling coordinate. These dwelling coordinates can then be used to link the population registry to the digital map of the ^{137}Cs, hence creating an individual deposition value of ^{137}Cs at each dwelling.

A total of 1,113,564 males lived in the nine counties in 1986. The final cohort for analyses included 826,401 persons, that is, ≥18 years of age in 28 April 1986 after excluding duplicates of re-used social identity numbers (n = 834), missing information on dwelling coordinates (n = 4,943), having a cancer diagnosis between 1958 and 27 April 1986 (n = 17,553), and persons <18 years age in 28 April 1986 (n = 264,739), with or without a combination of these excluding factors.

In Sweden, all hunters need a license for their hunting weapon, issued and registered by the Swedish National Police Agency, and registered under the social identity number. This register from 1986 was linked to the population registry data base by SCB. The total number of male hunters in the nine counties was 41,378. Hence, the final cohort for further analyses consisted of male hunters (n = 40,874) and male non-hunters (n = 785,527) ≥18 years of age with no known cancer prior to the follow-up from 28 April 1986 to 31 December 2015.

Exposure assessment

The Geological Survey of Sweden (SGU) has performed repeated aerial measurements of ^{137}Cs since 1986, on the authorization of the Swedish Radiation Safety Authority (SSM), with a flight line spacing of 200 to 5000 meters depending on deposition density, and all measurement results have been stored in a database.[12] This database includes about 9.9 million measurement points that were used by the SSM to calculate the county average surface equivalent deposition, Aesd (kBq/m^2), (Table 1). The ^{137}Cs measurements have been visualized in a 200 meter by 200 meter digital grid map, and all the measurements have been backdated to 1 May 1986, accounting for the physical decay of ^{137}Cs. To allow for contrast exposure and statistical power, tertiles were created using the ground deposition to ^{137}Cs for hunters in the counties (Aesd).

SCB has provided data on rural and non-rural residence at each dwelling. The definition of rural and non-rural (including urban) areas was created by SCB in the year 1960 and updated every fifth year since then by SCB. Rural residence is defined as a population center having <200 inhabitants. Moreover, a population center is defined as a congregation of buildings with the largest distance between buildings being 200 meters. This definition is purely geographical, ignoring administrative boundaries, such as parishes or municipalities.[13] In the analysis, we used data on rural and non-rural categories for the study population in 1986. Rural residence by this definition is a very sparsely populated area and non-rural residence is more of a mixed category including both urban and semi-urban residence.

Cancer statistics

In Sweden, all individuals have a unique social identity number registered with SCB, and this number can be linked to the national cancer registry at the National Board of Health and Welfare. The national cancer registry started in 1958, and

Table 1.

Male population (≥18 years of age in 1986) in the 9 counties included in this study. The inhabitants are divided into hunters and non-hunters with Aesd ^{137}Cs (kBq/m^2) and presented in tertiles based on hunters.

County	Hunter			Non-hunter				
		Years of age			Years of age		Aesd ^{137}Cs	Exposure category
	n	Median	5 - 95 perc	n	Median	5 - 95 perc	kBq/m^2	
Norrbotten	8,124	41.6	22.5 - 64.1	89,828	42.8	20.2 - 76.1	2.05	lowest
Dalarna	5,174	44.7	23.2 - 67.4	99,974	44.6	20.4 - 77.9	2.45	lowest
Södermanland	2,293	45.4	24.7 - 66.3	88,982	43.4	20.2 - 77.0	5.04	medium
Jämtland	3,627	43.5	23.4 - 67.0	47,007	45.5	20.4 - 78.7	6.35	medium
Västmanland	2,385	46.3	24.0 - 67.5	92,647	43.0	20.1 - 76.2	10.9	medium
Gävleborg	4,710	44.1	23.4 - 66.3	103,117	44.6	20.4 - 77.8	13.1	medium
Västerbotten	6,839	42.9	22.4 - 65.6	83,127	43.1	20.3 - 76.7	14.4	highest
Uppsala	3,042	45.0	23.9 - 67.4	88,118	41.0	20.4 - 76.4	15.2	highest
Västernorrland	4,680	43.8	23.1 - 65.5	92,727	45.0	20.4 - 77.7	27.9	highest
All 9 counties	40,874	43.7	23.0 - 66.1	785,527	43.4	20.3 - 77.1		

The inhabitants are divided into hunters and non-hunters with Aesd ^{137}Cs (kBq/m^2) and presented in tertiles based on hunters.

therefore all individuals in our cohort with a diagnosis of cancer between 1958 and 31 December 2015 could be retrieved. All cancer diagnoses have consistently been coded according to the International Classification of Diseases, version 7. Using BEIR VII all malignant cancers could be coded as Organ-specific, Remainder and Cancer not regarded as caused by ionizing radiation (Not in BEIR VII), respectively (Table 2).[14]

Potential confounding factors

We had only limited access to register data on variables that can be investigated for asserting confounding. Educational level in 1986 was classified as low (lower secondary school), medium (upper secondary school), and high (university). Hence 89.0% of the total cohort could be classified, with the remaining 11.0% missing information. Data on tobacco smoking was not available on an individual level and we therefore classified cancer sites as a smoking-associated cancer if tobacco smoking had sufficient evidence as being a carcinogenic agent according to the present list from the International Agency for Research on Cancer.[15]

Statistical methods

The cancer incidence was directly standardized in 1-year classes using the Swedish population year 2000 as the standard (from SCB). The population was censored for date of emigration or death with follow-up to the date of the first cancer diagnosis. Hence, the age-standardized cancer incidence could be expressed as number of cancer cases per 1000 person-years with 95% confidence intervals (95% CI). Based on the directly age standardized cancer incidence, an incidence rate ratio (IRR) with 95% CI could be calculated using non-hunters as the reference or the lowest exposure category as the reference for hunters and non-hunters, respectively.

All calculations were performed in SAS software version 9.4 for data management and the procedure STDRATE for the age standardization.

The study was approved by the regional ethics committee in Uppsala (Reg. No. 2014/184 with the extension Reg. No. 2014/184/1).

Results

In the nine counties, 40,874 males had a license for a hunting weapon, representing 4.95% of the total population (Table 1). However, the proportion of hunters varied between counties from the lowest of 2.51% (Västmanland) to the highest 8.29% (Norrbotten). The lowest ^{137}Cs category of hunters (n = 13,298) can be regarded as almost unexposed of ^{137}Cs from the Chernobyl NPP accident, representing pre-Chernobyl accident deposition levels. Median age was almost identical comparing hunters and non-hunters, but the age distribution showed that non-hunters have relatively higher proportions of both younger and older persons, respectively (Figure 1).

Using the ^{137}Cs contamination at the dwelling coordinate, a population-weighted ^{137}Cs average could be created for the rural and non-rural classification used by SCB. Hunters had a higher proportion of people living in the rural setting in all counties and overall in all nine counties 43.5% of hunters lived in rural areas compared with 23.6% of non-hunters, (Table 3). The rural deposition average was slightly higher than non-rural average deposition for both hunters and non-hunters, but non-hunters had a higher deposition both in the rural and non-rural areas, reflecting the fact that coastal areas with higher population density received higher fallout.

Analyzing the directly age standardized total cancer incidence over time, there is a monotonous increasing trend in the non-hunter population in the follow-up period 1986–2015. For hunters, the total cancer incidence was significantly lower than for non-hunters in each 5-year time period up to 2001 when the total cancer incidence remained significantly higher for the following 15 years as analyzed in 5-year time periods (Figure 2).

Hunters had a higher IRR for total cancer in all counties 1986–2015, with IRR in the range of 1.03 to 1.14, except for Västmanland with an IRR 0.97 (Figure 3).

Exposure response was analyzed separately for hunters and non-hunters in 3 time periods, 1986–1995, 1986–2005, and 1986–2015, respectively (Figure 4). The patterns were similar within hunters and non-hunters for all time periods, showing a weak tendency of exposure response for the Organ-specific cancer sites for both hunters and non-hunters. Due to skewed distribution of rural status between hunters and non-hunters, the directly age standardized incidence rates are stratified in Table 4 and presented as IRR in Figure 5 using non-hunters as the reference in each cancer category.

Hunters with high and medium education level had a slightly higher directly age standardized total cancer incidence 1986-2015 of 7.38 and 6.99 per 1,000 person years, respectively compared to 6.45 and 6.23 per 1,000 person years for non-hunters in high and medium education level, respectively. For low education level the confidence intervals overlapped between hunters having a directly age standardized total

Table 2.

All cancer cases during follow-up 28 April 1986 to 31 December 2015.

Radiation-associated		Cancer sites	ICD-7 (male)	hunter n	hunter %	non-hunter n	non-hunter %
Yes	organ-specific BEIR VII	Stomach	151, 1510, 1511, 1518, 1519	305	3.29	4,486	3.23
		Colon	1530, 1531, 1532, 1533, 1534, 1536, 1538, 1539	659	7.11	9,448	6.80
		Liver	1550	115	1.24	1,766	1.27
		Lung	1620, 1621	686	7.40	10,223	7.36
		Prostate	177	3,360	36.26	49,077	35.33
		Urinary bladder	1810, 1816	545	5.88	9,098	6.55
		Thyroid	194	30	0.32	500	0.36
		Leukaemia	2040, 2044, 2047, 2049, 2050, 2051, 2059, 2060, 2061, 2069, 2070, 2071, 2072, 2073, 2079	145	1.56	1,828	1.32
Yes	remainder BEIR VII	Remainder	all other ICD-7 codes	2,742	29.59	42,740	30.77
No	not in BEIR VII	Male breast	170, 1701, 1702, 1707, 1708, 1709	12	0.13	179	0.13
		Lymphoma	2001, 2002, 2003, 201, 2021, 2022	348	3.76	5,258	3.79
		Other leukaemia	2024, 203, 2041, 208, 209	320	3.45	4,306	3.10
	total cancer			9,267	100.00	138,909	100.00

Organ-specific cancers and Remainder according to BEIR VII, respectively, and cancer not associated to radiation in BEIR VII. All diagnosis codes according to ICD-7 as registered consistently over time by the National Board of Health and Welfare in Sweden since 1958.

Table 3.

Ground deposition of ^{137}Cs 1986 on dwelling coordinate for hunters and non-hunters, respectively

	Hunter					Non-hunter				
^{137}Cs (kBq/m^2)	n (%)	Mean	Median	5 - 95 perc	min–max	n (%)	Mean	Median	5 - 95 perc	min–max
Rural	17,779 (43.5)	10.5	5.38	1.43–34.1	0.00–98.1	185,402 (23.6)	11.1	5.93	1.47–35.3	0.00–118
Non-rural	23,095 (56.5)	9.16	3.09	1.36–32.6	0.00–95.4	600,125 (76.4)	10.1	4.99	1.46–32.5	0.00–112
Total	40,874 (100)	9.74	4.12	1.39–33.4	0.00–98.1	785,527 (100)	10.3	5.14	1.47–33.4	0.00–118

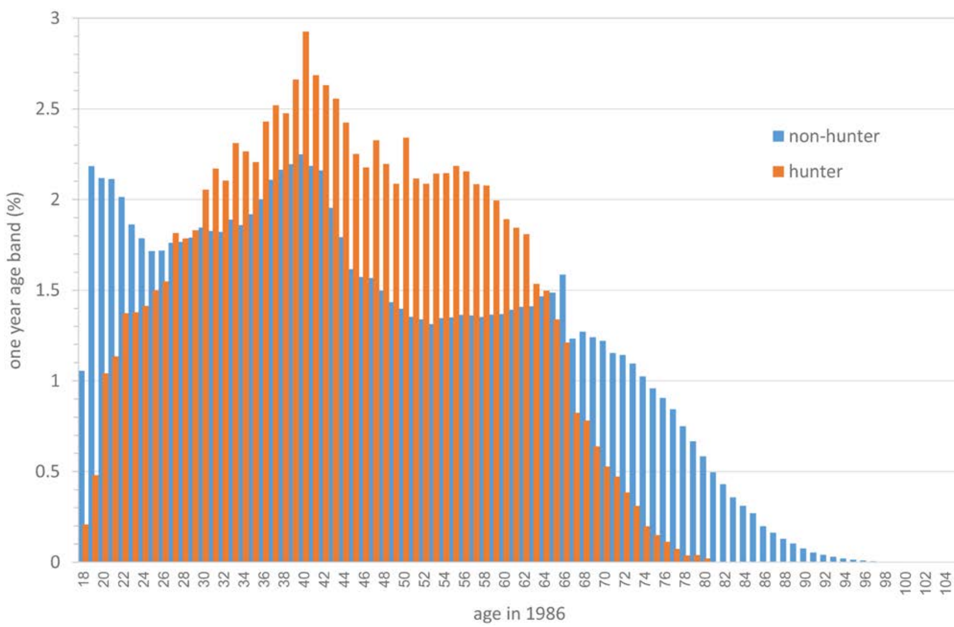

Figure 1. Age distribution for hunter versus non-hunter in 1986.

cancer incidence 1986-2015 of 6.10 versus 5.96 per 1,000 person years in non-hunters, respectively.

Rural hunters had a higher risk of total cancer compared with rural non-hunters, IRR 1.11 (95% CI 1.07–1.15) 1986–2015. Hunters living in non-rural areas also showed an increased risk of total cancer compared with non-hunters in non-rural areas, IRR 1.05 (95% CI 1.02–1.09) Figure 5 (right end). The overall IRR for hunters (using non-hunters as the reference) was 1.06 (95% CI 1.04–1.08) 1986–2015, representing an excess of 531 cancer cases in hunters. The overall IRR for hunters and smoking associated cancer sites (using non-hunters as the reference) was 1.06 (95% CI 1.03–1.10) and for non-smoking associated cancer sites a corresponding IRR is 1.06 (95% CI 1.03–1.09).

Discussion

The main findings in our study is the difference in time trends in total cancer incidence between hunters and non-hunters and also a tendency of increasing trend for organ-specific cancers incidence related to the average ground deposition of ^{137}Cs in the counties, both in hunters and non-hunters 1986–2015. The IRR for total cancer in hunters was 1.06 (95% CI 1.04–1.08) 1986–2015, representing an excess of 531 cancer cases in hunters.

It could be argued that a healthy hunter life style could explain a lower total cancer incidence during a latency period, and then the increased cancer incidence after 2001 could indicate an effect of higher internal ^{137}Cs exposure. If that were the case, the IRR in the reference category (Norrbotten and Dalarna) would be close to unity, as hunters and non-hunters in these two counties can be assumed to have the same internal dose, since there was low-level fallout from the Chernobyl NPP accident in these two counties. On the other hand, if hunters were to have an increased risk of cancer related to the Chernobyl NPP accident, the IRR would be higher in those counties with higher average ground deposition, with the highest IRR in Västernorrland. Instead, the IRR showed relatively small variations in all counties irrespective of the ground deposition without any clear exposure response relationship, which argues against an effect from the Chernobyl NPP accident fallout in Sweden.

The exposure response seen for organ-specific cancers in the hunter category could be interpreted as a weak dose response, although a similar trend was seen in the non-hunter category at the same magnitude, thus contradicting this hypothesis. The exposure response relationship for organ-specific cancers in non-hunters could potentially be an effect of the Chernobyl fallout, and such an effect can be leveled out by lumping together not so strongly radiation-related cancers when analyzing total cancer.

Hunters are assumed to have a higher internal dose than non-hunters living in the same area. People living in contaminated areas in Ukraine, Belarus, and Western Russia also had increased internal doses as they relied on locally produced foodstuffs, in contrast to people in the Fukushima prefecture where the internal dose was much reduced due to strict food control.[16,17] Epidemiological studies in Belarus, Russia, and Ukraine have shown a clear exposure–response relationship between the individual thyroid radiation dose and the risk of thyroid cancer after the Chernobyl NPP accident in 1986.[18–23] In these three republics, the total number of thyroid cancer cases among those <18 years of age in 1986, amount to 19,233

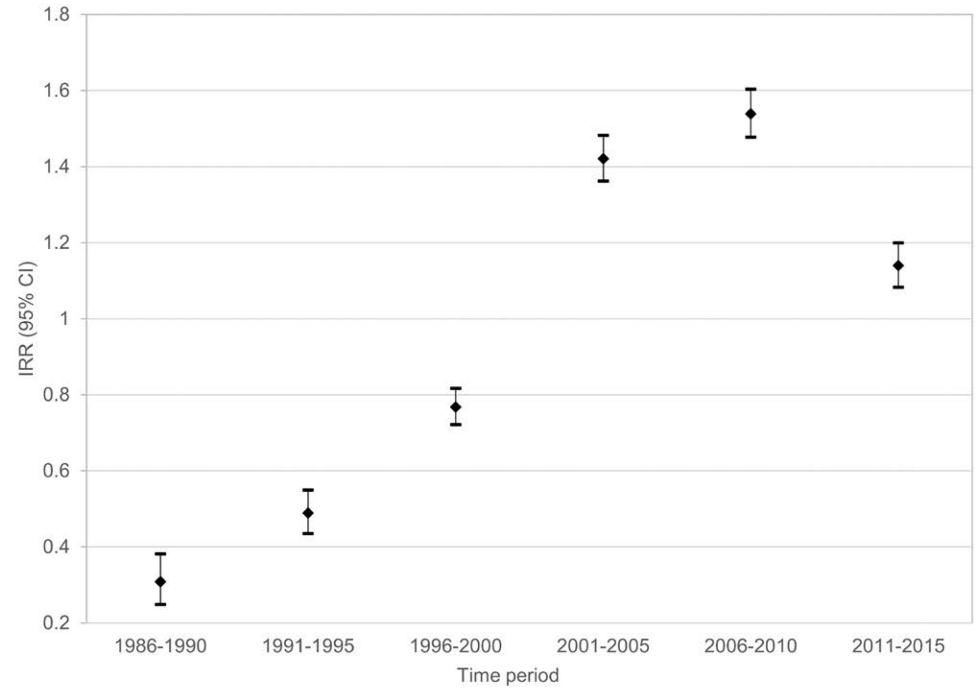

Figure 2. IRR for total cancer with 95% confidence intervals (95% CI) using directly age standardized cancer incidence rate (the Swedish population year 2000 as the standard) for hunters using non-hunters as the reference (1.0) in each 5-year time period.

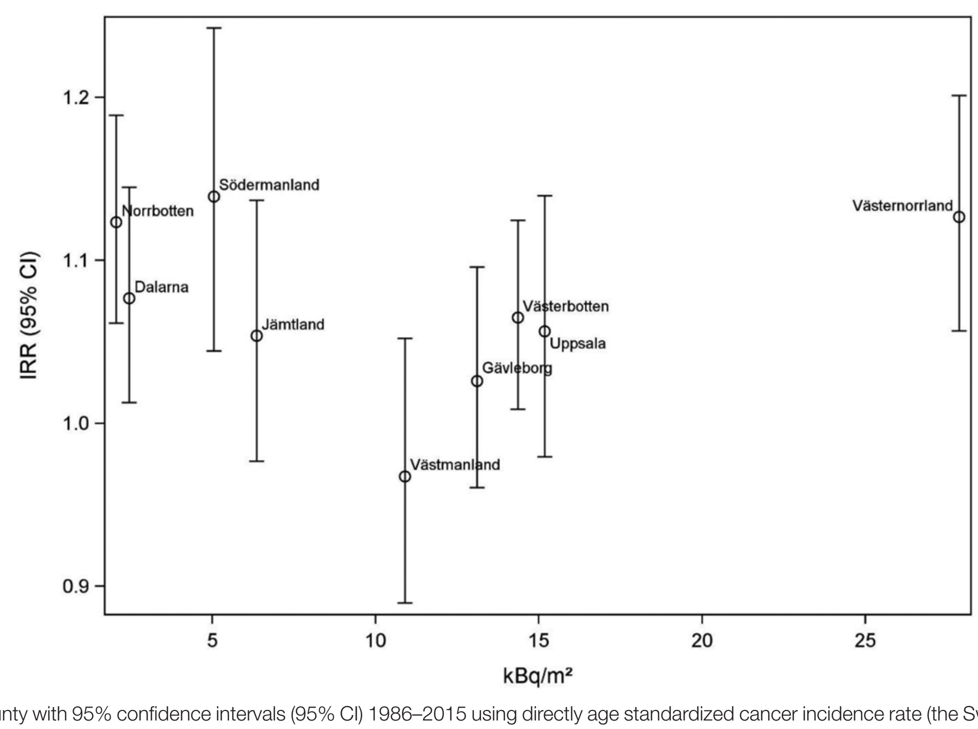

Figure 3. IRR by county with 95% confidence intervals (95% CI) 1986–2015 using directly age standardized cancer incidence rate (the Swedish population year 2000 as the standard) and compared with non-hunters as the reference (1.0) in each county. The county of Norrbotten and Dalarna were almost unexposed for ^{137}Cs from the Chernobyl NPP accident with levels of remaining ^{137}Cs from the atmospheric nuclear weapons test fallout.

thyroid cancer cases 1991–2015. UNSCEAR estimates the fraction of the incidence of thyroid cancer attributed to radiation exposure, mainly from internal ^{131}I exposure, at 0.25, or almost 5,000 thyroid cancer cases in those who were children and adolescents at time of the Chernobyl NPP accident.[24]

The hunter diet, with a higher proportion of red meat than the average Swedish diet, can by itself be a potential risk factor for cancer among hunters. The International Agency for Research on Cancer (IARC) has classified consumption of red meat as probably carcinogenic to humans (Group 2A). IARC has concluded that there is limited evidence in humans for the carcinogenicity of consumption of red meat with positive associations observed for cancers of the colorectum, pancreas, and prostate.[25] A Swedish longitudinal cohort study showed that a

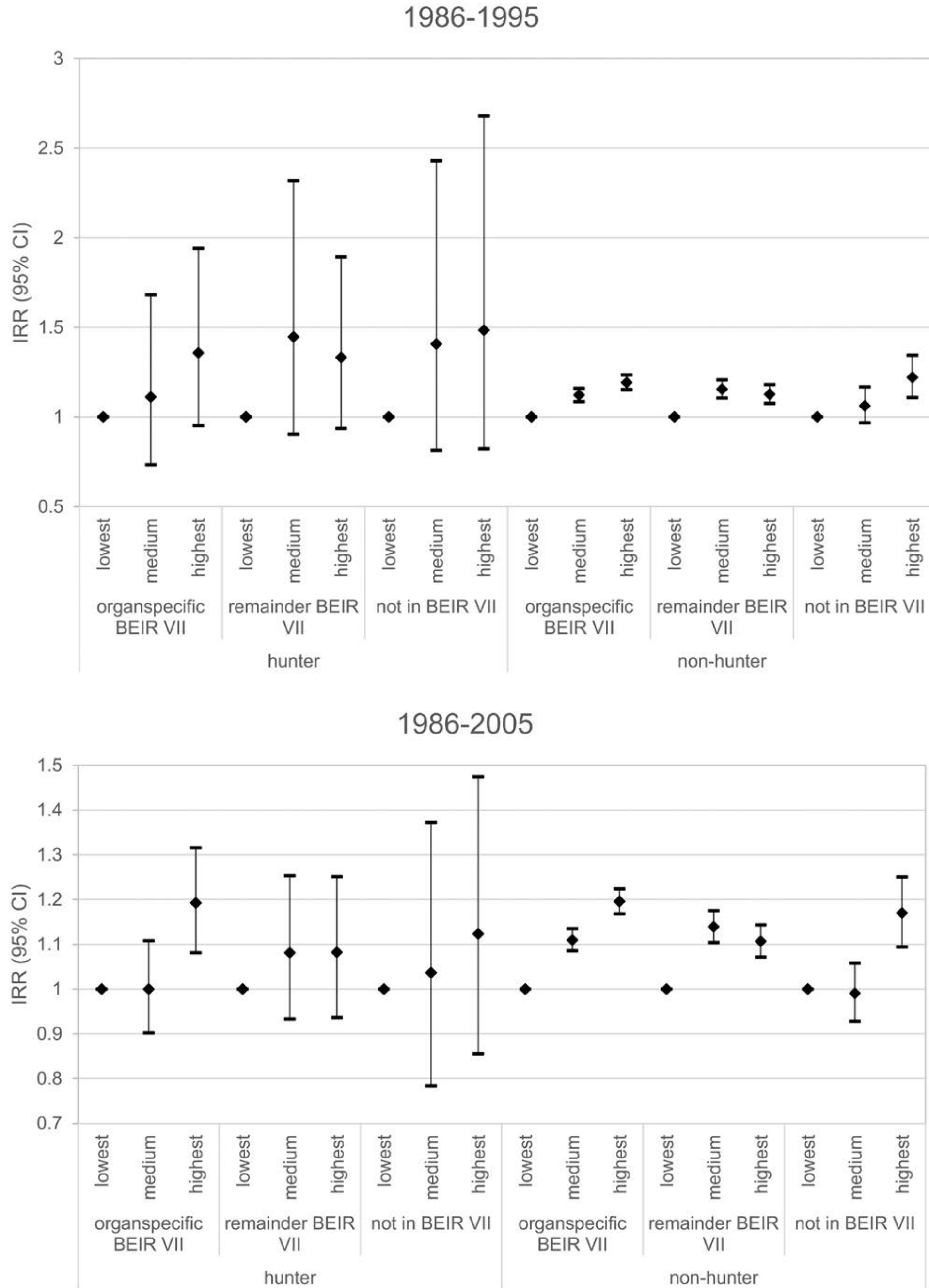

Figure 4. (*Continued*)

diet with more red meat, fatty fish, total fat content and berries and less vegetables, bread and fibers was related to an increased mortality among men, but not women. The risk was equally attributable to cancer and cardiovascular disease.[26] Red meat can be seen as mediator for ^{137}Cs exposure through game for hunters, but if hunters at the same time have a higher red meat consumption not contaminated with ^{137}Cs e.g. beef, veal, pork, lamb, this uncontaminated meat can be regarded as a potential confounding factor. The potential confounding effect from red meat consumption is difficult to adjust for as hunters from different counties most likely have the same proportion of red meat in their diet, but it cannot be ruled out that part of the increased IRR for hunters can be attributed to red meat consumption (Figure 5). Other potential confounding factors could be socioeconomic factors and tobacco smoking. We had only access to education as proxy for socioeconomic status in our register with higher education indicating a higher risk of total cancer 1986-2015, but because high education level was not skewed between hunters (12.3%) and non-hunters (14.5%), it is unlikely to affect the main results in our study. Tobacco smoking related cancer sites and not smoking related cancer sites showed identical IRR for hunters compared to non-hunters 1986-2015 and therefore no epidemiological support in our study for difference in smoking habits between hunters and non-hunters.

Besides the population living in the vicinity of the Chernobyl NPP, high internal contamination of a large population is relatively rare. Studies on inhabitants living near the nuclear weapons testsite Semipalatinsk (n = 19,545), with an average dose of 634 mSv, have shown a significant dose response trend for solid cancers 1960–1999 based on

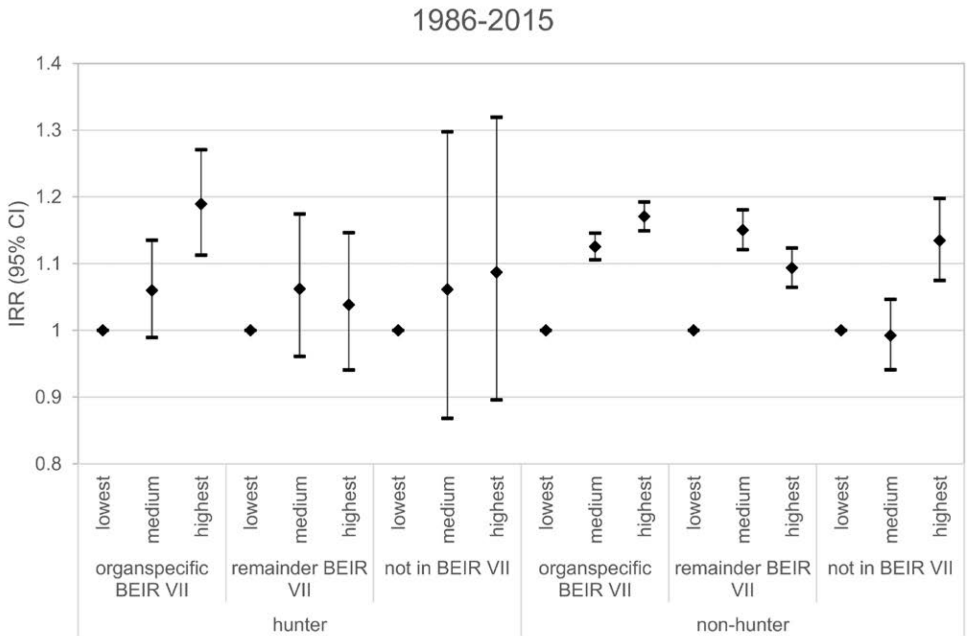

Figure 4. IRR with 95% confidence intervals (95% CI) using directly age standardized cancer incidence rate (the Swedish population year 2000 as the standard) for hunters and non-hunters using lowest category from Table 1 as the reference (1.0). Three time periods are shown: 1986–1995, 1986–2005, and 1986–2015, respectively (different scale on the *y*-axis).

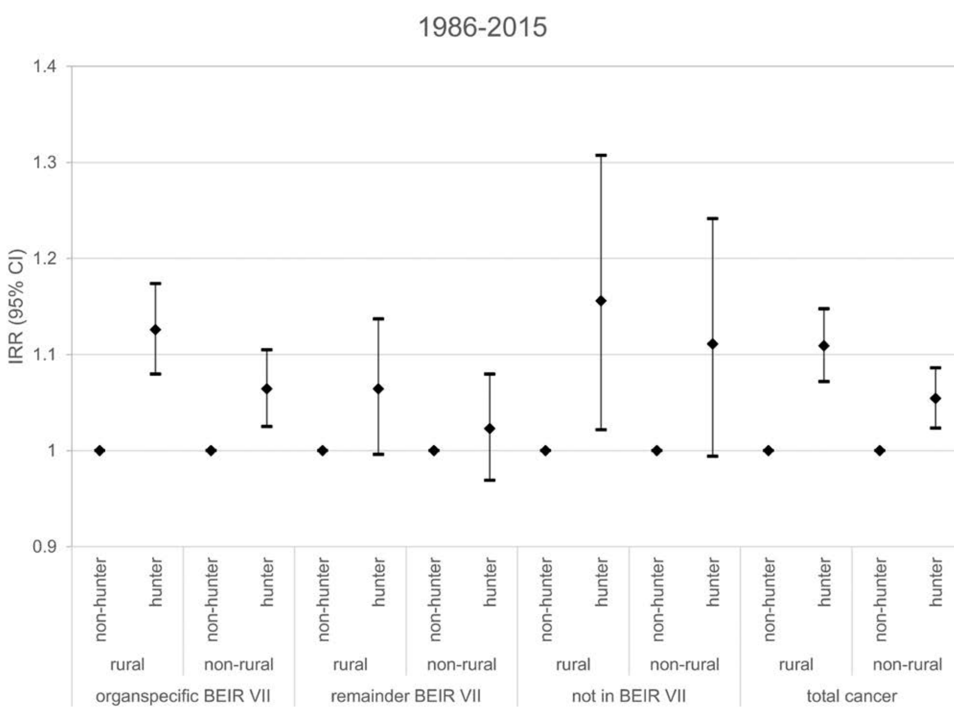

Figure 5. IRR with 95% confidence intervals (95% CI) using directly age standardized cancer incidence rate (the Swedish population year 2000 as the standard) stratified for rural and non-rural residence, using non-hunters as the reference. Classification of cancers according to Table 2.

individual dose estimates, including exposure from internal dose.[27] Between 1949 and 1956 radioactive material was released into the Techa River from the Mayak production facility, in the Southern Urals, which was part of the nuclear weapons program in the Soviet Union.[28] People in the villages along the Techa River (n = 17,435) were exposed from external radiation, but also through consumption of water, milk, and food contaminated with ^{137}Cs, ^{90}Sr, ^{89}Sr and other uranium fission products with a mean estimated stomach dose of 52 mGy. A significant linear dose-response trend for solid cancer incidence was observed in this cohort 1956–2007.[28] BEIR VII concluded there are no strong reasons to think that the dose-response from internal low-LET exposure would differ from that from external exposure, although there is still uncertainty in applying the BEIR VII risk models to estimate risks from internal exposure.[14]

Studying cancer risks in Swedish hunters in counties with different deposition of ^{137}Cs after the Chernobyl NPP accident can

Table 4.

Directly age standardized cancer incidence rate, IR, (using the Swedish population year 2000 as the standard) 1986–2015 and expressed as number of cancer cases per 1000 person years with 95% confidence intervals (95% CI) stratified for rural and non-rural residence.

			Hunter			Non-hunter		
			IR	95% CI		IR	95% CI	
Rural	Organ-specific BEIR VII	Lowest	3.62	3.32	3.91	3.11	3.01	3.20
		Medium	3.94	3.68	4.20	3.56	3.48	3.64
		Highest	4.21	3.95	4.47	3.74	3.65	3.82
	Remainder BEIR VII	Lowest	1.87	1.65	2.10	1.68	1.60	1.75
		Medium	1.92	1.72	2.12	1.81	1.74	1.87
		Highest	1.86	1.67	2.05	1.78	1.72	1.85
	Not in BEIR VII	Lowest	0.44	0.33	0.54	0.42	0.38	0.45
		Medium	0.55	0.45	0.66	0.42	0.39	0.45
		Highest	0.49	0.40	0.58	0.45	0.43	0.48
	Total cancer	Lowest	5.92	5.54	6.31	5.20	5.08	5.33
		Medium	6.41	6.07	6.76	5.79	5.68	5.89
		Highest	6.56	6.23	6.90	5.97	5.87	6.08
Non-rural	Organ-specific BEIR VII	Lowest	3.73	3.49	3.97	3.45	3.40	3.51
		Medium	3.88	3.63	4.14	3.86	3.81	3.90
		Highest	4.59	4.31	4.87	4.02	3.97	4.08
	Remainder BEIR VII	Lowest	1.88	1.71	2.05	1.78	1.74	1.82
		Medium	2.11	1.91	2.30	2.09	2.05	2.12
		Highest	2.08	1.89	2.27	1.97	1.93	2.01
	Not in BEIR VII	Lowest	0.49	0.40	0.58	0.41	0.39	0.43
		Medium	0.44	0.35	0.53	0.41	0.39	0.42
		Highest	0.52	0.42	0.61	0.48	0.46	0.49
	Total cancer	Lowest	6.10	5.79	6.41	5.65	5.57	5.72
		Medium	6.43	6.09	6.76	6.36	6.30	6.41
		Highest	7.19	6.83	7.54	6.47	6.40	6.54
Rural + non-rural	Organ-specific BEIR VII	Lowest	3.70	3.51	3.88	3.37	3.32	3.41
		Medium	3.92	3.73	4.10	3.79	3.75	3.83
		Highest	4.40	4.21	4.58	3.94	3.90	3.99
	Remainder BEIR VII	Lowest	1.89	1.76	2.03	1.76	1.72	1.79
		Medium	2.01	1.87	2.15	2.02	1.99	2.05
		Highest	1.97	1.83	2.10	1.92	1.89	1.95
	Not in BEIR VII	Lowest	0.46	0.40	0.53	0.41	0.40	0.43
		Medium	0.49	0.42	0.56	0.41	0.40	0.42
		Highest	0.50	0.44	0.57	0.47	0.45	0.49
	Total cancer	Lowest	6.05	5.81	6.29	5.54	5.47	5.60
		Medium	6.42	6.18	6.66	6.22	6.17	6.27
		Highest	6.87	6.63	7.11	6.33	6.27	6.39

Counties of Norrbotten and Dalarna (lowest), Södermanland, Jämtland, Västmanland, Gävleborg (medium), Västerbotten, Uppsala, Västernorrland (highest) based on county deposition of ^{137}Cs, Table 1.

therefore be justified, as they can be assumed to have different internal radiation doses. In our study, we used tertiles of exposure based on county deposition of ^{137}Cs. If hunters in the medium and higher exposure categories are regarded as exposed from predominantly internal exposure those hunters can be regarded as a relatively large internally exposed cohorts in terms of person years (681,498 person years), which is larger than the exposed cohort in Semipalatinsk (284,260 person-years) and the total Techa River cohort (472,788 person-years), even though the Swedish hunters have been exposed at much lower radiation doses.[11,27,28]

To the best of our knowledge, this is the first study on cancer incidence in hunters. The strength of our study is the distinct definition of hunter, the high-resolution ^{137}Cs map, and the completeness and accuracy of the cancer diagnosis on the individual level. Another strength is the study design with all individuals free of cancer at baseline which avoids a potential secondary cancer caused by treatment of cytostatics and/or radiation masking an effect from ^{137}Cs.

The limitation is the risk of misclassification, as having a hunting weapon is the sole proxy of consuming contaminated foodstuff to a higher extent than non-hunters. Another misclassification can occur if hunters in counties with higher average ^{137}Cs deposition reduce their intake due to higher contaminated game meat compared with hunters with lower ground deposition, potentially obfuscating an underlying effect of internal dose exposure from the Chernobyl NPP accident, as has been suggested by Ågren.[29]

Conclusions

An increased risk of cancer was identified for male hunters compared with male non-hunters in the nine northern-most counties in Sweden during the follow-up period from 1986 to 2015. An association between cancer and exposure to ^{137}Cs from the Chernobyl NPP accident was not seen, although the exposure classification was too crude to exclude such association.

Conflict of interest statement

The authors declare that they have no financial conflict of interest with regard to the content of this report.

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Correction Notice

A revision to the title of Table 2 and formatting changes were made to this article after publication per the author's request.

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