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Site-specific cancer risk in the Baltic cohort of Chernobyl cleanup workers, 1986–2007

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Abstract

Objective—To assess site-specific cancer risk in the Baltic cohort of Chernobyl cleanup workers 1986–2007.

Methods—The Baltic cohort includes 17,040 men from Estonia, Latvia and Lithuania who participated in the environmental cleanup after the accident at the Chernobyl Nuclear Power Station in 1986–1991, and who were followed for cancer incidence until the end of 2007. Cancer cases diagnosed in the cohort and in the male population of each country were identified from the respective national cancer registers. The proportional incidence ratio (PIR) with 95% confidence interval (CI) was used to estimate the site-specific cancer risk in the cohort. For comparison and as it was possible, the site-specific standardized incidence ratio (SIR) was calculated for the Estonian sub-cohort, which was not feasible for the other countries.

Results—Overall, 756 cancer cases were reported during 1986–2007. A higher proportion of thyroid cancers in relation to the male population was found (PIR=2.76; 95%CI 1.63–4.36), especially among those who started their mission shortly after the accident, in April–May 1986 (PIR=6.38; 95% CI 2.34–13.89). Also, an excess of oesophageal cancers was noted (PIR=1.52; 95% CI 1.06–2.11). No increased PIRs for leukaemia or radiation-related cancer sites combined were observed. PIRs and SIRs for the Estonian sub-cohort demonstrated the same site-specific cancer risk pattern.

Conclusion—Consistent evidence of an increase in radiation-related cancers in the Baltic cohort was not observed with the possible exception of thyroid cancer, where conclusions are hampered by known medical examination including thyroid screening among cleanup workers.

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Keywords

Chernobyl nuclear accident; neoplasms; incidence; radiation effects; Estonia; Latvia; Lithuania

1. Introduction

At the time of the accident in the Chernobyl Nuclear Power station in April 1986, the three Baltic countries – Estonia, Latvia and Lithuania – were part of the Soviet Union, and about 17,000 men (mostly military reservists) from these countries were sent for the environmental cleanup in the Chernobyl area in 1986–1991. After the Baltic countries regained their independence in 1991, comparably designed cohort studies were initiated in each country to investigate radiation-induced cancer risk among Chernobyl cleanup workers.^{1–3} The approach was to follow the cohort members through cancer, mortality and population registers in each country and compare cancer incidence in the cohort with that in the male population. A combined cohort of Chernobyl cleanup workers from the three countries was assembled to achieve higher statistical power. Similar procedures and data available in the Baltic countries – nationwide population-based registries using personal identification number as the key variable for linkages – were anticipated to provide high quality results in a timely fashion. Unfortunately, delays were severe in large part due to restrictive data protection laws, which prohibited record linkages based on personal identifiers, and, disallowed using death certificate information to update cancer data. The resulting difficulties in disease registration and epidemiological research in Estonia were described by Rahu and McKee⁴, and similar circumstances prevailed in Latvia and Lithuania. The present analysis is the first to assess site-specific cancer risk in the combined Baltic Chernobyl cleanup workers cohort.

2. Materials and methods

Chernobyl cleanup workers cohorts in Estonia, Latvia and Lithuania were identified retrospectively in 1992–1994 using official lists, mostly personal records of the former Soviet Army and Chernobyl Registers. The procedures for assembling the cohorts in each country are described in detail elsewhere.^{1–3} We excluded 574 persons from the analysis (21 from Estonia, 314 from Latvia, and 239 from Lithuania) because available information was inadequate for follow-up for cancer incidence. The final cohort included 17,040 men – 4810 from Estonia, 5546 from Latvia and 6684 from Lithuania.

Information on cancer cases diagnosed in the Baltic Chernobyl cohort and in the male population of each country in 1986–2007 was obtained from the national cancer registers and was coded according to the Tenth Revision of the International Classification of Diseases (ICD-10 C00–C97). Due to incomplete follow-up for deaths and emigrations, and impossible calculation of the person-time at risk for Latvian and Lithuanian sub-cohorts, the proportional incidence ratio (PIR) – based on number of cancer cases by site, age group and year of diagnosis in the cohort, and in the respective male population – was used to estimate the site-specific cancer risk.⁵ The PIR was expressed as the ratio of observed to expected number of cancer cases. The expected number of site-specific cancer cases was calculated by multiplying the total number of cancer cases in the cohort by the respective site-specific proportion in the male population taken into account five-year age group, five-year calendar period and country. To obtain the total observed and expected numbers of cancer cases by site in the Baltic cohort, corresponding numbers in each country were summed. For calculating 95% confidence intervals (CI), a Poisson distribution for the observed number of cancer cases was assumed.

Prostate cancer (13 cases from Estonian, 53 from Latvian, and 29 from Lithuanian sub-cohort) was excluded from the analysis because of an obvious detection bias among the Latvian cleanup workers compared with the Latvian male population, likely as the result of screening opportunities offered to the Chernobyl veterans. This exclusion helped reduce the well-known limitation of the PIR – site-specific PIRs are mutually dependent, i.e., an increased PIR for one site will, by definition, imply lower PIRs for the other sites.⁶ Excess cases of prostate cancer in the Latvian sub-cohort also would have skewed the PIRs in the combined Baltic cohort.

Along with the site-specific PIRs for the cohort as a whole, PIRs were calculated for the selected radiation-related cancer sites stratified according to time of arrival (1986, April–May/ 1986, June–December/ 1987–1991) and duration of the mission (<90/ 90 days) as the proxy indicators for radiation exposure. Age at arrival to the Chernobyl area was stratified as <30/ 30–39/ 40 full years, and recorded external radiation dose obtained from military passports as <5.0/ 5.0–9.9/ 10.0 cGy. Direct information about internal doses was not available.

In addition to follow-up for cancer incidence, the Estonian sub-cohort was followed for deaths and emigrations through mortality and population registers up to December 31, 2007 in order to count person-years at risk. Thus, site-specific standardized incidence ratio (SIR) was calculated to compare this commonly preferred measure with the PIR. The SIR was defined as the ratio of observed number of cancer cases to the expected – based on cancer incidence rates for the male population of Estonia, stratified by five-year age groups and five-year calendar periods. As PIR and SIR are inter-related – the site-specific SIR is approximately equal to the site-specific PIR multiplied by the overall SIR⁷ – we applied the SIR for all cancers (except prostate) in the Estonian sub-cohort as a conversion coefficient to estimate the site-specific SIRs for the Baltic cohort as a whole. We assumed that the SIR for all cancer sites (except prostate) for the Baltic cohort would be comparable to that for the Estonian sub-cohort.

PIRs were calculated for combined radiation-related cancer sites, including salivary glands (ICD-10 C07–C08), oesophagus (C15), stomach (C16), colon (C18), trachea, bronchus and lung (C33–C34), bone (C40–C41), non-melanoma skin (C44), urinary organs (C64–C68), central nervous system (C70–C72), thyroid gland (C73), and leukaemia (except chronic lymphocytic leukaemia) (C91–C95, except C91.1); combined alcohol-related cancer sites including oral cavity (C01–C08), pharynx (C09–C14), oesophagus (C15), colon (C18), rectum (C19–C21), liver (C22), and larynx (C32); and combined smoking-related cancer sites including oral cavity (C01–C08), pharynx (C09–C14), oesophagus (C15), stomach (C16), colon (C18), rectum (C19–C21), liver (C22), pancreas (C25), nose and sinuses (C30–C31), larynx (C32), trachea, bronchus and lung (C33–C34), urinary organs (C64–C68), and myeloid leukemia (C92).⁸

3. Results

The Baltic cohort of Chernobyl cleanup workers consisted of 17,040 men, with 28.2% from Estonia, 32.5% from Latvia and 39.2% from Lithuania (Table 1). About half of the cohort members were sent to the Chernobyl area in 1986, one third of them during the first month after the accident. The mean duration of the mission was 106 days, with a median of 82 days. This duration was not longer in later years: the mean and median duration for those men sent to Chernobyl in April–May 1986 was 102 and 84 days, in June–December 1986 100 and 93 days, and in 1987–1991 112 and 77 days, respectively. One fourth of the men began their mission in 1986 and stayed in the contaminated area for more than three months (37.5% from Estonian, 23.0% from Latvian and 17.3% from Lithuanian sub-cohort). The

mean and median age at arrival to the Chernobyl area was 31 years, and was equal in the three sub-cohorts. External whole-body radiation dose was recorded for 78.5% of the cohort members, with an average dose of 10.9 cGy (9.9 cGy, 11.8 cGy, and 10.9 cGy in Estonian, Latvian, and Lithuanian sub-cohorts, respectively), and interquartile range of 5.2–16.3 cGy.

During the study period 1986–2007, 756 cancer cases were diagnosed in the Baltic cohort (Table 2). A higher proportion of thyroid cancers was found among Chernobyl cleanup workers in relation to the general male population of the three countries (PIR=2.76; 95% CI 1.63–4.36), especially among those who were sent to Chernobyl shortly after the accident, in April–May 1986 (PIR=6.38; 95% CI 2.34–13.89), or those who were younger than 30 years at the beginning of their mission (PIR=3.59; 95% CI 1.32–7.82), or those who had higher documented external radiation doses (PIR=4.12; 95% CI 1.97–7.57) (Table 3); all three conditions were met for one thyroid cancer case. There was an excess of oesophageal cancers (PIR=1.52; 95% CI 1.06–2.11), to which contributed the group who worked in the area for more than three months (PIR=1.85; 95% CI 1.11–2.89). Brain cancers were overrepresented among men who arrived in the Chernobyl area in 1986 and had the longer mission (PIR=2.08; 95% CI 1.07–3.63). We did not observe increased PIRs for leukaemia or radiation-related cancer sites combined.

Overall cancer risk (except prostate) in the Estonian sub-cohort quantified by SIR was 1.08 (95% CI 0.93–1.23) (Table 4). Incidence of prostate cancer in the Estonian sub-cohort was not elevated (SIR=0.88; 95% CI 0.47–1.51). SIRs, converted from PIRs (multiplied by the coefficient 1.08), were close to the actual site-specific SIRs in the Estonian sub-cohort (Table 4). Although in our case PIRs probably underestimated the cancer risk (conversion coefficient >1), approximate SIRs in the Baltic cohort demonstrated the same site-specific cancer risk pattern (with slightly higher point estimates) as was seen from PIRs (Table 4). Excess risk for all cancer sites (except prostate) and alcohol-related cancer sites combined reached borderline statistical significance (SIR=1.08; 95% CI 1.00–1.16 and SIR=1.16; 95% CI 1.00–1.31, respectively).

4. Discussion

This first attempt to analyze cancer incidence in the Baltic cohort of Chernobyl cleanup workers during 22 years of follow-up demonstrated an elevated thyroid cancer risk which concentrated among those who began their mission in 1986 and had the highest potential for exposure to radioiodine. A causal link between exposure to ionizing radiation and thyroid cancer is well documented, but primarily following exposures in childhood and not at adult ages⁹ and not following ¹³¹I exposures to adults at mean thyroid doses of about 1 Gy.¹⁰ Although previous studies have reported higher thyroid cancer risk in relation to the general population among Estonian-Latvian¹¹ and Russian¹² Chernobyl cleanup workers cohorts, and a recent nested case-control study by Kesminiene et al. showed the dose-dependent increase of thyroid cancer incidence among Chernobyl cleanup workers from Russia, Belarus and Baltic countries¹³, our finding should be interpreted with caution. Thyroid screening among Estonian cleanup workers in 1995¹⁴, and regular medical examinations in the Latvian¹⁵ and Lithuanian cohorts¹⁶ likely contributed to the excess number of thyroid cancers. Early cleanup workers were at greater risk for thyroid exposures because of the release of the short-lived radioactive isotope ¹³¹I during the explosion; any inhalation would result in internal radiation doses.¹⁷ We found the highest PIR (6.38) for those men who were sent to the Chernobyl area within a month after the accident. Even if the PIR is divided by the coefficient of 1.5–3 to take into account the screening effect¹⁸, an excess of thyroid cancer still remains among early cleanup workers. Although the proportion of thyroid cancers among cleanup workers who received higher doses was four times of that in the general male population, we cannot infer with confidence that higher dose has contributed to

the excess risk nor can we completely exclude this possibility. Recorded doses were based on whole-body external radiation and were documented in the military passports, but the reliability of these doses remained unclear, i.e., errors to higher or to lower recordings of dose were possible.¹⁹ Uncertainties in the individual doses have been discussed¹, but biodosimetry and dose reconstruction have confirmed that the average of the received true doses is unlikely to have exceeded the average of the recorded doses (10–11 cGy).^{20–22}

Since an increased incidence of brain cancer was observed in the Estonian-Latvian cohort in relation to the general male population in 1986–1998¹¹, and a dose-dependent excess of central nervous system tumours was reported in atomic bomb survivors²³, the risk of brain cancer was of interest. We found an elevated proportion of brain cancer cases in the group of men whose mission began earlier and lasted longer; however, this outcome was based on just 12 cases and could easily be a chance finding.

The twenty six leukaemia cases detected in the cohort did not represent a higher proportion of incident cases. Although statistically significant leukaemia risk was not observed in the previous Estonian-Latvian study¹¹ and the recent Estonian study²⁴, two nested case-control studies of Chernobyl cleanup workers from Ukraine²⁵, and Russia, Belarus and Baltic countries²⁶ indicated dose-dependent excesses of leukaemias. Insofar a radiation-induced leukaemia should have occurred earlier than radiation-related solid cancers⁹, we conclude that any increase in the risk of leukaemia in the Baltic cohort, relative to the general male population of the three countries, was too small to be detectable in the cohort of this size. Hence, our result is consistent with no effect, as well as an effect of the size expected given the dose level.

PIRs for the combined category of radiation-related sites remained near unity, showing no differences between groups by time of arrival, duration of the mission or documented radiation dose. The significantly higher proportion of oesophageal cancers gave some hints about alcohol misuse in the cohort, as alcohol is a strong risk factor for oesophageal cancer.²⁷

We used PIRs as cancer risk estimates because of incomplete information about person-years at risk for the Latvian and Lithuanian sub-cohorts. Site-specific PIRs underestimate site-specific cancer risk when the overall SIR exceeds unity, and overestimate it when the overall SIR is less than unity.⁷ Thus, we calculated overall SIR and site-specific SIRs for the Estonian sub-cohort, and multiplied the site-specific PIRs by the overall SIR=1.08 to approximate the site-specific SIRs. Converted SIRs were quite close to the actual SIRs. As we did not know the true overall SIR for the whole Baltic cohort, we assumed it to be equal to that in the Estonian sub-cohort, since in the Estonian-Latvian study with follow-up to 1998, overall SIRs for the two countries were similar: 1.17 in Estonia and 1.15 in Latvia.¹¹ If this assumption holds, PIRs underestimated the site-specific cancer risk in the cohort. However, converted SIRs did not change the main findings, which support the validity of the PIR estimates. Further, they added some indication about alcohol-related cancer risk and overall cancer risk.

Our study demonstrates that Baltic Chernobyl cleanup workers were at small to no increased cancer risk after 22 years of observation. Such data are of value to contrast with claims of substantially higher radiation risks in other populations. This subject area is replete with ongoing debate, controversies and uncertainties.^{28,29}

The Baltic cohort persists as long as similar data sets exist and comparable epidemiological measures are calculable for each of the Baltic countries. In Estonia, the cohort data are managed by a team of epidemiologists at the national research and development institute; these data can be linked to national population, cancer and death registers by using

dominantly a unique personal identification number assigned to each citizen.^{1,24} In Latvia, however, this cohort study was the responsibility of the staff of the cancer registry^{2,11}, but a major organisational restructuring of the cancer registration system since 2009 and the retirement of a key investigator has left future research activities in limbo. An initial set of cleanup workers' exposure and health data (at the Center of Occupational and Radiological Medicine, Pauls Stradins Clinical University Hospital) form a "state register" that was used for "analysis of morbidity".¹⁵ A chronic lack of epidemiological expertise to conduct cohort studies is an important barrier to effectively studying the health of cleanup workers, although record linkages between registers and other data could be theoretically feasible. In Lithuania, where cleanup workers were recruited into the cohort over a long period of time, some ambiguity surrounds the date of start of follow-up. A change in the principal investigator in the cancer registry resulted in additional delays. Currently, no obstacles exist for measuring cancer incidence in the cohort as was done in a recent study of woodworkers.³⁰ Follow-up for cause-specific mortality is planned, but slowed due to former restrictions for linkages between registers. The fate of epidemiological research in the Baltic countries like elsewhere depends heavily on the influence of data protection regulations for which a balance between privacy and the public's interest must be found.^{4,31–33}

In conclusion, the study of cancer risk in a cohort of Chernobyl cleanup workers from three Baltic countries revealed an elevated proportion of thyroid cancers in relation to the general male population; however, this finding could be attributable, at least in part, to more intensive medical examination, including thyroid screening. No excess of leukaemia cases or radiation-related cancers as a group was found. Further studies are needed to investigate the role of alcohol and other potential confounders, in addition to radiation, in this population. Continued effort should be directed to follow-up the well-defined Baltic cohort through population, cancer and mortality registries.

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Table 1

Baseline characteristics of the Estonian, Latvian and Lithuanian sub-cohorts, and the Baltic cohort of Chernobyl cleanup workers.

Characteristic	Estonian sub-cohort		Latvian sub-cohort		Lithuanian sub-cohort		Baltic cohort	
	No.	%	No.	%	No.	%	No.	%
Total	4810	100	5546	100	6684	100	17,040	100
Age at arrival in the Chernobyl area (full years)								
<20	103	2.1	118	2.1	146	2.2	367	2.2
20–29	1811	37.7	2180	39.3	2416	36.1	6407	37.6
30–39	2260	47.0	2593	46.8	3058	45.8	7911	46.4
40–49	480	10.0	596	10.7	900	13.5	1976	11.6
50	28	0.6	59	1.1	67	1.0	154	0.9
Unknown	128	2.7	0	–	97	1.5	225	1.3
Time of arrival in the Chernobyl area								
1986, April–May	1393	29.0	857	15.5	500	7.5	2750	16.1
1986, June–December	1508	31.4	2167	39.1	1845	27.6	5520	32.4
1986, month unknown	22	0.5	0	–	1	0.0	23	0.1
1987–1991	1759	36.6	2522	45.5	4241	63.5	8522	50.0
Unknown	128	2.7	0	–	97	1.5	225	1.3
Duration of stay in the Chernobyl area (days)								
<30	270	5.6	389	7.0	439	6.6	1098	6.4
30–89	1915	39.8	2867	51.7	3439	51.5	8221	48.2
90–149	1531	31.8	1407	25.4	1520	22.7	4458	26.2
150–209	852	17.7	700	12.6	825	12.3	2377	14.0
210	75	1.6	183	3.3	363	5.4	621	3.6
Unknown	167	3.5	0	–	98	1.5	265	1.6
Documented dose (cGy)								
<5.0	1101	22.9	845	15.2	908	13.6	2854	16.7
5.0–9.9	1272	26.4	1312	23.7	1657	24.8	4241	24.9
10.0	1673	34.8	2240	40.4	2376	35.5	6289	36.9
Unknown	764	15.9	1149	20.7	1743	26.1	3656	21.5

Table 2

Number of cancer cases, proportional incidence ratios (PIR) with 95% confidence intervals (CI) by cancer site in the Estonian, Latvian and Lithuanian sub-cohorts, and in the Baltic cohort of Chemobyl cleanup workers, 1986–2007.

ICD-10	Cancer site	Estonian sub-cohort		Latvian sub-cohort		Lithuanian sub-cohort		Baltic cohort	
		No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)
C00–C97, except C61	All sites (except prostate)	195	1.00	228	1.00	333	1.00	756	1.00
C00–C14	Mouth, pharynx	20	1.41 (0.86–2.18)	18	1.13 (0.67–1.78)	34	1.05 (0.73–1.46)	72	1.15 (0.90–1.45)
C09–C14	Pharynx	13	1.95 (1.04–3.33)	3	0.42 (0.09–1.24)	18	1.21 (0.72–1.91)	34	1.19 (0.82–1.66)
C15–C26	Digestive organs	55	1.00 (0.76–1.31)	65	1.00 (0.77–1.28)	97	0.95 (0.77–1.16)	217	0.98 (0.85–1.11)
C15	Oesophagus	10	2.09 (1.00–3.85)	10	1.48 (0.71–2.72)	15	1.30 (0.73–2.14)	35	1.52 (1.06–2.11)
C16	Stomach	17	0.83 (0.49–1.33)	28	1.13 (0.75–1.64)	33	0.85 (0.59–1.20)	78	0.93 (0.74–1.16)
C18	Colon	10	0.99 (0.48–1.83)	10	1.04 (0.50–1.91)	13	0.88 (0.47–1.50)	33	0.96 (0.66–1.34)
C19–C21	Rectum	9	1.24 (0.57–2.35)	7	0.76 (0.30–1.56)	11	0.78 (0.39–1.40)	27	0.88 (0.58–1.28)
C22	Liver	2	0.87 (0.11–3.13)	4	1.54 (0.42–3.95)	6	1.49 (0.55–3.24)	12	1.34 (0.69–2.35)
C25	Pancreas	7	0.82 (0.33–1.70)	5	0.48 (0.16–1.12)	19	1.18 (0.71–1.84)	31	0.89 (0.60–1.26)
C30–C39	Respiratory organs	45	0.92 (0.67–1.23)	66	1.04 (0.80–1.32)	78	0.80 (0.63–0.99)	189	0.90 (0.77–1.03)
C32	Larynx	5	0.65 (0.21–1.52)	12	1.14 (0.59–1.98)	17	0.87 (0.50–1.39)	34	0.90 (0.62–1.25)
C33–C34	Trachea, bronchus, lung	38	0.96 (0.68–1.31)	54	1.06 (0.79–1.38)	59	0.78 (0.60–1.01)	151	0.91 (0.76–1.05)
C40–C41	Bone	2	1.97 (0.24–7.12)	1	1.02 (0.03–5.67)	0	0.00 (0.00–1.84)	3	0.75 (0.15–2.19)
C43	Melanoma of skin	6	1.16 (0.43–2.52)	4	0.93 (0.25–2.38)	7	1.00 (0.40–2.05)	17	1.03 (0.60–1.65)
C44	Other skin	12	0.78 (0.40–1.36)	6	0.45 (0.16–0.98)	27	0.96 (0.63–1.40)	45	0.79 (0.58–1.06)
C45–C49	Mesothelial and soft tissues	1	0.42 (0.01–2.35)	3	1.02 (0.21–2.99)	3	0.61 (0.13–1.80)	7	0.69 (0.28–1.42)
C50	Breast	0	0.00 (0.00–18.82)	0	0.00 (0.00–7.82)	0	0.00 (0.00–7.21)	0	0.00 (0.00–3.13)
C60–C63, except C61	Male genital organs (except prostate)	3	0.76 (0.16–2.23)	6	1.32 (0.48–2.87)	1	0.17 (0.00–0.95)	10	0.70 (0.33–1.28)
C64–C68	Urinary organs	13	0.63 (0.33–1.08)	23	0.87 (0.55–1.31)	29	0.82 (0.55–1.18)	65	0.79 (0.61–1.01)
C69	Eye	0	0.00 (0.00–9.14)	0	0.00 (0.00–5.43)	1	0.79 (0.02–4.40)	1	0.43 (0.01–2.37)
C70–C72	Central nervous system	12	1.87 (0.97–3.27)	10	1.41 (0.68–2.59)	10	0.82 (0.39–1.50)	32	1.24 (0.85–1.75)
C71	Brain	10	1.69 (0.81–3.10)	8	1.22 (0.53–2.41)	10	0.86 (0.41–1.58)	28	1.16 (0.77–1.68)
C73	Thyroid gland	2	1.44 (0.17–5.21)	8	4.87 (2.10–9.59)	8	2.29 (0.99–4.51)	18	2.76 (1.63–4.36)
C74–C75	Other endocrine	0	0.00 (0.00–17.03)	1	2.87 (0.07–16.00)	3	3.61 (0.75–10.56)	4	2.87 (0.78–7.34)

ICD-10	Cancer site	Estonian sub-cohort		Latvian sub-cohort		Lithuanian sub-cohort		Baltic cohort	
		No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)
C76-C80	Site unknown or uncertain	7	1.35 (0.54-2.78)	6	1.25 (0.46-2.72)	7	0.82 (0.33-1.68)	20	1.08 (0.66-1.67)
C81	Hodgkin lymphoma	3	1.37 (0.28-4.02)	1	0.36 (0.01-1.99)	6	1.17 (0.43-2.55)	10	0.99 (0.47-1.82)
C82-C85, C96	Non-Hodgkin lymphoma	6	1.19 (0.44-2.58)	2	0.40 (0.05-1.44)	9	1.15 (0.52-2.18)	17	0.95 (0.55-1.52)
C88, C90	Multiple myeloma, immunoproliferative diseases	2	1.02 (0.12-3.69)	0	0.00 (0.00-2.22)	1	0.34 (0.01-1.88)	3	0.46 (0.09-1.33)
C91-C95	Leukaemia	6	1.05 (0.39-2.29)	8	1.23 (0.53-2.42)	12	0.94 (0.49-1.64)	26	1.04 (0.68-1.52)
See footnote ^a	Radiation-related sites	119	0.96 (0.79-1.13)	157	1.07 (0.90-1.23)	201	0.97 (0.84-1.11)	477	1.00 (0.91-1.09)
See footnote ^b	Alcohol-related sites	56	1.23 (0.93-1.59)	57	1.06 (0.80-1.37)	94	0.99 (0.80-1.22)	207	1.07 (0.92-1.21)
See footnote ^c	Smoking-related sites	134	0.97 (0.81-1.13)	170	1.00 (0.85-1.15)	236	0.89 (0.77-1.00)	540	0.94 (0.86-1.02)

^aICD-10 C07-C08, C15, C16, C18, C33-C34, C40-C41, C44, C64-C68, C70-C73, C91-C95 (except C91.1)

^bICD-10 C01-C15, C18-C22, C32

^cICD-10 C01-C16, C18-C22, C25, C30-C34, C64-C68, C92

Table 3

Number of cancer cases, proportional incidence ratios (PIR) with 95% confidence intervals (CI) by selected radiation-related cancer sites and by characteristics in the Baltic cohort of Chernobyl cleanup workers, 1986–2007.

Characteristic	Thyroid gland		Brain		Leukaemia		Radiation-related sites ^a	
	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)	No. of cases	PIR (95% CI)
Time of arrival in the Chernobyl area								
1986	11	3.87 (1.93–6.93)	15	1.36 (0.76–2.24)	17	1.43 (0.83–2.29)	221	1.00 (0.87–1.13)
1986, April–May	6	6.38 (2.34–13.89)	6	1.63 (0.60–3.55)	5	1.21 (0.39–2.83)	70	0.96 (0.75–1.22)
1986, June–December	5	2.63 (0.85–6.14)	9	1.22 (0.56–2.32)	12	1.55 (0.80–2.71)	151	1.01 (0.85–1.18)
1987–1991	7	1.93 (0.78–3.97)	13	1.01 (0.54–1.73)	9	0.70 (0.32–1.33)	251	0.99 (0.87–1.12)
Duration of stay in the Chernobyl area (days)								
<90	10	2.82 (1.35–5.20)	12	0.92 (0.48–1.61)	16	1.15 (0.66–1.87)	257	1.00 (0.88–1.12)
90	8	2.72 (1.17–5.36)	16	1.47 (0.84–2.38)	10	0.92 (0.44–1.70)	214	0.99 (0.86–1.12)
Age at arrival in the Chernobyl area (full years)								
<30	6	3.59 (1.32–7.82)	9	1.55 (0.71–2.95)	4	0.74 (0.20–1.89)	48	0.91 (0.67–1.20)
30–39	9	2.58 (1.18–4.90)	14	1.05 (0.57–1.76)	15	1.21 (0.68–2.00)	256	0.99 (0.87–1.12)
40	3	2.27 (0.47–6.64)	5	1.05 (0.34–2.44)	7	1.01 (0.41–2.08)	168	1.02 (0.87–1.18)
Arrival in the Chernobyl area 1986 and duration of stay 90 days	4	2.61 (0.71–6.69)	12	2.08 (1.07–3.63)	5	0.87 (0.28–2.03)	107	0.97 (0.79–1.15)
Documented dose (cGy)								
<5.0	3	2.44 (0.50–7.13)	6	1.32 (0.48–2.86)	9	2.07 (0.95–3.94)	99	1.04 (0.85–1.27)
5.0–9.9	3	1.82 (0.37–5.31)	6	0.99 (0.36–2.16)	8	1.30 (0.56–2.56)	110	0.91 (0.74–1.08)
10.0	10	4.12 (1.97–7.57)	10	1.10 (0.53–2.03)	7	0.78 (0.31–1.60)	169	0.99 (0.84–1.14)

^aICD-10 C07–C08, C15, C16, C18, C33–C34, C40–C41, C44, C64–C68, C70–C73, C91–C95 (except C91.1)

Table 4

Number of cancer cases, standardized incidence ratios (SIR) with 95% confidence intervals (CI) by cancer site in the Estonian sub-cohort and in the Baltic cohort of Chernobyl cleanup workers, 1986–2007.

ICD-10	Cancer site	Estonian sub-cohort			Baltic cohort	
		No. of cases	SIR (95% CI), actual	SIR (95% CI), converted from PIR ^a	No. of cases	SIR (95% CI), converted from PIR ^a
C00–C97, except C61	All sites (except prostate)	195	1.08 (0.93–1.23)	1.08 (0.93–1.23)	756	1.08 (1.00–1.16)
C00–C14	Mouth, pharynx	20	1.56 (0.95–2.40)	1.52 (0.93–2.35)	72	1.24 (0.97–1.56)
C15–C26	Digestive organs	55	1.09 (0.82–1.42)	1.08 (0.82–1.41)	217	1.06 (0.92–1.20)
C15	Oesophagus	10	2.26 (1.09–4.16)	2.26 (1.08–4.15)	35	1.64 (1.14–2.28)
C16	Stomach	17	0.91 (0.53–1.46)	0.90 (0.52–1.44)	78	1.00 (0.79–1.25)
C18–C21	Colon, rectum	19	1.19 (0.71–1.85)	1.19 (0.71–1.85)	60	0.99 (0.76–1.28)
C30–C39	Respiratory organs	45	0.99 (0.72–1.32)	0.99 (0.73–1.33)	189	0.97 (0.83–1.11)
C33–C34	Trachea, bronchus, lung	38	1.02 (0.72–1.40)	1.04 (0.73–1.42)	151	0.98 (0.82–1.14)
C43	Melanoma of skin	6	1.29 (0.47–2.80)	1.25 (0.46–2.73)	17	1.11 (0.65–1.78)
C44	Other skin	12	0.84 (0.43–1.46)	0.84 (0.44–1.47)	45	0.85 (0.62–1.14)
C64–C68	Urinary organs	13	0.68 (0.36–1.16)	0.68 (0.36–1.16)	65	0.85 (0.66–1.09)
C70–C72	Central nervous system	12	2.06 (1.06–3.59)	2.02 (1.04–3.53)	32	1.34 (0.92–1.89)
C71	Brain	10	1.84 (0.88–3.39)	1.83 (0.87–3.35)	28	1.25 (0.83–1.81)
C73	Thyroid gland	2	1.69 (0.21–6.12)	1.56 (0.19–5.60)	18	2.98 (1.76–4.71)
C81	Hodgkin lymphoma	3	1.41 (0.29–4.12)	1.48 (0.31–4.34)	10	1.07 (0.51–1.97)
C82–C85, C96	Non-Hodgkin lymphoma	6	1.26 (0.46–2.75)	1.29 (0.47–2.79)	17	1.03 (0.60–1.64)
C91–C95	Leukaemia	6	1.14 (0.42–2.49)	1.13 (0.42–2.47)	26	1.12 (0.73–1.65)
See footnote ^b	Radiation-related sites	119	1.04 (0.85–1.23)	1.04 (0.85–1.22)	476	1.08 (0.98–1.17)
See footnote ^c	Alcohol-related sites	56	1.34 (1.01–1.74)	1.33 (1.00–1.72)	207	1.16 (1.00–1.31)
See footnote ^d	Smoking-related sites	134	1.05 (0.87–1.23)	1.05 (0.88–1.21)	540	1.02 (0.93–1.10)

^aSite-specific proportional incidence ratio (PIR) has been multiplied by SIR for all sites (except prostate) in the Estonian sub-cohort (1.08)

^bICD-10 C07–C08, C15, C16, C18, C33–C34, C40–C41, C44, C64–C68, C70–C73, C91–C95 (except C91.1)

^cICD-10 C01–C15, C18–C22, C32

^dICD-10 C01–C16, C18–C22, C25, C30–C34, C64–C68, C92