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Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based cohort study

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ABSTRACT

Objective: To examine non-cancer morbidity in the Estonian Chernobyl cleanup workers cohort compared with the population sample with special attention to radiation-related diseases and mental health disorders.

Design: Register-based cohort study.

Setting: Estonia.

Participants: An exposed cohort of 3680 men (cleanup workers) and an unexposed cohort of 7631 men (population sample) were followed from 2004 to 2012 through the Population Registry and Health Insurance Fund database.

Methods: Morbidity in the exposed cohort compared with the unexposed controls was estimated in terms of rate ratio (RR) with 95% CIs using Poisson regression models.

Results: Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischaemic heart disease and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38 to 2.07), intentional self-harm (RR=1.47; 95% CI 1.04 to 2.09) and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12 to 1.39). No increase in morbidity for stress reactions, depression, headaches or sleep disorders was detected.

Conclusions: No obvious excess morbidity consistent with biological effects of radiation was seen in the exposed cohort, with the possible exception of benign thyroid diseases. Increased alcohol-induced morbidity may reflect alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably under-reported. The future challenge will be to study mental and physical comorbidities in the Chernobyl cleanup workers cohort.

Strengths and limitations of this study

- Morbidity information provided in this study was obtained from population-based registries via electronic record linkages using personal identification number as the key variable.
- The follow-up of cohort members was complete.
- Limitations of the study are as follows: relatively short follow-up; the probable presence of tentative and preliminary diagnoses in the health insurance database; questionable accuracy and precision of officially documented doses.

INTRODUCTION

In the aftermath of the accident at the Chernobyl nuclear power station in April 1986, about 530 000 men from throughout the former Soviet Union were commissioned to the area to clean up the environment.[1] Among them were nearly 5000 (mostly) military reservists from Estonia who worked in the contaminated area for 3 months on average; their mean received cumulative whole-body radiation dose was 0.1 Gy.[2]

Epidemiological evidence of non-cancer disease risk in the cohorts exposed to ionising radiation is mainly based on mortality since administratively registered death records are available and easy to use for linkages. Most of these studies have focused on circulatory diseases, the major cause of death in developed countries. Excess mortality from all circulatory diseases, stroke and heart disease was observed in atomic-bomb survivors; however, the association below a dose of 0.5 Gy was not significant.[3] Follow-up of nuclear industry workers from 15 countries resulted in no significant findings for a dose-dependent rise in mortality from circulatory diseases.[4] Elevated risk of death for the broad categories of diseases of the respiratory and digestive systems has been found among atomic-bomb survivors,[5] but not in other environmentally exposed populations[6] or in nuclear industry workers.[4]

A few studies have reported morbidity outcomes. The most informative non-cancer disease incidence study of atomic-bomb survivors found significant radiation effects for thyroid diseases, liver diseases, cataract and calculus of the kidney and ureter.[7] The morbidity study of Mayak nuclear weapons facility

workers demonstrated an increasing dose-related trend for cerebrovascular diseases[8] and ischaemic heart disease,[9] but did not provide information on risk at doses below 0.2 Gy. A meta-analysis by Little *et al*[10] combining morbidity and mortality studies of occupationally and environmentally exposed populations with mean dose below 0.5 Gy demonstrated significantly increased dose-dependent risk for ischaemic heart disease, cerebrovascular diseases and other circulatory diseases.

Analyses of non-cancer morbidity in a cohort of Russian Chernobyl cleanup workers have shown dose-dependent excess (per 1 Gy) for endocrine and metabolic diseases, mental disorders, diseases of the nervous system, diseases of the digestive system, cerebrovascular diseases, hypertension and ischaemic heart disease.[11 12] However, risk estimates at low doses still remain uncertain.[13]

Although the psychological aftermath of the Chernobyl accident has been acknowledged as the major long-term public health problem in the exposed populations,[1 14] the mental health of cleanup workers has only been assessed in small-scale studies in Ukraine.[15 16] There is an urgent need to examine mental health along with somatic diseases when considering the health of cleanup workers.[16]

An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has been persistently elevated since the beginning of follow-up.[17 18] The current research provides the first overview of morbidity other than cancer in the Estonian cohort of Chernobyl cleanup workers with special attention to radiation-related diseases and mental health disorders.

METHODS

Sample and follow-up

The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men recruited between 1986 and 1991 to the Chernobyl area by the Soviet authorities for decontamination, building and other related activities. The 'Chernobyl area' here denotes the 30 km zone (an area of 30 km radius from the nuclear power station) and territories outside, where the workers were engaged with different activities during their mission period. Detailed information on the assembly and description of the cohort is given elsewhere.[19] To examine morbidity in this cohort, we used data from the Estonian Health Insurance Fund (EHIF) database available since January 2004. Thus, for the morbidity analyses we identified all cohort members aged 35–69 years and living in Estonia on 1 January 2004. Altogether, of the 4831 men in the initial cohort, 1129 were excluded because of loss to follow-up (21), death (602) and emigration (506). In addition, we did not include men aged under 35 (9) and over 69 years (13) to have a more homogeneous age group. This left just 3680 cleanup workers in the study. An unexposed population-based comparison cohort was selected corresponding to the age distribution of the exposed cohort. A random sample stratified by 5-year age groups with the exposed to unexposed ratio of 1:2 and 5% extra men in each age group was extracted from the Estonian Population Registry (EPR). In the unexposed cohort, after excluding 87 men who had worked in the Chernobyl area (cleanup workers), there remained 7631 men.

The cohort of cleanup workers was linked to the EPR to update vital status (emigration or death with corresponding date), ethnicity and education. Each person in both cohorts was followed up from 1 January 2004 until death, emigration or 31 December 2012 (whichever date came first). From the EHIF database, we obtained dates and international classification of diseases (ICD-10) codes for each contact with a health provider. All linkages were performed using the unique personal identification number (assigned to all permanent residents of Estonia) as the key variable. EHIF manages the mandatory universal health insurance system that is based on solidarity and covers 95% of the Estonian population.[20] All employees and self-employed persons contribute 13% of their wages; some groups of the population are financed by the State (eg, registered unemployed, Chernobyl veterans) and some groups are insured without contribution (eg, children, students, pensioners). People without coverage from the aforementioned sources can pay tax voluntarily.

Healthcare contacts were identified from the EHIF database for 2004–2012 using the first occurrence of the three-digit ICD-10 code. If the contact involved multiple diagnoses, the first occurrence of each of them was separately counted. All diseases (except cancer, ICD-10 C00-C97), external causes of morbidity and examinations or counselling were considered. Four-digit codes were taken separately only for some alcohol-induced diseases. A combined category of alcohol-induced diagnoses included mental disorders due to alcohol (F10), degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65) and poisoning by alcohol, undetermined intent (Y15). The accuracy of diagnosis was the responsibility of the physician issuing the invoice to EHIF for ambulatory or hospital care.

Morbidity measures and statistical analysis

We estimated morbidity in the cleanup workers cohort by means of rate ratio (RR) with 95% CIs using Poisson regression models with the logarithm of the person-years at risk (summed by 5-year age groups) as the offset.[21] At first, we performed an analysis comparing the exposed cohort with the unexposed cohort (external analysis) to obtain an overview of morbidity RRs. Diagnoses were grouped into broad categories with selected specific diagnoses. Analyses were adjusted for age at diagnosis by 5-year age groups.

Additionally, analysis was carried out on different subgroups within the exposed cohort (internal analysis) to assess possible effects of year of arrival in the Chernobyl area (1986; 1987–1991), duration of stay (<92; ≥92 days) and documented cumulative whole-body radiation dose (<5.0; 5.0–9.9; ≥10.0 cGy) on morbidity risk. As described elsewhere,[1 22 23] the cleanup workers were dominantly exposed to γ-radiation released mainly by ^{131}I, ^{134}Cs and ^{137}Cs. Received radiation doses were measured by individual or group dosimeters, or estimated by work area measurements. The readings were documented in the workers' military passports/records. Considering that documented doses were unreliable,[19] and not recorded for 15.2% of the cohort members, we used year of arrival and duration of stay as proxy variables for radiation exposure.

Potential confounders—educational level (higher or secondary; basic or less) and ethnicity (Estonian; non-Estonian (mainly Russians))—were included in the analysis as surrogates for health behaviour. The prevalence of alcohol consumption at least once a week (28.5%) and current smoking (69%) among the cleanup workers was studied in a postal questionnaire survey conducted in 1992–1993,[19] but not included in current analyses due to small cohort size and lack of longitudinal data on these factors of health behaviour. Thus, the selection of variables (potential confounders) was determined by their availability and a review of our previous studies.

Analyses within the exposed cohort focused on disease risks previously reported in atomic-bomb survivors and Chernobyl cleanup workers.[7 11 12] The first set of models included the year of arrival in the Chernobyl area, duration of stay, age at diagnosis, education and ethnicity. One hundred and seventy-four participants with missing information for any characteristic were excluded from the analysis. In the second set of models we included documented radiation dose; due to unrecorded values, an additional 452 participants were excluded.

We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, Washington, USA) for database management, and Stata 12 (StataCorp LP, College Station, Texas, USA) for statistical modelling.

RESULTS

Description of the exposed and unexposed cohorts

We followed 3680 exposed and 7631 unexposed men from 1 January 2004 to 31 December 2012 (table 1). The exposed and unexposed cohorts contributed 30 674 and 65 112 person-years, respectively. Mean age at the start of follow-up was 48 years in both cohorts. During the follow-up, 12.9% of the exposed cohort and 10.5% of the unexposed cohort died. The proportions of non-Estonians (mainly Russians) and less educated persons were higher in the exposed cohort, although educational level was unknown for 16.4% of the participants in the unexposed cohort. Two-thirds of the cleanup workers entered the Chernobyl area in 1986; the mean and median durations of the mission were 102 and 92 days, respectively (range: 1–833 days). The cohort was exposed to low-level whole-body radiation with the mean and median documented radiation doses of 9.9 and 8.9 cGy, respectively (range: 0.0–54.5 cGy).

Nearly all men had at least one record in the EHIF database (93.6% of the exposed and 95.3% of the unexposed cohort). On average, members of both cohorts had 12 different diagnoses (3-digit ICD-10 codes). Men in the exposed cohort had their first health services contact on average half a year earlier than their unexposed counterparts (52.1 vs 52.6 years of age).

Morbidity in the exposed cohort in relation to the unexposed cohort (external analysis)

In the external analysis (table 2), we observed a very small increase of borderline significance in all-disease risk among Chernobyl cleanup workers (RR=1.01; 95% CI 1.00 to 1.03). From the non-cancer late effects that might be related to the Chernobyl accident (UNSCEAR 2011), we found significantly elevated morbidity for diseases of the thyroid gland (RR=1.69; 95% CI 1.38 to 2.07) and ischaemic heart disease (RR=1.09; 95% CI 1.00 to 1.18). There was evidence of lower occurrence of cataract in the exposed cohort. Stress reactions, depression, severe headaches and sleep disorders were not diagnosed more frequently in the exposed cohort than in the reference cohort.

Increased morbidity was apparent for the broad categories of diseases of the nervous system, digestive system, musculoskeletal system and alcohol-induced diagnoses. Morbidity from external causes in the exposed cohort exceeded that in the unexposed cohort (RR=1.07; 95% CI 1.03 to 1.11). Significantly higher morbidity was registered for falls, intentional self-harm and exposure to excessive cold. Cleanup workers did not undergo medical observations for suspected diseases (ICD-10 Z03) more frequently than unexposed men (RR=1.06; 95% CI 0.94 to 1.19). Additional adjustments for ethnicity and education (RRs not presented) did not materially alter these results.

Differences between subgroups in the exposed cohort (internal analysis)

Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI 1.00 to 1.62) and severe headaches (RR=1.69; 95% CI 1.10 to 2.60) among cleanup workers who entered the area shortly after the accident than in those arriving later (table 3). Higher thyroid disease morbidity was not related to year or month (April–May vs June–December, 1986) of arrival in the contaminated area. Longer mission did not increase the morbidity of any disease. Acute myocardial infarction, cerebrovascular diseases, diseases of liver, calculus of kidney and ureter, headaches and alcohol-induced morbidity occurred more frequently among non-Estonians, while mental disorders were more frequent among

Table 1 Characteristics of the Estonian cohort of Chernobyl cleanup workers (exposed cohort) and the unexposed comparison cohort

	Exposed cohort		Unexposed cohort	
Characteristic	**N**	**(%)**	**N**	**(%)**
Total	3680	100	7631	100
Vital status on 31 December 2012				
Living in Estonia	3132	85.1	6795	89.0
Dead	474	12.9	798	10.5
Emigrated	74	2.0	38	0.5
Age at start of follow-up (full years				
35–44	1265	34.4	2645	34.7
45–54	1850	50.3	3738	49.0
55–64	536	14.6	1186	15.5
≥65	29	0.8	62	0.8
Person-years in an age group (2004–2012				
35–44	4718.4	15.4	9416.1	14.5
45–54	15,513.5	50.6	32 825.3	50.4
55–64	9303.9	30.3	20 126.9	30.9
≥65	1138.6	3.7	2743.5	4.2
Total	30 674.4	100	65 111.8	100
Ethnicity				
Estonian	2036	55.3	4690	61.5
Non-Estonian	1643	44.6	2848	37.3
Unknown	1	0.0	93	1.2
Education				
Higher	322	8.8	1159	15.2
Secondary	2446	66.5	4017	52.6
Basic or less	824	22.4	1200	15.7
Unknown	88	2.4	1255	16.4
Time of arrival in the Chernobyl area				
1986, April–May	1154	31.4		
1986, June–December	1128	30.7		
1986, month unknown	13	0.4		
1987	820	22.3		
1988	417	11.3		
1989–1991	67	1.8		
Unknown	81	2.2		
Duration of stay in the Chernobyl area (days				
<30	220	6.0		
30–89	1487	40.4		
90–149	1163	31.6		
150–209	648	17.6		
≥210	60	1.6		
Unknown	102	2.8		
Documented dose (cGy				
<5.0	810	22.0		
5.0–9.9	1022	27.8		
10.0–14.9	555	15.1		
15.0–19.9	519	14.1		
20.0–24.9	195	5.3		
≥25.0	21	0.6		
Unknown	558	15.2		

Estonians. Less educated cleanup workers had higher risk for diseases of the nervous system, cerebrovascular diseases, intentional self-harm and alcohol-induced morbidity, and lower risk for in situ and benign neoplasms.

Including education and ethnicity in the model did not alter markedly the crude point estimates of RR for year of arrival or duration of stay (RRs not presented). Higher documented radiation dose (5.0–9.9 or ≥10.0 vs <5.0 cGy) was not associated with higher morbidity of thyroid diseases (RR=0.92; 95% CI 0.60 to 1.40; 0.92; 0.60 to 1.40, respectively), cataract (RR=1.26; 95% CI 0.80 to 1.98; 1.13; 0.70 to 1.83, respectively) or any of the other selected diseases.

Table 2 Number of morbidity cases* and age-adjusted morbidity RR† with 95% CIs in the Estonian cohort of Chernobyl cleanup workers (exposed cohort) in relation to the unexposed comparison cohort, 2004–2012

ICD-10	Diagnosis/external cause of morbidity	No. of cases: Exposed cohort	No. of cases: Unexposed cohort	RR (95% CI)
A00–R99, V01–Z99	All diagnoses and external causes	41 370	86 441	1.02 (1.01 to 1.03)‡
A00–R99, except C00–C97	All diseases, except cancer	31 757	66 799	1.01 (1.00 to 1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88 to 1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81 to 1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94 to 1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84 to 1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90 to 1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38 to 2.07)‡
F00–F99	Mental disorders	1380	2918	1.00 (0.94 to 1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06 to 1.39)‡
F32–F33	Depressive disorders	290	633	0.97 (0.84 to 1.11)
F41	Anxiety disorders	119	275	0.91 (0.74 to 1.13)
F43	Stress reactions	55	162	0.72 (0.53 to 0.97)‡
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06 to 1.21)‡
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04 to 2.18)‡
G40	Epilepsy	148	223	1.40 (1.14 to 1.73)‡
G43–G44	Migraine and other headache	125	256	1.03 (0.83 to 1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02 to 1.29)‡
F51, G47	Sleep disorders	267	529	1.08 (0.93 to 1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89 to 0.98)‡
H25–H26, H28	Cataract	155	449	0.77 (0.64 to 0.92)‡
H40, H42	Glaucoma	109	247	0.96 (0.77 to 1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91 to 1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97 to 1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93 to 1.04)
I20–I25	Ischaemic heart disease	773	1537	1.09 (1.00 to 1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83 to 1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91 to 1.20)
J00–J99	Diseases of the respiratory system	4699	10 079	0.99 (0.95 to 1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79 to 0.96)‡
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00 to 1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07 to 1.16)‡
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06 to 1.21)‡
K25–K27	Peptic ulcer	464	857	1.15 (1.02 to 1.28)‡
K70–K77	Diseases of liver	194	357	1.16 (0.97 to 1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91 to 1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02 to 1.58)‡
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77 to 2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97 to 1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12 623	1.06 (1.03 to 1.09)‡
M15–M19	Arthrosis	925	1881	1.06 (0.98 to 1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04 to 1.18)‡
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84 to 0.95)‡
N20	Calculus of kidney and ureter	140	321	0.93 (0.76 to 1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79 to 0.99)‡
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94 to 1.09)
V01–Y98	External causes of morbidity	5084	10 055	1.07 (1.03 to 1.11)‡
V01–V99	Transport accidents	171	423	0.85 (0.71 to 1.02)
W00–W19	Falls	2010	3817	1.11 (1.06 to 1.18)‡
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98 to 1.09)
X31	Excessive cold	26	32	1.74 (1.04 to 2.92)‡

Continued

Table 2 Continued

ICD-10	Diagnosis/external cause of morbidity	No. of cases: Exposed cohort	No. of cases: Unexposed cohort	RR (95% CI)
X40–X49	Accidental poisoning	34	69	1.05 (0.69 to 1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04 to 2.09)‡
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96 to 1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94 to 1.19)
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	528	896	1.25 (1.12 to 1.39)‡

*The first occurrence of the three-digit ICD-10 code in the study period was considered.
†Adjusted for age at diagnosis.
‡p<0.05.
ICD, international classification of diseases; RR, rate ratio.

DISCUSSION

The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers revealed elevated morbidity for diseases of the nervous system, digestive system, musculoskeletal system, ischaemic heart disease and for external causes. The most salient excess risk was

Table 3 Adjusted morbidity RR* with 95% CIs by exposure for selected diagnoses and external causes of morbidity in the Estonian cohort of Chernobyl cleanup workers (3506 persons), 2004–2012

ICD-10	Diagnosis/external cause of morbidity	Year of arrival 1986†	Duration of stay ≥92 days†	Ethnicity Non-Estonian†	Education Basic or less†
D00–D48	In situ and benign neoplasms	1.15 (0.95 to 1.39)	0.77 (0.64 to 0.92)‡	1.09 (0.91 to 1.30)	0.76 (0.61 to 0.96)‡
E00–E07	Diseases of thyroid gland	0.94 (0.68 to 1.31)	1.00 (0.73 to 1.38)	0.85 (0.62 to 1.17)	0.82 (0.55 to 1.22)
F00–F99	Mental disorders	1.08 (0.96 to 1.21)	0.85 (0.76 to 0.95)‡	0.82 (0.74 to 0.92)‡	1.11 (0.97 to 1.27)
F32–F33, F43	Depressive disorders and stress reactions	1.27 (1.00 to 1.62)	0.72 (0.58 to 0.90)‡	0.53 (0.41 to 0.67)‡	0.88 (0.66 to 1.17)
G00–G99	Diseases of the nervous system	1.01 (0.90 to 1.13)	0.93 (0.83 to 1.04)	0.97 (0.87 to 1.09)	1.20 (1.05 to 1.37)‡
G43–G44	Migraine and other headache	1.69 (1.10 to 2.60)‡	0.79 (0.55 to 1.14)	1.48 (1.03 to 2.12)‡	0.97 (0.59 to 1.58)
H25–H26, H28	Cataract	1.07 (0.77 to 1.49)	1.05 (0.76 to 1.45)	1.29 (0.93 to 1.77)	0.93 (0.65 to 1.33)
H40, H42	Glaucoma	1.26 (0.83 to 1.89)	0.78 (0.52 to 1.15)	1.20 (0.81 to 1.78)	0.80 (0.51 to 1.27)
I10–I15	Hypertensive diseases	1.03 (0.94 to 1.14)	0.92 (0.84 to 1.01)	1.07 (0.98 to 1.17)	0.99 (0.88 to 1.11)
I20–I25	Ischaemic heart disease	1.15 (0.99 to 1.34)	0.81 (0.70 to 0.94)‡	1.12 (0.97 to 1.30)	1.10 (0.93 to 1.30)
I21	Acute myocardial infarction	1.11 (0.74 to 1.68)	0.94 (0.63 to 1.39)	1.53 (1.03 to 2.26)‡	1.17 (0.74 to 1.83)
I60–I69	Cerebrovascular diseases	1.11 (0.86 to 1.42)	1.03 (0.81 to 1.42)	1.65 (1.30 to 2.11)‡	1.61 (1.25 to 2.08)‡
K70–K77	Diseases of liver	1.13 (0.82 to 1.54)	1.13 (0.84 to 1.51)	1.42 (1.07 to 1.90)‡	1.12 (0.79 to 1.58)
N20	Calculus of kidney and ureter	1.08 (0.74 to 1.57)	0.88 (0.62 to 1.26)	1.99 (1.39 to 2.85)‡	0.73 (0.45 to 1.19)
X60–X84	Intentional self-harm	1.27 (0.68 to 2.36)	0.77 (0.43 to 1.37)	1.43 (0.82 to 2.52)	2.73 (1.48 to 5.05)‡
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	0.92 (0.76 to 1.11)	0.98 (0.82 to 1.17)	1.37 (1.15 to 1.63)‡	1.76 (1.44 to 2.15)‡

*Models include age at diagnosis, year of arrival, duration of stay, ethnicity and education.
†The reference categories for these variables are as follows: year of arrival 1987–1991; duration of stay <92 days; ethnicity Estonian; education higher/ secondary.
‡p<0.05.
ICD, international classification of diseases; RR, rate ratio.

observed for thyroid diseases, and as expected, for intentional self-harm and selected alcohol-induced diagnoses.

Limitations

First, this study was limited to morbidity cases between 2004 and 2012. We had no information about morbidity prior to this time period. Thus, it was not possible to specify incident cases or assess early effects of exposure.

Second, among the given diseases there could be tentative and preliminary diagnoses unconfirmed afterwards. We are aware of the possibility of diagnostic errors, upcoding and unbundling of codes associated with the use of a reimbursement-administrative database, originally created not for research purposes, but proved to be an important source for medical studies in Estonia.[24–26] A small number of cases might have been diagnosed by commercial healthcare providers and not reported to the EHIF. However, because of universal health insurance, these limitations would be expected to affect the exposed and unexposed cohorts in a similar fashion. This kind of non-differential misclassification of disease or of disease status probably either does not bias the RR or biases it towards the null. The same may be said in a hypothetical situation when the validity of diagnoses in the EHIF will be almost perfect. In the last case as the most important, the number and heterogeneity of diagnostic entries would be reduced and the accuracy of measurements improved.

Third, the documented radiation doses are not entirely accurate, and there could be incorrect readings in both directions as discussed elsewhere.[2 19] Although no correlation was observed between individual doses from military passports (lists) and the biodosimetry estimates for the subcohort of cleanup workers, it is estimated that the cohort was exposed to low-dose radiation around 0.1 Gy on average.[22 27] A similar dose level was reported for Latvian and Lithuanian Chernobyl cleanup workers.[28] Thus, we used year of arrival and duration of stay as proxy variables for radiation exposure.

Fourth, the small size of the cohort has reduced the power of analysis. In addition, because of multiple comparisons, it is possible that some statistically significant findings could be due to chance. Given these limitations, our conclusions are duly tempered.

Possible radiation effects?

Thyroid diseases have been under close surveillance after the Chernobyl accident since radioiodine (mainly ^{131}I with a half-life of 8 days) released during the explosion is concentrated in the thyroid gland. Ron and Brenner[29] summarised the evidence of benign thyroid diseases after radiation exposure. They concluded that associations have been weak and elevated risk occurred mainly in participants with high doses, exposed at young ages and in women. Keeping in mind that the cohort of cleanup workers includes only adult men who were exposed to low doses, we cannot attribute the thyroid findings to radiation. This interpretation is supported by the lack of excess among the early entrants or participants with the highest documented radiation doses. At the same time, we cannot exclude the possibility that a higher RR among the cleanup workers is caused by close medical attention sought by them. During thyroid screening among the Estonian cleanup workers in 1995, no clear correlation was found between the prevalence of thyroid nodules and the year of arrival or recorded radiation dose.[30]

High radiation doses increase the risk of circulatory diseases, but less is known about the effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose–response at low dose levels is due to paucity of large cohorts with high-quality data on doses and confounders.[10 31] As the Estonian cohort of cleanup workers is small and with low average radiation dose, we cannot attribute the small increase in ischaemic heart disease morbidity seen in the cohort to biological effects of radiation exposure. This conclusion is also supported by the mortality analyses, where no excess deaths from circulatory diseases were found.[2]

An increased risk of cataract, observed in atomic-bomb survivors[7] and Ukrainian cleanup workers,[32] did not emerge in the Estonian cohort. An observed statistically significant deficit of cataract cases may be an occasional finding without any epidemiological relevance. Although cataract has been conventionally regarded as a late deterministic effect of radiation with a threshold dose of 0.5 Gy, recent studies have suggested a need to lower this dose limit and reconsider the threshold model.[31 33] Nevertheless, it is unlikely that radiation-related cataracts will be detectable among the Estonian cleanup workers in the future, given the low-dose level.

Mental and neurological disorders

Natural or man-made disasters can inflict psychological consequences on the affected populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and mental health effects such as post-traumatic stress, depression, anxiety and somatisation can be long lasting.[34] After the Chernobyl accident, the mental health of the local population and cleanup workers was considered to be the main public health concern.[1 14] Cleanup workers were exposed to radiation, lack of protective gear and poor living conditions, sometimes doing meaningless jobs and drinking large amounts of alcohol (mainly home-distilled).[19 35] Misleading or no information about the possible long-term health effects generated rumours and misapprehensions and radiation fears were exaggerated.[36 37] The situation bred profound mistrust of all authorities. One of the most difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific information about radiation risks, as there exists an insuperable gap between the experts' and public's perceptions about radiation.[38–40]

Until now, the persistently elevated suicide risk in the Estonian cohort has been the definitive indication of psychological impairment as a result of working as a

Chernobyl cleanup worker.[2] However, current morbidity analyses showed a mixed pattern of mental and neurological disorders. Based on the results from a study of Ukrainian cleanup workers,[15] we expected higher rates of depression, anxiety, post-traumatic stress disorder and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00), or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup workers used healthcare services significantly less frequently for stress reactions than the unexposed cohort. No excess of severe headaches or sleep disorders was found among cleanup workers. However, depression and stress reactions and severe headaches were more frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an indicator of psychological distress. This finding is consistent with the increased suicide rate in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in Estonia.[41]

Smoking and heavy alcohol consumption are more prevalent in less educated men in Estonia.[42 43] Although population-based health (behaviour) prevalence studies do not report differences in smoking and drinking habits between Estonians and non-Estonians,[42 43] mortality is higher in non-Estonians,[44] particularly alcohol-related mortality.[45]

Excess morbidity emerged for alcohol-induced diseases—mental disorders due to alcohol and degeneration of the nervous system due to alcohol. Morbidity from alcohol-induced diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort. Considering common alcohol abuse among men in Estonia (especially with lower educational level),[43] it is not surprising that cleanup workers used alcohol to cope with stressful situations, and still do. Higher morbidity due to excessive cold is most likely attributable to homelessness and suggests that periods of homelessness were more common in cleanup workers than in men in the comparison cohort. Results of our study demonstrate that the men with Estonian ethnicity and/or higher educational level coped better with Chernobyl consequences including alcohol abuse.

Although Ukrainian cleanup workers had more mental disorders than controls, no excess of alcoholism was observed.[15] This illustrates how analysis of similar cohorts with different design and risk measures can produce entirely opposite results. Very likely, mental disorders other than alcoholism were underdiagnosed in the Estonian cohort, and the prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common that people do not seek professional help for mental health problems.[34] Untreated mental disorders can manifest as unexplained physical symptoms such as headache or back pain, or they are risk factors for somatic diseases (eg, thyroid diseases or diseases of the digestive system).[46 47] Thus, it is important to pay attention to mental and somatic diseases of Chernobyl cleanup workers simultaneously.

CONCLUSIONS

No obvious excess morbidity consistent with biological effects of radiation was seen in the exposed cohort, with the possible exception of benign thyroid diseases. Increased alcohol-induced morbidity reflects alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably under-reported. The future challenge will be to study mental and physical comorbidities in the Chernobyl cleanup workers cohort.

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