



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

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3 **Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based**  
4 **cohort study**  
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## ABSTRACT

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

**Design:** Register-based cohort study.

**Setting:** Estonia.

**Participants:** A total of 3680 cleanup workers (exposed cohort) and 7631 population controls (unexposed cohort) were followed 2004–2012 through the Population Registry and Health Insurance Fund database.

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

**Results:** Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischemic heart disease, and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38–2.07), intentional self-harm (RR=1.47; 95% CI 1.04–2.09), and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12–1.39). 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 reflects alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

## ARTICLE SUMMARY

### Article focus

- Psychological aftermath of the accident at the Chernobyl nuclear power station has been acknowledged as the major long-term public health concern in the exposed populations (including cleanup workers), but the number of publications on this issue is limited.
- Earlier studies of Estonian cleanup workers revealed higher incidence of alcohol-related cancers and excess of suicide.

### Key messages

- No obvious excess morbidity consistent with biological effects of radiation was found in the cleanup workers cohort, with the possible exception of benign thyroid diseases.
- Increased alcohol-induced morbidity in the cleanup workers cohort reflects alcohol abuse, and could underlie some of the higher morbidity rates.
- It is important to study and treat mental and physical co-morbidities in the Chernobyl cleanup workers cohorts.

### 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.
- This study was limited to morbidity cases in 2004–2012, no prior information was available.
- The documented radiation doses were not entirely reliable.

## INTRODUCTION

In the aftermath of the accident at the Chernobyl nuclear power station in April, 1986, about 600,000 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 three 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 ionizing radiation is mainly based on mortality since administratively registered death records are available and easy to use for linkages. Dose-dependent risk of death for the broad categories of the circulatory, respiratory and digestive systems has been found among atomic-bomb survivors,[3] but not in other environmentally exposed populations,[4] or in nuclear industry workers.[5] Most of these studies focused on circulatory diseases, the major cause of death in developed countries. Excess mortality from stroke and heart disease was observed in atomic-bomb survivors; however the association below dose of 0.5 Gy was not significant.[6]

A few studies have reported morbidity outcomes. The most informative non-cancer disease incidence study in atomic-bomb survivors found significant radiation effects for thyroid diseases, liver disease, 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 ischemic heart disease,[9] but did not provide information on risk at doses below 0.2 Gy. 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 ischemic heart disease.[10, 11] However, risk estimates at low doses still remain uncertain.[12]

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3 Although the psychological aftermath of the Chernobyl accident has been acknowledged  
4 as the major long-term public health problem in the exposed populations,[1, 13] the mental  
5 health of cleanup workers has only been assessed in small-scale studies in Ukraine.[14–15]  
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7 There is an urgent need to examine mental health along with somatic diseases when  
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9 considering the health of cleanup workers.[15]  
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14 An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort  
15 revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has  
16 been persistently elevated since the beginning of follow-up.[16, 17] The current research  
17 provides the first overview of morbidity other than cancer in the Estonian cohort of  
18 Chernobyl cleanup workers with special attention to radiation-related diseases and mental  
19 health disorders.  
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## 29 **METHODS**

### 30 **Sample and follow-up**

31  
32 The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men  
33 recruited in 1986–1991 to the area by the Soviet authorities for decontamination, building and  
34 other related activities. Detailed information on the assembly and description of the cohort is  
35 given elsewhere.[18] To examine morbidity in this cohort, we used data from the Estonian  
36 Health Insurance Fund (EHIF) database available since January 2004. Thus, for the morbidity  
37 analyses we identified all cohort members aged 35–69 years and living in Estonia on January  
38 1, 2004 (3680 men). An unexposed population-based comparison cohort was selected  
39 corresponding to the age distribution of the exposed cohort. A random sample stratified by 5-  
40 year age groups with the exposed to unexposed ratio of 1:2 and 5% extra men in each age  
41 group was extracted from the Estonian Population Registry (EPR). After excluding 87 men  
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3 who had worked in the Chernobyl area, 7631 men remained in the unexposed cohort (Table  
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7 The cohort of cleanup workers was linked to the EPR to update vital status (emigration or  
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9 death with corresponding date), ethnicity and education. Each person in both cohorts was  
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11 followed up from January 1, 2004 until death, emigration or December 31, 2012 (whichever  
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13 date came first). From the EHIF database, we obtained dates and ICD-10 codes for each  
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15 contact with a health provider. All linkages were performed using the unique personal  
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17 identification number (assigned to all permanent residents of Estonia) as the key variable.  
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19 EHIF manages the mandatory universal health insurance system that is based on solidarity  
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21 and covers 95% of the Estonian population.[19] All employees and self-employed persons  
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23 contribute 13% of their wages, some groups of the population are financed by the State (e.g.  
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25 registered unemployed, Chernobyl veterans), and some groups are insured without  
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27 contribution (e.g. children, students, pensioners). People without coverage from the above  
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29 mentioned sources can pay the tax voluntarily.  
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34 Health care contacts were identified from the EHIF database for 2004–2012 using the  
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36 first occurrence of the three-digit ICD-10 code. All diseases (except cancer, ICD-10 C00–  
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38 C97), external causes of morbidity, and examinations or counseling were considered. Four-  
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40 digit codes were taken separately only for some alcohol-induced diseases. A combined  
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42 category of alcohol-induced diagnoses included mental disorders due to alcohol (F10),  
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44 degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy  
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46 (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental  
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48 poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65), and poisoning by  
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50 alcohol, undetermined intent (Y15). The accuracy of the diagnosis was the responsibility of  
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52 the physician issuing the invoice to EHIF for ambulatory or hospital care.  
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### Morbidity measures and statistical analysis

We estimated morbidity in the cleanup workers cohort by means of rate ratio (RR) with 95% confidence intervals (CI) using Poisson regression models with the logarithm of the person-years at risk (summed by five-year age groups) as the offset.[20] At first, we performed analysis comparing the exposed cohort with the unexposed cohort (external analysis) to obtain an overview of morbidity rate ratios. Diagnoses were grouped into broad categories with selected specific diagnoses (Table 2). Analyses were adjusted for age at diagnosis by five-year age groups.

Additionally, analysis was done between different subgroups within the exposed cohort (internal analysis) to assess possible effects of year of arrival to Chernobyl area (1986; 1987–1991), duration of stay (<92; ≥92 days), documented whole-body radiation dose (<5.0; 5.0–9.9; ≥10.0 cGy), education (higher or secondary; basic or less), and ethnicity (Estonian; non-Estonian (mainly Russians)) on morbidity risk. We used year of arrival and duration of stay as proxy variables for radiation exposure estimates for two reasons – radiation doses documented in military passports were unreliable,[18] and for 15% of the cohort members the dose was not recorded. Ethnicity and educational level were included in the analysis as surrogates for health behavior. Smoking and heavy alcohol consumption are more prevalent in less educated men in Estonia.[21, 22] Although population-based health (behavior) prevalence studies do not report differences in smoking and drinking habits between Estonians and non-Estonians,[21, 22] mortality is higher in non-Estonians than in Estonians,[23] particularly alcohol-related mortality.[24]

Analyses within the exposed cohort focused on disease risks previously reported in atomic-bomb survivors and Chernobyl cleanup workers (Table 3). 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 subjects with missing information for



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3 any characteristic were excluded from the analysis. In the second set of models we included  
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5 documented radiation dose; due to unrecorded values, an additional 452 subjects were  
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7 excluded.  
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10 We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, WA, USA) for database  
11  
12 management, and Stata 12 (StataCorp LP, College Station, TX, USA) for statistical  
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14 modeling.  
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## 16 17 18 **RESULTS**

### 19 20 **Description of the exposed and unexposed cohorts**

21  
22 We followed 3680 exposed and 7631 unexposed men from January 1, 2004 until December  
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24 31, 2012 (Table 1). The exposed and unexposed cohorts contributed 30,674 and 65,112  
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26 person-years, respectively. Mean age at the start of follow-up was 48 years in both cohorts.  
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28 During the follow-up, 12.9% of the exposed cohort and 10.5% of the unexposed cohort died.  
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30 The proportions of non-Estonians (mainly Russians) and less educated persons were higher in  
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32 the exposed cohort, although educational level was unknown for the 16.4% of the subjects in  
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34 the unexposed cohort. Two-thirds of the cleanup workers entered the Chernobyl area in 1986;  
35  
36 the mean and median durations of the mission were 102 and 92 days, respectively (range: 1–  
37  
38 833 days). The cohort was exposed to low-level whole-body radiation with the mean and  
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40 median documented radiation doses of 9.9 and 8.9 cGy, respectively (range: 0.0–54.5 cGy).  
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46 Nearly all men had at least one record in the EHIF database (93.6% of the exposed and  
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48 95.3% of the unexposed cohort). On average, members of both cohorts had 12 different  
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50 diagnoses (three-digit ICD-10 codes). Men in the exposed cohort had their first health  
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52 services contact on average half a year earlier than their unexposed counterparts (52.1 vs.  
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54 52.6 years of age).  
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57 (Insert Table 1 here)  
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### **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 1.00–1.03). From the non-cancer late effects that might be related to the Chernobyl accident (UNSCEAR 2011), we found significantly elevated morbidity for diseases of thyroid gland (RR=1.69; 95% CI 1.38–2.07) and ischemic heart disease (RR=1.09; 95% CI 1.00–1.18). There was no evidence for excess cataract cases 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 1.03–1.11). 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 0.94–1.19).

(Insert Table 2 here)

### **Differences between subgroups in the exposed cohort (internal analysis)**

Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI 1.00–1.62), and severe headaches (RR=1.69; 95% CI 1.10–2.60) among cleanup workers who entered the area shortly after the accident than in those arriving later (Table 3). Higher thyroid diseases morbidity was not related to year 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

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3 disorders were more frequent among Estonians. Less educated cleanup workers had higher  
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5 risk for diseases of the nervous system, cerebrovascular diseases, intentional self-harm, and  
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7 alcohol-induced morbidity, and lower risk for in situ and benign neoplasms.  
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10 Including education and ethnicity in the model did not alter markedly the point estimates  
11  
12 of RR for year of arrival or duration of stay. Higher documented radiation dose (5.0–9.9 or  
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14  $\geq 10.0$  vs.  $< 5.0$  cGy) was not associated with higher morbidity of thyroid diseases (RR=0.92;  
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16 95% CI 0.60–1.40; 0.92; 0.60–1.40, respectively), cataract (RR=1.26; 95% CI 0.80–1.98;  
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18 1.13; 0.70–1.83, respectively), or any of the other selected diseases.  
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21 (Insert Table 3 here)  
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## 23 **DISCUSSION**

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25 The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers  
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27 revealed elevated morbidity for diseases of the nervous system, digestive system,  
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29 musculoskeletal system, ischemic heart disease, and for external causes. The most salient  
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31 excess risk was observed for thyroid diseases, and as expected, for intentional self-harm and  
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33 selected alcohol-induced diagnoses.  
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## 36 **Limitations**

37  
38 First, this study was limited to morbidity cases in 2004–2012. We had no information about  
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40 morbidity prior to this time period. Thus, it was not possible to specify incident cases or  
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42 assess early effects of exposure. Among given diseases there could be suspicions or  
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44 preliminary diagnoses unconfirmed afterwards. We are aware of the possibility of diagnostic  
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46 errors associated with the use of an reimbursement-administrative database. A small number  
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48 of cases might have been diagnosed by commercial health care providers and not reported to  
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50 the EHIF. However, because of universal health insurance, these limitations would be  
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3 expected to affect the exposed and unexposed cohorts in a similar fashion (non-differential  
4 misclassification).  
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7 Second, the documented radiation doses are not entirely accurate, and there could be  
8 incorrect readings in both directions as discussed elsewhere.[2, 18] Although no correlation  
9 was observed between individual doses from military passports (lists) and the biodosimetry  
10 estimates for the sub-cohort of cleanup workers, it is estimated that the cohort was exposed to  
11 low-dose radiation around 0.1 Gy on average.[25, 26] A similar dose level was reported for  
12 Latvian and Lithuanian Chernobyl cleanup workers.[27] Thus, we used year of arrival and  
13 duration of stay as proxy variables for radiation exposure. Given these limitations, our  
14 conclusions are duly tempered.  
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### 25 26 27 **Possible radiation effects?**

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29 Thyroid diseases have been under close surveillance after the Chernobyl accident since  
30 radioiodine (mainly  $^{131}\text{I}$  with a half-life of eight days) released during the explosion is  
31 concentrated in the thyroid gland. Ron and Brenner [28] summarized the evidence of benign  
32 thyroid diseases after radiation exposure. They concluded that associations have been weak  
33 and elevated risk occurred mainly in subjects with high doses, exposed at young ages, and in  
34 women. Keeping in mind that the cohort of cleanup workers includes only adult men who  
35 were exposed to low doses, we cannot attribute the thyroid findings to radiation. This  
36 interpretation is supported by the lack of general increase in thyroid diseases in the exposed  
37 cohort as well as lack of more pronounced excess among the early entrants or subjects with  
38 the highest documented radiation doses. During thyroid screening among the Estonian  
39 cleanup workers in 1995, no clear correlation was found between the prevalence of thyroid  
40 nodules and the year of arrival or recorded radiation dose.[29]  
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3 High radiation doses increase the risk of circulatory diseases, but less is known about the  
4 effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose-response at low dose  
5 levels is due to paucity of large cohorts with high-quality data on doses and confounders.[30]  
6  
7 As the Estonian cohort of cleanup workers is small and with low average radiation dose, we  
8 cannot attribute the small increase in ischemic heart disease morbidity seen in the cohort to  
9 biological effects of radiation exposure. This conclusion is also supported by the mortality  
10 analyses, where no excess deaths from circulatory diseases were found.[2]  
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14 An increased risk of cataract, observed in atomic-bomb survivors [7] and Ukrainian  
15 cleanup workers,[31] did not emerge in the Estonian cohort. Although cataract has been  
16 conventionally regarded as a late deterministic effect of radiation with a threshold dose of 0.5  
17 Gy, recent studies have suggested a need to lower this dose limit and reconsider the threshold  
18 model.[30, 32] Nevertheless, it is unlikely that radiation-related cataracts will be detectable  
19 among the Estonian cleanup workers in the future, given the low dose level.  
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### 34 **Mental and neurological disorders**

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36 Natural or man-made disasters can inflict psychological consequences to the affected  
37 populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and  
38 mental health effects such as post-traumatic stress, depression, anxiety, and somatization can  
39 be long-lasting.[33] After the Chernobyl accident, the mental health of the local population  
40 and cleanup workers was considered to be the main public health concern.[1, 13] Cleanup  
41 workers were exposed not only to radiation, but also to the lack of protective gear and to the  
42 poor living conditions, sometimes doing meaningless jobs, and drinking large amounts of  
43 alcohol (mainly home-distilled).[18, 34] Misleading or no information about the possible  
44 long-term health effects generated rumors and misapprehensions, and radiation fears were  
45 exaggerated.[35, 36] The situation bred profound mistrust of all authorities. One of the most  
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3 difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific  
4 information about the radiation risks, as there exists an insuperable gap between the experts'  
5 and public's perceptions about radiation.[37–39]  
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10 To date, the persistently elevated suicide risk in the Estonian cohort has been the  
11 definitive indication of psychological impairment as a result of working as a Chernobyl  
12 cleanup worker.[2] However, the current morbidity analyses showed a mixed pattern of  
13 mental and neurological disorders. Based on the results from a study of Ukrainian cleanup  
14 workers,[14] we expected higher rates of depression, anxiety, post-traumatic stress disorder,  
15 and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00),  
16 or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup  
17 workers used health care services significantly less frequently for stress reactions than the  
18 unexposed cohort. No excess of severe headaches or sleep disorders was found among  
19 cleanup workers. However, depression and stress reactions, and severe headaches were more  
20 frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an  
21 indicator of psychological distress. This finding is consistent with the increased suicide rate  
22 in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in  
23 Estonia.[40]  
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40 Excess morbidity emerged for alcohol-induced diseases – mental disorders due to alcohol  
41 and degeneration of nervous system due to alcohol. Morbidity from alcohol-induced  
42 diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort.  
43 Considering common alcohol abuse among men in Estonia (especially with lower educational  
44 level),[22] it is not surprising that cleanup workers used alcohol to cope with stressful  
45 situation, and still do. Higher morbidity due to excessive cold is most likely attributable to  
46 homelessness and suggests that periods of homelessness were more common in cleanup  
47 workers than in men in the comparison cohort. Results of our study demonstrate that the men  
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3 with Estonian ethnicity and/ or higher educational level coped better with Chernobyl  
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5 consequences including alcohol abuse.  
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8 Although Ukrainian cleanup workers had more mental disorders than controls, no excess  
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10 of alcoholism was observed.[14] This illustrates how analysis of similar cohorts with  
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12 different design and risk measures can produce entirely opposite results. Very likely, mental  
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14 disorders other than alcoholism were under-diagnosed in the Estonian cohort, and the  
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16 prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common  
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18 that people do not seek professional help for mental health problems.[33] Untreated mental  
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20 disorders can manifest as unexplained physical complaints such as headache or back pain, or  
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22 they are risk factors for somatic diseases (e.g. thyroid diseases or diseases of the digestive  
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24 system).[41, 42] Thus, it is important to pay attention to both mental and somatic diseases of  
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26 Chernobyl cleanup workers simultaneously.  
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### 31 32 **CONCLUSIONS**

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34 No obvious excess morbidity consistent with biological effects of radiation was seen in the  
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36 exposed cohort, with the possible exception of benign thyroid diseases. Increased alcohol-  
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38 induced morbidity reflects alcohol abuse, and could underlie some of the higher morbidity  
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40 rates. Mental disorders in the exposed cohort were probably underreported. The future  
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42 challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup  
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44 workers cohort.  
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4 drafted the manuscript. EB, TH, AA, AU and MR contributed to the interpretation of the  
5 results and revised critically the manuscript. MR supervised the whole process. All authors  
6 have seen and approved the final version of the manuscript.  
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23 **Competing interests** None.  
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36 **Data sharing statement** No additional data are available.  
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Table 1 Characteristics of the Estonian cohort of Chernobyl cleanup workers (exposed cohort) and the unexposed population cohort

Characteristic	Exposed cohort		Unexposed cohort	
	No.	(%)	No.	(%)
Total	3680	(100)	7631	(100)
Vital status on December 31, 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)		

Table 2 Number of morbidity cases and age-adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) in the Estonian cohort of Chernobyl cleanup workers (exposed cohort) in relation to the unexposed population cohort, 2004–2012

ICD-10	Diagnosis/ external cause of morbidity	No. of cases		RR (95% CI)
		Exposed cohort	Unexposed cohort	
A00–R99, V01–Z99	All diagnoses and external causes	41,370	86,441	1.02 (1.01–1.03)
A00–R99, except C00–C97	All diseases, except cancer	31,757	66,799	1.01 (1.00–1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88–1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81–1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94–1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84–1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90–1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38–2.07)
F00–F99	Mental disorders	1380	2918	1.00 (0.94–1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06–1.39)
F32–F33	Depressive disorders	290	633	0.97 (0.84–1.11)
F41	Anxiety disorders	119	275	0.91 (0.74–1.13)
F43	Stress reactions	55	162	0.72 (0.53–0.97)
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06–1.21)
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04–2.18)
G40	Epilepsy	148	223	1.40 (1.14–1.73)
G43–G44	Migraine and other headache	125	256	1.03 (0.83–1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02–1.29)
F51, G47	Sleep disorders	267	529	1.08 (0.93–1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89–0.98)
H25–H26, H28	Cataract	155	449	0.77 (0.64–0.92)
H40, H42	Glaucoma	109	247	0.96 (0.77–1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91–1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97–1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93–1.04)
I20–I25	Ischemic heart disease	773	1537	1.09 (1.00–1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83–1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91–1.20)
J00–J99	Diseases of the respiratory system	4699	10,079	0.99 (0.95–1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79–0.96)
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00–1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07–1.16)
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06–1.21)
K25–K27	Peptic ulcer	464	857	1.15 (1.02–1.28)
K70–K77	Diseases of liver	194	357	1.16 (0.97–1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91–1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02–1.58)
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77–2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97–1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12,623	1.06 (1.03–1.09)
M15–M19	Arthrosis	925	1881	1.06 (0.98–1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04–1.18)
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84–0.95)
N20	Calculus of kidney and ureter	140	321	0.93 (0.76–1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79–0.99)
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94–1.09)
V01–Y98	External causes of morbidity	5084	10,055	1.07 (1.03–1.11)
V01–V99	Transport accidents	171	423	0.85 (0.71–1.02)
W00–W19	Falls	2010	3817	1.11 (1.06–1.18)
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98–1.09)
X31	Excessive cold	26	32	1.74 (1.04–2.92)
X40–X49	Accidental poisoning	34	69	1.05 (0.69–1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04–2.09)
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96–1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94–1.19)

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3 F10, G31.2, I42.6, K70, Selected alcohol-induced diagnoses and 528 896 1.25 (1.12–1.39)  
4 K86.0, X45, X65, Y15 external causes of morbidity

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5 \* Adjusted for age at diagnosis  
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Table 3 Adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) by exposure for selected diagnoses and external causes of morbidity in the Estonian cohort of Chernobyl cleanup workers (exposed cohort), 2004–2012

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

\* Models include age at diagnosis, year of arrival, duration of stay, ethnicity, and education

† 1987–1991 as the reference category

‡ <92 days as the reference category

§ Estonian as the reference category

¶ Higher/ secondary as the reference category



STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5
		(b) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	7-8
Study size	10	Explain how the study size was arrived at	5-6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-8
		(b) Describe any methods used to examine subgroups and interactions	7-8
		(c) Explain how missing data were addressed	7-8
		(d) If applicable, explain how loss to follow-up was addressed	no losses (Table 1)
		(e) Describe any sensitivity analyses	
<b>Results</b>			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, Table 1
		(b) Give reasons for non-participation at each stage	5-6
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	8, Table 1
		(c) Summarise follow-up time (eg, average and total amount)	8, Table 1
Outcome data	15*	Report numbers of outcome events or summary measures over time	8, Table 2
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-10, Table 2-3
		(b) Report category boundaries when continuous variables were categorized	8
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-10, Table 3
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10
<b>Limitations</b>			10-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
<b>Other information</b>			14-15
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).

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

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3 **Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based**  
4 **cohort study**  
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50 morbidity, radiation effects  
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## ABSTRACT

**Objective:** To examine non-cancer morbidity in the Estonian Chernobyl cleanup workers cohort compared to 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 2004–2012 through the Population Registry and Health Insurance Fund database.

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

**Results:** Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischemic heart disease, and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38–2.07), intentional self-harm (RR=1.47; 95% CI 1.04–2.09), and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12–1.39). 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

## ARTICLE SUMMARY

### Article focus

- There is limited information about the impact of the Chernobyl accident on the non-cancer morbidity among the cleanup workers. Earlier studies of Estonian cleanup workers revealed an excess of suicide.
- This study provides insight into non-cancer morbidity in the cohort of Estonian cleanup workers with emphasis on radiation-related diseases and mental health disorders.

### Key messages

- No obvious excess morbidity consistent with biological effects of radiation was found in the cleanup workers cohort, with the possible exception of benign thyroid diseases.
- Increased alcohol-induced morbidity in the cleanup workers cohort may reflect alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably underreported.

### 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.
- Limitations of the study are as follows: relatively short follow-up; the probable presence of tentative and preliminary diagnoses in the health insurance database; the documented radiation doses were not entirely reliable; the small size of the cohort; probable overestimation of findings due to multiple comparisons.

## INTRODUCTION

In the aftermath of the accident at the Chernobyl nuclear power station in April, 1986, about 600,000 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 three 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 ionizing 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 dose of 0.5 Gy was not significant.[3] Follow-up of nuclear industry workers from 15 countries resulted with no significant findings for a dose-dependent rise in mortality from circulatory diseases.[4] Elevated risk of death for the broad categories 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 in atomic-bomb survivors found significant radiation effects for thyroid diseases, liver disease, 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 ischemic 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-

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2  
3 dependent risk for ischemic heart disease, cerebrovascular diseases and other circulatory  
4  
5 diseases.

6  
7 Analyses of non-cancer morbidity in a cohort of Russian Chernobyl cleanup workers have  
8  
9 shown dose-dependent excess (per 1 Gy) for endocrine and metabolic diseases, mental  
10  
11 disorders, diseases of the nervous system, diseases of the digestive system, cerebrovascular  
12  
13 diseases, hypertension, and ischemic heart disease.[11, 12] However, risk estimates at low  
14  
15 doses still remain uncertain.[13]

16  
17 Although the psychological aftermath of the Chernobyl accident has been acknowledged  
18  
19 as the major long-term public health problem in the exposed populations,[1, 14] the mental  
20  
21 health of cleanup workers has only been assessed in small-scale studies in Ukraine.[15–16]  
22  
23 There is an urgent need to examine mental health along with somatic diseases when  
24  
25 considering the health of cleanup workers.[16]

26  
27 An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort  
28  
29 revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has  
30  
31 been persistently elevated since the beginning of follow-up.[17, 18] The current research  
32  
33 provides the first overview of morbidity other than cancer in the Estonian cohort of  
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35 Chernobyl cleanup workers with special attention to radiation-related diseases and mental  
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37 health disorders.  
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## 45 **METHODS**

### 46 **Sample and follow-up**

47  
48 The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men  
49  
50 recruited in 1986–1991 to the Chernobyl area by the Soviet authorities for decontamination,  
51  
52 building and other related activities. The “Chernobyl area” here denotes the 30-km zone (an  
53  
54 area of 30-km radius from the nuclear power station) and territories outside, where the  
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3 workers were engaged with different activities during their mission period. Detailed  
4  
5 information on the assembly and description of the cohort is given elsewhere.[19] To  
6  
7 examine morbidity in this cohort, we used data from the Estonian Health Insurance Fund  
8  
9 (EHIF) database available since January 2004. Thus, for the morbidity analyses we identified  
10  
11 all cohort members aged 35–69 years and living in Estonia on January 1, 2004. Altogether, of  
12  
13 4831 men in the initial cohort, 1129 were excluded because of loss in follow-up (21), death  
14  
15 (602) and emigration (506). In addition, we did not include men aged under 35 (9) and over  
16  
17 69 years (13) to have more homogeneous age group. This left just 3680 cleanup workers in  
18  
19 the study. An unexposed population-based comparison cohort was selected corresponding to  
20  
21 the age distribution of the exposed cohort. A random sample stratified by 5-year age groups  
22  
23 with the exposed to unexposed ratio of 1:2 and 5% extra men in each age group was extracted  
24  
25 from the Estonian Population Registry (EPR). After excluding 87 men who had worked in the  
26  
27 Chernobyl area, 7631 men remained in the unexposed cohort.  
28  
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31  
32 The cohort of cleanup workers was linked to the EPR to update vital status (emigration or  
33  
34 death with corresponding date), ethnicity and education. Each person in both cohorts was  
35  
36 followed up from January 1, 2004 until death, emigration or December 31, 2012 (whichever  
37  
38 date came first). From the EHIF database, we obtained dates and ICD-10 codes for each  
39  
40 contact with a health provider. All linkages were performed using the unique personal  
41  
42 identification number (assigned to all permanent residents of Estonia) as the key variable.  
43  
44 EHIF manages the mandatory universal health insurance system that is based on solidarity  
45  
46 and covers 95% of the Estonian population.[20] All employees and self-employed persons  
47  
48 contribute 13% of their wages, some groups of the population are financed by the State (e.g.  
49  
50 registered unemployed, Chernobyl veterans), and some groups are insured without  
51  
52 contribution (e.g. children, students, pensioners). People without coverage from the above  
53  
54 mentioned sources can pay the tax voluntarily.  
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3 Health care contacts were identified from the EHIF database for 2004–2012 using the  
4 first occurrence of the three-digit ICD-10 code. If the contact involved multiple diagnoses,  
5 the first occurrence of each of them was separately counted. All diseases (except cancer,  
6 ICD-10 C00–C97), external causes of morbidity, and examinations or counseling were  
7 considered. Four-digit codes were taken separately only for some alcohol-induced diseases. A  
8 combined category of alcohol-induced diagnoses included mental disorders due to alcohol  
9 (F10), degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy  
10 (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental  
11 poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65), and poisoning by  
12 alcohol, undetermined intent (Y15). The accuracy of the diagnosis was the responsibility of  
13 the physician issuing the invoice to EHIF for ambulatory or hospital care.  
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### 30 **Morbidity measures and statistical analysis**

31 We estimated morbidity in the cleanup workers cohort by means of rate ratio (RR) with 95%  
32 confidence intervals (CI) using the Poisson regression models with the logarithm of the  
33 person-years at risk (summed by five-year age groups) as the offset.[21] At first, we  
34 performed analysis comparing the exposed cohort with the unexposed cohort (external  
35 analysis) to obtain an overview of morbidity rate ratios. Diagnoses were grouped into broad  
36 categories with selected specific diagnoses. Analyses were adjusted for age at diagnosis by  
37 five-year age groups.  
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47 Additionally, analysis was done between different subgroups within the exposed cohort  
48 (internal analysis) to assess possible effects of year of arrival in the Chernobyl area (1986;  
49 1987–1991), duration of stay (<92; ≥92 days), documented cumulative whole-body radiation  
50 dose (<5.0; 5.0–9.9; ≥10.0 cGy), education (higher or secondary; basic or less), and ethnicity  
51 (Estonian; non-Estonian (mainly Russians)) on morbidity risk. As described elsewhere, [1,  
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3 22, 23] the cleanup workers were dominantly exposed to  $\gamma$ -radiation released mainly by  $^{131}\text{I}$ ,  
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5  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ . Received radiation doses were measured by individual or group dosimeters,  
6  
7 or estimated by work area measurements. The readings were documented in the workers'  
8  
9 military passports/ records. Considering, that documented doses were unreliable,[19] and not  
10  
11 recorded for 15.2% of the cohort members, we used the year of arrival and duration of stay as  
12  
13 proxy variables for radiation exposure.  
14

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16 Ethnicity and educational level were included in the analysis as surrogates for health  
17  
18 behavior. The prevalence of alcohol consumption at least once a week (28.5%) and current  
19  
20 smoking (69.0%) among the cleanup workers was studied in a postal questionnaire survey  
21  
22 conducted in 1992–1993,[19] but not included in current analyses due to small cohort size  
23  
24 and lack of longitudinal data on these factors of health behavior.  
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28 Analyses within the exposed cohort focused on disease risks previously reported in  
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30 atomic-bomb survivors and Chernobyl cleanup workers.[7, 11, 12] The first set of models  
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32 included the year of arrival in the Chernobyl area, duration of stay, age at diagnosis,  
33  
34 education and ethnicity. One hundred and seventy four subjects with missing information for  
35  
36 any characteristic were excluded from the analysis. In the second set of models we included  
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38 documented radiation dose; due to unrecorded values, an additional 452 subjects were  
39  
40 excluded.  
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43 We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, WA, USA) for database  
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45 management, and Stata 12 (StataCorp LP, College Station, TX, USA) for statistical  
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47 modeling.  
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## 50 51 52 **RESULTS**

### 53 54 **Description of the exposed and unexposed cohorts**

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3 We followed 3680 exposed and 7631 unexposed men from January 1, 2004 until December  
4 31, 2012 (Table 1). The exposed and unexposed cohorts contributed 30,674 and 65,112  
5 person-years, respectively. Mean age at the start of follow-up was 48 years in both cohorts.  
6  
7 During the follow-up, 12.9% of the exposed cohort and 10.5% of the unexposed cohort died.  
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9 The proportions of non-Estonians (mainly Russians) and less educated persons were higher in  
10  
11 the exposed cohort, although educational level was unknown for the 16.4% of the subjects in  
12  
13 the unexposed cohort. Two-thirds of the cleanup workers entered the Chernobyl area in 1986;  
14  
15 the mean and median durations of the mission were 102 and 92 days, respectively (range: 1–  
16  
17 833 days). The cohort was exposed to low-level whole-body radiation with the mean and  
18  
19 median documented radiation doses of 9.9 and 8.9 cGy, respectively (range: 0.0–54.5 cGy).  
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25 Nearly all men had at least one record in the EHIF database (93.6% of the exposed and  
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27 95.3% of the unexposed cohort). On average, members of both cohorts had 12 different  
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29 diagnoses (three-digit ICD-10 codes). Men in the exposed cohort had their first health  
30  
31 services contact on average half a year earlier than their unexposed counterparts (52.1 vs.  
32  
33 52.6 years of age).  
34

35  
36 (Insert Table 1 here)  
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### 38 **Morbidity in the exposed cohort in relation to the unexposed cohort (external analysis)**

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40 In the external analysis (Table 2), we observed a very small increase of borderline  
41  
42 significance in all-disease risk among Chernobyl cleanup workers (RR=1.01; 95% CI 1.00–  
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44 1.03). From the non-cancer late effects that might be related to the Chernobyl accident  
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46 (UNSCEAR 2011), we found significantly elevated morbidity for diseases of thyroid gland  
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48 (RR=1.69; 95% CI 1.38–2.07) and ischemic heart disease (RR=1.09; 95% CI 1.00–1.18).  
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50  
51 There was evidence of lower occurrence of cataract in the exposed cohort. Stress reactions,  
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53 depression, severe headaches and sleep disorders were not diagnosed more frequently in the  
54  
55 exposed cohort than in the reference cohort.  
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3 Increased morbidity was apparent for the broad categories of diseases of the nervous  
4 system, digestive system, musculoskeletal system, and alcohol-induced diagnoses. Morbidity  
5 from external causes in the exposed cohort exceeded that in the unexposed cohort (RR=1.07;  
6 95% CI 1.03–1.11). Significantly higher morbidity was registered for falls, intentional self-  
7 harm and exposure to excessive cold. Cleanup workers did not undergo medical observations  
8 for suspected diseases (ICD-10 Z03) more frequently than unexposed men (RR=1.06; 95%  
9 CI 0.94–1.19). Additional adjustments for ethnicity and education (rate ratios not presented)  
10 did not materially alter these results.  
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21 (Insert Table 2 here)  
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### 23 **Differences between subgroups in the exposed cohort (internal analysis)**

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25 Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI  
26 1.00–1.62), and severe headaches (RR=1.69; 95% CI 1.10–2.60) among cleanup workers  
27 who entered the area shortly after the accident than in those arriving later (Table 3). Higher  
28 thyroid diseases morbidity was not related to year or month (April-May versus June-  
29 December, 1986) of arrival in the contaminated area. Longer mission did not increase the  
30 morbidity of any disease. Acute myocardial infarction, cerebrovascular diseases, diseases of  
31 liver, calculus of kidney and ureter, headaches, and alcohol-induced morbidity occurred more  
32 frequently among non-Estonians, while mental disorders were more frequent among  
33 Estonians. Less educated cleanup workers had higher risk for diseases of the nervous system,  
34 cerebrovascular diseases, intentional self-harm, and alcohol-induced morbidity, and lower  
35 risk for in situ and benign neoplasms.  
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50 Including education and ethnicity in the model did not alter markedly the crude point  
51 estimates of RR for year of arrival or duration of stay (rate ratios not presented). Higher  
52 documented radiation dose (5.0–9.9 or  $\geq 10.0$  vs.  $< 5.0$  cGy) was not associated with higher  
53 morbidity of thyroid diseases (RR=0.92; 95% CI 0.60–1.40; 0.92; 0.60–1.40, respectively),  
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3 cataract (RR=1.26; 95% CI 0.80–1.98; 1.13; 0.70–1.83, respectively), or any of the other  
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5 selected diseases.  
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7  
8 (Insert Table 3 here)  
9

## 10 **DISCUSSION**

11 The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers  
12 revealed elevated morbidity for diseases of the nervous system, digestive system,  
13 musculoskeletal system, ischemic heart disease, and for external causes. The most salient  
14 excess risk was observed for thyroid diseases, and as expected, for intentional self-harm and  
15 selected alcohol-induced diagnoses.  
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### 22 **Limitations**

23  
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25 First, this study was limited to morbidity cases in 2004–2012. We had no information about  
26 morbidity prior to this time period. Thus, it was not possible to specify incident cases or  
27 assess early effects of exposure.  
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34 Second, among given diseases there could be tentative and preliminary diagnoses  
35 unconfirmed afterwards. We are aware of the possibility of diagnostic errors, upcoding and  
36 unbundling of codes associated with the use of an reimbursement-administrative database,  
37 originally created not for research purposes, but proved to be an important source for medical  
38 studies in Estonia.[24–26] A small number of cases might have been diagnosed by  
39 commercial health care providers and not reported to the EHIF. However, because of  
40 universal health insurance, these limitations would be expected to affect the exposed and  
41 unexposed cohorts in a similar fashion. This kind of non-differential misclassification of  
42 disease or of disease status probably either does not bias the rate ratio or biases it towards the  
43 null. The same may be said in a hypothetical situation when the validity of diagnoses in the  
44 EHIF will be almost perfect. In the last case as the most important, the number and  
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3 heterogeneity of diagnostic entries would be reduced, and the accuracy of measurements  
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5 improved.  
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8 Third, the documented radiation doses are not entirely accurate, and there could be  
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10 incorrect readings in both directions as discussed elsewhere.[2, 19] Although no correlation  
11  
12 was observed between individual doses from military passports (lists) and the biodosimetry  
13  
14 estimates for the sub-cohort of cleanup workers, it is estimated that the cohort was exposed to  
15  
16 low-dose radiation around 0.1 Gy on average.[22, 27] A similar dose level was reported for  
17  
18 Latvian and Lithuanian Chernobyl cleanup workers.[28] Thus, we used year of arrival and  
19  
20 duration of stay as proxy variables for radiation exposure. Given these limitations, our  
21  
22 conclusions are duly tempered.  
23

24  
25 Fourth, the small size of the cohort has reduced the power of analysis. In addition,  
26  
27 because of multiple comparisons, it is possible that some statistically significant findings  
28  
29 could be due to chance.  
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### 32 33 34 **Possible radiation effects?**

35  
36 Thyroid diseases have been under close surveillance after the Chernobyl accident since  
37  
38 radioiodine (mainly  $^{131}\text{I}$  with a half-life of eight days) released during the explosion is  
39  
40 concentrated in the thyroid gland. Ron and Brenner [29] summarized the evidence of benign  
41  
42 thyroid diseases after radiation exposure. They concluded that associations have been weak  
43  
44 and elevated risk occurred mainly in subjects with high doses, exposed at young ages, and in  
45  
46 women. Keeping in mind that the cohort of cleanup workers includes only adult men who  
47  
48 were exposed to low doses, we cannot attribute the thyroid findings to radiation. This  
49  
50 interpretation is supported by the lack of excess among the early entrants or subjects with the  
51  
52 highest documented radiation doses. At the same time, we cannot exclude the possibility that  
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54 a higher rate ratio among the cleanup workers is caused by close medical attention sought by  
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3 them. During thyroid screening among the Estonian cleanup workers in 1995, no clear  
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5 correlation was found between the prevalence of thyroid nodules and the year of arrival or  
6  
7 recorded radiation dose.[30] Moreover, these whole-body external doses have little relevance  
8  
9 to thyroid diseases because they are not thyroid doses.  
10

11  
12 High radiation doses increase the risk of circulatory diseases, but less is known about the  
13  
14 effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose-response at low dose  
15  
16 levels is due to paucity of large cohorts with high-quality data on doses and confounders.[10,  
17  
18 31] As the Estonian cohort of cleanup workers is small and with low average radiation dose,  
19  
20 we cannot attribute the small increase in ischemic heart disease morbidity seen in the cohort  
21  
22 to biological effects of radiation exposure. This conclusion is also supported by the mortality  
23  
24 analyses, where no excess deaths from circulatory diseases were found.[2]  
25  
26

27  
28 An increased risk of cataract, observed in atomic-bomb survivors [7] and Ukrainian  
29  
30 cleanup workers,[31] did not emerge in the Estonian cohort. An observed statistically  
31  
32 significant deficit of cataract cases may be an occasional finding without any epidemiological  
33  
34 relevance. Although cataract has been conventionally regarded as a late deterministic effect  
35  
36 of radiation with a threshold dose of 0.5 Gy, recent studies have suggested a need to lower  
37  
38 this dose limit and reconsider the threshold model.[31- 33] Nevertheless, it is unlikely that  
39  
40 radiation-related cataracts will be detectable among the Estonian cleanup workers in the  
41  
42 future, given the low dose level.  
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### 47 **Mental and neurological disorders**

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49 Natural or man-made disasters can inflict psychological consequences to the affected  
50  
51 populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and  
52  
53 mental health effects such as post-traumatic stress, depression, anxiety, and somatization can  
54  
55 be long-lasting.[34] After the Chernobyl accident, the mental health of the local population  
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3 and cleanup workers was considered to be the main public health concern.[1, 14] Cleanup  
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5 workers were exposed not only to radiation, but also to the lack of protective gear and to the  
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7 poor living conditions, sometimes doing meaningless jobs, and drinking large amounts of  
8  
9 alcohol (mainly home-distilled).[19, 35] Misleading or no information about the possible  
10  
11 long-term health effects generated rumors and misapprehensions, and radiation fears were  
12  
13 exaggerated.[36, 37] The situation bred profound mistrust of all authorities. One of the most  
14  
15 difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific  
16  
17 information about the radiation risks, as there exists an insuperable gap between the experts'  
18  
19 and public's perceptions about radiation.[38–40]  
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22  
23 To date, the persistently elevated suicide risk in the Estonian cohort has been the  
24  
25 definitive indication of psychological impairment as a result of working as a Chernobyl  
26  
27 cleanup worker.[2] However, the current morbidity analyses showed a mixed pattern of  
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29 mental and neurological disorders. Based on the results from a study of Ukrainian cleanup  
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31 workers,[15] we expected higher rates of depression, anxiety, post-traumatic stress disorder,  
32  
33 and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00),  
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35 or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup  
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37 workers used health care services significantly less frequently for stress reactions than the  
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39 unexposed cohort. No excess of severe headaches or sleep disorders was found among  
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41 cleanup workers. However, depression and stress reactions, and severe headaches were more  
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43 frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an  
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45 indicator of psychological distress. This finding is consistent with the increased suicide rate  
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47 in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in  
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49 Estonia.[41]  
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54 Smoking and heavy alcohol consumption are more prevalent in less educated men in  
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56 Estonia.[42, 43] Although population-based health (behavior) prevalence studies do not  
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3 report differences in smoking and drinking habits between Estonians and non-Estonians,[42,  
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5 43] mortality is higher in non-Estonians,[44] particularly alcohol-related mortality.[45]  
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7 Excess morbidity emerged for alcohol-induced diseases – mental disorders due to alcohol  
8 and degeneration of nervous system due to alcohol. Morbidity from alcohol-induced  
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10 diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort.  
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12 Considering common alcohol abuse among men in Estonia (especially with lower educational  
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14 level),[43] it is not surprising that cleanup workers used alcohol to cope with stressful  
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16 situation, and still do. Higher morbidity due to excessive cold is most likely attributable to  
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18 homelessness and suggests that periods of homelessness were more common in cleanup  
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20 workers than in men in the comparison cohort. Results of our study demonstrate that the men  
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22 with Estonian ethnicity and/ or higher educational level coped better with Chernobyl  
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24 consequences including alcohol abuse.  
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29 Although Ukrainian cleanup workers had more mental disorders than controls, no excess  
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31 of alcoholism was observed.[15] This illustrates how analysis of similar cohorts with  
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33 different design and risk measures can produce entirely opposite results. Very likely, mental  
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35 disorders other than alcoholism were under-diagnosed in the Estonian cohort, and the  
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37 prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common  
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39 that people do not seek professional help for mental health problems.[34] Untreated mental  
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41 disorders can manifest as unexplained physical complaints such as headache or back pain, or  
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43 they are risk factors for somatic diseases (e.g. thyroid diseases or diseases of the digestive  
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45 system).[46, 47] Thus, it is important to pay attention to both mental and somatic diseases of  
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48 Chernobyl cleanup workers simultaneously.  
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## 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

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**Contributors** KR and MR designed the study. KR performed the statistical analyses and drafted the manuscript. EB, TH, AA, AU and MR contributed to the interpretation of the results and revised critically the manuscript. MR supervised the whole process. All authors have seen and approved the final version of the manuscript.

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**Competing interests** None.

**Ethics approval** The study was approved by the Tallinn Medical Ethics Committee (no. 1939, February 11, 2010), and by the Estonian Data Protection Inspectorate (no. 2.2-3/10/120r, April 9, 2010).

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**Data sharing statement** No additional data are available.

For peer review only

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

Characteristic	Exposed cohort		Unexposed cohort	
	No.	(%)	No.	(%)
Total	3680	(100)	7631	(100)
Vital status on December 31, 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)		

Table 2 Number of morbidity cases\* and age-adjusted morbidity rate ratios† (RR) with 95% confidence intervals (CI) 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		RR (95% CI)
		Exposed cohort	Unexposed cohort	
A00–R99, V01–Z99	All diagnoses and external causes	41,370	86,441	1.02 (1.01–1.03)‡
A00–R99, except C00–C97	All diseases, except cancer	31,757	66,799	1.01 (1.00–1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88–1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81–1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94–1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84–1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90–1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38–2.07)‡
F00–F99	Mental disorders	1380	2918	1.00 (0.94–1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06–1.39)‡
F32–F33	Depressive disorders	290	633	0.97 (0.84–1.11)
F41	Anxiety disorders	119	275	0.91 (0.74–1.13)
F43	Stress reactions	55	162	0.72 (0.53–0.97)‡
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06–1.21)‡
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04–2.18)‡
G40	Epilepsy	148	223	1.40 (1.14–1.73)‡
G43–G44	Migraine and other headache	125	256	1.03 (0.83–1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02–1.29)‡
F51, G47	Sleep disorders	267	529	1.08 (0.93–1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89–0.98)‡
H25–H26, H28	Cataract	155	449	0.77 (0.64–0.92)‡
H40, H42	Glaucoma	109	247	0.96 (0.77–1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91–1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97–1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93–1.04)
I20–I25	Ischemic heart disease	773	1537	1.09 (1.00–1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83–1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91–1.20)
J00–J99	Diseases of the respiratory system	4699	10,079	0.99 (0.95–1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79–0.96)‡
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00–1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07–1.16)‡
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06–1.21)‡
K25–K27	Peptic ulcer	464	857	1.15 (1.02–1.28)‡
K70–K77	Diseases of liver	194	357	1.16 (0.97–1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91–1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02–1.58)‡
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77–2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97–1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12,623	1.06 (1.03–1.09)‡
M15–M19	Arthrosis	925	1881	1.06 (0.98–1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04–1.18)‡
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84–0.95)‡
N20	Calculus of kidney and ureter	140	321	0.93 (0.76–1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79–0.99)‡
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94–1.09)
V01–Y98	External causes of morbidity	5084	10,055	1.07 (1.03–1.11)‡
V01–V99	Transport accidents	171	423	0.85 (0.71–1.02)
W00–W19	Falls	2010	3817	1.11 (1.06–1.18)‡
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98–1.09)
X31	Excessive cold	26	32	1.74 (1.04–2.92)‡
X40–X49	Accidental poisoning	34	69	1.05 (0.69–1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04–2.09)‡
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96–1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94–1.19)
F10, G31.2, I42.6, K70,	Selected alcohol-induced diagnoses and	528	896	1.25 (1.12–1.39)‡

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K86.0, X45, X65, Y15 external causes of morbidity

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\* The first occurrence of the three-digit ICD-10 code in the study period was considered.

† Adjusted for age at diagnosis.

‡ p<0.05

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Table 3 Adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) 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	Duration of stay	Ethnicity	Education
		1986†	≥92 days†	Non-Estonian†	Basic or less†
D00–D48	In situ and benign neoplasms	1.15 (0.95–1.39)	0.77 (0.64–0.92)‡	1.09 (0.91–1.30)	0.76 (0.61–0.96)‡
E00–E07	Diseases of thyroid gland	0.94 (0.68–1.31)	1.00 (0.73–1.38)	0.85 (0.62–1.17)	0.82 (0.55–1.22)
F00–F99	Mental disorders	1.08 (0.96–1.21)	0.85 (0.76–0.95)‡	0.82 (0.74–0.92)‡	1.11 (0.97–1.27)
F32–F33, F43	Depressive disorders and stress reactions	1.27 (1.00–1.62)	0.72 (0.58–0.90)‡	0.53 (0.41–0.67)‡	0.88 (0.66–1.17)
G00–G99	Diseases of the nervous system	1.01 (0.90–1.13)	0.93 (0.83–1.04)	0.97 (0.87–1.09)	1.20 (1.05–1.37)‡
G43–G44	Migraine and other headache	1.69 (1.10–2.60)‡	0.79 (0.55–1.14)	1.48 (1.03–2.12)‡	0.97 (0.59–1.58)
H25–H26, H28	Cataract	1.07 (0.77–1.49)	1.05 (0.76–1.45)	1.29 (0.93–1.77)	0.93 (0.65–1.33)
H40, H42	Glaucoma	1.26 (0.83–1.89)	0.78 (0.52–1.15)	1.20 (0.81–1.78)	0.80 (0.51–1.27)
I10–I15	Hypertensive diseases	1.03 (0.94–1.14)	0.92 (0.84–1.01)	1.07 (0.98–1.17)	0.99 (0.88–1.11)
I20–I25	Ischemic heart disease	1.15 (0.99–1.34)	0.81 (0.70–0.94)‡	1.12 (0.97–1.30)	1.10 (0.93–1.30)
I21	Acute myocardial infarction	1.11 (0.74–1.68)	0.94 (0.63–1.39)	1.53 (1.03–2.26)‡	1.17 (0.74–1.83)
I60–I69	Cerebrovascular diseases	1.11 (0.86–1.42)	1.03 (0.81–1.42)	1.65 (1.30–2.11)‡	1.61 (1.25–2.08)‡
K70–K77	Diseases of liver	1.13 (0.82–1.54)	1.13 (0.84–1.51)	1.42 (1.07–1.90)‡	1.12 (0.79–1.58)
N20	Calculus of kidney and ureter	1.08 (0.74–1.57)	0.88 (0.62–1.26)	1.99 (1.39–2.85)‡	0.73 (0.45–1.19)
X60–X84	Intentional self-harm	1.27 (0.68–2.36)	0.77 (0.43–1.37)	1.43 (0.82–2.52)	2.73 (1.48–5.05)‡
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	0.92 (0.76–1.11)	0.98 (0.82–1.17)	1.37 (1.15–1.63)‡	1.76 (1.44–2.15)‡

\* 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.

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3 **Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based**  
4  
5 **cohort study**  
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8  
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48 **Keywords:** alcohol-induced disorders, Chernobyl nuclear accident, Estonia, mental health,  
49 morbidity, radiation effects  
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52 **Running head:** Morbidity among Estonian Chernobyl cleanup workers  
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54 **Word count:** 3526  
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**ABSTRACT**

**Objective:** To examine non-cancer morbidity in the Estonian Chernobyl cleanup workers cohort compared to 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 2004–2012 through the Population Registry and Health Insurance Fund database.

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

**Results:** Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischemic heart disease, and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38–2.07), intentional self-harm (RR=1.47; 95% CI 1.04–2.09), and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12–1.39). 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

## ARTICLE SUMMARY

### Article focus

- There is limited information about the impact of the Chernobyl accident on the non-cancer morbidity among the cleanup workers. Earlier studies of Estonian cleanup workers revealed an excess of suicide.
- This study provides insight into non-cancer morbidity in the cohort of Estonian cleanup workers with emphasis on radiation-related diseases and mental health disorders.

### Key messages

- No obvious excess morbidity consistent with biological effects of radiation was found in the cleanup workers cohort, with the possible exception of benign thyroid diseases.
- Increased alcohol-induced morbidity in the cleanup workers cohort may reflect alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably underreported.

### 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.
- Limitations of the study are as follows: relatively short follow-up; the probable presence of tentative and preliminary diagnoses in the health insurance database; the documented radiation doses were not entirely reliable; the small size of the cohort; probable overestimation of findings due to multiple comparisons.



## INTRODUCTION

In the aftermath of the accident at the Chernobyl nuclear power station in April, 1986, about 600,000 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 three 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 ionizing 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 dose of 0.5 Gy was not significant.[3] Follow-up of nuclear industry workers from 15 countries resulted with no significant findings for a dose-dependent rise in mortality from circulatory diseases.[4] Elevated risk of death for the broad categories 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 in atomic-bomb survivors found significant radiation effects for thyroid diseases, liver disease, 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 ischemic 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-

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3 dependent risk for ischemic heart disease, cerebrovascular diseases and other circulatory  
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5 diseases.  
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8 Analyses of non-cancer morbidity in a cohort of Russian Chernobyl cleanup workers have  
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10 shown dose-dependent excess (per 1 Gy) for endocrine and metabolic diseases, mental  
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12 disorders, diseases of the nervous system, diseases of the digestive system, cerebrovascular  
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14 diseases, hypertension, and ischemic heart disease.[11, 12] However, risk estimates at low  
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16 doses still remain uncertain.[13]  
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19 Although the psychological aftermath of the Chernobyl accident has been acknowledged  
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21 as the major long-term public health problem in the exposed populations,[1, 14] the mental  
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23 health of cleanup workers has only been assessed in small-scale studies in Ukraine.[15–16]  
24  
25 There is an urgent need to examine mental health along with somatic diseases when  
26  
27 considering the health of cleanup workers.[16]  
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29  
30 An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort  
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32 revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has  
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34 been persistently elevated since the beginning of follow-up.[17, 18] The current research  
35  
36 provides the first overview of morbidity other than cancer in the Estonian cohort of  
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38 Chernobyl cleanup workers with special attention to radiation-related diseases and mental  
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40 health disorders.  
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## 45 **METHODS**

### 46 **Sample and follow-up**

47  
48 The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men  
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50 recruited in 1986–1991 to the Chernobyl area by the Soviet authorities for decontamination,  
51  
52 building and other related activities. The “Chernobyl area” here denotes the 30-km zone (an  
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54 area of 30-km radius from the nuclear power station) and territories outside, where the  
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3 workers were engaged with different activities during their mission period. Detailed  
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5 information on the assembly and description of the cohort is given elsewhere.[19] To  
6  
7 examine morbidity in this cohort, we used data from the Estonian Health Insurance Fund  
8  
9 (EHIF) database available since January 2004. Thus, for the morbidity analyses we identified  
10  
11 all cohort members aged 35–69 years and living in Estonia on January 1, 2004. **Altogether, of**  
12  
13 **4831 men in the initial cohort, 1129 were excluded because of loss in follow-up (21), death**  
14  
15 **(602) and emigration (506). In addition, we did not include men aged under 35 (9) and over**  
16  
17 **69 years (13) to have more homogeneous age group. This left just 3680 cleanup workers in**  
18  
19 **the study.** An unexposed population-based comparison cohort was selected corresponding to  
20  
21 the age distribution of the exposed cohort. A random sample stratified by 5-year age groups  
22  
23 with the exposed to unexposed ratio of 1:2 and 5% extra men in each age group was extracted  
24  
25 from the Estonian Population Registry (EPR). After excluding 87 men who had worked in the  
26  
27 Chernobyl area, 7631 men remained in the unexposed cohort.  
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32 The cohort of cleanup workers was linked to the EPR to update vital status (emigration or  
33  
34 death with corresponding date), ethnicity and education. Each person in both cohorts was  
35  
36 followed up from January 1, 2004 until death, emigration or December 31, 2012 (whichever  
37  
38 date came first). From the EHIF database, we obtained dates and ICD-10 codes for each  
39  
40 contact with a health provider. All linkages were performed using the unique personal  
41  
42 identification number (assigned to all permanent residents of Estonia) as the key variable.  
43  
44 EHIF manages the mandatory universal health insurance system that is based on solidarity  
45  
46 and covers 95% of the Estonian population.[20] All employees and self-employed persons  
47  
48 contribute 13% of their wages, some groups of the population are financed by the State (e.g.  
49  
50 registered unemployed, Chernobyl veterans), and some groups are insured without  
51  
52 contribution (e.g. children, students, pensioners). People without coverage from the above  
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54 mentioned sources can pay the tax voluntarily.  
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3 Health care contacts were identified from the EHIF database for 2004–2012 using the  
4 first occurrence of the three-digit ICD-10 code. **If the contact involved multiple diagnoses,**  
5 **the first occurrence of each of them was separately counted.** All diseases (except cancer,  
6 ICD-10 C00–C97), external causes of morbidity, and examinations or counseling were  
7 considered. Four-digit codes were taken separately only for some alcohol-induced diseases. A  
8 combined category of alcohol-induced diagnoses included mental disorders due to alcohol  
9 (F10), degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy  
10 (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental  
11 poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65), and poisoning by  
12 alcohol, undetermined intent (Y15). The accuracy of the diagnosis was the responsibility of  
13 the physician issuing the invoice to EHIF for ambulatory or hospital care.  
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### 30 **Morbidity measures and statistical analysis**

31 We estimated morbidity in the cleanup workers cohort by means of rate ratio (RR) with 95%  
32 confidence intervals (CI) using **the** Poisson regression models with the logarithm of the  
33 person-years at risk (summed by five-year age groups) as the offset.[21] At first, we  
34 performed analysis comparing the exposed cohort with the unexposed cohort (external  
35 analysis) to obtain an overview of morbidity rate ratios. Diagnoses were grouped into broad  
36 categories with selected specific diagnoses. Analyses were adjusted for age at diagnosis by  
37 five-year age groups.  
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47 Additionally, analysis was done between different subgroups within the exposed cohort  
48 (internal analysis) to assess possible effects of year of arrival **in the** Chernobyl area (1986;  
49 1987–1991), duration of stay (<92; ≥92 days), documented **cumulative** whole-body radiation  
50 dose (<5.0; 5.0–9.9; ≥10.0 cGy), education (higher or secondary; basic or less), and ethnicity  
51 (Estonian; non-Estonian (mainly Russians)) on morbidity risk. **As described elsewhere, [1,**  
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3 22, 23] the cleanup workers were dominantly exposed to  $\gamma$ -radiation released mainly by  $^{131}\text{I}$ ,  
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5  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ . Received radiation doses were measured by individual or group dosimeters,  
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7 or estimated by work area measurements. The readings were documented in the workers'  
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9 military passports/ records. Considering, that documented doses were unreliable,[19] and not  
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11 recorded for 15.2% of the cohort members, we used the year of arrival and duration of stay as  
12  
13 proxy variables for radiation exposure.  
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16 Ethnicity and educational level were included in the analysis as surrogates for health  
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18 behavior. The prevalence of alcohol consumption at least once a week (28.5%) and current  
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20 smoking (69.0%) among the cleanup workers was studied in a postal questionnaire survey  
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22 conducted in 1992–1993,[19] but not included in current analyses due to small cohort size  
23  
24 and lack of longitudinal data on these factors of health behavior.  
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27 **Analyses** within the exposed cohort focused on disease risks previously reported in  
28  
29 atomic-bomb survivors and Chernobyl cleanup workers.[7, 11, 12] The first set of models  
30  
31 included the year of arrival in the Chernobyl area, duration of stay, age at diagnosis,  
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33 education and ethnicity. One hundred and seventy four subjects with missing information for  
34  
35 any characteristic were excluded from the analysis. In the second set of models we included  
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37 documented radiation dose; due to unrecorded values, an additional 452 subjects were  
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39 excluded.  
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43 We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, WA, USA) for database  
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45 management, and Stata 12 (StataCorp LP, College Station, TX, USA) for statistical  
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47 modeling.  
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## 49 50 51 **RESULTS**

### 52 53 54 **Description of the exposed and unexposed cohorts**

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3 We followed 3680 exposed and 7631 unexposed men from January 1, 2004 until December  
4 31, 2012 (Table 1). The exposed and unexposed cohorts contributed 30,674 and 65,112  
5 person-years, respectively. Mean age at the start of follow-up was 48 years in both cohorts.  
6  
7 During the follow-up, 12.9% of the exposed cohort and 10.5% of the unexposed cohort died.  
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9 The proportions of non-Estonians (mainly Russians) and less educated persons were higher in  
10  
11 the exposed cohort, although educational level was unknown for the 16.4% of the subjects in  
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13 the unexposed cohort. Two-thirds of the cleanup workers entered the Chernobyl area in 1986;  
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15 the mean and median durations of the mission were 102 and 92 days, respectively (range: 1–  
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17 833 days). The cohort was exposed to low-level whole-body radiation with the mean and  
18  
19 median documented radiation doses of 9.9 and 8.9 cGy, respectively (range: 0.0–54.5 cGy).  
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25 Nearly all men had at least one record in the EHIF database (93.6% of the exposed and  
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27 95.3% of the unexposed cohort). On average, members of both cohorts had 12 different  
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29 diagnoses (three-digit ICD-10 codes). Men in the exposed cohort had their first health  
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31 services contact on average half a year earlier than their unexposed counterparts (52.1 vs.  
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33 52.6 years of age).  
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36 (Insert Table 1 here)  
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### 38 **Morbidity in the exposed cohort in relation to the unexposed cohort (external analysis)**

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40 In the external analysis (Table 2), we observed a very small increase of borderline  
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42 significance in all-disease risk among Chernobyl cleanup workers (RR=1.01; 95% CI 1.00–  
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44 1.03). From the non-cancer late effects that might be related to the Chernobyl accident  
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46 (UNSCEAR 2011), we found significantly elevated morbidity for diseases of thyroid gland  
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48 (RR=1.69; 95% CI 1.38–2.07) and ischemic heart disease (RR=1.09; 95% CI 1.00–1.18).  
49

50 **There was evidence of lower occurrence of cataract in the exposed cohort.** Stress reactions,  
51  
52 depression, severe headaches and sleep disorders were not diagnosed more frequently in the  
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54 exposed cohort than in the reference cohort.  
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3 Increased morbidity was apparent for the broad categories of diseases of the nervous  
4 system, digestive system, musculoskeletal system, and alcohol-induced diagnoses. Morbidity  
5 from external causes in the exposed cohort exceeded that in the unexposed cohort (RR=1.07;  
6 95% CI 1.03–1.11). Significantly higher morbidity was registered for falls, intentional self-  
7 harm and exposure to excessive cold. Cleanup workers did not undergo medical observations  
8 for suspected diseases (ICD-10 Z03) more frequently than unexposed men (RR=1.06; 95%  
9 CI 0.94–1.19). Additional adjustments for ethnicity and education (rate ratios not presented)  
10 did not materially alter these results.  
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21 (Insert Table 2 here)  
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### 23 Differences between subgroups in the exposed cohort (internal analysis)

24 Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI  
25 1.00–1.62), and severe headaches (RR=1.69; 95% CI 1.10–2.60) among cleanup workers  
26 who entered the area shortly after the accident than in those arriving later (Table 3). Higher  
27 thyroid diseases morbidity was not related to year or month (April-May versus June-  
28 December, 1986) of arrival in the contaminated area. Longer mission did not increase the  
29 morbidity of any disease. Acute myocardial infarction, cerebrovascular diseases, diseases of  
30 liver, calculus of kidney and ureter, headaches, and alcohol-induced morbidity occurred more  
31 frequently among non-Estonians, while mental disorders were more frequent among  
32 Estonians. Less educated cleanup workers had higher risk for diseases of the nervous system,  
33 cerebrovascular diseases, intentional self-harm, and alcohol-induced morbidity, and lower  
34 risk for in situ and benign neoplasms.  
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49 Including education and ethnicity in the model did not alter markedly the crude point  
50 estimates of RR for year of arrival or duration of stay (rate ratios not presented). Higher  
51 documented radiation dose (5.0–9.9 or ≥10.0 vs. <5.0 cGy) was not associated with higher  
52 morbidity of thyroid diseases (RR=0.92; 95% CI 0.60–1.40; 0.92; 0.60–1.40, respectively),  
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3 cataract (RR=1.26; 95% CI 0.80–1.98; 1.13; 0.70–1.83, respectively), or any of the other  
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5 selected diseases.

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7 (Insert Table 3 here)

## 8 9 **DISCUSSION**

10 The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers  
11  
12 revealed elevated morbidity for diseases of the nervous system, digestive system,  
13  
14 musculoskeletal system, ischemic heart disease, and for external causes. The most salient  
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16 excess risk was observed for thyroid diseases, and as expected, for intentional self-harm and  
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18 selected alcohol-induced diagnoses.  
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### 22 23 24 **Limitations**

25 First, this study was limited to morbidity cases in 2004–2012. We had no information about  
26  
27 morbidity prior to this time period. Thus, it was not possible to specify incident cases or  
28  
29 assess early effects of exposure.  
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34 **Second, among** given diseases there could be **tentative and** preliminary diagnoses  
35  
36 unconfirmed afterwards. We are aware of the possibility of diagnostic errors, **upcoding and**  
37  
38 **unbundling of codes** associated with the use of an reimbursement-administrative database,  
39  
40 **originally created not for research purposes, but proved to be an important source for medical**  
41  
42 **studies in Estonia.[24–26]** A small number of cases might have been diagnosed by  
43  
44 commercial health care providers and not reported to the EHIF. However, because of  
45  
46 universal health insurance, these limitations would be expected to affect the exposed and  
47  
48 unexposed cohorts in a similar **fashion. This kind of non-differential misclassification of**  
49  
50 **disease or of disease status probably either does not bias the rate ratio or biases it towards the**  
51  
52 **null. The same may be said in a hypothetical situation when the validity of diagnoses in the**  
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54 **EHIF will be almost perfect. In the last case as the most important, the number and**  
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3 heterogeneity of diagnostic entries would be reduced, and the accuracy of measurements  
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5 improved.  
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8 **Third**, the documented radiation doses are not entirely accurate, and there could be  
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10 incorrect readings in both directions as discussed elsewhere.[2, 19] Although no correlation  
11  
12 was observed between individual doses from military passports (lists) and the biodosimetry  
13  
14 estimates for the sub-cohort of cleanup workers, it is estimated that the cohort was exposed to  
15  
16 low-dose radiation around 0.1 Gy on average.[22, 27] A similar dose level was reported for  
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18 Latvian and Lithuanian Chernobyl cleanup workers.[28] Thus, we used year of arrival and  
19  
20 duration of stay as proxy variables for radiation exposure. Given these limitations, our  
21  
22 conclusions are duly tempered.  
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25 **Fourth**, the small size of the cohort has reduced the power of analysis. In addition,  
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27 because of multiple comparisons, it is possible that some statistically significant findings  
28  
29 could be due to chance.  
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### 31 32 33 **Possible radiation effects?**

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36 Thyroid diseases have been under close surveillance after the Chernobyl accident since  
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38 radioiodine (mainly  $^{131}\text{I}$  with a half-life of eight days) released during the explosion is  
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40 concentrated in the thyroid gland. Ron and Brenner [29] summarized the evidence of benign  
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42 thyroid diseases after radiation exposure. They concluded that associations have been weak  
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44 and elevated risk occurred mainly in subjects with high doses, exposed at young ages, and in  
45  
46 women. Keeping in mind that the cohort of cleanup workers includes only adult men who  
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48 were exposed to low doses, we cannot attribute the thyroid findings to radiation. **This**  
49  
50 **interpretation is supported by the lack of excess among the early entrants or subjects with the**  
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52 **highest documented radiation doses. At the same time, we cannot exclude the possibility that**  
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54 **a higher rate ratio among the cleanup workers is caused by close medical attention sought by**  
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3 **them.** During thyroid screening among the Estonian cleanup workers in 1995, no clear  
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5 correlation was found between the prevalence of thyroid nodules and the year of arrival or  
6  
7 recorded radiation dose.[30] **Moreover, these whole-body external doses have little relevance**  
8  
9 **to thyroid diseases because they are not thyroid doses.**

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12 High radiation doses increase the risk of circulatory diseases, but less is known about the  
13  
14 effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose-response at low dose  
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16 levels is due to paucity of large cohorts with high-quality data on doses and confounders.[10,  
17  
18 31] As the Estonian cohort of cleanup workers is small and with low average radiation dose,  
19  
20 we cannot attribute the small increase in ischemic heart disease morbidity seen in the cohort  
21  
22 to biological effects of radiation exposure. This conclusion is also supported by the mortality  
23  
24 analyses, where no excess deaths from circulatory diseases were found.[2]

25  
26  
27 An increased risk of cataract, observed in atomic-bomb survivors [7] and Ukrainian  
28  
29 cleanup workers,[31] did not emerge in the Estonian cohort. **An observed statistically**  
30  
31 **significant deficit of cataract cases may be an occasional finding without any epidemiological**  
32  
33 **relevance.** Although cataract has been conventionally regarded as a late deterministic effect  
34  
35 of radiation with a threshold dose of 0.5 Gy, recent studies have suggested a need to lower  
36  
37 this dose limit and reconsider the threshold model.[31, 33] Nevertheless, it is unlikely that  
38  
39 radiation-related cataracts will be detectable among the Estonian cleanup workers in the  
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41 future, given the low dose level.  
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#### 47 **Mental and neurological disorders**

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49 Natural or man-made disasters can inflict psychological consequences to the affected  
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51 populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and  
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53 mental health effects such as post-traumatic stress, depression, anxiety, and somatization can  
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55 be long-lasting.[34] After the Chernobyl accident, the mental health of the local population  
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3 and cleanup workers was considered to be the main public health concern.[1, 14] Cleanup  
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5 workers were exposed not only to radiation, but also to the lack of protective gear and to the  
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7 poor living conditions, sometimes doing meaningless jobs, and drinking large amounts of  
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9 alcohol (mainly home-distilled).[19, 35] Misleading or no information about the possible  
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11 long-term health effects generated rumors and misapprehensions, and radiation fears were  
12  
13 exaggerated.[36, 37] The situation bred profound mistrust of all authorities. One of the most  
14  
15 difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific  
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17 information about the radiation risks, as there exists an insuperable gap between the experts'  
18  
19 and public's perceptions about radiation.[38–40]

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22 To date, the persistently elevated suicide risk in the Estonian cohort has been the  
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24 definitive indication of psychological impairment as a result of working as a Chernobyl  
25  
26 cleanup worker.[2] However, the current morbidity analyses showed a mixed pattern of  
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28 mental and neurological disorders. Based on the results from a study of Ukrainian cleanup  
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30 workers,[15] we expected higher rates of depression, anxiety, post-traumatic stress disorder,  
31  
32 and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00),  
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34 or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup  
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36 workers used health care services significantly less frequently for stress reactions than the  
37  
38 unexposed cohort. No excess of severe headaches or sleep disorders was found among  
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40 cleanup workers. However, depression and stress reactions, and severe headaches were more  
41  
42 frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an  
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44 indicator of psychological distress. This finding is consistent with the increased suicide rate  
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46 in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in  
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48 Estonia.[41]

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54 Smoking and heavy alcohol consumption are more prevalent in less educated men in  
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56 Estonia.[42, 43] Although population-based health (behavior) prevalence studies do not  
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3 report differences in smoking and drinking habits between Estonians and non-Estonians,[42,  
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5 43] mortality is higher in non-Estonians,[44] particularly alcohol-related mortality.[45]  
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7 Excess morbidity emerged for alcohol-induced diseases – mental disorders due to alcohol  
8 and degeneration of nervous system due to alcohol. Morbidity from alcohol-induced  
9 diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort.  
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11 Considering common alcohol abuse among men in Estonia (especially with lower educational  
12 level),[43] it is not surprising that cleanup workers used alcohol to cope with stressful  
13 situation, and still do. Higher morbidity due to excessive cold is most likely attributable to  
14 homelessness and suggests that periods of homelessness were more common in cleanup  
15 workers than in men in the comparison cohort. Results of our study demonstrate that the men  
16 with Estonian ethnicity and/ or higher educational level coped better with Chernobyl  
17 consequences including alcohol abuse.  
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29 Although Ukrainian cleanup workers had more mental disorders than controls, no excess  
30 of alcoholism was observed.[15] This illustrates how analysis of similar cohorts with  
31 different design and risk measures can produce entirely opposite results. Very likely, mental  
32 disorders other than alcoholism were under-diagnosed in the Estonian cohort, and the  
33 prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common  
34 that people do not seek professional help for mental health problems.[34] Untreated mental  
35 disorders can manifest as unexplained physical complaints such as headache or back pain, or  
36 they are risk factors for somatic diseases (e.g. thyroid diseases or diseases of the digestive  
37 system).[46, 47] Thus, it is important to pay attention to both mental and somatic diseases of  
38 Chernobyl cleanup workers simultaneously.  
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## 51 52 53 54 **CONCLUSIONS** 55 56 57 58 59 60

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3 No obvious excess morbidity consistent with biological effects of radiation was seen in the  
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5 exposed cohort, with the possible exception of benign thyroid diseases. Increased alcohol-  
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7 induced morbidity reflects alcohol abuse, and could underlie some of the higher morbidity  
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9 rates. Mental disorders in the exposed cohort were probably underreported. The future  
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11 challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup  
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13 workers cohort.  
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26  
27 drafted the manuscript. EB, TH, AA, AU and MR contributed to the interpretation of the  
28  
29 results and revised critically the manuscript. MR supervised the whole process. All authors  
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31 have seen and approved the final version of the manuscript.  
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51  
52 1939, February 11, 2010), and by the Estonian Data Protection Inspectorate (no. 2.2-  
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54 3/10/120r, April 9, 2010).  
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Table 1 Characteristics of the Estonian cohort of Chernobyl cleanup workers (exposed cohort) and the unexposed **comparison** cohort

Characteristic	Exposed cohort		Unexposed cohort	
	No.	(%)	No.	(%)
Total	3680	(100)	7631	(100)
Vital status on December 31, 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)		

Table 2 Number of morbidity cases\* and age-adjusted morbidity rate ratios† (RR) with 95% confidence intervals (CI) 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		RR (95% CI)
		Exposed cohort	Unexposed cohort	
A00–R99, V01–Z99	All diagnoses and external causes	41,370	86,441	1.02 (1.01–1.03)‡
A00–R99, except C00–C97	All diseases, except cancer	31,757	66,799	1.01 (1.00–1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88–1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81–1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94–1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84–1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90–1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38–2.07)‡
F00–F99	Mental disorders	1380	2918	1.00 (0.94–1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06–1.39)‡
F32–F33	Depressive disorders	290	633	0.97 (0.84–1.11)
F41	Anxiety disorders	119	275	0.91 (0.74–1.13)
F43	Stress reactions	55	162	0.72 (0.53–0.97)‡
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06–1.21)‡
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04–2.18)‡
G40	Epilepsy	148	223	1.40 (1.14–1.73)‡
G43–G44	Migraine and other headache	125	256	1.03 (0.83–1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02–1.29)‡
F51, G47	Sleep disorders	267	529	1.08 (0.93–1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89–0.98)‡
H25–H26, H28	Cataract	155	449	0.77 (0.64–0.92)‡
H40, H42	Glaucoma	109	247	0.96 (0.77–1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91–1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97–1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93–1.04)
I20–I25	Ischemic heart disease	773	1537	1.09 (1.00–1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83–1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91–1.20)
J00–J99	Diseases of the respiratory system	4699	10,079	0.99 (0.95–1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79–0.96)‡
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00–1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07–1.16)‡
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06–1.21)‡
K25–K27	Peptic ulcer	464	857	1.15 (1.02–1.28)‡
K70–K77	Diseases of liver	194	357	1.16 (0.97–1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91–1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02–1.58)‡
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77–2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97–1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12,623	1.06 (1.03–1.09)‡
M15–M19	Arthrosis	925	1881	1.06 (0.98–1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04–1.18)‡
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84–0.95)‡
N20	Calculus of kidney and ureter	140	321	0.93 (0.76–1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79–0.99)‡
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94–1.09)
V01–Y98	External causes of morbidity	5084	10,055	1.07 (1.03–1.11)‡
V01–V99	Transport accidents	171	423	0.85 (0.71–1.02)
W00–W19	Falls	2010	3817	1.11 (1.06–1.18)‡
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98–1.09)
X31	Excessive cold	26	32	1.74 (1.04–2.92)‡
X40–X49	Accidental poisoning	34	69	1.05 (0.69–1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04–2.09)‡
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96–1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94–1.19)
F10, G31.2, I42.6, K70,	Selected alcohol-induced diagnoses and	528	896	1.25 (1.12–1.39)‡

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3 K86.0, X45, X65, Y15 external causes of morbidity

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4 \* The first occurrence of the three-digit ICD-10 code in the study period was considered.

5 † Adjusted for age at diagnosis.

6 ‡ p<0.05

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Table 3 Adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) 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	Duration of stay	Ethnicity	Education
		1986†	≥92 days†	Non-Estonian†	Basic or less†
D00–D48	In situ and benign neoplasms	1.15 (0.95–1.39)	0.77 (0.64–0.92)‡	1.09 (0.91–1.30)	0.76 (0.61–0.96)‡
E00–E07	Diseases of thyroid gland	0.94 (0.68–1.31)	1.00 (0.73–1.38)	0.85 (0.62–1.17)	0.82 (0.55–1.22)
F00–F99	Mental disorders	1.08 (0.96–1.21)	0.85 (0.76–0.95)‡	0.82 (0.74–0.92)‡	1.11 (0.97–1.27)
F32–F33, F43	Depressive disorders and stress reactions	1.27 (1.00–1.62)	0.72 (0.58–0.90)‡	0.53 (0.41–0.67)‡	0.88 (0.66–1.17)
G00–G99	Diseases of the nervous system	1.01 (0.90–1.13)	0.93 (0.83–1.04)	0.97 (0.87–1.09)	1.20 (1.05–1.37)‡
G43–G44	Migraine and other headache	1.69 (1.10–2.60)‡	0.79 (0.55–1.14)	1.48 (1.03–2.12)‡	0.97 (0.59–1.58)
H25–H26, H28	Cataract	1.07 (0.77–1.49)	1.05 (0.76–1.45)	1.29 (0.93–1.77)	0.93 (0.65–1.33)
H40, H42	Glaucoma	1.26 (0.83–1.89)	0.78 (0.52–1.15)	1.20 (0.81–1.78)	0.80 (0.51–1.27)
I10–I15	Hypertensive diseases	1.03 (0.94–1.14)	0.92 (0.84–1.01)	1.07 (0.98–1.17)	0.99 (0.88–1.11)
I20–I25	Ischemic heart disease	1.15 (0.99–1.34)	0.81 (0.70–0.94)‡	1.12 (0.97–1.30)	1.10 (0.93–1.30)
I21	Acute myocardial infarction	1.11 (0.74–1.68)	0.94 (0.63–1.39)	1.53 (1.03–2.26)‡	1.17 (0.74–1.83)
I60–I69	Cerebrovascular diseases	1.11 (0.86–1.42)	1.03 (0.81–1.42)	1.65 (1.30–2.11)‡	1.61 (1.25–2.08)‡
K70–K77	Diseases of liver	1.13 (0.82–1.54)	1.13 (0.84–1.51)	1.42 (1.07–1.90)‡	1.12 (0.79–1.58)
N20	Calculus of kidney and ureter	1.08 (0.74–1.57)	0.88 (0.62–1.26)	1.99 (1.39–2.85)‡	0.73 (0.45–1.19)
X60–X84	Intentional self-harm	1.27 (0.68–2.36)	0.77 (0.43–1.37)	1.43 (0.82–2.52)	2.73 (1.48–5.05)‡
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	0.92 (0.76–1.11)	0.98 (0.82–1.17)	1.37 (1.15–1.63)‡	1.76 (1.44–2.15)‡

\* 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.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of *cohort studies*

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study's design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5
		(b) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	7-8
Study size	10	Explain how the study size was arrived at	5-6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-8
		(b) Describe any methods used to examine subgroups and interactions	7-8
		(c) Explain how missing data were addressed	7-8
		(d) If applicable, explain how loss to follow-up was addressed	no losses (Table 1)
		(e) Describe any sensitivity analyses	
<b>Results</b>			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, Table 1
		(b) Give reasons for non-participation at each stage	5-6
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	8, Table 1
		(c) Summarise follow-up time (eg, average and total amount)	8, Table 1
Outcome data	15*	Report numbers of outcome events or summary measures over time	8, Table 2
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-10, Table 2-3
		(b) Report category boundaries when continuous variables were categorized	8
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-10, Table 3
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10
<b>Limitations</b>			10-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
<b>Other information</b>			14-15
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).



# BMJ Open

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

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Keywords:	alcohol-induced disorders, Chernobyl nuclear accident, Estonia, MENTAL HEALTH, morbidity, radiation effects

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3 **Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based**  
4 **cohort study**  
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50 morbidity, radiation effects  
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## ABSTRACT

**Objective:** To examine non-cancer morbidity in the Estonian Chernobyl cleanup workers cohort compared to 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 2004–2012 through the Population Registry and Health Insurance Fund database.

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

**Results:** Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischemic heart disease, and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38–2.07), intentional self-harm (RR=1.47; 95% CI 1.04–2.09), and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12–1.39). 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

## ARTICLE SUMMARY

### Article focus

- There is limited information about the impact of the Chernobyl accident on the non-cancer morbidity among the cleanup workers. Earlier studies of Estonian cleanup workers revealed an excess of suicide.
- This study provides insight into non-cancer morbidity in the cohort of Estonian cleanup workers with emphasis on radiation-related diseases and mental health disorders.

### Key messages

- No obvious excess morbidity consistent with biological effects of radiation was found in the cleanup workers cohort, with the possible exception of benign thyroid diseases.
- Increased alcohol-induced morbidity in the cleanup workers cohort may reflect alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably underreported.

### 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.
- 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; probable overestimation of findings due to multiple comparisons.

## 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 three 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 ionizing 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 dose of 0.5 Gy was not significant.[3] Follow-up of nuclear industry workers from 15 countries resulted with no significant findings for a dose-dependent rise in mortality from circulatory diseases.[4] Elevated risk of death for the broad categories 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 in atomic-bomb survivors found significant radiation effects for thyroid diseases, liver disease, 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 ischemic 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-

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3 dependent risk for ischemic heart disease, cerebrovascular diseases and other circulatory  
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5 diseases.

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

16  
17 Although the psychological aftermath of the Chernobyl accident has been acknowledged  
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19 as the major long-term public health problem in the exposed populations,[1, 14] the mental  
20  
21 health of cleanup workers has only been assessed in small-scale studies in Ukraine.[15–16]  
22  
23 There is an urgent need to examine mental health along with somatic diseases when  
24  
25 considering the health of cleanup workers.[16]

26  
27 An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort  
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29 revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has  
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31 been persistently elevated since the beginning of follow-up.[17, 18] The current research  
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33 provides the first overview of morbidity other than cancer in the Estonian cohort of  
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35 Chernobyl cleanup workers with special attention to radiation-related diseases and mental  
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37 health disorders.  
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## 45 **METHODS**

### 46 **Sample and follow-up**

47  
48 The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men  
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50 recruited in 1986–1991 to the Chernobyl area by the Soviet authorities for decontamination,  
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52 building and other related activities. The “Chernobyl area” here denotes the 30-km zone (an  
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54 area of 30-km radius from the nuclear power station) and territories outside, where the  
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3 workers were engaged with different activities during their mission period. Detailed  
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5 information on the assembly and description of the cohort is given elsewhere.[19] To  
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7 examine morbidity in this cohort, we used data from the Estonian Health Insurance Fund  
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9 (EHIF) database available since January 2004. Thus, for the morbidity analyses we identified  
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11 all cohort members aged 35–69 years and living in Estonia on January 1, 2004. Altogether, of  
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13 4831 men in the initial cohort, 1129 were excluded because of loss in follow-up (21), death  
14  
15 (602) and emigration (506). In addition, we did not include men aged under 35 (9) and over  
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17 69 years (13) to have more homogeneous age group. This left just 3680 cleanup workers in  
18  
19 the study. An unexposed population-based comparison cohort was selected corresponding to  
20  
21 the age distribution of the exposed cohort. A random sample stratified by 5-year age groups  
22  
23 with the exposed to unexposed ratio of 1:2 and 5% extra men in each age group was extracted  
24  
25 from the Estonian Population Registry (EPR). In the unexposed cohort, after excluding 87  
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27 men who had worked in the Chernobyl area (cleanup workers), there remained 7631 men.  
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31  
32 The cohort of cleanup workers was linked to the EPR to update vital status (emigration or  
33  
34 death with corresponding date), ethnicity and education. Each person in both cohorts was  
35  
36 followed up from January 1, 2004 until death, emigration or December 31, 2012 (whichever  
37  
38 date came first). From the EHIF database, we obtained dates and ICD-10 codes for each  
39  
40 contact with a health provider. All linkages were performed using the unique personal  
41  
42 identification number (assigned to all permanent residents of Estonia) as the key variable.  
43  
44 EHIF manages the mandatory universal health insurance system that is based on solidarity  
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46 and covers 95% of the Estonian population.[20] All employees and self-employed persons  
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48 contribute 13% of their wages, some groups of the population are financed by the State (e.g.  
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50 registered unemployed, Chernobyl veterans), and some groups are insured without  
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52 contribution (e.g. children, students, pensioners). People without coverage from the above  
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54 mentioned sources can pay the tax voluntarily.  
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3 Health care contacts were identified from the EHIF database for 2004–2012 using the  
4 first occurrence of the three-digit ICD-10 code. If the contact involved multiple diagnoses,  
5 the first occurrence of each of them was separately counted. All diseases (except cancer,  
6 ICD-10 C00–C97), external causes of morbidity, and examinations or counseling were  
7 considered. Four-digit codes were taken separately only for some alcohol-induced diseases. A  
8 combined category of alcohol-induced diagnoses included mental disorders due to alcohol  
9 (F10), degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy  
10 (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental  
11 poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65), and poisoning by  
12 alcohol, undetermined intent (Y15). The accuracy of the diagnosis was the responsibility of  
13 the physician issuing the invoice to EHIF for ambulatory or hospital care.  
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### 30 **Morbidity measures and statistical analysis**

31 We estimated morbidity in the cleanup workers cohort by means of rate ratio (RR) with 95%  
32 confidence intervals (CI) using the Poisson regression models with the logarithm of the  
33 person-years at risk (summed by five-year age groups) as the offset.[21] At first, we  
34 performed analysis comparing the exposed cohort with the unexposed cohort (external  
35 analysis) to obtain an overview of morbidity rate ratios. Diagnoses were grouped into broad  
36 categories with selected specific diagnoses. Analyses were adjusted for age at diagnosis by  
37 five-year age groups.  
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47 Additionally, analysis was done between different subgroups within the exposed cohort  
48 (internal analysis) to assess possible effects of year of arrival in the Chernobyl area (1986;  
49 1987–1991), duration of stay (<92; ≥92 days), and documented cumulative whole-body  
50 radiation dose (<5.0; 5.0–9.9; ≥10.0 cGy) on morbidity risk. As described elsewhere, [1, 22,  
51 23] the cleanup workers were dominantly exposed to  $\gamma$ -radiation released mainly by  $^{131}\text{I}$ ,  
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3  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ . Received radiation doses were measured by individual or group dosimeters,  
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5 or estimated by work area measurements. The readings were documented in the workers'  
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7 military passports/ records. Considering, that documented doses were unreliable,[19] and not  
8  
9 recorded for 15.2% of the cohort members, we used the year of arrival and duration of stay as  
10  
11 proxy variables for radiation exposure.  
12

13  
14 Potential confounders – educational level (higher or secondary; basic or less) and  
15  
16 ethnicity (Estonian; non-Estonian (mainly Russians)) – were included in the analysis as  
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18 surrogates for health behavior. The prevalence of alcohol consumption at least once a week  
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20 (28.5%) and current smoking (69.0%) among the cleanup workers was studied in a postal  
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22 questionnaire survey conducted in 1992–1993,[19] but not included in current analyses due to  
23  
24 small cohort size and lack of longitudinal data on these factors of health behavior. Thus, the  
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26 selection of variables (potential confounders) was determined by the availability of them and  
27  
28 a review of our previous studies.  
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32 Analyses within the exposed cohort focused on disease risks previously reported in  
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34 atomic-bomb survivors and Chernobyl cleanup workers.[7, 11, 12] The first set of models  
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36 included the year of arrival in the Chernobyl area, duration of stay, age at diagnosis,  
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38 education and ethnicity. One hundred and seventy four subjects with missing information for  
39  
40 any characteristic were excluded from the analysis. In the second set of models we included  
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42 documented radiation dose; due to unrecorded values, an additional 452 subjects were  
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44 excluded.  
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48 We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, WA, USA) for database  
49  
50 management, and Stata 12 (StataCorp LP, College Station, TX, USA) for statistical  
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52 modeling.  
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## 55 56 **RESULTS**

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### Description of the exposed and unexposed cohorts

We followed 3680 exposed and 7631 unexposed men from January 1, 2004 until December 31, 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 the 16.4% of the subjects 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 (three-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).

(Insert Table 1 here)

### 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 1.00–1.03). From the non-cancer late effects that might be related to the Chernobyl accident (UNSCEAR 2011), we found significantly elevated morbidity for diseases of thyroid gland (RR=1.69; 95% CI 1.38–2.07) and ischemic heart disease (RR=1.09; 95% CI 1.00–1.18). There was evidence of lower occurrence of cataract in the exposed cohort. Stress reactions,

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3 depression, severe headaches and sleep disorders were not diagnosed more frequently in the  
4  
5 exposed cohort than in the reference cohort.  
6

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8 Increased morbidity was apparent for the broad categories of diseases of the nervous  
9  
10 system, digestive system, musculoskeletal system, and alcohol-induced diagnoses. Morbidity  
11  
12 from external causes in the exposed cohort exceeded that in the unexposed cohort (RR=1.07;  
13  
14 95% CI 1.03–1.11). Significantly higher morbidity was registered for falls, intentional self-  
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16 harm and exposure to excessive cold. Cleanup workers did not undergo medical observations  
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18 for suspected diseases (ICD-10 Z03) more frequently than unexposed men (RR=1.06; 95%  
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20 CI 0.94–1.19). Additional adjustments for ethnicity and education (rate ratios not presented)  
21  
22 did not materially alter these results.  
23

24  
25 (Insert Table 2 here)  
26

### 27 **Differences between subgroups in the exposed cohort (internal analysis)**

28  
29 Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI  
30  
31 1.00–1.62), and severe headaches (RR=1.69; 95% CI 1.10–2.60) among cleanup workers  
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33 who entered the area shortly after the accident than in those arriving later (Table 3). Higher  
34  
35 thyroid diseases morbidity was not related to year or month (April-May versus June-  
36  
37 December, 1986) of arrival in the contaminated area. Longer mission did not increase the  
38  
39 morbidity of any disease. Acute myocardial infarction, cerebrovascular diseases, diseases of  
40  
41 liver, calculus of kidney and ureter, headaches, and alcohol-induced morbidity occurred more  
42  
43 frequently among non-Estonians, while mental disorders were more frequent among  
44  
45 Estonians. Less educated cleanup workers had higher risk for diseases of the nervous system,  
46  
47 cerebrovascular diseases, intentional self-harm, and alcohol-induced morbidity, and lower  
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49 risk for in situ and benign neoplasms.  
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54 Including education and ethnicity in the model did not alter markedly the crude point  
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56 estimates of RR for year of arrival or duration of stay (rate ratios not presented). Higher  
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3 documented radiation dose (5.0–9.9 or  $\geq 10.0$  vs.  $< 5.0$  cGy) was not associated with higher  
4 morbidity of thyroid diseases (RR=0.92; 95% CI 0.60–1.40; 0.92; 0.60–1.40, respectively),  
5  
6 cataract (RR=1.26; 95% CI 0.80–1.98; 1.13; 0.70–1.83, respectively), or any of the other  
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8 selected diseases.  
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12 (Insert Table 3 here)  
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## 14 **DISCUSSION**

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16 The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers  
17 revealed elevated morbidity for diseases of the nervous system, digestive system,  
18 musculoskeletal system, ischemic heart disease, and for external causes. The most salient  
19 excess risk was observed for thyroid diseases, and as expected, for intentional self-harm and  
20 selected alcohol-induced diagnoses.  
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### 30 **Limitations**

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32 First, this study was limited to morbidity cases in 2004–2012. We had no information about  
33 morbidity prior to this time period. Thus, it was not possible to specify incident cases or  
34 assess early effects of exposure.  
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39 Second, among given diseases there could be tentative and preliminary diagnoses  
40 unconfirmed afterwards. We are aware of the possibility of diagnostic errors, upcoding and  
41 unbundling of codes associated with the use of a reimbursement-administrative database,  
42 originally created not for research purposes, but proved to be an important source for medical  
43 studies in Estonia.[24–26] A small number of cases might have been diagnosed by  
44 commercial health care providers and not reported to the EHIF. However, because of  
45 universal health insurance, these limitations would be expected to affect the exposed and  
46 unexposed cohorts in a similar fashion. This kind of non-differential misclassification of  
47 disease or of disease status probably either does not bias the rate ratio or biases it towards the  
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3 null. The same may be said in a hypothetical situation when the validity of diagnoses in the  
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5 EHIF will be almost perfect. In the last case as the most important, the number and  
6  
7 heterogeneity of diagnostic entries would be reduced, and the accuracy of measurements  
8  
9 improved.

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11 Third, the documented radiation doses are not entirely accurate, and there could be  
12  
13 incorrect readings in both directions as discussed elsewhere.[2, 19] Although no correlation  
14  
15 was observed between individual doses from military passports (lists) and the biodosimetry  
16  
17 estimates for the sub-cohort of cleanup workers, it is estimated that the cohort was exposed to  
18  
19 low-dose radiation around 0.1 Gy on average.[22, 27] A similar dose level was reported for  
20  
21 Latvian and Lithuanian Chernobyl cleanup workers.[28] Thus, we used year of arrival and  
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23 duration of stay as proxy variables for radiation exposure.  
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27 Fourth, the small size of the cohort has reduced the power of analysis. In addition,  
28  
29 because of multiple comparisons, it is possible that some statistically significant findings  
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31 could be due to chance. Given these limitations, our conclusions are duly tempered.  
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### 34 35 36 **Possible radiation effects?**

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38 Thyroid diseases have been under close surveillance after the Chernobyl accident since  
39  
40 radioiodine (mainly <sup>131</sup>I with a half-life of eight days) released during the explosion is  
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42 concentrated in the thyroid gland. Ron and Brenner [29] summarized the evidence of benign  
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44 thyroid diseases after radiation exposure. They concluded that associations have been weak  
45  
46 and elevated risk occurred mainly in subjects with high doses, exposed at young ages, and in  
47  
48 women. Keeping in mind that the cohort of cleanup workers includes only adult men who  
49  
50 were exposed to low doses, we cannot attribute the thyroid findings to radiation. This  
51  
52 interpretation is supported by the lack of excess among the early entrants or subjects with the  
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54 highest documented radiation doses. At the same time, we cannot exclude the possibility that  
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3 a higher rate ratio among the cleanup workers is caused by close medical attention sought by  
4 them. During thyroid screening among the Estonian cleanup workers in 1995, no clear  
5 correlation was found between the prevalence of thyroid nodules and the year of arrival or  
6 recorded radiation dose.[30]  
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11 High radiation doses increase the risk of circulatory diseases, but less is known about the  
12 effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose-response at low dose  
13 levels is due to paucity of large cohorts with high-quality data on doses and confounders.[10,  
14 31] As the Estonian cohort of cleanup workers is small and with low average radiation dose,  
15 we cannot attribute the small increase in ischemic heart disease morbidity seen in the cohort  
16 to biological effects of radiation exposure. This conclusion is also supported by the mortality  
17 analyses, where no excess deaths from circulatory diseases were found.[2]  
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27 An increased risk of cataract, observed in atomic-bomb survivors [7] and Ukrainian  
28 cleanup workers,[32] did not emerge in the Estonian cohort. An observed statistically  
29 significant deficit of cataract cases may be an occasional finding without any epidemiological  
30 relevance. Although cataract has been conventionally regarded as a late deterministic effect  
31 of radiation with a threshold dose of 0.5 Gy, recent studies have suggested a need to lower  
32 this dose limit and reconsider the threshold model.[31, 33] Nevertheless, it is unlikely that  
33 radiation-related cataracts will be detectable among the Estonian cleanup workers in the  
34 future, given the low dose level.  
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#### 47 **Mental and neurological disorders**

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49 Natural or man-made disasters can inflict psychological consequences to the affected  
50 populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and  
51 mental health effects such as post-traumatic stress, depression, anxiety, and somatization can  
52 be long-lasting.[34] After the Chernobyl accident, the mental health of the local population  
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3 and cleanup workers was considered to be the main public health concern.[1, 14] Cleanup  
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5 workers were exposed not only to radiation, but also to the lack of protective gear and to the  
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7 poor living conditions, sometimes doing meaningless jobs, and drinking large amounts of  
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9 alcohol (mainly home-distilled).[19, 35] Misleading or no information about the possible  
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11 long-term health effects generated rumors and misapprehensions, and radiation fears were  
12  
13 exaggerated.[36, 37] The situation bred profound mistrust of all authorities. One of the most  
14  
15 difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific  
16  
17 information about the radiation risks, as there exists an insuperable gap between the experts'  
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19 and public's perceptions about radiation.[38–40]  
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23 To date, the persistently elevated suicide risk in the Estonian cohort has been the  
24  
25 definitive indication of psychological impairment as a result of working as a Chernobyl  
26  
27 cleanup worker.[2] However, the current morbidity analyses showed a mixed pattern of  
28  
29 mental and neurological disorders. Based on the results from a study of Ukrainian cleanup  
30  
31 workers,[15] we expected higher rates of depression, anxiety, post-traumatic stress disorder,  
32  
33 and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00),  
34  
35 or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup  
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37 workers used health care services significantly less frequently for stress reactions than the  
38  
39 unexposed cohort. No excess of severe headaches or sleep disorders was found among  
40  
41 cleanup workers. However, depression and stress reactions, and severe headaches were more  
42  
43 frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an  
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45 indicator of psychological distress. This finding is consistent with the increased suicide rate  
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47 in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in  
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49 Estonia.[41]  
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54 Smoking and heavy alcohol consumption are more prevalent in less educated men in  
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56 Estonia.[42, 43] Although population-based health (behavior) prevalence studies do not  
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3 report differences in smoking and drinking habits between Estonians and non-Estonians,[42,  
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5 43] mortality is higher in non-Estonians,[44] particularly alcohol-related mortality.[45]  
6

7 Excess morbidity emerged for alcohol-induced diseases – mental disorders due to alcohol  
8 and degeneration of nervous system due to alcohol. Morbidity from alcohol-induced  
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10 diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort.  
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12 Considering common alcohol abuse among men in Estonia (especially with lower educational  
13  
14 level),[43] it is not surprising that cleanup workers used alcohol to cope with stressful  
15  
16 situation, and still do. Higher morbidity due to excessive cold is most likely attributable to  
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18 homelessness and suggests that periods of homelessness were more common in cleanup  
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20 workers than in men in the comparison cohort. Results of our study demonstrate that the men  
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22 with Estonian ethnicity and/ or higher educational level coped better with Chernobyl  
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24 consequences including alcohol abuse.  
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29 Although Ukrainian cleanup workers had more mental disorders than controls, no excess  
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31 of alcoholism was observed.[15] This illustrates how analysis of similar cohorts with  
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33 different design and risk measures can produce entirely opposite results. Very likely, mental  
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35 disorders other than alcoholism were under-diagnosed in the Estonian cohort, and the  
36  
37 prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common  
38  
39 that people do not seek professional help for mental health problems.[34] Untreated mental  
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41 disorders can manifest as unexplained physical complaints such as headache or back pain, or  
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43 they are risk factors for somatic diseases (e.g. thyroid diseases or diseases of the digestive  
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45 system).[46, 47] Thus, it is important to pay attention to both mental and somatic diseases of  
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47 Chernobyl cleanup workers simultaneously.  
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## 52 53 54 **CONCLUSIONS**



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3 No obvious excess morbidity consistent with biological effects of radiation was seen in the  
4  
5 exposed cohort, with the possible exception of benign thyroid diseases. Increased alcohol-  
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7 induced morbidity reflects alcohol abuse, and could underlie some of the higher morbidity  
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9 rates. Mental disorders in the exposed cohort were probably underreported. The future  
10  
11 challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup  
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13 workers cohort.  
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21  
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26  
27 drafted the manuscript. EB, TH, AA, AU and MR contributed to the interpretation of the  
28  
29 results and revised critically the manuscript. MR supervised the whole process. All authors  
30  
31 have seen and approved the final version of the manuscript.  
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51  
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54 3/10/120r, April 9, 2010).  
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Table 1 Characteristics of the Estonian cohort of Chernobyl cleanup workers (exposed cohort) and the unexposed comparison cohort

Characteristic	Exposed cohort		Unexposed cohort	
	No.	(%)	No.	(%)
Total	3680	(100)	7631	(100)
Vital status on December 31, 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)		

Table 2 Number of morbidity cases\* and age-adjusted morbidity rate ratios† (RR) with 95% confidence intervals (CI) 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		RR (95% CI)
		Exposed cohort	Unexposed cohort	
A00–R99, V01–Z99	All diagnoses and external causes	41,370	86,441	1.02 (1.01–1.03)‡
A00–R99, except C00–C97	All diseases, except cancer	31,757	66,799	1.01 (1.00–1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88–1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81–1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94–1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84–1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90–1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38–2.07)‡
F00–F99	Mental disorders	1380	2918	1.00 (0.94–1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06–1.39)‡
F32–F33	Depressive disorders	290	633	0.97 (0.84–1.11)
F41	Anxiety disorders	119	275	0.91 (0.74–1.13)
F43	Stress reactions	55	162	0.72 (0.53–0.97)‡
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06–1.21)‡
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04–2.18)‡
G40	Epilepsy	148	223	1.40 (1.14–1.73)‡
G43–G44	Migraine and other headache	125	256	1.03 (0.83–1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02–1.29)‡
F51, G47	Sleep disorders	267	529	1.08 (0.93–1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89–0.98)‡
H25–H26, H28	Cataract	155	449	0.77 (0.64–0.92)‡
H40, H42	Glaucoma	109	247	0.96 (0.77–1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91–1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97–1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93–1.04)
I20–I25	Ischemic heart disease	773	1537	1.09 (1.00–1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83–1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91–1.20)
J00–J99	Diseases of the respiratory system	4699	10,079	0.99 (0.95–1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79–0.96)‡
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00–1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07–1.16)‡
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06–1.21)‡
K25–K27	Peptic ulcer	464	857	1.15 (1.02–1.28)‡
K70–K77	Diseases of liver	194	357	1.16 (0.97–1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91–1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02–1.58)‡
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77–2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97–1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12,623	1.06 (1.03–1.09)‡
M15–M19	Arthrosis	925	1881	1.06 (0.98–1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04–1.18)‡
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84–0.95)‡
N20	Calculus of kidney and ureter	140	321	0.93 (0.76–1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79–0.99)‡
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94–1.09)
V01–Y98	External causes of morbidity	5084	10,055	1.07 (1.03–1.11)‡
V01–V99	Transport accidents	171	423	0.85 (0.71–1.02)
W00–W19	Falls	2010	3817	1.11 (1.06–1.18)‡
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98–1.09)
X31	Excessive cold	26	32	1.74 (1.04–2.92)‡
X40–X49	Accidental poisoning	34	69	1.05 (0.69–1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04–2.09)‡
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96–1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94–1.19)
F10, G31.2, I42.6, K70,	Selected alcohol-induced diagnoses and	528	896	1.25 (1.12–1.39)‡



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3 K86.0, X45, X65, Y15 external causes of morbidity

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4 \* The first occurrence of the three-digit ICD-10 code in the study period was considered.

5 † Adjusted for age at diagnosis.

6 ‡ p<0.05

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Table 3 Adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) 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	Duration of stay	Ethnicity	Education
		1986 <sup>†</sup>	≥92 days <sup>†</sup>	Non-Estonian <sup>†</sup>	Basic or less <sup>†</sup>
D00–D48	In situ and benign neoplasms	1.15 (0.95–1.39)	0.77 (0.64–0.92) <sup>‡</sup>	1.09 (0.91–1.30)	0.76 (0.61–0.96) <sup>‡</sup>
E00–E07	Diseases of thyroid gland	0.94 (0.68–1.31)	1.00 (0.73–1.38)	0.85 (0.62–1.17)	0.82 (0.55–1.22)
F00–F99	Mental disorders	1.08 (0.96–1.21)	0.85 (0.76–0.95) <sup>‡</sup>	0.82 (0.74–0.92) <sup>‡</sup>	1.11 (0.97–1.27)
F32–F33, F43	Depressive disorders and stress reactions	1.27 (1.00–1.62)	0.72 (0.58–0.90) <sup>‡</sup>	0.53 (0.41–0.67) <sup>‡</sup>	0.88 (0.66–1.17)
G00–G99	Diseases of the nervous system	1.01 (0.90–1.13)	0.93 (0.83–1.04)	0.97 (0.87–1.09)	1.20 (1.05–1.37) <sup>‡</sup>
G43–G44	Migraine and other headache	1.69 (1.10–2.60) <sup>‡</sup>	0.79 (0.55–1.14)	1.48 (1.03–2.12) <sup>‡</sup>	0.97 (0.59–1.58)
H25–H26, H28	Cataract	1.07 (0.77–1.49)	1.05 (0.76–1.45)	1.29 (0.93–1.77)	0.93 (0.65–1.33)
H40, H42	Glaucoma	1.26 (0.83–1.89)	0.78 (0.52–1.15)	1.20 (0.81–1.78)	0.80 (0.51–1.27)
I10–I15	Hypertensive diseases	1.03 (0.94–1.14)	0.92 (0.84–1.01)	1.07 (0.98–1.17)	0.99 (0.88–1.11)
I20–I25	Ischemic heart disease	1.15 (0.99–1.34)	0.81 (0.70–0.94) <sup>‡</sup>	1.12 (0.97–1.30)	1.10 (0.93–1.30)
I21	Acute myocardial infarction	1.11 (0.74–1.68)	0.94 (0.63–1.39)	1.53 (1.03–2.26) <sup>‡</sup>	1.17 (0.74–1.83)
I60–I69	Cerebrovascular diseases	1.11 (0.86–1.42)	1.03 (0.81–1.42)	1.65 (1.30–2.11) <sup>‡</sup>	1.61 (1.25–2.08) <sup>‡</sup>
K70–K77	Diseases of liver	1.13 (0.82–1.54)	1.13 (0.84–1.51)	1.42 (1.07–1.90) <sup>‡</sup>	1.12 (0.79–1.58)
N20	Calculus of kidney and ureter	1.08 (0.74–1.57)	0.88 (0.62–1.26)	1.99 (1.39–2.85) <sup>‡</sup>	0.73 (0.45–1.19)
X60–X84	Intentional self-harm	1.27 (0.68–2.36)	0.77 (0.43–1.37)	1.43 (0.82–2.52)	2.73 (1.48–5.05) <sup>‡</sup>
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	0.92 (0.76–1.11)	0.98 (0.82–1.17)	1.37 (1.15–1.63) <sup>‡</sup>	1.76 (1.44–2.15) <sup>‡</sup>

\* Models include age at diagnosis, year of arrival, duration of stay, ethnicity, and education.

<sup>†</sup> The reference categories for these variables are as follows: year of arrival 1987–1991; duration of stay <92 days; ethnicity Estonian; education higher/ secondary.

<sup>‡</sup> p<0.05.

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3 **Non-cancer morbidity among Estonian Chernobyl cleanup workers: a register-based**  
4 **cohort study**  
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50 **Keywords:** alcohol-induced disorders, Chernobyl nuclear accident, Estonia, mental health,  
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54 **Running head:** Morbidity among Estonian Chernobyl cleanup workers  
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**ABSTRACT**

**Objective:** To examine non-cancer morbidity in the Estonian Chernobyl cleanup workers cohort compared to 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 2004–2012 through the Population Registry and Health Insurance Fund database.

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

**Results:** Elevated morbidity in the exposed cohort was found for diseases of the nervous system, digestive system, musculoskeletal system, ischemic heart disease, and for external causes. The most salient excess risk was observed for thyroid diseases (RR=1.69; 95% CI 1.38–2.07), intentional self-harm (RR=1.47; 95% CI 1.04–2.09), and selected alcohol-related diagnoses (RR=1.25; 95% CI 1.12–1.39). 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

## ARTICLE SUMMARY

### Article focus

- There is limited information about the impact of the Chernobyl accident on the non-cancer morbidity among the cleanup workers. Earlier studies of Estonian cleanup workers revealed an excess of suicide.
- This study provides insight into non-cancer morbidity in the cohort of Estonian cleanup workers with emphasis on radiation-related diseases and mental health disorders.

### Key messages

- No obvious excess morbidity consistent with biological effects of radiation was found in the cleanup workers cohort, with the possible exception of benign thyroid diseases.
- Increased alcohol-induced morbidity in the cleanup workers cohort may reflect alcohol abuse, and could underlie some of the higher morbidity rates. Mental disorders in the exposed cohort were probably underreported.

### 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.
- 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**; probable overestimation of findings due to multiple comparisons.

## 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 three 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 ionizing 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 dose of 0.5 Gy was not significant.[3] Follow-up of nuclear industry workers from 15 countries resulted with no significant findings for a dose-dependent rise in mortality from circulatory diseases.[4] Elevated risk of death for the broad categories 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 in atomic-bomb survivors found significant radiation effects for thyroid diseases, liver disease, 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 ischemic 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-

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3 dependent risk for ischemic heart disease, cerebrovascular diseases and other circulatory  
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5 diseases.  
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8 Analyses of non-cancer morbidity in a cohort of Russian Chernobyl cleanup workers have  
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10 shown dose-dependent excess (per 1 Gy) for endocrine and metabolic diseases, mental  
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12 disorders, diseases of the nervous system, diseases of the digestive system, cerebrovascular  
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14 diseases, hypertension, and ischemic heart disease.[11, 12] However, risk estimates at low  
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16 doses still remain uncertain.[13]  
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19 Although the psychological aftermath of the Chernobyl accident has been acknowledged  
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21 as the major long-term public health problem in the exposed populations,[1, 14] the mental  
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23 health of cleanup workers has only been assessed in small-scale studies in Ukraine.[15–16]  
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25 There is an urgent need to examine mental health along with somatic diseases when  
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27 considering the health of cleanup workers.[16]  
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30 An updated analysis of mortality and cancer incidence in the Estonian Chernobyl cohort  
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32 revealed higher incidence of alcohol-related cancers and excess of suicide.[2] Suicide risk has  
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34 been persistently elevated since the beginning of follow-up.[17, 18] The current research  
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36 provides the first overview of morbidity other than cancer in the Estonian cohort of  
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38 Chernobyl cleanup workers with special attention to radiation-related diseases and mental  
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40 health disorders.  
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## 45 **METHODS**

### 46 **Sample and follow-up**

47  
48 The Estonian cohort of Chernobyl cleanup workers (exposed cohort) includes 4831 men  
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50 recruited in 1986–1991 to the Chernobyl area by the Soviet authorities for decontamination,  
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52 building and other related activities. The “Chernobyl area” here denotes the 30-km zone (an  
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54 area of 30-km radius from the nuclear power station) and territories outside, where the  
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3 workers were engaged with different activities during their mission period. Detailed  
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5 information on the assembly and description of the cohort is given elsewhere.[19] To  
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7 examine morbidity in this cohort, we used data from the Estonian Health Insurance Fund  
8  
9 (EHIF) database available since January 2004. Thus, for the morbidity analyses we identified  
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11 all cohort members aged 35–69 years and living in Estonia on January 1, 2004. Altogether, of  
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13 4831 men in the initial cohort, 1129 were excluded because of loss in follow-up (21), death  
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15 (602) and emigration (506). In addition, we did not include men aged under 35 (9) and over  
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17 69 years (13) to have more homogeneous age group. This left just 3680 cleanup workers in  
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19 the study. An unexposed population-based comparison cohort was selected corresponding to  
20  
21 the age distribution of the exposed cohort. A random sample stratified by 5-year age groups  
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23 with the exposed to unexposed ratio of 1:2 and 5% extra men in each age group was extracted  
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25 from the Estonian Population Registry (EPR). **In the unexposed cohort, after excluding 87**  
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27 **men who had worked in the Chernobyl area (cleanup workers), there remained 7631 men.**  
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32 The cohort of cleanup workers was linked to the EPR to update vital status (emigration or  
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34 death with corresponding date), ethnicity and education. Each person in both cohorts was  
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36 followed up from January 1, 2004 until death, emigration or December 31, 2012 (whichever  
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38 date came first). From the EHIF database, we obtained dates and ICD-10 codes for each  
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40 contact with a health provider. All linkages were performed using the unique personal  
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42 identification number (assigned to all permanent residents of Estonia) as the key variable.  
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44 EHIF manages the mandatory universal health insurance system that is based on solidarity  
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46 and covers 95% of the Estonian population.[20] All employees and self-employed persons  
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48 contribute 13% of their wages, some groups of the population are financed by the State (e.g.  
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50 registered unemployed, Chernobyl veterans), and some groups are insured without  
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52 contribution (e.g. children, students, pensioners). People without coverage from the above  
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54 mentioned sources can pay the tax voluntarily.  
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3 Health care contacts were identified from the EHIF database for 2004–2012 using the  
4 first occurrence of the three-digit ICD-10 code. If the contact involved multiple diagnoses,  
5 the first occurrence of each of them was separately counted. All diseases (except cancer,  
6 ICD-10 C00–C97), external causes of morbidity, and examinations or counseling were  
7 considered. Four-digit codes were taken separately only for some alcohol-induced diseases. A  
8 combined category of alcohol-induced diagnoses included mental disorders due to alcohol  
9 (F10), degeneration of the nervous system due to alcohol (G31.2), alcoholic cardiomyopathy  
10 (I42.6), alcoholic liver disease (K70), alcohol-induced pancreatitis (K86.0), accidental  
11 poisoning by alcohol (X45), intentional self-poisoning by alcohol (X65), and poisoning by  
12 alcohol, undetermined intent (Y15). The accuracy of the diagnosis was the responsibility of  
13 the physician issuing the invoice to EHIF for ambulatory or hospital care.

### 30 **Morbidity measures and statistical analysis**

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

38 Additionally, analysis was done between different subgroups within the exposed cohort  
39 (internal analysis) to assess possible effects of year of arrival in the Chernobyl area (1986;  
40 1987–1991), duration of stay (<92; ≥92 days), and documented cumulative whole-body  
41 radiation dose (<5.0; 5.0–9.9; ≥10.0 cGy), ~~education (higher or secondary; basic or less), and~~  
42 ~~ethnicity (Estonian; non-Estonian (mainly Russians))~~ on morbidity risk. As described  
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3 elsewhere, [1, 22, 23] the cleanup workers were dominantly exposed to  $\gamma$ -radiation released  
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5 mainly by  $^{131}\text{I}$ ,  $^{134}\text{Cs}$  and  $^{137}\text{Cs}$ . Received radiation doses were measured by individual or  
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7 group dosimeters, or estimated by work area measurements. The readings were documented  
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9 in the workers' military passports/ records. Considering, that documented doses were  
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11 unreliable,[19] and not recorded for 15.2% of the cohort members, we used the year of arrival  
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13 and duration of stay as proxy variables for radiation exposure.  
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16 **Potential confounders – educational level (higher or secondary; basic or less) and**  
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18 **ethnicity (Estonian; non-Estonian (mainly Russians)) – were included in the analysis as**  
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20 surrogates for health behavior. The prevalence of alcohol consumption at least once a week  
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22 (28.5%) and current smoking (69.0%) among the cleanup workers was studied in a postal  
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24 questionnaire survey conducted in 1992–1993,[19] but not included in current analyses due to  
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26 small cohort size and lack of longitudinal data on these factors of health behavior. **Thus, the**  
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28 **selection of variables (potential confounders) was determined by the availability of them and**  
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30 **a review of our previous studies.**  
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34 Analyses within the exposed cohort focused on disease risks previously reported in  
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36 atomic-bomb survivors and Chernobyl cleanup workers.[7, 11, 12] The first set of models  
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38 included the year of arrival in the Chernobyl area, duration of stay, age at diagnosis,  
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40 education and ethnicity. One hundred and seventy four subjects with missing information for  
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42 any characteristic were excluded from the analysis. In the second set of models we included  
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44 documented radiation dose; due to unrecorded values, an additional 452 subjects were  
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46 excluded.  
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50 We used Visual FoxPro 6.0 (Microsoft Corporation, Redmond, WA, USA) for database  
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52 management, and Stata 12 (StataCorp LP, College Station, TX, USA) for statistical  
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54 modeling.  
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## RESULTS

### Description of the exposed and unexposed cohorts

We followed 3680 exposed and 7631 unexposed men from January 1, 2004 until December 31, 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 the 16.4% of the subjects 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 (three-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).

(Insert Table 1 here)

### 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 1.00–1.03). From the non-cancer late effects that might be related to the Chernobyl accident (UNSCEAR 2011), we found significantly elevated morbidity for diseases of thyroid gland (RR=1.69; 95% CI 1.38–2.07) and ischemic heart disease (RR=1.09; 95% CI 1.00–1.18). There was evidence of lower occurrence of cataract in the exposed cohort. Stress reactions,

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3 depression, severe headaches and sleep disorders were not diagnosed more frequently in the  
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5 exposed cohort than in the reference cohort.  
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8 Increased morbidity was apparent for the broad categories of diseases of the nervous  
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10 system, digestive system, musculoskeletal system, and alcohol-induced diagnoses. Morbidity  
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12 from external causes in the exposed cohort exceeded that in the unexposed cohort (RR=1.07;  
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14 95% CI 1.03–1.11). Significantly higher morbidity was registered for falls, intentional self-  
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16 harm and exposure to excessive cold. Cleanup workers did not undergo medical observations  
17  
18 for suspected diseases (ICD-10 Z03) more frequently than unexposed men (RR=1.06; 95%  
19  
20 CI 0.94–1.19). Additional adjustments for ethnicity and education (rate ratios not presented)  
21  
22 did not materially alter these results.  
23

24  
25 (Insert Table 2 here)  
26

### 27 **Differences between subgroups in the exposed cohort (internal analysis)**

28  
29 Internal analysis revealed more depressive disorders and stress reactions (RR=1.27; 95% CI  
30  
31 1.00–1.62), and severe headaches (RR=1.69; 95% CI 1.10–2.60) among cleanup workers  
32  
33 who entered the area shortly after the accident than in those arriving later (Table 3). Higher  
34  
35 thyroid diseases morbidity was not related to year or month (April-May versus June-  
36  
37 December, 1986) of arrival in the contaminated area. Longer mission did not increase the  
38  
39 morbidity of any disease. Acute myocardial infarction, cerebrovascular diseases, diseases of  
40  
41 liver, calculus of kidney and ureter, headaches, and alcohol-induced morbidity occurred more  
42  
43 frequently among non-Estonians, while mental disorders were more frequent among  
44  
45 Estonians. Less educated cleanup workers had higher risk for diseases of the nervous system,  
46  
47 cerebrovascular diseases, intentional self-harm, and alcohol-induced morbidity, and lower  
48  
49 risk for in situ and benign neoplasms.  
50  
51

52  
53  
54 Including education and ethnicity in the model did not alter markedly the crude point  
55  
56 estimates of RR for year of arrival or duration of stay (rate ratios not presented). Higher  
57  
58  
59  
60

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2  
3 documented radiation dose (5.0–9.9 or  $\geq 10.0$  vs.  $< 5.0$  cGy) was not associated with higher  
4 morbidity of thyroid diseases (RR=0.92; 95% CI 0.60–1.40; 0.92; 0.60–1.40, respectively),  
5  
6 cataract (RR=1.26; 95% CI 0.80–1.98; 1.13; 0.70–1.83, respectively), or any of the other  
7  
8 selected diseases.  
9  
10

11  
12 (Insert Table 3 here)  
13

## 14 **DISCUSSION**

15  
16 The first non-cancer morbidity analysis of the Estonian cohort of Chernobyl cleanup workers  
17 revealed elevated morbidity for diseases of the nervous system, digestive system,  
18  
19 musculoskeletal system, ischemic heart disease, and for external causes. The most salient  
20  
21 excess risk was observed for thyroid diseases, and as expected, for intentional self-harm and  
22  
23 selected alcohol-induced diagnoses.  
24  
25  
26  
27  
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29

### 30 **Limitations**

31  
32 First, this study was limited to morbidity cases in 2004–2012. We had no information about  
33  
34 morbidity prior to this time period. Thus, it was not possible to specify incident cases or  
35  
36 assess early effects of exposure.  
37

38  
39 Second, among given diseases there could be tentative and preliminary diagnoses  
40  
41 unconfirmed afterwards. We are aware of the possibility of diagnostic errors, upcoding and  
42  
43 unbundling of codes associated with the use of a reimbursement-administrative database,  
44  
45 originally created not for research purposes, but proved to be an important source for medical  
46  
47 studies in Estonia.[24–26] A small number of cases might have been diagnosed by  
48  
49 commercial health care providers and not reported to the EHIF. However, because of  
50  
51 universal health insurance, these limitations would be expected to affect the exposed and  
52  
53 unexposed cohorts in a similar fashion. This kind of non-differential misclassification of  
54  
55 disease or of disease status probably either does not bias the rate ratio or biases it towards the  
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3 null. The same may be said in a hypothetical situation when the validity of diagnoses in the  
4  
5 EHIF will be almost perfect. In the last case as the most important, the number and  
6  
7 heterogeneity of diagnostic entries would be reduced, and the accuracy of measurements  
8  
9 improved.  
10

11  
12 Third, the documented radiation doses are not entirely accurate, and there could be  
13  
14 incorrect readings in both directions as discussed elsewhere.[2, 19] Although no correlation  
15  
16 was observed between individual doses from military passports (lists) and the biodosimetry  
17  
18 estimates for the sub-cohort of cleanup workers, it is estimated that the cohort was exposed to  
19  
20 low-dose radiation around 0.1 Gy on average.[22, 27] A similar dose level was reported for  
21  
22 Latvian and Lithuanian Chernobyl cleanup workers.[28] Thus, we used year of arrival and  
23  
24 duration of stay as proxy variables for radiation exposure. ~~Given these limitations, our~~  
25  
26 ~~conclusions are duly tempered.~~  
27  
28

29  
30 Fourth, the small size of the cohort has reduced the power of analysis. In addition,  
31  
32 because of multiple comparisons, it is possible that some statistically significant findings  
33  
34 could be due to chance. ~~Given these limitations, our conclusions are duly tempered.~~  
35  
36  
37

### 38 **Possible radiation effects?**

39  
40 Thyroid diseases have been under close surveillance after the Chernobyl accident since  
41  
42 radioiodine (mainly <sup>131</sup>I with a half-life of eight days) released during the explosion is  
43  
44 concentrated in the thyroid gland. Ron and Brenner [29] summarized the evidence of benign  
45  
46 thyroid diseases after radiation exposure. They concluded that associations have been weak  
47  
48 and elevated risk occurred mainly in subjects with high doses, exposed at young ages, and in  
49  
50 women. Keeping in mind that the cohort of cleanup workers includes only adult men who  
51  
52 were exposed to low doses, we cannot attribute the thyroid findings to radiation. This  
53  
54 interpretation is supported by the lack of excess among the early entrants or subjects with the  
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3 highest documented radiation doses. At the same time, we cannot exclude the possibility that  
4  
5 a higher rate ratio among the cleanup workers is caused by close medical attention sought by  
6  
7 them. During thyroid screening among the Estonian cleanup workers in 1995, no clear  
8  
9 correlation was found between the prevalence of thyroid nodules and the year of arrival or  
10  
11 recorded radiation dose.[30] ~~Moreover, these whole body external doses have little relevance~~  
12  
13 ~~to thyroid diseases because they are not thyroid doses.~~  
14  
15

16  
17 High radiation doses increase the risk of circulatory diseases, but less is known about the  
18  
19 effect of low or moderate doses (<0.5 Gy). Difficulty in estimating dose-response at low dose  
20  
21 levels is due to paucity of large cohorts with high-quality data on doses and confounders.[10,  
22  
23 31] As the Estonian cohort of cleanup workers is small and with low average radiation dose,  
24  
25 we cannot attribute the small increase in ischemic heart disease morbidity seen in the cohort  
26  
27 to biological effects of radiation exposure. This conclusion is also supported by the mortality  
28  
29 analyses, where no excess deaths from circulatory diseases were found.[2]  
30  
31

32  
33 An increased risk of cataract, observed in atomic-bomb survivors [7] and Ukrainian  
34  
35 cleanup workers,[32] did not emerge in the Estonian cohort. An observed statistically  
36  
37 significant deficit of cataract cases may be an occasional finding without any epidemiological  
38  
39 relevance. Although cataract has been conventionally regarded as a late deterministic effect  
40  
41 of radiation with a threshold dose of 0.5 Gy, recent studies have suggested a need to lower  
42  
43 this dose limit and reconsider the threshold model.[31, 33] Nevertheless, it is unlikely that  
44  
45 radiation-related cataracts will be detectable among the Estonian cleanup workers in the  
46  
47 future, given the low dose level.  
48  
49

## 50 51 52 **Mental and neurological disorders**

53  
54 Natural or man-made disasters can inflict psychological consequences to the affected  
55  
56 populations. Radiation events evoke images of the bombings of Hiroshima and Nagasaki, and  
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3 mental health effects such as post-traumatic stress, depression, anxiety, and somatization can  
4 be long-lasting.[34] After the Chernobyl accident, the mental health of the local population  
5 and cleanup workers was considered to be the main public health concern.[1, 14] Cleanup  
6 workers were exposed not only to radiation, but also to the lack of protective gear and to the  
7 poor living conditions, sometimes doing meaningless jobs, and drinking large amounts of  
8 alcohol (mainly home-distilled).[19, 35] Misleading or no information about the possible  
9 long-term health effects generated rumors and misapprehensions, and radiation fears were  
10 exaggerated.[36, 37] The situation bred profound mistrust of all authorities. One of the most  
11 difficult lessons from Chernobyl has been to gain the public's trust and to deliver scientific  
12 information about the radiation risks, as there exists an insuperable gap between the experts'  
13 and public's perceptions about radiation.[38–40]

14  
15  
16 To date, the persistently elevated suicide risk in the Estonian cohort has been the  
17 definitive indication of psychological impairment as a result of working as a Chernobyl  
18 cleanup worker.[2] However, the current morbidity analyses showed a mixed pattern of  
19 mental and neurological disorders. Based on the results from a study of Ukrainian cleanup  
20 workers,[15] we expected higher rates of depression, anxiety, post-traumatic stress disorder,  
21 and headaches. Yet, there was no overall increase of mental disorders as a group (RR=1.00),  
22 or of physician-diagnosed depression or anxiety. During the follow-up period, the cleanup  
23 workers used health care services significantly less frequently for stress reactions than the  
24 unexposed cohort. No excess of severe headaches or sleep disorders was found among  
25 cleanup workers. However, depression and stress reactions, and severe headaches were more  
26 frequent in the early entrants. Elevated morbidity due to intentional self-harm is also an  
27 indicator of psychological distress. This finding is consistent with the increased suicide rate  
28 in the cohort,[2] which is strongly related to alcohol dependence among middle-aged men in  
29 Estonia.[41]



1  
2  
3 Smoking and heavy alcohol consumption are more prevalent in less educated men in  
4  
5 Estonia.[42, 43] Although population-based health (behavior) prevalence studies do not  
6  
7 report differences in smoking and drinking habits between Estonians and non-Estonians,[42,  
8  
9 43] mortality is higher in non-Estonians,[44] particularly alcohol-related mortality.[45]

10  
11 Excess morbidity emerged for alcohol-induced diseases – mental disorders due to alcohol  
12  
13 and degeneration of nervous system due to alcohol. Morbidity from alcohol-induced  
14  
15 diagnoses as a group was 25% higher among cleanup workers than in the unexposed cohort.  
16  
17 Considering common alcohol abuse among men in Estonia (especially with lower educational  
18  
19 level),[43] it is not surprising that cleanup workers used alcohol to cope with stressful  
20  
21 situation, and still do. Higher morbidity due to excessive cold is most likely attributable to  
22  
23 homelessness and suggests that periods of homelessness were more common in cleanup  
24  
25 workers than in men in the comparison cohort. Results of our study demonstrate that the men  
26  
27 with Estonian ethnicity and/ or higher educational level coped better with Chernobyl  
28  
29 consequences including alcohol abuse.  
30  
31  
32  
33

34 Although Ukrainian cleanup workers had more mental disorders than controls, no excess  
35  
36 of alcoholism was observed.[15] This illustrates how analysis of similar cohorts with  
37  
38 different design and risk measures can produce entirely opposite results. Very likely, mental  
39  
40 disorders other than alcoholism were under-diagnosed in the Estonian cohort, and the  
41  
42 prevalence of alcohol problems was underestimated in the Ukrainian cohort. It is common  
43  
44 that people do not seek professional help for mental health problems.[34] Untreated mental  
45  
46 disorders can manifest as unexplained physical complaints such as headache or back pain, or  
47  
48 they are risk factors for somatic diseases (e.g. thyroid diseases or diseases of the digestive  
49  
50 system).[46, 47] Thus, it is important to pay attention to both mental and somatic diseases of  
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52 Chernobyl cleanup workers simultaneously.  
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## 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 underreported. The future challenge will be to study mental and physical co-morbidities in the Chernobyl cleanup workers cohort.

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**Contributors** KR and MR designed the study. KR performed the statistical analyses and drafted the manuscript. EB, TH, AA, AU and MR contributed to the interpretation of the results and revised critically the manuscript. MR supervised the whole process. All authors have seen and approved the final version of the manuscript.

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**Competing interests** None.

**Ethics approval** The study was approved by the Tallinn Medical Ethics Committee (no. 1939, February 11, 2010), and by the Estonian Data Protection Inspectorate (no. 2.2-3/10/120r, April 9, 2010).

**Data sharing statement** No additional data are available.

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

Characteristic	Exposed cohort		Unexposed cohort	
	No.	(%)	No.	(%)
Total	3680	(100)	7631	(100)
Vital status on December 31, 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)		



Table 2 Number of morbidity cases\* and age-adjusted morbidity rate ratios† (RR) with 95% confidence intervals (CI) 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		RR (95% CI)
		Exposed cohort	Unexposed cohort	
A00–R99, V01–Z99	All diagnoses and external causes	41,370	86,441	1.02 (1.01–1.03)‡
A00–R99, except C00–C97	All diseases, except cancer	31,757	66,799	1.01 (1.00–1.03)
A00–B99	Infectious diseases	1338	3022	0.94 (0.88–1.00)
A15–A16	Respiratory tuberculosis	41	73	1.19 (0.81–1.74)
D00–D48	In situ and benign neoplasms	517	1060	1.04 (0.94–1.16)
D50–D89	Diseases of the blood and blood-forming organs	97	195	1.07 (0.84–1.36)
E00–E90	Endocrine, nutritional and metabolic diseases	806	1754	0.98 (0.90–1.07)
E00–E07	Diseases of thyroid gland	167	211	1.69 (1.38–2.07)‡
F00–F99	Mental disorders	1380	2918	1.00 (0.94–1.07)
F10	Mental disorders due to alcohol	328	570	1.21 (1.06–1.39)‡
F32–F33	Depressive disorders	290	633	0.97 (0.84–1.11)
F41	Anxiety disorders	119	275	0.91 (0.74–1.13)
F43	Stress reactions	55	162	0.72 (0.53–0.97)‡
G00–G99	Diseases of the nervous system	1352	2550	1.13 (1.06–1.21)‡
G31.2	Degeneration of nervous system due to alcohol	48	68	1.51 (1.04–2.18)‡
G40	Epilepsy	148	223	1.40 (1.14–1.73)‡
G43–G44	Migraine and other headache	125	256	1.03 (0.83–1.28)
G50–G59	Nerve, nerve root and plexus disorders	447	829	1.15 (1.02–1.29)‡
F51, G47	Sleep disorders	267	529	1.08 (0.93–1.25)
H00–H59	Diseases of the eye	2004	4592	0.93 (0.89–0.98)‡
H25–H26, H28	Cataract	155	449	0.77 (0.64–0.92)‡
H40, H42	Glaucoma	109	247	0.96 (0.77–1.20)
H60–H95	Diseases of the ear	1228	2707	0.97 (0.91–1.04)
I00–I99	Diseases of the circulatory system	4432	9477	1.00 (0.97–1.04)
I10–I15	Hypertensive diseases	1936	4210	0.98 (0.93–1.04)
I20–I25	Ischemic heart disease	773	1537	1.09 (1.00–1.18)
I21	Acute myocardial infarction	104	214	1.05 (0.83–1.33)
I60–I69	Cerebrovascular diseases	291	606	1.05 (0.91–1.20)
J00–J99	Diseases of the respiratory system	4699	10,079	0.99 (0.95–1.02)
J30–J39	Diseases of upper respiratory tract	592	1431	0.87 (0.79–0.96)‡
J40–J47	Lower respiratory diseases	580	1130	1.10 (1.00–1.22)
K00–K93	Diseases of the digestive system	3179	6068	1.11 (1.07–1.16)‡
K20–K31	Diseases of oesophagus, stomach and duodenum	1415	2648	1.14 (1.06–1.21)‡
K25–K27	Peptic ulcer	464	857	1.15 (1.02–1.28)‡
K70–K77	Diseases of liver	194	357	1.16 (0.97–1.38)
K70	Alcoholic liver disease	68	117	1.23 (0.91–1.66)
K85–K86	Diseases of pancreas	128	213	1.27 (1.02–1.58)‡
K86.0	Alcohol-induced pancreatitis	25	41	1.27 (0.77–2.09)
L00–L99	Diseases of the skin	1793	3730	1.02 (0.97–1.08)
M00–M99	Diseases of the musculoskeletal system	6296	12,623	1.06 (1.03–1.09)‡
M15–M19	Arthrosis	925	1881	1.06 (0.98–1.14)
M54	Dorsalgia	1475	2817	1.11 (1.04–1.18)‡
N00–N99	Diseases of the genitourinary system	1518	3648	0.89 (0.84–0.95)‡
N20	Calculus of kidney and ureter	140	321	0.93 (0.76–1.14)
N40	Hyperplasia of prostate	418	1032	0.88 (0.79–0.99)‡
R00–R99	Findings, not elsewhere classified	1091	2297	1.01 (0.94–1.09)
V01–Y98	External causes of morbidity	5084	10,055	1.07 (1.03–1.11)‡
V01–V99	Transport accidents	171	423	0.85 (0.71–1.02)
W00–W19	Falls	2010	3817	1.11 (1.06–1.18)‡
W20–W49	Exposure to mechanical forces	1864	3799	1.03 (0.98–1.09)
X31	Excessive cold	26	32	1.74 (1.04–2.92)‡
X40–X49	Accidental poisoning	34	69	1.05 (0.69–1.58)
X60–X84	Intentional self-harm	53	76	1.47 (1.04–2.09)‡
Z00–Z99	Contact with health services	4135	8862	0.99 (0.96–1.03)
Z03	Medical observation for suspected disease	389	788	1.06 (0.94–1.19)
F10, G31.2, I42.6, K70,	Selected alcohol-induced diagnoses and	528	896	1.25 (1.12–1.39)‡

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K86.0, X45, X65, Y15 external causes of morbidity

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\* The first occurrence of the three-digit ICD-10 code in the study period was considered.  
† Adjusted for age at diagnosis.  
‡ p<0.05

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Table 3 Adjusted morbidity rate ratios\* (RR) with 95% confidence intervals (CI) 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	Duration of stay	Ethnicity	Education
		1986 <sup>†</sup>	≥92 days <sup>†</sup>	Non-Estonian <sup>†</sup>	Basic or less <sup>†</sup>
D00–D48	In situ and benign neoplasms	1.15 (0.95–1.39)	0.77 (0.64–0.92) <sup>‡</sup>	1.09 (0.91–1.30)	0.76 (0.61–0.96) <sup>‡</sup>
E00–E07	Diseases of thyroid gland	0.94 (0.68–1.31)	1.00 (0.73–1.38)	0.85 (0.62–1.17)	0.82 (0.55–1.22)
F00–F99	Mental disorders	1.08 (0.96–1.21)	0.85 (0.76–0.95) <sup>‡</sup>	0.82 (0.74–0.92) <sup>‡</sup>	1.11 (0.97–1.27)
F32–F33, F43	Depressive disorders and stress reactions	1.27 (1.00–1.62)	0.72 (0.58–0.90) <sup>‡</sup>	0.53 (0.41–0.67) <sup>‡</sup>	0.88 (0.66–1.17)
G00–G99	Diseases of the nervous system	1.01 (0.90–1.13)	0.93 (0.83–1.04)	0.97 (0.87–1.09)	1.20 (1.05–1.37) <sup>‡</sup>
G43–G44	Migraine and other headache	1.69 (1.10–2.60) <sup>‡</sup>	0.79 (0.55–1.14)	1.48 (1.03–2.12) <sup>‡</sup>	0.97 (0.59–1.58)
H25–H26, H28	Cataract	1.07 (0.77–1.49)	1.05 (0.76–1.45)	1.29 (0.93–1.77)	0.93 (0.65–1.33)
H40, H42	Glaucoma	1.26 (0.83–1.89)	0.78 (0.52–1.15)	1.20 (0.81–1.78)	0.80 (0.51–1.27)
I10–I15	Hypertensive diseases	1.03 (0.94–1.14)	0.92 (0.84–1.01)	1.07 (0.98–1.17)	0.99 (0.88–1.11)
I20–I25	Ischemic heart disease	1.15 (0.99–1.34)	0.81 (0.70–0.94) <sup>‡</sup>	1.12 (0.97–1.30)	1.10 (0.93–1.30)
I21	Acute myocardial infarction	1.11 (0.74–1.68)	0.94 (0.63–1.39)	1.53 (1.03–2.26) <sup>‡</sup>	1.17 (0.74–1.83)
I60–I69	Cerebrovascular diseases	1.11 (0.86–1.42)	1.03 (0.81–1.42)	1.65 (1.30–2.11) <sup>‡</sup>	1.61 (1.25–2.08) <sup>‡</sup>
K70–K77	Diseases of liver	1.13 (0.82–1.54)	1.13 (0.84–1.51)	1.42 (1.07–1.90) <sup>‡</sup>	1.12 (0.79–1.58)
N20	Calculus of kidney and ureter	1.08 (0.74–1.57)	0.88 (0.62–1.26)	1.99 (1.39–2.85) <sup>‡</sup>	0.73 (0.45–1.19)
X60–X84	Intentional self-harm	1.27 (0.68–2.36)	0.77 (0.43–1.37)	1.43 (0.82–2.52)	2.73 (1.48–5.05) <sup>‡</sup>
F10, G31.2, I42.6, K70, K86.0, X45, X65, Y15	Selected alcohol-induced diagnoses and external causes of morbidity	0.92 (0.76–1.11)	0.98 (0.82–1.17)	1.37 (1.15–1.63) <sup>‡</sup>	1.76 (1.44–2.15) <sup>‡</sup>

\* Models include age at diagnosis, year of arrival, duration of stay, ethnicity, and education.

<sup>†</sup> The reference categories for these variables are as follows: year of arrival 1987–1991; duration of stay <92 days; ethnicity Estonian; education higher/ secondary.

<sup>‡</sup> p<0.05.

STROBE 2007 (v4) Statement—Checklist of items that should be included in reports of cohort studies

Section/Topic	Item #	Recommendation	Reported on page #
Title and abstract	1	(a) Indicate the study’s design with a commonly used term in the title or the abstract	1
		(b) Provide in the abstract an informative and balanced summary of what was done and what was found	2
<b>Introduction</b>			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4-5
Objectives	3	State specific objectives, including any prespecified hypotheses	5
<b>Methods</b>			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5-6
Participants	6	(a) Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up	5
		(b) For matched studies, give matching criteria and number of exposed and unexposed	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6-7
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	6-7
Bias	9	Describe any efforts to address potential sources of bias	7-8
Study size	10	Explain how the study size was arrived at	5-6
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	7-8
Statistical methods	12	(a) Describe all statistical methods, including those used to control for confounding	7-8
		(b) Describe any methods used to examine subgroups and interactions	7-8
		(c) Explain how missing data were addressed	7-8
		(d) If applicable, explain how loss to follow-up was addressed	no losses (Table 1)
		(e) Describe any sensitivity analyses	
<b>Results</b>			

Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	8, Table 1
		(b) Give reasons for non-participation at each stage	5-6
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	8, Table 1
		(b) Indicate number of participants with missing data for each variable of interest	8, Table 1
		(c) Summarise follow-up time (eg, average and total amount)	8, Table 1
Outcome data	15*	Report numbers of outcome events or summary measures over time	8, Table 2
Main results	16	(a) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	9-10, Table 2-3
		(b) Report category boundaries when continuous variables were categorized	8
		(c) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	9-10, Table 3
<b>Discussion</b>			
Key results	18	Summarise key results with reference to study objectives	10
<b>Limitations</b>			10-11
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	10-14
Generalisability	21	Discuss the generalisability (external validity) of the study results	14
<b>Other information</b>			14-15
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	15

\*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at <http://www.plosmedicine.org/>, Annals of Internal Medicine at <http://www.annals.org/>, and Epidemiology at <http://www.epidem.com/>). Information on the STROBE Initiative is available at [www.strobe-statement.org](http://www.strobe-statement.org).