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# Chernobyl cleanup workers from Estonia: follow-up for cancer incidence and mortality

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## Abstract

This study examined cancer incidence (1986–2008) and mortality (1986–2011) among the Estonian Chernobyl cleanup workers in comparison with the Estonian male population. The cohort of 4,810 men was followed through nationwide population, mortality and cancer registries. Cancer and death risks were measured by standardized incidence ratio (SIR) and standardized mortality ratio (SMR), respectively. Poisson regression was used to analyze the effects of year of arrival, duration of stay, and time since return on cancer and death risks. The SIR for all cancers was 1.06 with 95% confidence interval 0.93–1.20 (232 cases). Elevated risks were found for cancers of pharynx, oesophagus, and the joint category of alcohol-related sites. No clear evidence of an increased risk of thyroid cancer, leukaemia, or radiation-related cancer sites combined was apparent. The SMR for all causes of death was 1.02 with 95% confidence interval 0.96–1.08 (1,018 deaths). Excess mortality was observed for mouth and pharynx cancer, alcohol-related cancer sites together, and suicide. Duration of stay rather than year of arrival was associated with increased mortality. Twenty-six years of follow-up of this cohort indicates no definite health effects attributable to radiation, but the elevated suicide risk has persisted.

## 1. Introduction

Health consequences of the accident in the Chernobyl Nuclear Power Station on April 26, 1986 were summarized in 2011 by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [1] and in the related overview by Cardis and Hatch [2]. Early responders and fire fighters experienced acute high-dose radiation effects leading to death or serious conditions. The only other direct radiation effect of the accident convincingly demonstrated so far was an elevated incidence of thyroid neoplasms among the

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residents of Belarus, Ukraine and Russia who were exposed to radioactive iodines as children or adolescents [3–6]. To assess possible radiation-related health risks, the Estonian cohort study of Chernobyl cleanup workers, the first of its kind, was initiated. It concerned nearly 5,000 men from Estonia sent to the Chernobyl area to participate in the environmental cleanup activities [7]. Previously published Estonian data revealed an increased suicide rate [8], which did not diminish with time [9]. During the follow-up period 1986–1998 no elevated cancer incidence was observed in the cohort [10]. The current paper provides updated results of cancer incidence and mortality analyses.

## 2. Materials and Methods

The cohort of Estonian Chernobyl cleanup workers was assembled in 1992 from several data sources: the General Staff of Estonian Defense Forces (lists of the former Soviet Army), the former Estonian Chernobyl Radiation Registry, the former Ministry of Social Welfare, and the Estonian Chernobyl Committee (including lists of the former Green Movement) [7]. Compiling the database was a linkage task, because the same person could be in multiple lists. To identify cohort members we used surname, given name(s), father's name (commonly used during the Soviet rule), date of birth, and place of residence. Unique personal identification numbers were introduced in Estonia in 1992 with the establishment of the Estonian Population Registry; this greatly facilitated subsequent record linkages. The linkages resulted in a cohort of 4,831 men who had worked in the Chernobyl area in 1986–1991. Each cohort member was followed for vital status from his return to Estonia until December 31, 2011 via the population registry. We failed to trace 21 (0.4%) persons, and they were excluded from the analysis. Date of return to Estonia (start of follow-up) was missing for 144 cohort members. If for those persons date of arrival in the Chernobyl area was known (16 subjects), date of return was assumed to be 92 days (median duration of stay) later; otherwise (128 subjects) January 1, 1987 was imputed.

Follow-up for cancer incidence was restricted to the period 1986–2008. Cancer cases diagnosed in the cohort were obtained from the Estonian Cancer Registry, and were coded according to ICD-10 (C00–C97) [11]. Combined radiation-related sites (a), and alcohol-related sites (b) with sufficient evidence in humans were defined according to Cogliano *et al.* (12): (a) salivary glands (ICD-10 C07– C08), oesophagus (C15), stomach (C16), colon (C18), trachea, bronchus and lung (C33–C34), bone (C40–C41), non-melanoma skin (C44), urinary organs (C64–C68), central nervous system (CNS) (C70–C72), thyroid gland (C73), and leukaemia (except chronic lymphocytic leukaemia) (C91–C95, except C91.1); (b) oral cavity (C01–C08), pharynx (C09–C14), oesophagus (C15), colon (C18), rectum (C19–C21), liver (C22), and larynx (C32).

Deaths with date of death and underlying cause of death were determined by linkage with the Estonian scientific mortality database created for the purposes of linkage and mortality analysis, and containing all deaths with personal identifiers recorded in the Estonian Causes of Death Registry since 1983 [13, 14]. Overall and cause-specific mortality analyses covered the period 1986–2011, during which three classifications for coding causes of death were used: in 1986–1993 the abridged Soviet classification based on ICD-9 but less detailed [15], in 1994–1996 ICD-9, and in 1997–2011 ICD-10. Follow-up for deaths from radiation-related cancers and alcohol-related cancers started in 1994, because the Soviet classification did not have separate codes for all these sites. Selected alcohol-related deaths included mental disorders due to alcohol (ICD-10 F10), degeneration of nervous system due to alcohol (G31.2), alcoholic liver disease (K70), and alcohol poisoning (X45). Because of under-coding of alcohol poisoning in the Estonian Causes of Death Registry, it was not appropriate to treat this category separately [14].

The risk of cancer or death in the Chernobyl cohort, compared with the Estonian male population, was assessed by the standardized incidence ratio (SIR) or the standardized mortality ratio (SMR), respectively. Both measures were expressed as the ratio of observed to expected number of cases. The expected number of cancer or death cases was calculated by multiplying the number of person-years at risk stratified by 5-year age groups and 5-year calendar periods by corresponding cancer incidence or mortality rates in the male population. The 95% confidence intervals (CI) for the SIR and the SMR were computed assuming that the observed number of cases followed a Poisson distribution.

To estimate the effect of different characteristics on death or cancer risk, ratios of SIRs or SMRs (RR) for selected cancer sites and causes of death were modelled with Poisson regression, with logarithm of the expected number of cases as the offset variable [16]. The following characteristics were included in the models: age at start of follow-up (<30; 30–39; ≥40 years), year of arrival in the Chernobyl area (1986; 1987–1991), duration of stay (<92; ≥92 days), time since return from the Chernobyl area (<7; 7–13; ≥14 years), ethnicity (Estonian; non-Estonian), and education (higher or secondary; basic or less). Information on ethnicity and education has been obtained by a questionnaire study conducted among the cleanup workers mainly in 1992–1993 [7], and updated from the population registry and mortality records. We excluded from the first model data for 167 men with missing date of arrival in or return from the Chernobyl area. From the second model we excluded additionally 389 subjects because of unknown ethnicity or education. For the third model (not presented in the tables) we included documented radiation dose (<5.0; 5.0–9.9; ≥10.0 cGy), abstracted from the worker records and reflecting external whole-body exposure [7]. Because of unrecorded values we excluded an additional 561 subjects.

Linkages and data analyses were performed using Visual FoxPro 6.0 (Microsoft Corporation, Redmond, Washington) and Stata 10 (StataCorp LP, College Station, Texas).

This study stage was approved by the Tallinn Medical Ethics Committee (No. 1939, Feb. 11, 2010).

## 3. Results

Approximately a third of the cleanup workers were sent to the Chernobyl area immediately after the accident in April or May, 1986, and another third later in the same year (Table 1). The majority of the men worked in the contaminated area for less than five months with median duration of 92 days. Estonians and non-Estonians were almost equally represented in the cohort. Nearly 60% of the men had secondary level education. A total of 4,810 men contributed 98,979 person-years at risk (average, 20.6 person-years) during the follow-up period 1986–2011. The median age at the start of follow-up was 31 years. Documented radiation doses were not high (median, 8.8 cGy; average, 9.9 cGy; maximum 58.0 cGy), and, for 15.9% of the subjects, the dose was not recorded.

Overall, 232 cancer cases were reported in the cohort compared to 218.00 expected (SIR 1.06; 95% CI: 0.93–1.20) in 1986–2008 (Table 2). Significantly elevated risks were found for cancers of pharynx (SIR 2.41; 95% CI: 1.38–3.91) and oesophagus (SIR 2.38; 95% CI: 1.23–4.15) based on 16 and 12 cases, respectively. There were almost twice as many CNS cancers observed than expected, but the finding did not quite reach statistical significance (SIR 1.91; 95% CI: 0.99–3.34). An excess of cancer cases was found for the broad category of alcohol-related sites (SIR 1.42; 95% CI: 1.09–1.80). No evidence was observed for an increase in the incidence of radiation-related cancer sites combined. Elevated thyroid cancer and leukaemia risks were not seen – two thyroid cancers were diagnosed *vs.* 1.42 expected, and seven leukaemias *vs.* 5.75 expected. The first leukaemia was diagnosed in 2000, and four of the seven cases were chronic lymphocytic leukaemias.

The overall cancer incidence in the cohort was not influenced by the year of arrival, duration of stay, or time since return from the mission (Table 3). The RRs did not show statistically significant differences between subgroups in the cohort for risk of radiation-related or alcohol-related cancers either. Adding education and ethnicity to the model did not change noticeably the RRs for the variables concerning the Chernobyl mission but less educated persons had significantly higher risk for overall and alcohol-related cancer incidence (Table 3).

A total of 1,018 deaths registered *vs.* 999.32 expected (SMR 1.02; 95% CI: 0.96–1.08) in 1986– 2011 (Table 4). A statistically significant excess mortality was observed for cancer of the mouth and pharynx (SMR 1.82; 95% CI: 1.11–2.81), alcohol-related cancer sites together (SMR 1.64; 95% CI: 1.23–2.15), and suicide (SMR 1.30; 95% CI: 1.05–1.60). Suicide combined with undetermined injury gave a slightly lower point estimate for SMR than suicide alone (SMR 1.24; 95% CI: 1.01–1.47). No significant excess of mortality was found for the combined category of radiation-related cancer sites. No thyroid cancer deaths were reported, and the number of leukaemia deaths was close to the expected (4 *vs.* 4.33). We did not find elevated mortality for diseases of the circulatory, respiratory or digestive system. There was no increased mortality from all external causes combined or selected alcohol-related causes.

All-cause mortality was lower among persons who were sent to the Chernobyl area in 1986 (adjusted RR 0.87; 95% CI: 0.76–0.99), and higher for those who worked there longer (adjusted RR 1.23; 95% CI: 1.09–1.40) (Table 5). The risk of death rose significantly after seven years since return from the mission, and stayed at the same level in the latest time period ( 14 years). Mortality due to cancer or circulatory diseases did not depend on year of arrival, duration of stay, or time since return. Excess mortality from external causes or selected alcohol-related causes was seen for persons with duration of stay exceeding three months. Suicide risk did not decrease appreciably with time since return: adjusted RR 1.06; 95% CI: 0.63–1.78 for 7–13 years, and adjusted RR 0.91; 95% CI: 0.52– 1.58 for 14 years compared to less than seven years. RRs for the variables describing the Chernobyl mission remained almost the same after additional adjustment for education and ethnicity, but both characteristics had strong effect on mortality due to selected causes of death in Table 5 – non-Estonians and less educated experienced higher risk of death. Only mortality due to circulatory diseases or suicide was not associated with ethnicity.

We did not observe a radiation dose effect based on recorded doses (5.0–9.9 cGy *vs.* <5.0 cGy, and 10.0 cGy *vs.* <5.0 cGy) on overall cancer incidence (adjusted RR 1.01; 95% CI: 0.70–1.46, and adjusted RR 1.33; 95% CI: 0.93–1.92, respectively) or radiation-related cancer incidence (adjusted RR 0.83; 95% CI: 0.52–1.34 and adjusted RR 0.98; 95% CI: 0.61–1.58). The same pattern was seen in all-cause mortality (adjusted RR 0.88; 95% CI: 0.74–1.05 and adjusted RR 1.10; 95% CI: 0.93– 1.31) and mortality from malignant neoplasms (adjusted RR 0.95; 95% CI: 0.63–1.44 and adjusted RR 1.08; 95% CI: 0.71–1.64).

## 4. Discussion

The Estonian cohort study of Chernobyl cleanup workers was undertaken primarily to investigate the effect of protracted exposure to low-dose radiation on cancer incidence, with particular interest in leukaemia. However, 26 years of follow-up has not yielded evidence of an appreciable burden of radiation-related cancer. Instead, greater evidence has emerged of excess occurrence of outcomes not directly attributable to radiation exposure, namely, higher incidence of alcohol-related cancers and a persistent elevation in risk of suicide in the cohort compared to the Estonian male population.

We failed to find excess cases of leukaemia, frequently reported in populations exposed to radiation [17]. We did not expect to see increased leukaemia incidence in the period 1999–2008, the interval since the last published analysis [10]. Radiation-induced leukaemia risk should have emerged during 2–5 years after exposure and declined afterwards [1, 18], but, in the Estonian cohort, the first leukaemia case was diagnosed in 2000, 13 years following return from the Chernobyl area. This result is inconsistent with the increased leukaemia risk observed in Russian and Ukrainian cleanup worker studies, both of which were based on substantially larger cohorts [19, 20] but without advantage of a population-based cancer registry. We did not observe excess leukaemia mortality either, based on three years longer follow-up than for incidence. Thus, leukaemia risk in the cohort of Estonian cleanup workers has not been high, and a small excess would have been impossible to show in such a small cohort with low radiation doses.

In addition to leukaemia, there has been particular interest in thyroid cancer incidence in the cohorts of Chernobyl cleanup workers due to potential exposure to radioiodine. We observed a 41% higher, not statistically significant thyroid cancer risk in the cohort compared to the male population, but as thyroid cancer is a rare disease, this was based on just two cases. Both thyroid cancers were detected through screening [21], diagnosed in 1995 in men who were on mission soon after the explosion. High thyroid cancer risk in the cohorts of cleanup workers has been reported in the Latvian and Russian studies [10, 22]; however, thyroid screening and medical examinations offered to the cleanup workers have likely resulted in detection bias relative to the male population.

Elevated CNS cancer incidence in the Estonian Chernobyl cohort alone and in the combined cohort with Latvian veterans has been published for the period 1986–1998 [10]. In the current extended analysis we observed almost twofold excess of CNS cancers, although the SIR was of borderline statistical significance. Excess risk of CNS cancer per unit dose was not found in the Russian cohort of cleanup workers [23]. The association between adult radiation exposure and tumours of CNS (dominantly benign) has been documented in UNSCEAR 2006 Report [24], based mainly on atomic bomb survivor data [25]. Causal relationship between ionizing radiation and CNS cancer was evaluated recently by the Working Group at the International Agency for Research on Cancer [12]. We cannot confirm or exclude that the elevated CNS cancer risk in the cohort was attributable to radiation, given the low doses received by the cohort members, and small number of cases.

We did not find increased overall cancer risk, nor elevated incidence for a combined category of radiation-related sites; however, we did observe evidence of a possible effect of alcohol – twofold higher risk for pharyngeal and oesophageal cancers, and a 35% higher risk for combined alcohol-related sites in relation to the male population. We expected to see higher cancer risk for those cleanup workers who were sent to the Chernobyl area shortly after the accident or who remained there for longer periods, and probably received higher cumulative radiation doses. However, we did not find statistically significant differences between subgroups.

We did not observe significantly elevated overall cancer mortality, or mortality from radiation-related cancer sites. Alcohol was clearly involved – mortality from alcohol-related cancer sites combined was 61% higher in the cohort than in the male population. Cancer mortality did not increase with time since return from the mission.

So far, the burden of diseases other than cancer in the cohort could be estimated only through cause-specific mortality data. Inconsistent results have been reported in studies concerning the effect of low-dose radiation on circulatory diseases [26]. Evidence that low-dose radiation can increase the risk of circulatory disease mortality has been found in the Life Span Study, but no clear association was seen below 0.5 Gy [27]. Ivanov et al. [28] reported a dose-dependent excess of some diseases of the circulatory system in the Russian cohort of cleanup workers. We did not find elevated risk for circulatory disease mortality in the Estonian cohort; the SMRs for all circulatory diseases, ischemic heart disease and cerebrovascular disease were near one. Mortality rates for diseases of the respiratory or digestive system did not exceed those in the male population. Higher alcohol-related cancer incidence and mortality suggested higher mortality from selected alcohol-related causes other than cancer, but the respective SMR did not show increased risk.

All-cause mortality in the Chernobyl cohort was at the expected level, but this finding could be biased because of the healthy worker effect; i.e., a majority of cleanup workers were military reservists or in regular army service [7], and likely were healthier than the male population. On the other hand, it is known that less educated or non-Estonian (mainly Russian) men experience higher mortality (especially alcohol-related mortality) [29–31], and the Estonian Chernobyl cohort represents somewhat different distributions by education and ethnicity than the male population. According to the 1989 census, Estonians made up 60.3%, and persons with higher education 13.2% of the male population of Estonia aged over 20 years [32]. A small proportion of men with higher education, and overrepresentation of non-Estonians in the cohort should have given higher mortality compared to the male population. The healthy worker effect probably counterbalanced the effect of education and ethnicity.

The previously observed statistically significant suicide risk has not diminished with extended follow-up – SMR 1.30 (1986–2011) *vs.* SMR 1.32 (1986–2002) [9]. The rate of death due to undetermined injury increased rapidly after Estonia regained its independence, and some suicides could have been hidden in this nonspecific category [33]. The point estimate for the SMR for the joint category of suicide and undetermined injury was lower than for suicide alone but still demonstrated a statistically significant excess risk in the cohort. The increased suicide risk is in accord with results from a study of cleanup workers from Ukraine that found a twofold elevated risk of suicide ideation, major depression, and post-traumatic stress disorder relative to population-based controls [34]. Other studies of Chernobyl cleanup workers have also reported increased cognitive and emotional impairments [35], but these studies lack systematic methodologies. Epidemiologic studies of trauma [36] and recent studies of World Trade Center rescue and recovery workers [37, 38] confirm that psychiatric symptoms related to catastrophic environmental exposures are intractable; they are frequently associated with suicide attempts, depression, and post-traumatic stress disorder, which in turn relate strongly to the risk for suicide [39]. Systematic studies are needed to document the long-term psychiatric, cognitive, and psychosocial impairments in clean-up workers. Given the current findings, we recommend routinely incorporating these endpoints in ongoing medical monitoring surveys of these workers.

Ratios of SMRs indicated that duration of stay in the contaminated area rather than year of arrival to Chernobyl raised the mortality risk, with the sole exception of suicide. Tarlap described in his memoirs [40] that most of cleanup workers had drunk more during the mission than ever in their civil lives. Probably longer mission contributed to drinking habits. Since heavy alcohol use is highly prevalent in men in Estonia [41] and is a common method for coping with stress [42], it is reasonable to infer that the elevated rate of alcohol-related cancer incidence among the cleanup workers is also attributable to the chronic health-related anxiety in the cohort.

The emotional aftermath of Chernobyl led the Chernobyl Forum and UNSCEAR 2008 Report to consider mental health to be the major public health issue among the exposed populations [1, 43]. The Chernobyl cleanup workers in particular were sent into a stressful and dangerous environment without adequate information or protective gear. Although research has shown that the low-level radiation is not associated with substantially increased cancer incidence, the cleanup workers and other exposed populations live in fear about potential adverse health outcomes [1, 35]. Deliberate withholding of information by Soviet authorities has led to suspicion and mistrust of any attempts to put the potential health risk in perspective and relieve their anxiety. Uncertainty about the future has given rise to rumours and exaggerated fears which help to perpetuate myths about the health effects of low-level radiation [44].

Recent studies of Chernobyl cleanup workers have focused on dose-response analysis of leukaemia and thyroid cancer [19, 20, 22, 45, 46]. Because of low power and uncertainties in the dose estimates, Estonian study alone cannot substantially contribute to the evaluation of the shape of the dose-response curve. The expected effect size due to a mean dose of 10 cGy is approximately 10% increase in cancer incidence if risk estimates derived from atomic bomb survivors are applied [47]. Documented doses for Estonian cleanup workers could have been underestimated, when personal dosimeters did not work properly, or overestimated, when persons working close to the reactor took along dosimeters of friends to reach the maximum allowed cumulative dose of 25 roentgens [40]. Although the average documented dose was equal to the average dose estimated from biological markers (~10 cGy), the individual doses for the studied sub-cohort of cleanup workers showed little correlation, which may be due to dose level being close to the threshold of detectability for biodosimetric methods [48, 49]. We can treat the Estonian Chernobyl cohort as a cohort with low-dose radiation exposure in general, but we cannot trust documented individual doses. The small size and relatively low dose level of the cohort reduce the statistical power. However, the power was sufficient to detect an elevated risk of suicide among the cleanup workers.

The strengths of our study include comprehensive construction of the cohort from multiple sources, as well as long and nearly complete follow-up through computerized linkage with population-based registers.

In conclusion, our study suggests that after a quarter century follow-up of the Estonian cohort of Chernobyl cleanup workers, there is an increased risk of alcohol-related cancers, and of suicide. No definite indication of health effects directly attributable to radiation exposure was found.

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**Table 1**

Characteristics of the Estonian cohort of Chernobyl cleanup workers.

| Characteristic | No. | % |
|---|---|---|
| Total | 4,810 | 100 |
| Vital status on December 31, 2011 | | |
| Living in Estonia | 3,229 | 67.1 |
| Dead | 1,018 | 21.2 |
| Emigrated | 563 | 11.7 |
| Age at start of follow-up (full years) | | |
| <20 | 80 | 1.7 |
| 20–29 | 1,846 | 38.4 |
| 30–39 | 2,309 | 48.0 |
| 40–49 | 541 | 11.2 |
| ≥50 | 34 | 0.7 |
| Time of arrival in the Chernobyl area | | |
| 1986, April–May | 1,393 | 29.0 |
| 1986, June–December | 1,508 | 31.4 |
| 1986, month unknown | 22 | 0.5 |
| 1987 | 1,086 | 22.6 |
| 1988 | 564 | 11.7 |
| 1989–1991 | 109 | 2.3 |
| Unknown | 128 | 2.7 |
| Duration of stay in the Chernobyl area (days) | | |
| <30 | 270 | 5.6 |
| 30–89 | 1,915 | 39.8 |
| 90–149 | 1,531 | 31.8 |
| 150–209 | 852 | 17.7 |
| ≥210 | 75 | 1.6 |
| Unknown | 167 | 3.5 |
| Documented dose (cGy) | | |
| <5.0 | 1,101 | 22.9 |
| 5.0–9.9 | 1,272 | 26.4 |
| 10.0–14.9 | 702 | 14.6 |
| 15.0–19.9 | 673 | 14.0 |
| 20.0–24.9 | 270 | 5.6 |
| ≥25.0 | 28 | 0.6 |
| Unknown | 764 | 15.9 |
| Ethnicity | | |
| Estonian | 2,353 | 48.9 |
| Non-Estonian | 2,451 | 51.0 |
| Unknown | 6 | 0.1 |
| Education | | |

| Characteristic | No. | % |
|---|---|---|
| Higher | 370 | 7.7 |
| Secondary | 2,883 | 59.9 |
| Basic or less | 1,121 | 23.3 |
| Unknown | 436 | 9.1 |

**Table 2**

Observed number of cancer cases and standardized incidence ratio in the Estonian cohort of Chernobyl cleanup workers by cancer site, 1986–2008.

| ICD-10 | Cancer site | No. of cases | SIR | 95% CI |
|---|---|---|---|---|
| C00–C97 | All sites | 232 | 1.06 | 0.93–1.20 |
| C00–C97, except C44 | All sites, except other skin | 219 | 1.08 | 0.94–1.23 |
| C00–C14 | Mouth, pharynx | 24 | 1.70 | 1.09–2.52 |
| C07–C08 | Salivary glands | 0 | 0.00 | 0.00–4.57 |
| C09–C14 | Pharynx | 16 | 2.41 | 1.38–3.91 |
| C15–C26 | Digestive organs | 62 | 1.11 | 0.85–1.42 |
| C15 | Oesophagus | 12 | 2.38 | 1.23–4.15 |
| C16 | Stomach | 19 | 0.93 | 0.56–1.45 |
| C18 | Colon | 12 | 1.18 | 0.61–2.06 |
| C19–C21 | Rectum | 9 | 1.17 | 0.54–2.23 |
| C22 | Liver | 2 | 0.78 | 0.09–2.82 |
| C30–C39 | Respiratory organs | 51 | 1.02 | 0.76–1.34 |
| C32 | Larynx | 7 | 0.91 | 0.37–1.88 |
| C33–C34 | Trachea, bronchus, lung | 42 | 1.02 | 0.74–1.38 |
| C40–C41 | Bone | 2 | 2.08 | 0.25–7.50 |
| C43 | Melanoma of skin | 6 | 1.14 | 0.42–2.49 |
| C44 | Other skin | 13 | 0.82 | 0.43–1.39 |
| C45–C49 | Mesothelial and soft tissues | 1 | 0.44 | 0.01–2.42 |
| C50 | Breast | 0 | 0.00 | 0.00–13.54 |
| C60–C63 | Male genital organs | 16 | 0.70 | 0.40–1.14 |
| C61 | Prostate | 13 | 0.89 | 0.48–1.53 |
| C64–C68 | Urinary organs | 18 | 0.84 | 0.50–1.33 |
| C69 | Eye | 0 | 0.00 | 0.00–9.19 |
| C70–C72 | Central nervous system | 12 | 1.91 | 0.99–3.34 |
| C71 | Brain | 10 | 1.71 | 0.82–3.15 |
| C73 | Thyroid gland | 2 | 1.41 | 0.17–5.10 |
| C74–C75 | Other endocrine | 0 | 0.00 | 0.00–17.32 |
| C76–C80 | Site unknown or uncertain | 7 | 1.27 | 0.51–2.62 |
| C81 | Hodgkin lymphoma | 3 | 1.39 | 0.29–4.06 |
| C82–C85, C96 | Non-Hodgkin lymphoma | 6 | 1.16 | 0.43–2.53 |
| C88, C90 | Multiple myeloma, immunoproliferative diseases | 2 | 1.00 | 0.12–3.60 |
| C91–C95 | Leukaemia | 7 | 1.22 | 0.49–2.51 |
| C07–C08, C15, C16, C18, C33–C34, C40–C41, C44, C64–C68, C70–C73, C91–C95 (except C91.1) | Radiation-related sites | 135 | 1.06 | 0.88–1.24 |
| C01–C15, C18–C22, C32 | Alcohol-related sites | 66 | 1.42 | 1.09–1.80 |

## Table 3

Number of cancer cases, crude and adjusted relative cancer risks in the Estonian cohort of Chernobyl cleanup workers by cancer site and selected characteristics, 1986–2008.

| Cancer site/ Characteristic | No. of cases | Crude RR[a] | 95% CI | No. of cases | Adjusted RR[b] | 95% CI | No. of cases | Adjusted RR[c] | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| *All sites* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 137 | 1.00 | 0.76–1.30 | 137 | 1.02 | 0.78–1.34 | 137 | 1.01 | 0.77–1.33 |
| 1987–1991 | 92 | 1 | | 92 | 1 | | 92 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 118 | 1 | | 118 | 1 | | 118 | 1 | |
| ≥92 | 111 | 1.02 | 0.79–1.33 | 111 | 1.02 | 0.78–1.33 | 111 | 1.03 | 0.79–1.34 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 30 | 1 | | 30 | 1 | | 30 | 1 | |
| 7–13 | 66 | 1.11 | 0.72–1.71 | 66 | 1.10 | 0.72–1.70 | 66 | 1.07 | 0.70–1.65 |
| ≥14 | 133 | 1.02 | 0.68–1.51 | 133 | 1.01 | 0.68–1.51 | 133 | 0.99 | 0.66–1.47 |
| Ethnicity | | | | | | | | | |
| Estonian | 123 | 1 | | | | | 123 | 1 | |
| Non-Estonian | 106 | 1.04 | 0.80–1.35 | | | | 106 | 1.10 | 0.84–1.43 |
| Education | | | | | | | | | |
| Higher or secondary | 129 | 1 | | | | | 129 | 1 | |
| Basic or less | 100 | 1.54 | 1.19–2.00 | | | | 100 | 1.57 | 1.20–2.06 |
| *Radiation-related sites* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 80 | 1.02 | 0.72–1.44 | 80 | 1.06 | 0.75–1.52 | 80 | 1.05 | 0.74–1.49 |
| 1987–1991 | 53 | 1 | | 53 | 1 | | 53 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 69 | 1 | | 69 | 1 | | 69 | 1 | |
| ≥92 | 64 | 1.01 | 0.72–1.42 | 64 | 1.01 | 0.71–1.42 | 64 | 1.00 | 0.71–1.42 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 17 | 1 | | 17 | 1 | | 17 | 1 | |
| 7–13 | 40 | 1.14 | 0.65–2.02 | 40 | 1.14 | 0.65–2.01 | 40 | 1.11 | 0.63–1.96 |
| ≥14 | 76 | 1.06 | 0.63–1.79 | 76 | 1.07 | 0.63–1.81 | 76 | 1.04 | 0.61–1.77 |
| Ethnicity | | | | | | | | | |
| Estonian | 67 | 1 | | | | | 67 | 1 | |
| Non-Estonian | 66 | 1.19 | 0.84–1.67 | | | | 66 | 1.22 | 0.86–1.72 |
| Education | | | | | | | | | |
| Higher or secondary | 80 | 1 | | | | | 80 | 1 | |
| Basic or less | 53 | 1.31 | 0.93–1.85 | | | | 53 | 1.32 | 0.92–1.90 |

| Cancer site/ Characteristic | No. of cases | Crude RR[a] | 95% CI | No. of cases | Adjusted RR[b] | 95% CI | No. of cases | Adjusted RR[c] | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| *Alcohol-related sites* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 40 | 1.06 | 0.65–1.73 | 40 | 1.00 | 0.60–1.66 | 40 | 1.00 | 0.60–1.64 |
| 1987–1991 | 26 | 1 | | 26 | 1 | | 26 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 32 | 1 | | 32 | 1 | | 32 | 1 | |
| ≥92 | 34 | 1.15 | 0.71–1.86 | 34 | 1.13 | 0.69–1.84 | 33 | 1.13 | 0.69–1.85 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 7 | 1 | | 7 | 1 | | 7 | 1 | |
| 7–13 | 13 | 0.87 | 0.35–2.18 | 13 | 0.85 | 0.34–2.14 | 13 | 0.83 | 0.33–2.09 |
| ≥14 | 46 | 1.58 | 0.71–3.51 | 46 | 1.53 | 0.69–3.41 | 46 | 1.52 | 0.68–3.38 |
| Ethnicity | | | | | | | | | |
| Estonian | 35 | 1 | | | | | 35 | 1 | |
| Non-Estonian | 31 | 1.06 | 0.65–1.72 | | | | 31 | 1.18 | 0.72–1.94 |
| Education | | | | | | | | | |
| Higher or secondary | 33 | 1 | | | | | 33 | 1 | |
| Basic or less | 33 | 1.92 | 1.19–3.11 | | | | 33 | 2.18 | 1.32–3.62 |

[a]For year of arrival, duration of stay, and time since return from the Chernobyl area 167 subjects with unknown values were excluded; for ethnicity and education 556 subjects with unknown values were excluded.

[b]Model 1: includes age at start of follow-up, year of arrival, duration of stay, and time since return from the Chernobyl area (167 subjects with unknown values were excluded).

[c]Model 2: includes age at start of follow-up, year of arrival, duration of stay, time since return from the Chernobyl area, ethnicity and education (556 subjects with unknown values were excluded).

## Table 4

Observed number of deaths and standardized mortality ratio in the Estonian cohort of Chernobyl cleanup workers by cause of death, 1986–2011.

| ICD-10 | Cause of death | No. of deaths | SMR | 95% CI |
|---|---|---|---|---|
| A00–Y98 | All causes | 1,018 | 1.02 | 0.96–1.08 |
| A00–B99 | Infectious diseases | 17 | 0.85 | 0.49–1.36 |
| A15–A16 | Respiratory tuberculosis | 16 | 1.03 | 0.59–1.68 |
| C00–C97 | Malignant neoplasms | 178 | 1.14 | 0.98–1.31 |
| C00–C14 | Mouth, pharynx | 20 | 1.82 | 1.11–2.81 |
| C15–C26 | Digestive organs | 58 | 1.16 | 0.88–1.50 |
| C33–C34 | Trachea, bronchus, lung | 48 | 1.08 | 0.79–1.43 |
| C70–C72 | Central nervous system[a] | 10 | 1.75 | 0.84–3.22 |
| C73 | Thyroid gland[a] | 0 | 0.00 | 0.00–8.60 |
| C91–C95 | Leukemia | 4 | 0.92 | 0.25–2.37 |
| C07–C08, C15, C16, C18, C33–C34, C40–C41, C44, C64–C68, C70–C73, C91–C95 (except C91.1) | Radiation-related sites[a] | 103 | 1.19 | 0.96–1.42 |
| C01–C15, C18–C22, C32 | Alcohol-related sites[a] | 53 | 1.64 | 1.23–2.15 |
| I00–I99 | Diseases of the circulatory system | 284 | 0.93 | 0.82–1.03 |
| I20–I25 | Ischemic heart disease | 137 | 0.88 | 0.73–1.03 |
| I60–I69 | Cerebrovascular disease | 53 | 1.03 | 0.77–1.35 |
| J00–J99 | Diseases of the respiratory system | 46 | 1.12 | 0.82–1.50 |
| K00–K93 | Diseases of the digestive system | 56 | 0.99 | 0.75–1.29 |
| | Other nonviolent causes | 59 | 0.92 | 0.70–1.18 |
| V01–Y98 | External causes | 357 | 1.06 | 0.95–1.17 |
| V01–V99 | Transport accidents | 46 | 1.04 | 0.76–1.39 |
| X60–X84 | Suicide | 90 | 1.30 | 1.05–1.60 |
| X85–Y09, Y35, Y36 | Homicide | 28 | 0.74 | 0.49–1.07 |
| Y10–Y34 | Undetermined injury | 19 | 1.00 | 0.60–1.57 |
| F10, G31.2, K70, X45 | Selected alcohol-related causes | 92 | 1.04 | 0.84–1.28 |
| R99 | Unknown causes | 21 | 1.09 | 0.67–1.66 |

[a]Follow-up since 1994.

**Table 5**

Number of deaths, crude and adjusted relative death risks in the Estonian cohort of Chernobyl cleanup workers by cause of death and selected characteristics, 1986–2011.

| Cause of death/ Characteristic | No. of deaths | Crude RR[a] | 95% CI | No. of deaths | Adjusted RR[b] | 95% CI | No. of deaths | Adjusted RR[c] | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| *All causes* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 575 | 0.88 | 0.77–1.00 | 575 | 0.87 | 0.76–0.99 | 570 | 0.86 | 0.76–0.98 |
| 1987–1991 | 419 | 1 | | 419 | 1 | | 415 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 459 | 1 | | 459 | 1 | | 456 | 1 | |
| ≥92 | 535 | 1.20 | 1.06–1.36 | 535 | 1.23 | 1.09–1.40 | 529 | 1.21 | 1.06–1.37 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 156 | 1 | | 156 | 1 | | 153 | 1 | |
| 7–13 | 297 | 1.21 | 1.00–1.47 | 297 | 1.22 | 1.00–1.48 | 294 | 1.20 | 0.99–1.46 |
| ≥14 | 541 | 1.18 | 0.99–1.41 | 541 | 1.20 | 1.00–1.43 | 538 | 1.19 | 1.00–1.43 |
| Ethnicity | | | | | | | | | |
| Estonian | 485 | 1 | | | | | 485 | 1 | |
| Non-Estonian | 500 | 1.25 | 1.10–1.41 | | | | 500 | 1.33 | 1.17–1.51 |
| Education | | | | | | | | | |
| Higher or secondary | 585 | 1 | | | | | 585 | 1 | |
| Basic or less | 400 | 1.64 | 1.45–1.87 | | | | 400 | 1.73 | 1.51–1.98 |
| *Malignant neoplasms* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 101 | 0.92 | 0.68–1.24 | 101 | 0.96 | 0.70–1.30 | 101 | 0.94 | 0.69–1.28 |
| 1987–1991 | 74 | 1 | | 74 | 1 | | 74 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 94 | 1 | | 94 | 1 | | 94 | 1 | |
| ≥92 | 81 | 0.94 | 0.70–1.27 | 81 | 0.94 | 0.70–1.27 | 81 | 0.93 | 0.69–1.25 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 18 | 1 | | 18 | 1 | | 18 | 1 | |
| 7–13 | 35 | 0.97 | 0.55–1.70 | 35 | 0.95 | 0.54–1.69 | 35 | 0.93 | 0.53–1.65 |
| ≥14 | 122 | 1.12 | 0.68–1.83 | 122 | 1.11 | 0.67–1.82 | 122 | 1.09 | 0.67–1.80 |
| Ethnicity | | | | | | | | | |
| Estonian | 85 | 1 | | | | | 85 | 1 | |
| Non-Estonian | 90 | 1.29 | 0.96–1.73 | | | | 90 | 1.41 | 1.04–1.90 |
| Education | | | | | | | | | |
| Higher or secondary | 95 | 1 | | | | | 95 | 1 | |
| Basic or less | 80 | 1.68 | 1.25–2.26 | | | | 80 | 1.79 | 1.31–2.44 |

| Cause of death/ Characteristic | No. of deaths | Crude RR[a] | 95% CI | No. of deaths | Adjusted RR[b] | 95% CI | No. of deaths | Adjusted RR[c] | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| *Diseases of the circulatory system* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 153 | 0.83 | 0.65–1.05 | 153 | 0.81 | 0.63–1.03 | 153 | 0.80 | 0.63–1.03 |
| 1987–1991 | 125 | 1 | | 125 | 1 | | 124 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 130 | 1 | | 130 | 1 | | 129 | 1 | |
| ≥92 | 148 | 1.23 | 0.97–1.55 | 148 | 1.26 | 0.99–1.60 | 148 | 1.26 | 0.99–1.61 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 34 | 1 | | 34 | 1 | | 34 | 1 | |
| 7–13 | 79 | 1.21 | 0.81–1.82 | 79 | 1.22 | 0.82–1.83 | 78 | 1.18 | 0.79–1.77 |
| ≥14 | 165 | 1.05 | 0.72–1.52 | 165 | 1.07 | 0.74–1.55 | 165 | 1.05 | 0.73–1.53 |
| Ethnicity | | | | | | | | | |
| Estonian | 142 | 1 | | | | | 142 | 1 | |
| Non-Estonian | 135 | 1.15 | 0.91–1.46 | | | | 135 | 1.22 | 0.96–1.56 |
| Education | | | | | | | | | |
| Higher or secondary | 155 | 1 | | | | | 155 | 1 | |
| Basic or less | 122 | 1.63 | 1.29–2.07 | | | | 122 | 1.73 | 1.35–2.21 |
| *External causes* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 205 | 0.88 | 0.71–1.09 | 205 | 0.89 | 0.71–1.12 | 200 | 0.88 | 0.70–1.11 |
| 1987–1991 | 139 | 1 | | 139 | 1 | | 137 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 152 | 1 | | 152 | 1 | | 151 | 1 | |
| ≥92 | 192 | 1.23 | 0.99–1.52 | 192 | 1.27 | 1.02–1.58 | 186 | 1.22 | 0.98–1.52 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 94 | 1 | | 94 | 1 | | 92 | 1 | |
| 7–13 | 117 | 1.03 | 0.78–1.35 | 117 | 1.04 | 0.79–1.36 | 115 | 1.02 | 0.77–1.34 |
| ≥14 | 133 | 1.12 | 0.86–1.46 | 133 | 1.16 | 0.89–1.51 | 130 | 1.13 | 0.87–1.48 |
| Ethnicity | | | | | | | | | |
| Estonian | 168 | 1 | | | | | 168 | 1 | |
| Non-Estonian | 169 | 1.21 | 0.98–1.50 | | | | 169 | 1.28 | 1.03–1.58 |
| Higher or secondary | 213 | 1 | | | | | 213 | 1 | |
| Basic or less | 124 | 1.69 | 1.36–2.11 | | | | 124 | 1.72 | 1.36–2.17 |
| *Suicide* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 60 | 1.56 | 0.96–2.52 | 60 | 1.51 | 0.91–2.50 | 59 | 1.48 | 0.89–2.47 |
| 1987–1991 | 23 | 1 | | 23 | 1 | | 23 | 1 | |

| Cause of death/ Characteristic | No. of deaths | Crude RR[a] | 95% CI | No. of deaths | Adjusted RR[b] | 95% CI | No. of deaths | Adjusted RR[c] | 95% CI |
|---|---|---|---|---|---|---|---|---|---|
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 36 | 1 | | 36 | | 1 | 36 | 1 | |
| ≥92 | 47 | 1.27 | 0.82–1.96 | 47 | 1.16 | 0.75–1.81 | 46 | 1.14 | 0.73–1.79 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 26 | 1 | | 26 | 1 | | 26 | 1 | |
| 7–13 | 33 | 1.08 | 0.65–1.80 | 33 | 1.06 | 0.63–1.78 | 32 | 1.00 | 0.59–1.67 |
| ≥14 | 24 | 0.94 | 0.54–1.63 | 24 | 0.91 | 0.52–1.58 | 24 | 0.88 | 0.50–1.54 |
| Ethnicity | | | | | | | | | |
| Estonian | 47 | 1 | | | | | 47 | 1 | |
| Non-Estonian | 35 | 0.89 | 0.57–1.38 | | | | 35 | 0.95 | 0.61–1.49 |
| Education | | | | | | | | | |
| Higher or secondary | 52 | 1 | | | | | 52 | 1 | |
| Basic or less | 30 | 1.65 | 1.05–2.59 | | | | 30 | 1.77 | 1.10–2.85 |
| *Selected alcohol-related causes* | | | | | | | | | |
| Year of arrival in the Chernobyl area | | | | | | | | | |
| 1986 | 54 | 0.90 | 0.60–1.37 | 54 | 0.84 | 0.54–1.30 | 53 | 0.82 | 0.53–1.28 |
| 1987–1991 | 38 | 1 | | 38 | 1 | | 38 | 1 | |
| Duration of stay in the Chernobyl area (days) | | | | | | | | | |
| <92 | 36 | 1 | | 36 | 1 | | 36 | 1 | |
| ≥92 | 56 | 1.52 | 1.00–2.30 | 56 | 1.60 | 1.04–2.46 | 55 | 1.52 | 0.99–2.35 |
| Time since return from the Chernobyl area (years) | | | | | | | | | |
| <7 | 11 | 1 | | 11 | 1 | | 10 | 1 | |
| 7–13 | 19 | 1.00 | 0.48–2.11 | 19 | 1.05 | 0.50–2.22 | 19 | 1.14 | 0.53–2.45 |
| ≥14 | 62 | 1.45 | 0.76–2.76 | 62 | 1.62 | 0.85–3.11 | 62 | 1.77 | 0.90–3.48 |
| Ethnicity | | | | | | | | | |
| Estonian | 40 | 1 | | | | | 40 | 1 | |
| Non-Estonian | 51 | 1.54 | 1.02–2.33 | | | | 51 | 1.63 | 1.07–2.49 |
| Education | | | | | | | | | |
| Higher or secondary | 57 | 1 | | | | | 57 | 1 | |
| Basic or less | 34 | 1.68 | 1.10–2.56 | | | | 34 | 1.76 | 1.13–2.76 |

[a] For year of arrival, duration of stay, and time since return from the Chernobyl area 167 subjects with unknown values were excluded; for ethnicity and education 556 subjects with unknown values were excluded.

[b] Model 1: includes age at start of follow-up, year of arrival, duration of stay, and time since return from the Chernobyl area (167 subjects with unknown values were excluded).

[c] Model 2: includes age at start of follow-up, year of arrival, duration of stay, time since return from the Chernobyl area, ethnicity and education (556 subjects with unknown values were excluded).