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REVIEW

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Review

Chernobyl cleanup workers from Estonia: cohort description and related epidemiological research

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Abstract

The Estonian study of Chernobyl cleanup workers was one of the first investigations to evaluate the possible health consequences of working in the Chernobyl area (the 30 km exclusion zone and/or adjacent territories) after the 1986 reactor accident. The cohort consists of 4831 men who were dispatched in 1986–1991 for tasks involving decontamination, construction of buildings, transport, radiation measurement, guard duty or other activities. By 31 December 2012, the follow-up of the cohort yielded 102 158 person-years of observation. Exposure and health data were collected by postal questionnaires, biodosimetry evaluations, thyroid screenings, and record-linkages with cancer, causes of death and health insurance reimbursement registers and databases. These data cover socio-demographic factors, employment history, aspects of health behaviour, medical history, work and living conditions in the Chernobyl area, biomarkers of exposure, cancer and non-cancer disease occurrence and causes of death. Cancer incidence data were obtained for 1986–2008, mortality data for 1986–2011 and non-cancer morbidity data for 2004–2012. Although the cohort is relatively small, it has been extensively examined and benefited from comprehensive nationwide population and health registers. The major finding was an increased risk of suicide. Thyroid examinations did not reveal an association with thyroid nodular disease and radiation dose, but did indicate the importance of accounting for screening when making comparisons with unscreened populations. No risk of leukaemia was observed and risks higher than 2.5-fold could be excluded with 95% confidence. Biodosimetry included GPA analyses and chromosomal translocation analyses and indicated that the Estonian cleanup workers experienced a relatively low mean exposure of the order of 0.1 Gy. One value of the Estonian study is in the methodologic processes brought to bear in addressing possible health effects from the Chernobyl accident. Twenty-five years of research are summarised and opportunities for the future listed.

Keywords: Chernobyl cleanup workers, cancer incidence, cohort, mortality, radiation exposure, record linkage, suicide

1. Introduction

The accident at the Chernobyl nuclear power plant on 26 April 1986 caused substantial radioactive contamination in the immediate vicinity of the damaged reactor. Elevated levels of radiation were also detected across large areas of Europe. Some 530 000 persons from throughout the Soviet Union [1], including nearly 5000 men from Estonia, were brought into the most affected territories of Ukraine to help remediate and contain the consequences of the accident. In the summer of 1986, the All-Union Registry of Persons Exposed to Radiation from the Chernobyl Accident was established at the Research Institute of Medical Radiology in Obninsk [2]. The registry collected data from regional registries and sought to obtain individual medical and dosimetric information on cleanup workers and residents of contaminated areas. After the dissolution of the Soviet Union in 1991, some regional registries continued their activities including medical surveillance and/or epidemiological research. Here we give a short description of the Estonian cohort of Chernobyl cleanup workers and overview of related studies.

2. Methods

2.1. Aims and study components

The Estonian cohort of Chernobyl cleanup workers was set up with an aim to contribute to the knowledge about the effects of protracted low-dose radiation exposure on cancer risk, with particular emphasis on leukaemia [3]. When the study was designed in 1991–1992 [4], there was considerable uncertainty about the radiation doses received by the workers. It was realised, however, that the estimated number of cleanup workers from Estonia (4000–5000 men) was likely too small to detect a significant excess of leukaemia unless actual individual exposures to radiation were much higher than documented in the official personal military records. Determining an upper bound on the level of risk associated with the Chernobyl experience, however, was also thought to be of importance. Further, to increase study power, an extension of the study to other countries including Latvia, Lithuania and Belarus was considered [5].

The first phase of the study was designed to evaluate the feasibility of assembling the cohort of cleanup workers and linking it with the national cancer registry. A postal questionnaire study was developed to obtain details on the work carried out while at Chernobyl, as well as on potential confounders. A blood sampling study for biodosimetry based on glycophorin A (GPA) locus mutation assay analyses was planned.

The second phase conceptualised monitoring site-specific cancer incidence and cause-specific mortality in the cohort. In addition, a screening study for thyroid cancer and thyroid nodules was intended. The latter also included collection of peripheral blood lymphocyte samples for fluorescent *in situ* hybridisation (FISH) translocation analyses. GPA and FISH analyses were meant to confirm or refute the documented radiation doses and provide another estimate of the mean doses received by the cleanup workers.

Subsequently, molecular studies were developed to learn whether any radiation-related germline mutations in cleanup workers were inherited by their children. Specifically, length changes in minisatellites, tandemly repeated regions of DNA which occur at a high frequency throughout the genome, were to be evaluated. In the course of time, non-cancer morbidity study appeared to be feasible.

2.2. Population identification

The cohort (4833 men) was assembled in 1992 from four sources: the former Chernobyl Radiation Registry (an Obninsk-related regional registry), lists of former Soviet Army personnel, the former Ministry of Social Welfare, and the former Chernobyl Committee [6]. These men worked in the Chernobyl area in 1986–1991 for decontamination, construction of buildings, transport, radiation measurement, guard duty or other related activities. The 'Chernobyl area' denotes the officially designated 30 km exclusion zone (an area of 30 km radius from the nuclear power station) and adjoining territories, where work was performed.

2.3. Vital status determination

The cohort was followed through the national population register to identify persons from the lists, i.e. to obtain their unique personal identification numbers assigned to the Estonian residents since 1992, and update their vital status. Records were matched based on name, date of birth and place of residence. The initial cohort was reduced to 4811 men (analytic cohort) after excluding 20 persons who could not be traced because of inadequate personal identifiers and removal of two duplicate records [6, 7]. On 31 December 2012, 3148 cohort members (65.4%) were living in Estonia (table 1), and 102,158 person-years of follow-up (average, 21.2 years) were accumulated.

Our methods for tracing cleanup workers and obtaining cancer incidence and mortality outcomes are somewhat different from the other studies of Chernobyl cleanup workers where all necessary national registers did not exist. Estonia has a long standing cancer register, a mortality register and personal identification numbers to match to the registers in addition to name and date of birth. Living status in addition to mortality status could be confirmed as well as emigration. Overall, only 0.4% of the cohort was lost to follow-up.

Table 1. Characteristics of the Estonian cohort of Chernobyl cleanup workers[a].

Characteristic	No	%
Total (analytic cohort)	4811	100
Vital status as of 31 December 2012		
Living in Estonia	3148	65.4
Dead	1082	22.5
Emigrated	581	12.1
Age at start of follow-up (years)		
<20	80	1.7
20–29	1846	38.4
30–39	2310	48.0
40–49	541	11.2
⩾50	34	0.7
Time of arrival in the Chernobyl area		
1986, April–May	1393	29.0
1986, June–December	1509	31.4
1986, month unknown	22	0.5
1987	1086	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	1916	39.8
90–149	1531	31.8
150–209	852	17.7
⩾210	75	1.6
Unknown	167	3.5
Documented radiation dose (cGy)		
<5.0	1101	22.9
5.0–9.9	1272	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	765	15.9
Ethnicity[b]		
Estonian	2353	48.9
Non-Estonian	2453	51.0
Unknown	5	0.1
Education		
University/professional higher	373	7.8
Secondary	2892	60.1
Basic or less	1121	23.3
Unknown	425	8.8

[a] The cohort consists of 4831 men, of whom 20 (0.4%) could not be traced and were excluded, leaving 4811 men available for analysis. In earlier publications, the size of the cohort was stated to be 4833 [6, 14] or 4832 [15, 19]. Two duplicate records were subsequently identified and removed.
[b] According to the 1989 census, Estonians made up 57%, Russians 32%, Ukrainians 5%, Belarusians 2% and other ethnicities 4% of the male population of Estonia aged 20–49 years [30].

3. Results and discussion

After assembling the cohort, a number of studies were conducted on exposures and disease outcomes via postal questionnaires [6], thyroid examinations [8, 9], biodosimetry [10–13], record-linkages for cancer incidence [7, 14–18], cause-specific mortality [7, 14, 19] and non-cancer morbidity [20], and investigation of germline (heritable) mutations among children [21] (table 2). The Estonian cohort was included in a combined analysis of four Chernobyl cleanup worker studies [15–18].

Personal identification number was the key variable to link the cohort records with the cancer and causes of death registers, and health insurance reimbursement database. If necessary, name, date of birth and place of residence were also used. Annual or frequent updates unfortunately were not possible because of legal constraints [22] that prevented systematic linkages and otherwise paralysed normal operations within the health registers.

The information collected on the cohort is summarised in table 3. The self-administered questionnaire at the beginning of the cohort study, mainly in 1992–1993, is a major source of information concerning Chernobyl service and health behaviour. Since then, the collection of new data was based primarily on the linkages with the population, cancer and death registers, and health insurance reimbursement database. The major findings are listed below.

Information on individual radiation doses was obtained from multiple sources, including military lists for 4070 men [23], questionnaire responses for 3888 men [23], and blood evaluations incorporating the GPA locus mutation assay [10, 12] and FISH chromosomal translocation analyses [11, 13] for 3197 men [23]. The radiation doses from the official records were low (mean, 9.9 cGy; median, 8.8 cGy; maximum 58.0 cGy), and, for 15.9% of the cleanup workers, documented doses were not available. The biodosimetry evaluations confirmed the low mean dose of the order of 10 cGy, i.e. equal to the mean of the documented doses [1 (tables B1 and B3), 6] and lower than assumed in 1992 at the start of the study. For some epidemiologic analyses, the documented doses were used for contrasting higher dose workers with lower dose workers and provided little evidence for a radiation effect [7]. A crude excess relative risk (ERR) per Gy, however, could be computed based on the mean dose of 9.9 cGy and the SIR for all radiation-related cancers (SIR 1.06; 95% CI 0.88 to 1.24) [7]. Therefore, the crude ERR per Gy is 0.60 (95% CI −1.2 to 2.4). The confidence interval is broad and consistent with there not being a radiation effect at these levels, as well as with a radiation effect consistent with larger studies with higher doses. Because of small number of cancer cases, evaluations of individual sites were not informative. However, we did contribute our data to larger combined studies of cleanup workers were the RADRUE method for dose reconstruction [24] was used for case-control studies of thyroid cancer and hematological malignancies [17, 18].

Other larger studies of Chernobyl recovery workers in Russia, Ukraine and Belarus used various dose reconstruction methods, such as time-in-motion, electron paramagnetic resonance, tooth enamel approaches and buddy badges (grouped not individual dosimeters), to estimate organ doses as summarised in UNSCEAR [1] and in Kryuchkov *et al* [24]. The mean dose of 10 cGy in these larger studies is similar to the mean dose of about 9.9 cGy in our smaller study which had more complete sources of dosimetry per individual and did not have to rely as extensively on modelling for dose imputation. The larger studies, however, had broader dose distributions and thus more statistical power.

The overall and site-specific cancer incidence [7, 14–16], and all-cause and cause-specific mortality [7, 14, 19] among the cleanup workers were similar to the expected rates. In particular, there were no elevations in the incidence of leukaemia (7 observed versus 5.75 expected; SIR 1.22; 95% CI 0.49 to 2.51). Thus risk of the order of 2.5-fold and higher could

Table 2. Core[a] and supplemental studies of the Estonian cohort of Chernobyl cleanup workers.

Study name	Year/period	Description	Comment
Core studies			
Postal questionnaire[b] (Tekkel *et al* [6])	1992–1995[c]	Information obtained from 3704 cleanup workers. Questions cover history and conditions of work while at Chernobyl, lifestyle, demographic factors, etc.	Response rate to postal questionnaires 81.4%
Biodosimetry and biomarkers (Bigbee *et al* [10, 12], Granath *et al* [11], Littlefield *et al* [13])	1992–1996[d]	The GPA locus mutation assay and the FISH translocation analysis were used for radiation dose assessment in 3197 men from Estonia	Some publications include data on Latvian and Lithuanian cohorts
Cancer incidence (Rahu *et al* [14, 15], Rahu *et al* [7, 16])	1986–1993 1986–1998 1986–2008	Calculation of SIRs[e] during three follow-up periods	Linkage of cohort data with population and cancer registers
Cancer risk in the Baltic countries (Rahu *et al* [15], Rahu *et al* [16])	1986–1998 1986–2007	Calculation of SIRs and/or PIRs[f] during two follow-up periods	Linkage of cohort data with population and cancer registers
Supplemental studies			
Mortality (Rahu *et al* [14], Rahu *et al* [7, 19])	1986–1993 1986–2002 1986–2011	Calculation of SMRs[g] during three follow-up periods	Linkage of cohort data with population and death registers
Thyroid screening (Inskip *et al* [8], Wiest *et al* [9])	1995	Thyroid palpation, high-resolution ultrasonography and, selectively, fine-needle aspiration biopsy; calculation of the prevalence of thyroid nodules among 1984 screenees	Participation rate 66.2%
Minisatellite mutations among offspring (Kiuru *et al* [21])	1999[d]	DNA samples of 597 persons from 147 families (147 father, 147 mother, 155 pre- and 148 post-Chernobyl children) were analysed; calculation of mutation rates at eight minisatellite loci	Family participation rate 92.3%

(*Continued*)

Table 2. (*Continued*)

Study name	Year/period	Description	Comment
Risk of haematological malignancies (Kesminiene *et al* [17])	1990/1993–1998/2000	A nested case-control study (with dose reconstruction) in cohorts of five countries	Estonia contributed 4 cases and 16 controls
Risk of thyroid cancer (Kesminiene *et al* [18])	1990/1993–1998/2000	A nested case-control study (with dose reconstruction) in cohorts of five countries	Estonia contributed 2 cases and 8 controls
Non-cancer morbidity (Rahu *et al* [20])	2004–2012	Comparison of a cohort of 3680 cleanup workers with an unexposed cohort of 7631 men (population sample); calculation of morbidity RRs[h]	Linkage of data of two cohorts with a population register and Health Insurance Fund database

[a] Core studies cover those topics listed in the study protocol of 28 August 1992 [5].
[b] The questionnaire is available in a special booklet [3].
[c] The first mailing of questionnaires to cleanup workers took place from December 1992 to March 1993, and the second mailing from March to June 1993. Additional questionnaires were completed at the time of blood drawing and during a thyroid screening. The final number of completed questionnaires was 3888 in 1996.
[d] The year(s) of collection of blood samples.
[e] SIR—standardised incidence ratio.
[f] PIR—proportional incidence ratio.
[g] SMR—standardised mortality ratio.
[h] RR—rate ratio.

be excluded with 95% confidence following a mean dose of 10 cGy. For thyroid cancer there were 2 cases observed versus 1.42 expected, and little evidence of an effect following exposures in adulthood, consistent with most other studies [1].

The prevalence of thyroid nodules detected by ultrasonography among the cleanup workers (10%) was not higher than seen in a non-exposed population [8, 9]. Thus the examination studies confirmed of little to no detectable increase in thyroid nodular disease at mean doses of the order of 10 cGy following exposures in adulthood.

There was a unique screening bias that we were able to account for. During the thyroid examinations, including needle biopsies, unsuspected small thyroid cancers were in fact detected and subsequently recorded in the cancer register. When linkages were made later with the cohort, the thyroid cancers were revealed and suggested, in comparison with general population rates, an elevated incidence [15]. However, the elevation was entirely due to the special screenings afforded the workers which were not similarly received by the general population.

In the families of the cleanup workers, minisatellite mutations among children born after the Chernobyl accident were only slightly (and not significantly) more frequent than seen among their siblings born before the accident [21]. This added little support for the idea that minisatellite mutations might be a good indicator of possible heritable effects following gonadal irradiation suggested in some [25, 26], but not most [27–29] family studies of Chernobyl cleanup workers.

Table 3. Summary of data collected on the Estonian cohort of Chernobyl cleanup workers.

Data collected
Socio-demographic data
Date of birth
Ethnicity
Education
Marital status
Children (sex, date of birth)
Place of residence
Employment history
Occupation
Exposure to radiation
Exposure to hazardous chemicals
Health behaviour
Smoking habits
Alcohol drinking habits
Medical history
History of selected conditions
History of tumours and the type of therapy
History of x-ray procedures
History of cardiovascular diseases among blood relatives
History of cancers among blood relatives
Work and residence in the Chernobyl area
Date of arrival
Date of departure
Type of work
Use of protective clothing
Eating habits
Alcohol drinking habits
Official documented radiation dose[a]
Biodosimetry (whole-body radiation dose)
GPA locus mutation assay estimate[b]
FISH analysis estimate[b]
Health outcome
Cancer
Cause of death
Non-cancer disease (health insurance reimbursement data)

[a] It was estimated that uncertainties in individual dose estimates may vary from 50% to 500% [31]. For that reason, the month/year of arrival at the Chernobyl area and duration of the mission were used as proxy variables for radiation exposure.
[b] The majority of personal data on individual biodosimetry-based doses have not been saved, and therefore they were not available for inclusion in the database of cleanup workers.

Perhaps most notably, during the whole follow-up period since 1986, the risk of suicide in the cohort was significantly increased and was around 30% higher than that in the male population of Estonia [7, 14, 19].

Finally, the cleanup workers experienced an excess of alcohol-induced conditions, but not radiation-related diseases [20]. This observation highlights the importance of confounding influences in these unique populations of Chernobyl cleanup workers and should be considered when interpreting findings.

4. Strengths and weaknesses

The main strength of the cohort rests in its design, the inclusion of practically all cleanup workers from Estonia, the nearly complete follow-up for vital status and the personal contacts via questionnaire and special screenings. The cohort was assembled using several independent sources. Via record-linkages, the country-wide population and health registers facilitated the evaluation of disease outcomes in the cohort in comparison with the male population in a comprehensive and unbiased fashion. Similar data for the cleanup worker cohorts in other Baltic countries allowed a pooled analysis to increase the statistical power to identify a radiation effect at the dose levels experienced.

There are several limitations. The size of the cohort is small and therefore has a limited ability to detect modest effects or rare outcomes. Nonetheless, the confidence intervals about the point estimates of possible radiation-related risks provide important guidance as to the levels of risk that could be excluded. Further, the significant increase in suicides points to an important public health concern, i.e. anxiety and disruptive behaviours that are partially related to a fear of radiation and its consequences.

The small size of the cohort and limited range of dose estimates tempered the conclusions that could be drawn with regard to radiation effects. The consistency of the documented doses and the biological measures of dose (GPA and FISH) added some assurance that the mean dose of about 10 cGy was valid, as was the consistency with other larger studies of Chernobyl cleanup workers [1].

Health behaviour data were obtained only once at the beginning of the study and could have changed over time. Finally, there remains a concern in this as in other studies of Chernobyl cleanup workers that screening examinations resulted in detection of tumours that might not have been otherwise diagnosed and that ascertainment bias cannot be discounted among these workers who received intense surveillance and scrutiny after the accident [7, 15, 16, 18].

In summary, the Estonian Chernobyl cleanup worker study has the following features not often found in occupational studies: individual worker contact, physical examinations, blood analyses, cancer incidence and mortality ascertainment through national registers, and long-term follow-up. It provided new knowledge on the immediate psychosocial aspect of the fear of radiation, apart from the potential long-term health consequences of the radiation dose received. Even with regard to radiation risks, it provides upper levels of risk that can be reasonably excluded given the estimated low doses received. The study findings also have been combined with other Chernobyl investigations to gain more complete understanding of the potential radiation risks. Opportunities for the future are to provide lifetime evaluations of this well-described population group and confirm existing observations or reveal new aspects of the health consequence of response to a severe radiation accident. The authors welcome collaboration and new ideas to pursue for the future—so please contact us!

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