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Radiation and Epidemiological Analysis for Solid Cancer Incidence among Nuclear Workers Who Participated in Recovery Operations Following the Accident at the Chernobyl NPP

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Chernobyl/Solid cancer/Recovery operation/Nuclear workers/Risks.

This paper discusses the results of the analysis of the relationship between dose and solid cancer incidence among nuclear workers (males) who worked as liquidators after the Chernobyl accident. Information on this cohort of individuals is available at the regional center of Russian National Medical and Dosimetric Registry operating at the RF State Research Centre-Institute of Biophysics. Medical and dosimetric information on 8,654 persons 18–60 years of age with documented external radiation doses is used for the analysis. These data were gathered in the period from 1996 to 2001 and cover a total of 45,166.5 follow-up person-years. In the cohort under study, 179 solid cancers occurred during this period. The average age of liquidators at the time of exposure was 35.8 years, and the average dose as a result of the Chernobyl exposure was about 0.05 Sv. For an analysis of the dose-effect relationship (induction of radiation-induced malignant neoplasms) the statistical software EPICURE was used. The results of the analysis show that the cancer incidence in this cohort does not exceed cancer incidence in relevant age groups of the Russian population. The mean value of SIR for all cancer diseases was 0.88 (0.76, 1.02, 95% CI) for the whole period of follow-up. Risks for the induction of radiation-related cancer diseases were not statistically meaningful. Excess relative risk per 1 Sv was 0.95 (–1.52, 4.49, 95% CI).

INTRODUCTION

The large-scale epidemiological studies undertaken after the 1945 atomic bombing in Hiroshima and Nagasaki in Japan have shown that the incidence rate of malignant neoplasms increases with radiation dose.[1,2] From 1950 to 1990, the expected (spontaneous) number of cancers in the LSS cohort of 86,500 people exposed to radiation was 7,791 cases, whereas the number of cases actually registered in this time period was 8,040. The highest radiation risk was found for leukemia (except chronic leukemia): The frequency of this pathology increased by a factor of 5–7 for those who received high radiation doses (more than 1 Sv). Based on the studies undertaken in Japan, models for estimating radiation risk were developed and later recommended for use by the International Commission on Radiological Protection.

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There are some questions about using the radiation risks derived from Hiroshima and Nagasaki for predicting the health effects of the Chernobyl accident. First, the mean radiation dose in the Japanese cohort (about 0.3 Sv) is much higher than the doses received by emergency workers and the general public after the Chernobyl accident. Is it legitimate to extrapolate the radiation risk coefficients derived for the Japanese cohort to the domain of low radiation doses (less than 0.2 Sv)? This important question can be answered only on the basis of many—years of radiation-epidemiological studies conducted after the Chernobyl accident.[3)]

MATERIALS AND METHODS

Description of the cohort of emergency workers—employees of the nuclear industry

The Russian National Medical and Dosimetric Registry (RNMDR) currently contains individual data about 179,923 Chernobyl emergency workers[4,5)] A regional affiliation of the RNMDR is functioning in the Institute of Biophysics. This cohort is of special interest from the standpoint of epidemiological studies because its members have more reliable medical and dosimetric data.

The analysis of the dose response of cancers in this cohort

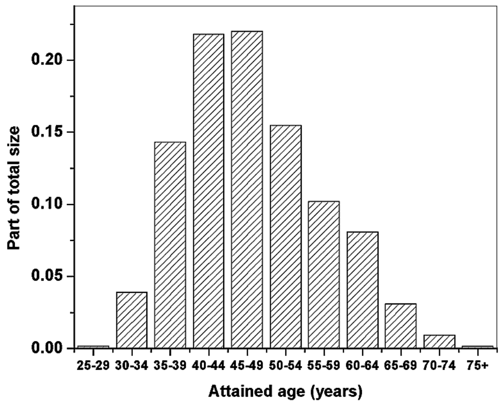

Fig. 1. Age distribution of the emergency workers at the beginning of the selected follow-up period (1996).

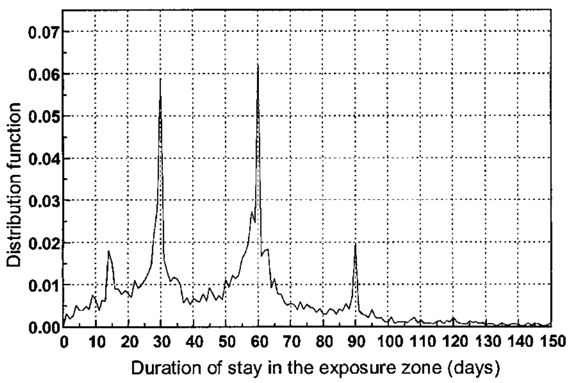

Fig. 2. Distribution of the emergency workers by the duration of stay in the exposure zone.

was performed for the follow-up period of 1996–2001. The year 1996 was chosen as a starting year of follow-up (10 years after the accident) with the assumption that by this time the system of collection and verification of medical and dosimetric data has been stabilized. Another reason for choosing this year was an allowance for the minimal latent period of solid cancers.

The age range covered by the study was 18–60 years. Older age groups were not included because of the limited accuracy of statistical data for these categories in Russia in general. As of December 31,2001, the total number of emergency workers—employees of the nuclear industry subjected to medical examination (at least once during the selected follow-up period from 1996 to 2001) and selected according to the indicated criteria was 17,945 people. Of them, the number of emergency workers with determined external radiation dose is 8,654 (or 48%), the number of person-years at risk being 45,166.5. A relatively low percentage of emergency workers with documented doses is explained by a limited availability of dosimeters at that time, especially in 1986. Doses from internal exposure in the exclusion zone were not measured.

Figure 1 shows the age distribution of the emergency workers (with documented doses) in 1996, the beginning of the study period. It can be seen from the figure that most emergency workers were 40–49 years old at the beginning of 1996.

The mean age of the emergency workers at the exposure time was 35.8 years.

During the follow-up period, 179 cases of solid cancer were detected in the studied group of emergency workers. The mean dose received in Chernobyl was about 0.05 Sv.

The distribution density for the emergency workers (with documented doses) with respect to the duration of stay in Chernobyl is presented in Fig. 2. The distribution shows two well-defined peaks corresponding to the duration of stay of one and two months.

Statistical methods

In the analysis data of 1996–2001 for solid cancer incidence in the dose range, 0.001–0.25 Sv was used. The cross-tabulation of cases and person-years used has dose categories with cut points of 1.0, 20.0, 80.0, and 250.0 mSv, along with 5-year intervals of attained age and 1-year intervals of calendar time.

A standard software EPICURE (AMFIT software) was used for the analyses of all solid cancers. These analyses were based on a general excess relative risk model that can be stated formally as

$$\lambda(a,t)\cdot(1+\rho(d)\cdot\varepsilon(t,a)), \tag{1}$$

in which $\lambda(.)$ is background cancer incidence, $\rho(.)$ is dose response function, and function $\varepsilon(.)$ describes dose-effect modification. The background rates were modeled as a function of attained age and calendar time. Calendar time was included to allow for time trends in the background rates. The effect modifiers included the covariates as well as time since exposure and age at exposure. The linear dose-response function is written as

$$\rho(d) = ERR_{1Sv}\cdot d.$$

In this equation, ERR_{1Sv} is excess relative risk per Sv and d is external dose (Sv).

The risk estimates were made by using the external (spontaneous cancer incidence in Russia as a whole) and the internal control group (spontaneous cancer incidence among emergency workers with zero doses).

In calculations using the external control group, the risk model takes this form:

$$\lambda^R(a,t)\cdot SIR^u\cdot(1+\rho(d)\cdot\varepsilon(t,a)), \tag{2}$$

in which $\lambda^R(a,t)$ is the spontaneous cancer incidence rate in Russia corresponding to the attained age (a) and calendar time (t); SIR^u is the coefficient accounting for the difference between the spontaneous incidence in the emergency workers cohort and the general population of respective age in the time period considered. In the model we used, this coefficient is equal to the standard incidence ratio (SIR) for unexposed members of the cohort. The variation of the coefficient SIR^u from unity may be explained by completeness and reliability of incidence data in the registry or a possible «healthy work-

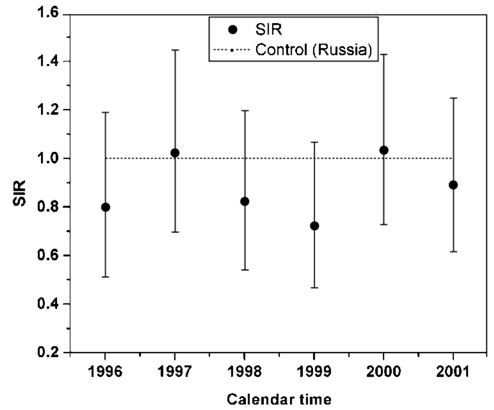

Fig. 3. Standardized incidence ratio (*SIR*) for all emergency workers (with documented dose).

Table 1. Results of estimating risk coefficients for malignant neoplasms among the emergency workers with documented doses.

Number of cases	179
Internal control, model (1)	
*ERR/*S [a]	0.95
(95% CI)	(–1.52, 4.49)
SIR[b]	0.88
(95% CI)	(0.76, 1.02)
External control, model (2)	
*ERR/*Sv	0.90
(95% CI)	(–1.54, 4.40)
SIR^u	0.83
(95% CI)	(0.69, 1.02)

[a]*ERR/*Sv is excess relative risk per 1 Sv. [b]*SIR* for all emergency workers.

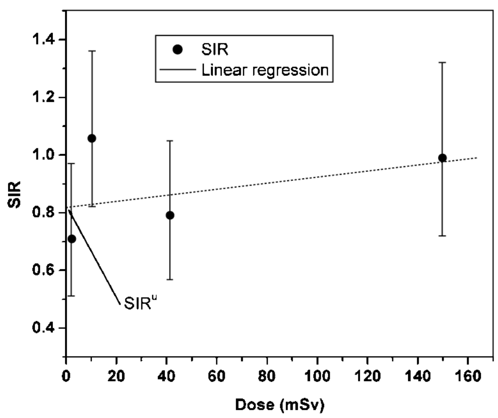

Fig. 4. Dose response for *SIR*.

ers effect», because the emergency workers were subjected to additional medical checks before going to work in the zone. The selected risk model has the advantage of estimating both the dose response and the difference in spontaneous cancer incidence in the followed up cohort and the referent Russian population.

Thus it is only the relative age distribution of spontaneous incidence rates that is used for risk estimation (with the use of external control), and this is a more robust characteristic than the absolute distribution. The value of SIR^u was assumed to be the same for all age groups. When risk coefficients were estimated when using the internal control, the data were stratified by attained age and calendar time.

RESULTS

Figure 3 shows the results of an estimation of the *SIR* for all cancers in the cohort of emergency workers (both with documented doses). The value of *SIR* is mostly below the control (the control is the incidence rate in corresponding age groups in Russia in general) and is consistent with the control within 95% confidence intervals (CI). The mean value of *SIR* for all cancers with 95% CI among all emergency workers over the whole follow-up period (with and without dose) is 0.88 (0.76, 1.02).

Table 1 includes the results of estimating risk coefficients for all solid cancers. As can be seen from Table 1, the values *ERR/Sv* for cancers of all solid cancer is not statistically significant. The value of SIR is consistent with the control (the cancer incidence rate in Russia in general) within 95% CI.

For an illustration of the dose response of cancer incidence in general, all data were divided into 4 dose intervals with close values of person-years at risk. The main characteristics of the dose groups are presented in Table 2.

Figure 4 shows a dose response for *SIR* and the linear regression.

DISCUSSION

The present work is a logical continuation of the study of cancer incidence among emergency workers conducted in Russia.[4–7] This issue remains topical because emergency workers on the average received higher radiation doses than the population of the affected regions.

In work[5] the value ERR_{1Sv} was estimated to be above zero for three classes of diseases (all solid cancers, malignant neoplasms of digestive and respiratory organs). The statistically significant excess of ERR_{1Sv} above zero was found only for the classes of "all solid cancer" and cancer of digestive organs. The values of risk coefficients derived in this study are much lower than those presented in work.[5] ERR_{1Sv} was 1.13 (0.14, 2.13, 95% CI) for all solid cancers and 2.41 (0.10, 4.71, 95% CI) for cancers of digestive organs. The radiation risk values for all solid cancers obtained in this study are close

Table 2. Main characteristics of the cohort of emergency workers by dose groups.

Dose interval (mSv)	1–5	5–20	20–80	80–250
Number of cases	37	58	42	42
Person-years at risk	10,716	12,304	11,670	9,903
Mean dose (mSv)[a]	2.21	10.37	41.49	149.70
Mean dose rate (mSv/day)[a]	0.05	0.19	0.66	2.44
Cancer incidence rate(number of cases per person-year)	0.0035	0.0047	0.0036	0.0042

[a]Person-year weighted averages.

to those in work,[5] but they are not statistically significant. The absence of statistical significance can be associated with a small size of the cohort, low radiation doses, and a relatively short follow-up period.

A possible dose response of malignant neoplasms was estimated for the Chernobyl emergency workers and nuclear workers of Russia during the period from 26.04.86 to 31.12.87 (1988–95), and the results were published in Tukov *et al.*[6] The relative risk of malignant neoplasms was found to be 1.2 (0.4, 2.2, 95% CI) for the dose group 10–49 mSv and 1.4 (0.1, 3.2, 95% CI) for the dose group 50–99 mSv. In this case the risks are statistically significant, which may be due to differences in the follow-up periods and neglect of the latent period in work.[4] As shown by the analysis of data since 1986, the risks are highest in the first five years after the Chernobyl accident. This can hardly be due to the effect of exposure in this period and is most probably explained by the way information in the national registry database was collected in the first years of the Registry's functioning, which is worth discussing in a separate study. Besides, the work[6] discusses emergency workers who were in the exclusion zone in the first two years after the accident and had, on the average, higher doses than the cohort as a whole.

The results of the present study should be treated as preliminary because there are many confounding factors such as harmful habits that influence the dose response of incidence and still remain unstudied. In the work,[8] for example, the relationship between alcohol consumption and smoking and radiation dose among workers of nuclear industry is discussed.

CONCLUSIONS

The analysis of the solid cancer incidence in the cohort of emergency workers—employees of the nuclear industry shows that the cancer incidence rate in the studied cohort does not exceed that in the respective age groups of the population of Russia as a whole. The mean value of *SIR* for all cancers with 95% CI is estimated to be 0.88 (0.76, 1.02). For all cancers the risk of induction of radiogenic cancers is found not to be statistically significant. The excess relative risk at 1 *Sv* with 95% CI is 0.95 (–1.52, 4.49).

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