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The cancer risk among workers of the nuclear centre at Świerk, Poland

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Abstract. Dosimetric information concerning 4606 workers at the nuclear centre at Świerk (Poland) from 1956 to 2001 and medical records of 575 workers are reviewed. The average cumulative doses per person were 34 mSv (effective dose) and 18 mSv (equivalent dose to hands). The calculated odds ratio of cancers, OR = 0.90 (0.62–1.18; 68% CI), shows a statistically insignificant decrease of the cancer risk among the irradiated workers. No cancer cases were detected neither among 52 people exposed to the highest cumulative doses (from 35 to 653 mSv) nor among 43 workers who had been chronically irradiated for a long time (from 13 to 26 years).

Key words: nuclear workers • low doses • radiation influence • Świerk • Poland

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Introduction

The nuclear centre at Świerk in the central Poland had been built in 1956 and the first experimental reactor begun operating two years later [7]. The individual dose registry from 1956 to 2001 contains the data of 4606 workers, however only 575 of them have their own detailed personal medical registry. Nonetheless, it is of interest to see what even such limited data show, especially in case of cancer incidence. A 10-year lag-time is applied in the analysis presented herein. The health status as described does not apply to workers employed after 2001. This paper is the first presentation of the results of analyses performed on the Świerk nuclear centre employees and is based on the final report [6] prepared at the end of 2011.

Three groups of workers are considered (Table 1):
- all workers with the individual dose registry (4606 people);
- the workers who received a significant dose in any single year of the dosimetric control (1703 people);
- the workers (with significant and insignificant doses) for whom the full medical data exist (575 people).

The "significant dose" means an effective dose (E) or an equivalent dose to hands (H) being equal to or higher than 0.5 mSv. Lower doses are assumed to be non-significant.

Dosimetry

The individual registry of doses concerns workers who received doses from external sources as well as from the

Table 1. Three groups of workers analyzed in the presented paper

Group of workers	No. of workers	Average birth date	Average length of individual dosimetric control (years)	Percent of women	Average cumulative doses (effective and equivalent, mSv)
All workers	4606	1942	10.5	25	6.7 (body) 4.5 (hands)
Workers with doses ≥ 0.5 mSv	1703[a]	1938	15.7	22	18.2 (body) 12.3 (hands)
Medical cohort	575[a]	1944	17.8	27	15.3 (body) 8 (hands)

[a] Groups of 1703 and 575 workers form parts of the main group of 4606 people; sets with 1703 and 575 workers overlap.

intake contamination, neutron and beta radiation, etc. All such cases were taken into account and included as part of the individual effective dose. The doses were usually measured by photometric dosimeters and read-out by an accredited laboratory. The individual cards of the dose registry contains exact values of the equivalent or effective doses measured in rems [6]. The uncertainty of dose measurement is on the level of 22–30%.

In the group of 4606 workers, 1142 people (25%) are women. Their statistical average year of birth is 1942. The average length of an individual dosimetric control is 10.5 years (statistically from 1973 to 1983). Their average cumulative effective dose was 6.7 mSv and the equivalent dose to hands was 4.5 mSv. Figure 1 presents the distribution of cumulative effective doses and Fig. 2 presents the distribution of equivalent doses to hands).

The collective time of the individual dosimetric control was 48.414 person-years. Figure 3 shows the distribution of the individual dosimetric control time. A group of 193 workers have been under their own individual dosimetric control for at least 30 years, while in the case of 42 workers this time has not been shorter than 40 years. For one worker, the dosimetric control time was 47 years.

1703 workers from the whole group (4606) fell into the group who acquired a significant dose (Tables 1, 2 and Figs. 1, 2). 663 of them received individual dose during one year only. In the case of 332 workers a significant

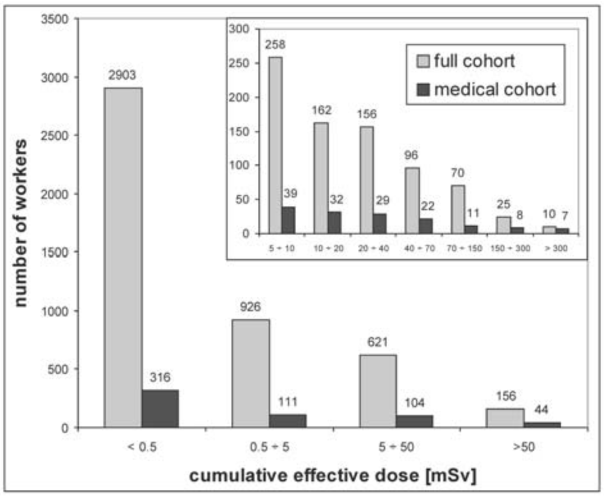

Fig. 1. The distribution of cumulative effective doses (only) among nuclear workers at Świerk between 1956 and 2001. Grey pillars – full cohort of 4606 workers; dark pillars – medical cohort of 575 workers (Table 1). The small plot represents the more detailed information for higher doses.

equivalent doses to hands were delivered (Fig. 2). In this group 30 workers received an equivalent dose to hands only (the effective doses were in-significant).

What follows from Figs. 1–3 is that although the distributions look very similar when displayed for all workers and for the ones with the known medical

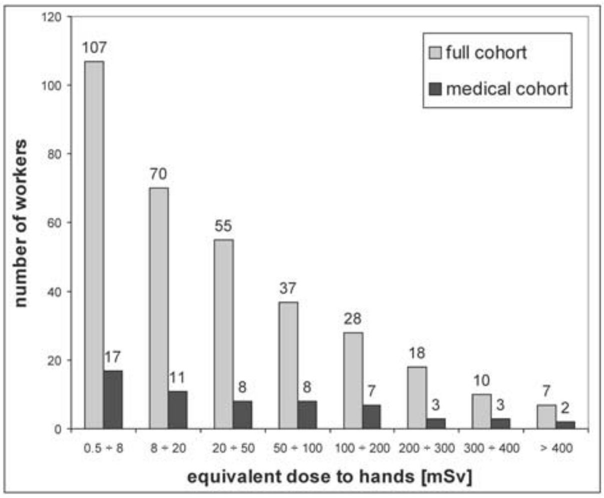

Fig. 2. The distribution of cumulative equivalent dose to hands among nuclear workers at Świerk between 1956 and 2001. The cohort was narrowed to workers, who have received doses to hands H ≥ 0.5 mSv. Grey pillars – full cohort; dark pillars – medical cohort.

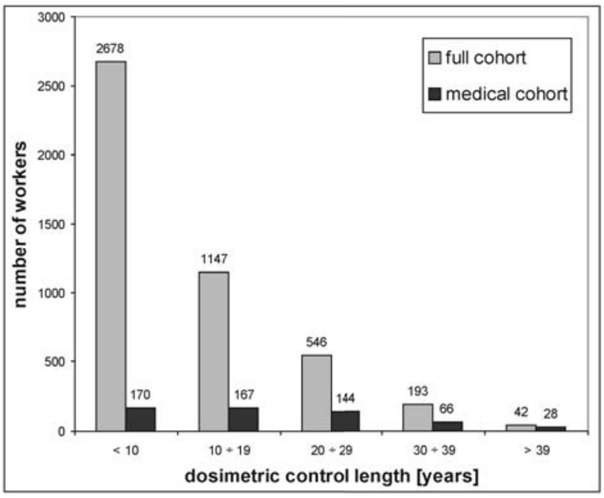

Fig. 3. The distribution of individual dosimetric control time among nuclear workers at Świerk between 1956 and 2001. Grey pillars – full cohort of 4606 workers; dark pillars – medical cohort of 575 workers (Table 1).

Table 2. The dose data of 1703 workers (Table 1) who received statistically significant doses (≥ 0.5 mSv). The data are divided into two groups: women and men

	Women	Men
Number of workers	381	1322
Collective dose (person-Sv)	3.31	27.82
The average cumulative dose per person (mSv)	8.7 (body) 12.7 (hands)	21 (body) 12.1 (hands)
The average annual dose per person (mSv/year)	0.6 (body) 1.0 (hands)	1.6 (body) 1.0 (hands)
The collective time of individual dosimetric control (person-years)	5 655	21 199
The average individual dosimetric control time per person (years)	14.7	16
The average number of years, when a worker has received statistically significant doses (years)	3.1	4.1

record, a relatively better statistics is achieved for the latter group at larger doses and a longer span of dosimetric control.

The data of special interest are as follows:
- 156 workers were exposed to the cumulative effective dose higher than 50 mSv. In this group the average value of the effective dose is 121.8 mSv and the equivalent dose to hands 90.3 mSv;
- 66 workers were exposed to the cumulative effective dose higher than 100 mSv. In this group the average value of the effective dose is 194.4 mSv and the equivalent dose to hands 150.7 mSv;
- In the case of 10 workers the cumulative effective dose turned out to be higher than 300 mSv while 4 workers received more than 400 mSv. One worker received the cumulative effective dose equal to 653.3 mSv and the equivalent dose to hands which equaled 435.6 mSv during 33 years of the individual dosimetric control.

Medical registry

Based on the medical record lead by the local medical clinic, one can find sufficient medical information for 575 workers out of the whole cohort of 4606 (Table 1 and Fig. 1). No follow-up procedure had ever been used, so the health status of workers who retired or changed the job is not known unless accidentally. The data from the medical registry contain information about cancers. Figure 4 provides the function of the workers' health status to their birth date.

265 workers from the medical cohort of 575 people (Table 1 and Fig. 4) received significant doses of ionizing radiation (effective or equivalent). In this group the average cumulative effective dose equals 33.3 mSv and equivalent dose to hands equals 17.3 mSv. The average time of the individual dosimetric control equals 23.3 years.

47 persons (8.2%) out of 575 contracted a cancer till 2011. One notes, however, a substantial fractional increase of cancers for people born during the II World War (1939–1945). One finds altogether 7 cases of breast cancer, 6 cases of lung cancer, 5 cases of kidney cancer, 3 cases of leukaemia, 3 cases of stomach cancer, 2 cases of pancreatic cancer, 2 cases of intestine cancer, 2 cases of thyroid cancer, 2 cases of eye cancer and 2 cases of prostate cancer. The rest of cancer types were single cases. In 3 cases the type of cancer is unknown. More information about cancer types assigned to each worker can be found in the original report [6].

The distribution of these specific cancers is well correlated with the cancer distribution for the whole population of Poland, which means that ionizing radiation can hardly be considered as a primary cause of cancers in the considered group of workers. In fact, in the group of those 47 cancer cases, 21 workers had

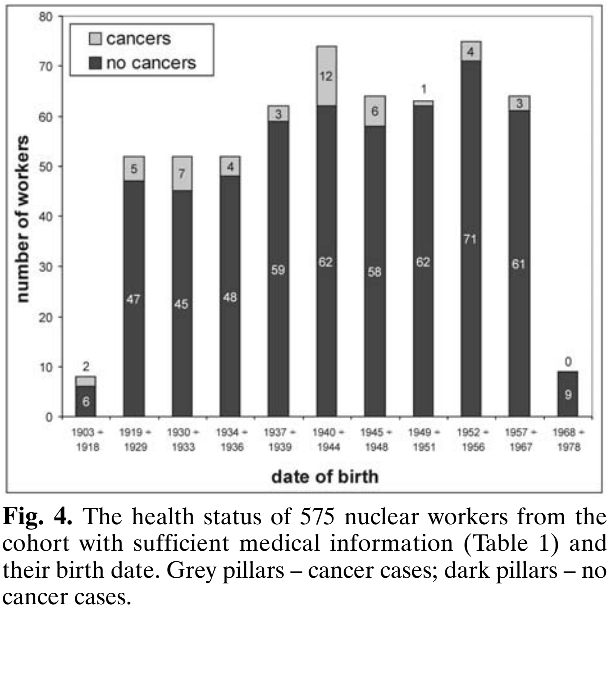

Fig. 4. The health status of 575 nuclear workers from the cohort with sufficient medical information (Table 1) and their birth date. Grey pillars – cancer cases; dark pillars – no cancer cases.

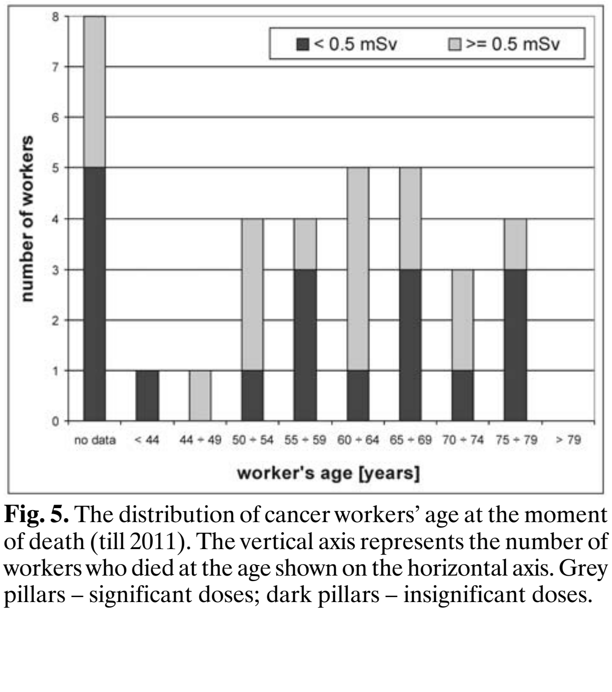

Fig. 5. The distribution of cancer workers' age at the moment of death (till 2011). The vertical axis represents the number of workers who died at the age shown on the horizontal axis. Grey pillars – significant doses; dark pillars – insignificant doses.

received significant doses (≥ 0.5 mSv), and no correlation between the frequency of cancer appearance and the received doses was found.

35 cancer persons out of all 47 died till 2011 (Fig. 5).

Results

No cancer case was detected among 52 workers with effective doses more than 35 mSv. Also no cancer case was detected among 43 workers who had been chronically irradiated for more than 12 years. The "chronic irradiation" means the period when the significant dose was registered by a worker's personal dosimeter.

In order to estimate the cancer risk, the medical cohort (575 workers) can be divided into two groups – irradiated workers (with significant both types of doses) and controls (workers with insignificant doses). The average cumulative effective dose in the irradiated group equals 33.3 mSv and the equivalent dose to hands – 17.3 mSv. Details are presented in Table 3. In the control group the cancer risk ratio equals RR = 8.4% (6.5–10.3, 68% CI, confidence intervals) while in the irradiated group RR = 7.9% (5.9–9.9, 68% CI). It is

Table 3. Detailed information about 575 workers of the medical cohort (Table 1). The cancer means the cancer incidence

	No cancer, insignificant dose (< 0.5 mSv)	No cancer, significant dose (≥ 0.5 mSv)	Cancer, insignificant dose (< 0.5 mSv)	Cancer, significant dose (≥ 0.5 mSv)
Number of workers (women)	284 (93)	244 (46)	26 (11)	21 (6)
The average date of birth	1947	1941	1941	1938
The average date of the start of the individual dosimetric control	1978	1969	1974	1966
The average date of the end of the individual dosimetric control	1992	1993	1990	1988
The average length of the individual dosimetric control (years)	12.9	23.6	15.2	20.2
The average number of years, when a worker has registered significant doses (years)	0	5.9	0	4
The average cumulative dose for each worker (mSv)	< 0.5	35.3 (body) 18.3 (hands)	< 0.5	9.2 (body) 6.0 (hands)
The average annual effective dose (mSv/year)	–	1.6	–	0.5
The maximal effective dose for mostly irradiated worker (mSv)	< 0.5	653.3	< 0.5	32.1

Table 4. The final results of the analysis as OR (the odds ratio) with different criteria of the dose sensitivity threshold and the type of dose. The uncertainties show one standard deviation (68% CI). The last collumn presents the average cumulative dose per an irradiated worker

Dose sensitivity threshold (the definition of significant dose)	OR (odds ratio of cancer incidence)	Average cumulative dose (mSv)
Dose sensitivity threshold for effective dose or equivalent dose to hands		
0.5 mSv [a, b]	0.94 (0.65–1.23) [b]	33.3 (body) 17.3 (hands)
1 mSv	0.90 (0.62–1.19)	37.7 (body) 19.7 (hands)
5 mSv	0.94 (0.61–1.27)	56.3 (body) 29.8 (hands)
10 mSv	0.82 (0.48–1.15)	73.1 (body) 39.5 (hands)
Dose sensitivity threshold for effective dose only [c]		
0.5 mSv [a]	0.90 (0.62–1.18)	34.0 (body) [17.6 (hands)]
1 mSv	0.86 (0.59–1.14)	38.9 (body) [20.1 (hands)]
5 mSv	0.87 (0.55–1.19)	58.1 (body) [29.8 (hands)]
10 mSv	0.60 (0.33–0.88)	76.3 (body) [39.8 (hands)]

[a] – the threshold of dose sensitivity (= 0.5 mSv) is taken as a default one in the presented paper.
[b] – this case was precisely described in Table 3.
[c] – only the effective dose is taken into account as a criterion of workers selection considered to fall into irradiated or non-irradiated (controls) groups (Fig. 1). The equivalent dose to hands is not taken into calculations of OR.

very difficult to compare those values with the average cancer incidence rate in Poland (equals 24.5% [8] in 2011), because this rate varies with time (the analyzed data concern at least partly the time when the rate was much lower) and what is more important – the large number of cancers appeared at the time when the workers have already retired.

Comparing the irradiated and control groups, one finds the odds ratio of cancer incidence as OR = 0.94 (0.65–1.23, 68% CI). However, this decrease of cancers (6.0 ± 28.8)% is statistically insignificant.

Table 4 contains the results using different criteria (effective or equivalent dose; effective dose only) and different dose sensitivity thresholds (0.5 mSv or more). The authors are aware, however, that ICRP (International Commission for Radiological Protection) recommendations says that the equivalent dose to hands cannot be taken as an irradiation criterion [9]. In all presented cases (Table 4) the results show a regular (although statistically insignificant) decrease of cancer incidence ratio. For example, when one takes irradiated workers as the ones who received the effective dose (only) not lower than 0.5 mSv, the result is OR = 0.90 (0.62–1.18, 68% CI), which means the risk decreases by (10.4 ± 27.6)%.

Discussion

During the last years, a number of papers about nuclear workers' health have been published and most of them were reviewed in [13]. In most cases autors found no risk increase in the low dose region (about < 200 mSv/year). Some papers even show a statistically significant decrease of the cancer risk among irradiated workers [1, 2, 10–12, 14–19]. Similar trend was found in the present paper. Such a decrease can hardly be connected with the so-called healthy worker effect (HWE), although such an interpretation is tempting. However, HWE cannot be related to cancer cases as discussed in [4, 5] and is used only during the comparison with external, not internal control group.

Unfortunately, the workers were never obliged to report contraction of a cancer to the medical service at the Świerk nuclear centre. On the other hand, no specific medical checks against cancers has ever been carried out there. Also no regular follow-up studies have ever been carried out, so the information on eventual cancers contracted after terminating the employment at Świerk is usually not available. Besides, possible confounding factors, that should be accounted for in rigorous studies, are neither known to us. This together with a relatively low statistics may result in very "soft" conclusions only.

Perhaps one could better optimize the cohorts when one notes that the most frequently met cancer is the breast cancer. Therefore, one could eliminate 47 women from the "healthy" group (with insignificant doses) and, proportionally, 5 women from the "cancer" group (also with insignificant doses) resulting in the same percentage number of women in both healthy and both cancer groups (Table 3). This adjustment, however, does not change the general conclusion – one arrives at the adjusted odds ratio AOR = 0.97 (0.65–1.29, 68% CI) when irradiated group is selected using the significant (≥ 0.5 mSv) effective or equivalent to hands dose. When only the effective dose is taken into account, one gets AOR = 0.86 (0.58–1.14, 68% CI). More complicated selection of the data makes the cohorts smaller, which consequently produces larger uncertainties, and finally makes results meaningless.

The percentage of cancers registered at the Świerk centre is lower than in the population of Poland, but it is difficult to measure the exact difference due to the fact that the cancer incidence rate varies with time [8] and was much lower in the past, when most of the workers were irradiated. It is to be noted, however, that the distribution of specific cancers at Świerk and in the whole Poland is much the same [3] (see 'Medical registry' section). Also the shape of the distribution of cancer workers' age at the moment of their death (Fig. 5) is very similar to the one for the whole Poland [3] and is not correlated with the received doses (see grey and dark pillars in Fig. 5). The significant decrease of SIR (the standard incidence ratio) at Świerk may be mainly connected, as aforementioned, with the lack of the follow-up procedure in medical control. Nevertheless, because the results for the Świerk nuclear centre are qualitatively not different from the ones reported for other nuclear centres [1, 2, 10–12, 14–19] one can say that they are showing at least the same trend.

Conclusions

The registry of personal doses received by 4606 Polish nuclear workers between 1956 and 2001 was inspected. An average statistical worker during 10.5 years of the individual dosimetric control has received the effective dose of 6.7 mSv. In this group 156 workers have received doses above 50 mSv, and 10 workers above 300 mSv. The sufficient medical data are available for 575 workers. In this group one can find the odds ratio of cancer incidence OR = 0.90 (0.62–1.18, 68% CI) taking effective dose into account only, and OR = 0.94 (0.65–1.23, 68%) taking both effective and equivalent to hands doses. This results show a statistically insignificant decrease of cancer incidences by (10.4 ± 27.6)% and (6.0 ± 28.8)% respectively, where the average doses per worker equals ~ 34 mSv (body) and ~ 18 mSv (hands). The most striking and important observation is that no cancer appeared among 52 workers who have received the maximal cumulative doses (from 35 to 653 mSv). Also no cancer case was detected among 43 workers who had been chronically irradiated for a long time (from 13 to 26 years) [6]. The distribution of specific cancers is not different from the one known for the whole Poland. Therefore, no correlation between the received doses and the cancer contractions is found. Because all characteristics of the considered 575 workers show similar variation (with the dose, time, etc.) to all 4606 workers, as well as the percentage of workers with medical control is increasing with the dose and with the length of dosimetric control, the gathered results can be considered as representative for the employees of the Świerk nuclear centre. One can safely conclude that nuclear workers at Świerk exhibit no elevated cancer risk.

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