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CANCER INCIDENCE AND NUCLEAR FACILITIES IN UKRAINE: A COMMUNITY-BASED STUDY

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The study *goal* was to investigate malignant tumors incidence in 5 Ukrainian cities with nuclear hazardous enterprises: extractive, processing enterprises of uranium ore (Zhovti Wody and Dniprodzerzhynsk of Dnipropetrovsk region) and nuclear power stations (Energodar of Zaporizhska region, Pivdennoukrainsk of Mykolayivska region, Netishyn of Khmelnytska region). *Materials and methods*: average annual population of the cities under study in 2003–2008 was 439 600 persons. Total and specific cancer incidence was investigated. Site specific incidence was analyzed for malignancies proved to be radiosensitive in previous studies: trachea, bronchus and lung, breast, kidney, thyroid cancer and leukemia. Data on cancer cases were received in National Cancer Registry of Ukraine (National Cancer Institute). There was used the data of the State Statistics Committee of Ukraine on the size of the studied population by gender — age groups. Standardized incidence ratio of cancer at a whole and for each of five specific forms of malignancies were calculated for the population of each city and group of cities depending on the nature of industrial activity. *Results*: During the observed period there were registered 9 381 cancer cases in inhabitants of Ukrainian cities with radiation hazardous facilities. There was stated that cancer incidence rate in population of 5 cities significantly exceeded national and regional levels. Among specific forms of malignancy there were observed excess of lung, trachea, bronchus, breast, kidney cancer and leukemia in population of extractive, processing uranium ore cities. No excess of thyroid cancer was identified. In cities with nuclear power station there were registered excess of kidney cancer. *Conclusion:* Results of the study suggest the necessity to explore the role of various factors in forming the identified cancer incidence features in the Ukrainian population living near the nuclear power facilities.

Key Words: **ionizing radiation, nuclear energy facilities, malignant tumors, cancer incidence.**

Extensive development of nuclear energy production, broad use of industrial radiation sources and recent accidents with radioactive contamination of large adjacent territories provoke concerns on the consequences of a long-term influence of these factors on human health. The problem is actual not only for radiation workers, but also for the residents of surrounding territories. Traditionally, an excess of leukaemia and/or solid cancers is regarded as a sign of radiation influence on health. Such remote consequences were demonstrated in A-bomb survivors in Hiroshima and Nagasaki, participants of nuclear tests, patients after medical exposure, and some exposed groups after the Chernobyl accident [1–4].

In response to the leukaemia cluster reported near the Sellafield nuclear site in Great Britain in 1984 [5] numerous studies have been done to assess the possible risk of childhood leukaemia due to irradiation. While many studies found positive associations, only few results were significant. Although an increased risk of developing leukaemia by irradiation is not doubted, there is disagreement about whether the amount of exposure received by children living near nuclear sites is sufficient to increase the risk. Baker and Hoel [6] statistically analyzed numerous studies of childhood leukaemia near nuclear facilities. Reports of 136 nuclear sites in nine countries (Europe and North America) met their criteria for meta-analysis. The main conclusion of the study was that dose-response studies do not support the leukaemia excess found near nuclear facilities. However, it cannot be ignored that the majority of studies have found elevated rates, although usually not statistically significant.

However results of studies of radiation risks in nuclear industry employee are less known. Contrary to effects in populations exposed at nuclear sites like Semipalatinsk, data on long-term health effects in uranium enrichment facilities and adjacent territories are sparse. For instance, a study of cancer incidence in workers employed at the Physical and Power Institute (in Obninsk, Russia) shows a statistically significant excess of several forms of cancer compared with incidence rates in the total population of this country. A higher cancer incidence was also demonstrated in residents of Obninsk [7]. Frequency and latency period of stochastic effects were studied in employees of nuclear power enterprises, who had long-term contact with combinations of natural and enriched uranium. The results of those studies show a 3.6 to 4.0 fold higher incidence of gastrointestinal cancer in comparison to a control group [8]. In a cohort of uranium miners of the Wismut Company, located in Eastern Germany [9] a statistically significant excess mortality of several cancer types is suggested, which is associated with occupational radon exposure. The highest excess is registered for lung cancer; less effects are found for larynx, tongue and liver cancers. In a combined analysis of three European case-control studies in cohorts of uranium miners the excess of lung cancer is also confirmed [10]. The carcinogenic effect of radon exposure is still stable even after elimination of the smoking factor. Health data are available also

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for the population of the town of Ozersk at South Urals where the first facility of the USSR military atomic industry was located, with substantial radiation exposure during the first years since 1946. An increased cancer mortality was demonstrated in the population together with a lower mortality of non-cancer diseases [11]. A study of the prevalence and incidence of haemoblastosis and also leukaemia in male radiation workers of the Siberian Chemical Combine showed substantially higher rates in comparison with controls from Tomsk city [12]. Thus, several findings indicate a higher risk of cancer in populations living in areas adjacent to hazardous radiation enterprises.

In Ukraine, there are two types of nuclear industry enterprises with professional radiation hazards [13]. The first type includes uranium mining and processing facilities in the Dnipropetrovsk region: in Zhovti Vody (State Enterprise (SE) — East Ore Mining and Processing Enterprise), SE "East OMPE" (with 2 working mines since 1956), and in Dniprodzerzhynsk the Production Association "Pridniprovsky chemical plant" (PA "PCP") which processed blast furnace slag, uranium concentrates, and uranium ore in the period from 1949 to 1991. The SE "East OMPE" is the largest enterprise in Europe of such type. The two operating uranium mines, which belong to this mill, are similar to 60 coal mines of energy equivalent. In the territory of PA "PCP" and outside seven tailing storages* are established as well as two uranium waste storages and a workshop for producing nitrous uranium oxide with nitric solutions [14]. These all are placed in the clay pits and ravines, which were not specially prepared for such items. Thus there are 9 tailing storages of precipitation waste from uranium processing, open to the atmosphere, with a total activity of 2.7×10^{15} Bq (average specific activity 6.4 kBq/kg). The total area of these stores, which accumulated to 42 million tons of uranium waste, is 270 hectares. The exposure dose in this area lies within 30 to 35 000 mkR/h (this is not the current accepted unity, must be mSv/h). F Each year 2.13×10^{13} Bq of radon and 23.9 tons of radioactive dust with an average specific activity of 3.7 kBq/kg are delivered from the tailing storages into the atmosphere, by the storage facilities of uranium waste 2.3×10^{13} Bq of radon and 8.9 tons of radioactive dust with an average activity of 2.9 mBq/kg. Tailing storages are a source of groundwater pollution at a distance of 370–860 meters from their path. The annual removal of natural radionuclides from the ground (the Konoplyanka River flows nearby) and groundwater in the Dnipro River is given in Table 1 [14].

Due to the mentioned tailing storages of uranium waste the additional effective dose of persons who belong to category B (population) is within 0.45–2.7 mSv/year. Uranium ores usually contain not only long-lived elements and ^{238}U fission products, but also toxic chemical elements: arsenic, lead, vanadium, selenium and others [14]. The mentioned data may indicate the considerable scope of the impact of the production activities on the health of the population living near the mentioned companies, although they are not always involved in this production

Table 1. The annual removal of natural radionuclides (Bq) in the Dnipro River from tailingstorages PA "PCP" with a total area of 2.7 km^2 [14]

Radioactive element	With ground waters	With the underground waters
Uranium-238	$5,5\times10^{10}$	$1,6\times10^{8}$
Radium-226	$1,9\times10^{10}$	$2,5\times10^{7}$
Lead-210	$4,4\times10^{10}$	$1,5\times10^{6}$
Polonium-210	$8,8\times10^{9}$	1.0×10^{7}
Thorium -230	$5,5\times10^{9}$	$2,5\times10^{7}$

The second type of potentially hazardous enterprises is represented by the nuclear power plants: Pivdennoukrainsk of the Mykolayiv region, Zaporizhzhya (town Energodar), Khmelnytska (town Netishyn) with 11 reactors of the VVER-1000 type and with a total capacity of 11 000 MWt. The Zaporizhzhya NPP is the largest in Europe.

The general characteristics of the listed nuclear power plants are shown in Table 2.

Table 2. Main information about nuclear power plants of Ukraine*

Name of NPP and their location	Start-up of the first unit	Total number of units	Total power capacity (MWt)
Pivdennoukrainsk NPP of Mykolayiv region	1982	3	3 000
Zaporizhzhya NPP, Energodar	1984	6	6 000
Khmelnytska NPP, Netishyn town	1987	2	2 000

*The data of the Rivnenska NPP are not analyzed in this work

The nature and duration of the impact of the listed types of nuclear facilities on the environment and, consequently, human health are different. However, common to them is the possibility to produce radiation exposure. Therefore, in order to study the possible stochastic effects, it is expedient to investigate the cancer incidence in the inhabitants of all cities associated with nuclear power, and separately for groups with regard to the nature of production.

The main aim of study is to examine the cancer incidence in the communities lying near the nuclear facilities: mining, uranium processing plants (residents of the towns Zhovti Vody and Dniprodzerzhynsk of the Dnipropetrovsk region), nuclear power plants (Pivdennooukrainsk of the Mykolaiv region, Energodar of the Zaporizhzhya region, Netishyn of the Khmelnytsky region). According to the State Statistics Committee of Ukraine the total population of these cities amounted to 436 000 in 2008.

MATERIALS AND METHODS

To study the incidence of malignant tumours in the population of the listed cities, the data on primary cancer cases of the National Cancer Registry of Ukraine conducted by the National Cancer Institute were used. It collects and stores individual information about the cancer patients of the whole country. The data were analyzed for the period 2003–2008. 9.381 incident cancer cases were identified in the mentioned cities. The average population in 2003–2008 according to the State statistics committee of Ukraine amounted to 439 632 persons. The total number of inhabitants

*Tailing storage – hydrotechnical construction to store waste from uranium processing.

of the cities of Nuclear Energy and the reported cancer cases are presented in Table 3.

Table 3. Numbers of inhabitants of Ukrainian cities surrounding with nuclear cycle facilities and number of cancer patients registered in 2003–2008

City	Average annual number of inhabitants 2003–2008	Number of registered cancer cases 2003–2008
Dniprodzerzhynsk	255 370	6 003
Zhovti Vody	54 417	1 350
Energodar	54 720	1 044
Pivdennoukrainsk	40 160	614
Netishyn	34 965	370
Total amount	439 632	9 381

From these data, the standardized incidence ratios were calculated for the population of the cities with nuclear industry as a whole, and separately, depending on the type of enterprises. Due to the fact that in the current pilot study the total number of observed cancer cases (O) was not differentiated by sex and age, it was decided to use the indirect method of standardizing, which is more accurate in the analysis of indicators for relatively small populations. The annual distribution by sex and age in the population for each studied territory was obtained from the State statistics committee of Ukraine data and gave the possibility to calculate the expected number of cancer cases (E). Age-specific incidences of the Ukrainian population in 2006 were used as a standard. Standardized incidence ratios (SIR %) as a ratio of observed (O) to expected (E) cancer cases were calculated. A comparison of the calculated rates was performed for the study regions: Dnipropetrovsk, Zaporizhzhya, Mykolayiv, and Khmelnytsky (regional incidence rates), excluding the cities listed in Table 2.

RESULTS

The cancer incidence rates in the period 2003–2008 in the population of the 4 regions and in the residents of five cities in Ukraine, where nuclear cycle facilities are located (uranium mining and processing enterprises, nuclear power plants) are presented in Table 4.

The incidence rate of all cancers in the population of the 4 Ukrainian regions are slightly higher compared to the national level: 103.4% (102.9–103.9). The cancer incidence rate in the 5 cities with nuclear cycle facilities was substantially higher: 113,0% (110.7–115.3).

For specific cancer sites the incidence of cancer of the trachea, bronchus, lung (C33, C34), breast (C50), kidney (C64, 65), and leukaemia (C91–C95) in cities with nuclear enterprises significantly exceeds the regional average rates for the 4 regions without. It should be also pointed out that the incidence of cancer of the trachea, bronchus, and lung in the 4 regions was 112.7% (111.1–114.2) and in the 5 cities with nuclear power facilities 122.9% (115.8–130.1) and therefore both are significantly higher than the national level. This allows to assume that the incidence of the mentioned cancers are influenced by other factors, which may be independent from each other and not necessarily related to nuclear power.

Another situation is observed for kidney cancer. In the four regions the incidence of this cancer site was significantly lower compared to national rates: SIR 95.6 % (92.8–98.4), but in the 5 "nuclear" cities it is much higher: 132.9% (118.8–146.9). Thus, on the basis of the data it can be assumed that the characteristics of industrial activity in these cities may affect the frequency of this cancer. As to thyroid cancer incidence, the figures do not show a significant difference from the national level.

Taking into account that the types of nuclear facilities in Ukraine and the duration of their activity is considerably different, it is appropriate to study some health indicators regarding the peculiarities of the production process. Therefore, the cancer incidence rates are calculated separately for the cities with uranium mining and processing facilities (Dniprodzerzhynsk and Zhovti Vody) and cities, where nuclear power plants (NPPs) are situated: Pivdennoukrainsk, Energodar, Netishyn. These data are presented in Table 5.

The incidence rate of all forms of malignancies in both city groups (respectively 111.9%, CI 109.4–114.5 and 117.0%, CI 111.9–122.0) significantly exceeds the rates for Ukraine in total, and in the 4 regions, which include the cities under study.

Table 4. Cancer incidence in the population of Dnipropetrovsk, Zaporizhzhya, Mykolayiv, Khmelnytsky regions and 5 cities with nuclear facilities in 2003–2008 (standardized incidence ratio SIR inn % with 95% confidence interval – CI)

Cancer code ICD-10	Four regions without cities with nuclear facilities				Communities near nuclear cycle facilities			
	Observed No of cases (O)	Expected No of cases (E)	SIR % (O/E×100)	95% CI	Observed No of cases (O)	Expected No of cases (E)	SIR % (O/E×100)	95% CI
All cancers (C00–C97)	160 624	155 361.2	103.4	102.9–103.9	9 381	8 302.8	113.0	110.7–115.3
Trachea, bronchus, lung (C33, C34)	20 340	18 055.9	112.7	111.1–114.2	1 141	928.1	122.9	115.8–130.1
Breast (C50)	15 855	15 302.5	103.6	102.0–105.2	1 000	874.5	114.4	107.3–121.4
Kidney (C64, C65)	4 482	4 687.0	95.6	92.8–98.4	342	257.4	132.9	118.8–146.9
Thyroid (C73)	2 401	2 481.8	96.7	92.9–100.6	156	146.9	106.2	89.5–122.9
Leukemia (C91–C95)	3 645	3 526.9	103.3	100.0–106.7	267	190.4	140.2	123.4–157.1

Table 5. The cancer incidence rate in the communities of Dniprodzerzhynsk, Zhovti Vody, Pivdennoukrainsk, Energodar, and Netishyn 2003–2008 (standardized incidence ratio SIR %)

Cancer code ICD-10	Communities near uranium mining, processing and radioactive waste storage facilities (Dniprodzerzhynsk, Zhovti Vody)				Communities near NPPs (Pivdennoukrainsk, Energodar, Netishyn)			
	Observed No of cases (O)	Expected No of cases (E)	SIR % (O/E×100)	95% CI	Observed No of cases (O)	Expected No of cases (E)	SIR % (O/E×100)	95% CI
All cancers (C00–C97)	7 353	6 568.8	111.9	109.4–114.5	2 028	1 734.0	117.0	111.9–122.0
Trachea, bronchus, lung (C33, C34)	931	741.1	125.6	117.6–133.7	210	187.0	112.3	97.1–127.5
Breast (C50)	770	671.8	114.6	106.5–122.7	230	202.7	113.5	98.8–128.1
Kidney (C64, C65)	246	198.9	123.7	108.2–139.1	96	58.7	163.5	130.8–196.2
Thyroid (C73)	107	107	100	81.1–118.9	49	39.8	123.1	88.6–157.6
Leukemia (C91–C95)	214	147.6	145.0	125.6–164.4	53	42.8	123.8	90.5–157.2

However, there is no significant difference of the rates between the two city groups. The common feature of these regions was also a significant excess of the national and regional levels for kidney cancer: 123.7% (108.2–139.1) and 163.5% (130.8–196.2), respectively. In addition, in the cities with uranium mining and processing enterprises a significantly higher incidence of trachea, bronchus, lung (125.6%, CI 117.6–133.7), and breast (114.6%, CI 106.5–122.7) cancer and leukaemia (145.0%, CI 125.6–164.4) was found. In the cities where the NPP are located, the three? five listed forms of malignancies did not differ significantly from national and regional rates. Note the considerable scope of the confidence interval, due to a relatively small number of observed cancer cases. This stimulates to increase the research capacity by means of an increase of the observation period. As to the thyroid cancer incidence, a significant difference between these groups of cities, and also in comparison with national and regional levels was not seen.

DISCUSSION AND CONCLUSIONS

Performing of this descriptive study was possible thanks to the establishment and work of the National Cancer Registry conducted by the National Cancer Institute. Its database contains personified information on the cancer cases among Ukraine's population, including the residents of cities with nuclear energy facilities. The obtained data about the cancer cases according to cancer site, year of diagnosis and the data of the State Statistics Committee of Ukraine on gender and age structure of the population allowed calculatingof the standardized incidence ratio (SIR %) for the population of each city, or for groups of cities depending on the nature of industrial activity. Therefore, for the first time in Ukraine the cancer incidence could be studied in residents of cities with radiation-dangerous production. It was found that the incidence of all cancer types among the inhabitants of these cities was significantly higher than both national and regional rates. Considering specific types, an excess of cancers of the trachea, bronchus, lung, breast, kidney, and of leukaemia was registered, mainly in the cities with extraction and processing of uranium ore (Zhovti Vody and Dniprodzerzhynsk). In the cities where the NPP are located (Pivdennoukrainsk, Energodar, Netishyn), only an excess of the incidence of kidney cancer was observed (1.6 times). The frequency of thyroid malignant tumors in these cities did not differ significantly from the national and regional levels.

It should be stressed that the results are the first experience in studies of malignant tumours in the population of cities with nuclear enterprises. According to existing legislation, the employees of these enterprises have to be subjected to more scrupulous medical surveillance in order to detect early forms of pathology, which may occur due to their professional activities. Therefore, the question naturally arises whether it is a higher cancer incidence resulting from programs for detection of early forms of pathology, i.e. a screening effect. Only a prolongation of the study may answer to this question.

It is further extremely important to compare the findings with the known results of epidemiological studies of this topic, especially among the victims of the atomic bombing in Japan. The data on the incidence of solid cancers in the Atomic Bomb Survivors 13–53 years after this tragic event are presented in the publications of Preston, et al. [15, 16]. They analyzed 17 448 registered cancer cases in a cohort of 105 427 persons for whom individual doses have been estimated. A statistically significant radiation-associated increase of risk was observed for the majority of types, including cancer of the mouth, esophagus, stomach, colon, liver, lung, skin (excluding melanoma), breast, ovary, bladder, nervous system, and thyroid. The risks of pancreas, prostate, and kidney cancers are not significantly elevated; however, they coincide with the tendencies inherent to all types of solid cancer. It should be noted that these publications summarize the consequences of a short intensive exposure due to the explosion of a nuclear weapon. On the other hand, Vozianov and Romanenko [17] documented an increased risk of carcinogenesis in the kidney in contaminated areas after the Chernobyl accident due to chronic exposure to low doses of ionizing radiation. Thus, the increased frequency of kidney cancer found among residents of the cities with nuclear enterprises is consistent with the results of the mentioned research. The highest figures shown in the communities near the nuclear cycle facilities of the former USSR could be explained by the poor radiation safety standards during the first period of competition for nuclear arms. Similar data were obtained in the Techa River cohort that consists of people who lived by the Techa River in Southern Urals and were exposed to radioactive materials and waste between 1948 and 1956 from the Mayak nuclear facility nearby. A follow-up of health effects in more than 30 000 residents indicate a dose-dependent increase in leukaemia and some solid tumours [18]. A large-scale ecologic study of cancer mortality around nuclear installations in the USA did not show any evidence that the mortality for cancer was higher in communities with nuclear facilities [19, 20]. In the Ukrainian cities with uranium mining and processing enterprises with a large area of tailing wastes which are not protected from rainfall, there is a chronic radiation impact on people living near or in contact with them due to occupational activity. An ingestion of radioactive isotopes, as specified in Table 1, into the human body is possible with water, fish, and food produced near the tailing storage. In addition to the radiation factor a negative impact on health cannot be excluded by intermediate processing products of natural uranium and other chemicals used to process ore. In cities with NPP the effects of ionizing radiation on the human body should be limited and very strictly regulated because the risks of stochastic aftereffects must be minimized. The excess of kidney cancer needs attention and search for the possible causes of this phenomenon. Attention should be drawn to the completeness and quality of cancer registration in the territories under study throughout the observation period with regard to the above mentioned screening effect. It should also be noted that in Ukraine the level of morphological (i.e. cytological or histological) verification for kidney cancer (67.9%) was significantly lower than these figures were for other types of cancer (81.4%) [21]. Therefore, it would be logical to assume that a certain number of diagnoses of cancer is not sufficiently substantiated. In addition, the extreme scope of the confidence intervals suggests that monitoring of this pathology should be continued to ensure sufficient study power. In this article, the analysis of the incidence is presented only for 5 cancer types not specified by gender and age.

However, there is an urgent need to study the incidence by taking into account gender and age, and other types of cancer, which may be of radiation origin. It is extremely important to study the cancer incidence in specific groups of employees considering the nature of production activities, especially in nuclear power plants. These arguments underline the need for further improvement of the research program, studying the possible impact of the screening effect on the registered incidence is a further aim, and the development from the descriptive, ecological methods to the analytical ones. Assessment of cancer risks of radiation-hazardous productions should be directed to study not only the cancer incidence, but also the factorial peculiarities — the nature and size of dose, and other health factors for the employees of these enterprises and the residents of these cities. Perspectives to be considered for such analytical epidemiological research are “case-control” and cohort studies.

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