Epidemiological Studies in Russia about the Consequences of the Chernobyl APS Accident

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1. Introduction

The final purpose of all efforts to study and mitigate the consequences of the accident at the 4th reactor of the Chernobyl atomic power station (ChAPS) is protection of health of the people who were more or less exposed to radiation action. This situation has not analogs in terms of scale and character. Certain experience was accumulated earlier through the studies of biological and medical effects of atomic bombing in Hiroshima and Nagasaki, other radiation catastrophes, diagnostic and therapeutic application of radiation, and the control of health state of professionals in atomic industries. However, these experiences can be used just partially in the assessment and the forecast of possible negative after-effects of the Chernobyl accident for the present and future generations.

The long-term irradiation of a large number of population at low doses is to be considered the principal peculiarity of the Chernobyl accident. The medical activities are complicated significantly by the absence of verifiable individual dosimetric information, natural or forced migration of the population, insufficient development of radiation epidemiology, complicated social-economic situation in the country, and other factors which are inevitable at large-scaled catastrophes. Besides, many fundamental questions related to biological effects of action of low doses of ionizing radiation are still being studied.

1.1 General assessment of radionuclide release into the environment by the Chernobyl accident

According to the official estimations, the total release of radioactivity constituted 50MCi (without noble gases) - near 4% of the total in the reactor. This is 1,000 times as high as it was at the accident at Three-Mile-Island APS (USA) in 1979.

Radionuclide releases were assessed by calculations using models of admixtures transfer in the atmosphere. The input information for calculation was taken from the results of study of radionuclide composition of aerosol samples picked up over the 4th reactor of ChAPS since 26 of April 1986, as well as from the results of gamma-aerosurvey around the APS area, analysis of precipitation samples, meteo-observations in the areas of polluted air mass moving. The data on radioactive pollution of the environment over the USSR territory were used therewith. The precision of the results of calculation was appraised in the report [1] as ± 50%. The radioactive noble gases were not taken into account here. The composition of released radioniclides as a whole corresponded to the isotope structure of fuel in reactor. The short-living radionuclides were dominant in them, first of all - ^{131}I. From the long-living radionuclides - ^{137}Cs. The release of ^{90}Sr was significantly lesser. Much lesser was ^{239}Pu which is the most dangerous in long-term aspect and enters into the

Table 1. Estimation of composition of major radionuclides released from ChAPS [1]

Nuclide	Release activity			
	26.04.1986*		06.05.1986**	
	10^{15} Bq	MCi	10^{15} Bq	MCi
Iodine-131	167	4.5	270	7.3
Cesium-134	5.6	0.15	18.5	0.5
Cesium-137	11.1	0.3	37	1.0
Ruthenium-103	22.2	0.6	118	3.2
Ruthenium-106	7.4	0.2	59.2	1.6
Cerium-141	14.8	0.4	104	2.8
Cerium-144	16.7	0.45	88.8	2.4
Strontium-89	9.2	0.25	81.4	2.2
Strontium-90	0.6	0.015	8.1	0.22
Plutonium-238	3.7×10^{-3}	0.1×10^{-3}	0.03	0.8×10^{-3}
Plutonium-239	3.7×10^{-3}	0.1×10^{-3}	0.026	0.7×10^{-3}
Plutonium-240	7.4×10^{-3}	0.2×10^{-3}	0.037	1×10^{-3}
Plutonium-241	0.74	0.02	5.2	0.14

* Release on the 1st day of the accident. Activity is decay-corrected to 06.05.1986.

** Total release until 06.05.1986.

composition of hot particles with extraordinary high specific activity (Table 1).

The assessment of released quantity of long-living ^{137}Cs is worth attention because it is determining now the radioecological situation on the major part of the Chernobyl trace territories. The report [1] - on the basis of data of radiocontamination on the USSR territory - gives an estimation of the total release of ^{137}Cs: 1 MCi (37×10^{15} Bq) or 13 ± 7% of its activity in the reactor core. The UNSCEAR experts - on the basis of analysis of data on precipitation in the Northern hemisphere - estimated ^{137}Cs release from ChAPS as 1.9 MCi (70×10^{15} Bq), i.e. 27% [2]. According to [3], up to 23% of its activity in the reactor fell into the atmosphere. By the estimation on the basis of analysis of quantity and radionuclide composition in the fuel remaining in "Shelter" object, 2.3 ± 0.7 MCi (85×10^{15} Bq) were released, or 33 ± 10% of primary activity of ^{137}Cs in the reactor [4].

1.2. Release of radioactive iodine as one of peculiarities of the Chernobyl accident

The most important characteristic of this accident is the release into the environment of significant quantity of radioactive iodine. However, there is uncertainty in the assessments of the total release of this radionuclide from the 4th reactor. The report [1] gives the value of 7.3 MCi or 20% of activity in core (calculation for 6.05.1986). UNSCEAR experts [2] estimated the total ^{131}I release as 8.9 MCi being quite near to the data of report [1]. According to the proceedings of 1st International Task Force on severe accidents and their consequences, estimations of the total ^{131}I release ranged from 20 % to 60% of its content in the core of the reactor [3]. By the WHO data, the release of this radionuclide into the environment is equal to 44 MCi, and, if we take into account the short-living ^{132}I-^{135}I isotopes, this value is to be increased considerably [5]. Note that, due to the relatively short period of half-decay, we have only the data on these radionuclides which were obtained before July 1986. Therefore, only the results of their analysis can be new ones. Iodine and its isotopes affect thyroid, and the effect on thyroid is one of principal consequences of the Chernobyl accident.

2. Epidemiological studies in Russia after the ChAPS accident

In 1986, immediately after the Chernobyl accident, the USSR Ministry of Health undertook a large-scaled programme to create All-Union Distributed Register of persons affected by radiation. By 1992 (the moment of USSR decay), the data base of the Register contained medical and dosimetric information about 659,292 persons including 284,919 participants of liquidation of the accident consequences (liquidators). All the republics of the former Soviet Union took part in the creation of the Register, as well as a large number of scientific and practical institutions [6].

At present, the National Radiation-Epidemiological Register is acting in Russian Federation. The Russian Ministry on Emergencies is the general customer of the Register. The head organization is Medical Radiological Scientific Center of RAMS (Russian Academy of Medical Sciences). It fulfils collection of primary medical and dosimetric data through 24 regional centres [7].

2.1 Russian State Medical-Dosimetric Register

Three principal data bases consist of the National Radiation-Epidemiological Register:

- Registration List of those who underwent irradiation. It is created according to special dosimetric categories;
- Chernobyl Register. In 1992, it was officially named Russian State Medical-Dosimetric Register (RSMDR);
- Register of inter-institutional expert councils.

In the present paper we will dwell on the radiation-epidemiological analysis of data of the Chernobyl Register of Russia.

During all years of functioning, the data bank of RSMDR was filled constantly with medical-dosimetric information. By 1 of December 1994, it comprehended 370,120 persons from all the Russian Federation. All persons registered in RSMDR are divided into 5 groups of primary account (GPA):

- 1 GPA - liquidators - 159,027 (43.0%);
- 2 GPA - evacuees - 8,091 (2.2%);
- 3 GPA - those who live or have lived on controlled territories - 185,912 (50.4%);
- 4 GPA - children born by liquidators of 1986-1987 - 16,226 (4.4%);
- 5 GPA - migrants from the zones of alienation (after 1986), resettlement and with right to resettlement - 864 (0.2%) [8].

Special attention is paid to observation of health state of the liquidators which have obtained the highest radiation loading as a result of accident. RSMDR contains data of external irradiation of 125,771 liquidators on the basis of certificates given in the zone of works on liquidation of the accident consequences. Regretfully, it is impossible now to establish types of dose values- absorbed or exposure one - put down in RSMDR. The maximum difference between exposure and absorbed doses for whole-body external irradiation can reach 30%, i.e. absorbed dose can constitute 0.7 exposure dose (this estimation was made on the results of measurements by the Institute of Biophysics of Minzdravmedprom of Russia in the 30-km zone of ChAPS). Considering that the error of each individual value of dose can be much higher than 30%, the mentioned possible difference due to dose types is not taken into consideration in further analysis. The unit of absorbed dose (cGy) is used in the analysis.

2.2 Dosimetric data of Russian State Medical-Dosimetric Register for liquidators

In order to understand clearly the character of dosimetric information put down in RSMDR, it is useful to describe briefly when and how the dosimetric surveillance of radiation loading was organized in the zones of liquidation of the accident consequences. After the ChAPS accident, the USSR Governmental Commission charged on 28 of May 1986 with the individual dosimetric surveillance (IDS) three institutions: USSR Ministry of Defence (MD), Ministry of Middle Machine-Industry and Ministry of Energy. The dosimetric surveillance was also carried out independently by USSR Ministry of Interior, USSR KGB (until September 1987), Academy of Sciences of Ukrainian SSR.

The staff of more than 600 organizations of 49 ministries and institutions of USSR was under IDS since 1986. The biggest share of them fell on units of USSR Ministry of Energy.

Since October 1986, the dosimetric data were put down in data base of computer of SM 1634 type. The automated information-reference system of IDS was formed on the basis of Administration of Dosimetric Surveillance (ADS) of science-production association "Pripyat" in April 1988. This system contained information about 103,800 participants of liquidation of the accident consequences. Since 1987, IDS of ChAPS personnel was carried out by the Service of Control of Radiation Safety of ChAPS. IDS of personnel engaged in works within alienation zone was carried out by ADS of science-production association "Pripyat".

Before the ChAPS accident, condenser dosimeter of KID type and individual film dosimeter (IFD) were used for controlling irradiation of ChAPS staff. These dosimeters were created at the Institute of Biophysics of USSR Ministry of Health. The measured dose range of them was from 50 mR to 2 R. 400 persons were working in ChAPS at night shift on 26 April of 1986. They were equipped only with IFD [9]. Thereby, at the moment of the accident, ChAPS personnel was not equipped with necessary accident means of IDS as well as the firemen which came to put out the fire on the 4th reactor. Meanwhile, exposure dose rate (EDR) on the ChAPS roof and in premises reached after the explosion several hundreds of R/h.

The equipment and methodical provision of dosimetric services of involved Ministries and institutions were different each other. The precision of individual dose values is thus different too. Besides, nonuniformity of radioactive precipitation is to be taken into account, which complicated the radiation situation significantly. In consequence, participants of liquidation of the accident were situated in non-uniform radiation field of β- and γ-radiation during the works within and out of the 30-km zone (especially in 1986-1987). Therefore, exposure dose can be assessed with admissible precision only by using IDS data, although they were practically absent in first weeks after the accident.

By the level of reliability, the dosimetric data for liquidators can be divided into three principal groups in dependence of the used methods for dosage assessment:

- Exposure or absorbed dose obtained by using individual dosimeter: maximum error is near 50% (supposing its correct use);
- Group dose attributed to groups of people working within the zone based on individual dosimeter of one of them: maximum uncertainty by the group can reach 300%;
- Itinerary dose evaluated based on the average exposure dose rate in the zone of works and the period of stay there of group of persons: maximum uncertainty by the group can reach 500%.

At present, the quality of dosimetric data for a significant number of liquidators can thus be low due to absence in the Register of additional information about the character, locality and time period of the works by each liquidator. All this justifies the extreme necessity to verify the dosimetric data for liquidators and other persons who underwent irradiation as a result of the ChAPS accident [10]. In spite of the difficulty of dosage assessment, some average statistical

Table 2. Average characteristics of dose commitments for liquidators [10]

N -number of liquidators, men;
D - average absorbed dose, cGy;
T - average period of stay in polluted zone, days;
R - average EEDR, mR/h;
σ - standard deviation of distribution D, T, R

Year of entering	N men	D, cGy	σ cGy	T, days	σ days	R, mR/h	σ mR/h
1986	46575	15.9	8.3	70	72	19.2	45.5
1987	48077	9.0	5.8	79	59	6.8	19.8
1988	18208	3.3	3.5	106	58	2.0	14.8
1989	5475	3.2	3.6	102	60	1.9	6.7
1990	1004	3.7	2.9	86	58	2.5	7.3

characteristics of dosage distribution contained in the Register are used here, because average values are considered to be more useful than individual values. Table 2 contains average values and their standard deviations of doses of liquidators, terms of their stay in the zone of works, and “effective exposure dose rate” in dependence of entering in the polluted zone.

The conclusion can be made by the data of Table 2 about the dynamics of average irradiation loading during the principal works within the accident zone. There was certain increase of average dose for liquidators who had come to the zone in 1990. This can be explained by the next: the mass works in the zone were concluded, therefore just professionals were sent there in order to fulfil special tasks. This can be confirmed also by the data on average period of stay (it is something less than that of 1989) and average EEDR (it is by 50 % higher than that of 1988-1989). The spread of D, T, R distributions is quite big because standard deviations are close to mean values and significantly exceed it in the EEDR distribution. This factor testifies also to the acceptable reliability of dosimetric data of the Register on the whole. It is impossible yet to make any conclusions about the reliability of every individual value [10]. Another estimations of irradiation dose for liquidators also exist, e.g. in the data base of the register of All-Russia Centre of Ecological Medicine (St. Petersburg). According to these estimations, the average dose of irradiation of liquidators constituted in 1986: 0.1207 ± 0.0025 Sv, in 1987 - 0.0838 ± 0.0009 Sv, in 1989 - 0.0312 ± 0.0012 and in 1990 - 0.0494 ± 0.0022 Sv. As a result of mathematical-statistical analysis, it was established that the time of coming to the zone of accident works was the most significant factor in the irradiation dose formation. The coefficient of correlation between irradiation dose and the time of coming constitutes 0.487 for all data. The dependence of individual irradiation doses on the time of coming of liquidators to the radiation zone turned out stepwise. Irradiation doses vary substantially and significantly by four time intervals: 0-15th day from the moment of the accident, 16-350th day, 351-700th day and more than 700 days. The average dose for liquidators which came in the first 15 days constituted 0.145 Sv, from 16th to 350th day - 0.119 Sv, from 351st to 700th day - 0.065 Sv, after 701 days - 0.03 Sv. The dependence between dose and the time of coming within each period is insignificant. From the point of view of authors [11], these time intervals must be the basis of forming risk groups of liquidators for scientific analysis of biological consequences of the ChAPS accident, and classification of medical and social assistance.

2.3 Long-term irradiation of population of Russian Federation as a result of the Chernobyl APS accident

As a result of the explosion of the 4th reactor of the Chernobyl APS, the territory of Russia was intensively polluted with radioactive substances released into the atmosphere. In the composition of mixture of radionuclides precipitated over the Russian territory, isotopes of iodine, cesium, strontium and transuranium elements are the most radiologically significant. A spot of high radioactive pollution formed in 6 western districts of the Bryansk region. The territory with density of soil pollution for ^{137}Cs over 15 Ci/km^2 stands out there. There are areas with radioactive pollution density up to 5-15 Ci/km^2 in the Bryansk, Tula, Kaluga and Orel regions. Besides, separate areas with pollution density from 1 to 5 Ci/km^2 for ^{137}Cs were found in the Belgorod, Voronezh, Kursk, Leningrad, Lipetsk, Penza, Ryazan, Smolensk, Tambov, Ulianovsk regions and the Republic of Mordovia. The ^{90}Sr content in soil of polluted areas of Russia is 10-100 times as low as that of ^{137}Cs. By the data of State Committee of Russian Federation on Hydrometeorology for 1991, the total area of radioactive pollution (more than 1 Ci/km^2 for ^{137}Cs) constituted in Russia 55,000 km^2 being bigger than that in Ukraine or Belarus.

From the moment of radioactive pollution of area, the population is subjected to external irradiation with gamma- and beta-radiation of mixture of radionuclides - products of nuclear fission and activation. The initial dose rate in the air has decreased tens of times by July 1986 and is determined thereafter mainly by gamma-radiation of ^{137}Cs and ^{134}Cs. ^{131}I was the leading factor of internal irradiation of people in May 1986. It entered the organism with food, principally with local milk and vegetables. Radioactive iodine gathered in human thyroid and irradiated it selectively.

^{137}Cs and ^{134}Cs are leading factors of internal irradiation since the summer of 1986. They enter the organisms of residents of polluted areas with milk and meat, natural products (mushrooms, forest berries and fish) and - in lesser degree - with vegetables and fruits. The content of cesium radionuclides in plant and animal products made on "chernozem" soils (Tula, Orel and other regions) is 10-100 times as low as that on soddy-podzolic soils with the same pollution level (Bryansk, Kaluga regions). These indices decreased 2 times every 1-1.5 years, and, in general, from the summer of 1986 to 1992 - tens of times.

Beside of cesium isotopes, ^{90}Sr is transferred from soil to plants and then to animals. This radionuclide also enters the organisms of habitants with milk (not with meat) and plant products. Its quantity, however, is much smaller than the quantity of cesium isotopes. Unlike the cesium and strontium isotopes, transuranium radionuclides exist in soil in the composition of low-soluble fuel particles and do not participate almost in biological processes. These radionuclides can be inhaled with dust into human organisms in small quantities. The contribution of ^{90}Sr and radionuclides of transuranium elements into irradiation doses of people is not big and constitutes in total 1-5% [12].

2.4 Doses of irradiation of thyroid of Russian population

The results of calculations, based on the data of direct measurements of ^{131}I content in thyroid, show strong age dependence of absorbed doses for thyroid.

The average thyroid doses estimated for different age groups in dependence of the level of pollution of areas in the Bryansk and Kaluga regions were within the range from 10 mGy to 2.2 Gy. Individual thyroid dose reached in separate cases 10 Gy and more. The statistical distribution of individual doses is characterized by a long "tail" in the area of high dose as well as by a big share of persons for which values of thyroid dose were assessed as zero within the limits of measurement errors. So far as the calculations in 1986 of individual absorbed dose were pointwise, presently, in order to determine the errors of calculations, the overall assessment of factors able to influence doses values is carried out. The results of assessment of values of average and collective thyroid doses of habitants in various Russian settlements with pollution density over 3.7 kBq/m^2 are adduced in Table 3.

2.5 Doses of whole-body irradiation of Russian population

The measurements of ^{137}Cs and ^{134}Cs radionuclides content in human bodies were carried out during annual examinations of the population in Kaluga region of Russia since September 1986. The measurements were carried out in Ulianovsk, Khvastovichi and Zhizdrin districts using movable and stationary calibrated whole-body counters with one-channel analysers, which gave calculation of annual irradiation doses in the last years. Near 60,000 measurements were held by 1994. Children and adolescents were mainly studied. The results of measurements show that the cesium radionuclides content in organism on the whole has decreased substantially in past years. The average doses of internal irradiation by different districts were not higher than 0.8 mSv per year since 1987 and were decreasing in the course of time. In 1990-1991, they were not higher than 0.25 mSv even in the mostly polluted Ulianovsk district. Nevertheless, individual doses up to 3 mSv/year were registered for separate persons (1990-1991). The highest irradiation levels took place in 1986. Though the average annual doses of internal irradiation did not overreach 20 mSv, the individual doses for separate persons (near 2.5%) were higher and reached 60 mSv [13].

By the estimations, the collective dose of external and internal whole-body irradiation from the moment of the accident for the average duration of life can be equal to 5,000 man-Sv (for the districts of the Kaluga region where radioactive precipitation took place). This value constitutes near 10% of expected collective dose for all Russian territories polluted by the accident.

Individual examinations with TL-dosimeters were held also on the territory of western districts of the Bryansk region with pollution density from 0.6 to 4.0 MBq/m^2. 8,000 individual measurements were held in 1986-1993 in 44 settlements. This number of habitants

Table 3. Doses of thyroid irradiation in different regions of Russian Federation [13]

Region	Soil pollution density for ^{137}Cs, kBq/m^2	Population, thousands	Mean thyroid dose per population, mGy	Collective thyroid dose for all population, 10^3 man-Sv
Bryansk region:	3.7 - 37	670.0	12.4	94.34
	37 - 185	227.0	76.5	
	185 - 555	147.0	229.0	
	>= 555	93.1	376.0	
Tula region:	3.7 - 37	370.0	30.6	92.34
	37 - 185	770.0	77.4	
	185 - 555	170.0	126.0	
Kaluga region:	3.7 - 37	120.0	28.4	10.12
	37 - 185	78.0	65.5	
	185 - 555	15.5	103.2	
Orel region:	3.7 - 37	100.0	22.6	21.37
	37 - 185	330.0	54.5	
	185 - 555	18.0	95.1	
Kursk region:	3.7 - 37	111.0	17.0	5.80
	37 - 185	134.0	29.3	
Ryazan region:	3.7 - 37	110.0	27.1	9.22
	37 - 185	182.0	34.3	
Leningrad region:	3.7 - 37	10.0	24.0	0.54
	37 - 185	182.0	27.9	

Table 4. Average accumulated doses for population of polluted districts of in Bryansk region [13]

Districts	Settlement with different levels of pollution with ^{137}Cs	Average accumulated dose of external and internal whole-body irradiation for1986-1993 period, mSv
Novozybkov	t. Novozybkov	30
Zlynka	v. Zlynka	50
	villages with > 555 kBq/m^2	90 - 140
	< 555 kBq/m^2	20 - 90
Krasnaya Gora	v. Krasnaya Gora	20
	villages with > 555 kBq/m^2	90 - 160
	< 555 kBq/m^2	20 - 90
Gordeevka	v. Gordeevka	60
	villages with > 555 kBq/m^2	90 - 130
	< 555 kBq/m^2	20 - 90
Klintsy	t. Klintsy	10
	villages with > 555 kBq/m^2	90 - 110
	< 555 kBq/m^2	20 - 90

constituted 90% of all population in the strict control zone.

The results of evaluation of accumulated doses of external and internal irradiation in 1986-1993 period are adduced in Table 4 for the territories of the Bryansk region with various pollution levels. These evaluations were made from one side - on the basis of results of calculations of internal irradiation using verified measurements of ^{137}Cs content in organism in various years after the accident; from other side - on the basis of results of calculations using measurements of γ-radiation dose rate in air in various years after the accident and extrapolations of these results for settlements with different levels of pollution with ^{137}Cs [13].

The highest value of average irradiation dose for adult population was registered in village Vyshkov of the Zlynka district (236 mGy). This settlement is situated close to the zone of increased pollution (1480 kBq/m^2) and is of interest in terms of dosimetric studies. The averaged dose for children in given settlement is substantially less (103 mGy). Considerable differences between irradiation doses of adults and children are observed also in other small settlements where the activity of population is connected mainly with agriculture, they do not differ practically among children in different settlements..

For Klintsy town the values of averaged dose for adults are considerably less than those for small settlements (123 mGy) and differ few from the values for children (105 mGy). Incidentally, low level of pollution with radionuclides (near 100 kBq/m^2 for ^{137}Cs [14]) is registered in Klintsy town as a whole, and the calculated averaged irradiation doses by the settlement are much less than measured ones.

2.6 Mortality, morbidity and disability of liquidators

In the analysis of mortality of liquidators living in Russian Federation, it is important to take into account that, in last years, negative demographic processes are observed on the territory of the country on the whole (increase of death rate and decrease of birth rate). The structure of principal causes of mortality of liquidators is also important.

RSMDR contains reports on 78 territorial regions of Russia: republics, lands, regions, Moscow, St. Petersburg, and compiled reports (annual) for all Russian Federation and for 5 regions (Bryansk, Smolensk, Tula, Kaluga and Orel) entering the zone of radioactive pollution of Russia - so-called “Chernobyl zone”.

It is stated - on the basis of data of these reports - that the mortality of participants of the ChAPS accident consequences liquidation from all causes (total mortality or simple mortality) increased from 4.6 to 6.9 per 1,000 persons in 1990-1992 period, i.e. the mortality index increased by 50%. This index increases by years for one regions and decreases for other regions, but does not on the average exceed the control level for Russia [13]. For example, until 1991, the death rate among liquidators in the Ryazan region was not higher than regional indices of death rate for the same age. In 1992-1993, the death rate among liquidators was higher than the regional indices 1.3-1.5 times and constituted 12.4 and 15.3 per 1,000 persons per year [14].

Table 5. Comparison of disease rate per 100,000 persons by the principal classes of diseases among Russian population and among liquidators in 1993 [16]

Classes of diseases	Population of Russia	Liquidators	Ratio of indices
Neoplasms	788	747	0.9
Malignant neoplasms*	140	233	1.6
Endocrine system diseases	327	6036	18.4
Diseases of blood and blood-forming organs	94	339	4.3
Mental disorders	599	5743	9.6
Diseases of blood circulation organs	1472	6306	4.3
Diseases of digestion organs	2635	9739	5.7
All classes of diseases	50785	75606	1.5

* - The standardized index on age distribution of liquidators for 1993 is adduced for malignant neoplasms.

Table 6. Comparison of disease rate per 100,000 persons by principal classes of diseases among liquidators of different dose groups in 1993 [16]

Classes of diseases	0-5 cGy	5-20 cGy	more than 20 cGy
Neoplasm	690	648	747
Malignant neoplasm	217	232	225
Endocrine system diseases	5270	6120*	6075*
Diseases of blood and blood-forming organs	213	354*	450*
Mental disorders	5178	5490	5472
Diseases of blood circulation organs	5287	6090*	6648**
Diseases of digestion organs	9106	9743	9515
All classes of diseases	69831	75346*	75785*

* - indices differ significantly ($p < 0.001$) from corresponding indices in group of 0-5 cGy;

** - indices differ significantly ($p < 0.01$) from corresponding indices in group of 5-20 cGy.

Table 7. Dynamics of invalids (per 1,000 persons) among liquidators by dosage groups in 1990-1993. Data of RSMDR

Years of observation	0-5 cGy	5-20 cGy	more than 20 cGy
1990	6.0	10.3	17.3
1991	12.5	21.4	31.1
1992	28.6	50.1	57.6
1993	43.5	74.0	87.4

According to the results of study of 814 deaths in 1989-1995 of liquidators, the share of oncological diseases (12%) among the causes of death is not higher than the mean indices for Russian population. Cardiovascular pathology occupies the first place among somatic diseases (35%). The most frequent causes of death (over 50%) are accidents among which suicides, alcoholic intoxications and road accidents prevail. By the data of study, 34% of liquidators were at the moment of death in state of middle or strong stage of alcoholic intoxication. Among those who committed suicide, alcohol was found in blood only in 28% of cases, another 72% did it consciously. These data indicate the necessity of deep examination of liquidators in the field of psychoneurological sphere [15].

The forecast and interpretation of data on morbidity and disability indices of liquidators are much more complicated. Comparison of morbidity indices by the principal classes of diseases among liquidators and Russian population as a whole is adduced in Table 5. This table shows that the indices of morbidity among liquidators in a number of cases are many times as high as those among the population of Russia. Undoubtedly, the level, completeness and quality of medical examination of liquidators differ significantly from all-Russia practice. The most modern methods of diagnostics are applied in examining liquidators, and mostly skilled and competent specialists are engaged. By the data of MRSC RAMS, the revealing rate of primarily registered diseases by means of specialists of this institution is several times as high as that by the means of local medical personnel. In such situation it is quite difficult to pick up the adequate control group for comparing.

It is known that factors of social and psychological character connected with the Chernobyl accident have great importance in the formation of pathological states and morbidity among liquidators. All this combined with radiation influence can be determined as “Chernobyl syndrome”. Attempts to analyse the weight of radiation factor from this very complicated syndromes are of great importance. Therefore, the authors [16] evaluated the indices of morbidity and disability by dosage groups - 0-5 cGy, 5-20 cGy and more than 20 cGy - grounding on dosimetric data of liquidators included in RSMDR. As internal control group the contingents of liquidators irradiated within 0-5 cGy interval were taken therewith.

As it is seen from Table 6, morbidity indices by a number of classes of diseases in groups of 5-20 cGy and more than 20 cGy turned out statistically higher than those in group of 0-5 cGy. It was established therewith that the group of more than 20 cGy consisted by 99.1% of liquidators of 1986-1987.

The liquidators of 1986-1987 constitute 91.2% of dosage group of 5-20 cGy and the smaller half of group of 0-5 cGy (48.9%). Therefore, 2 factors were studied within the framework of standard multifactor analysis: dosage (with 3 grades: 0-5 cGy, 5-20 cGy and more than 20 cGy) and date of entering the radiation zone (with 3 grades: liquidators of 1986, of 1987 and of 1988-1990). By the analysis of indices of rate of 3 classes of diseases (endocrine system, blood circulation organs and mental disorders), it was established that the factor of date of entering the radiation zone (1986, 1987, 1988-1990) is undoubtedly the determining one as compared with dosage factor from the point of view of its influence on morbidity. It means that first of all the health state of liquidators of 1986 and 1987 is of special worry.

The indices of disability of liquidators in dependence of obtained external irradiation doses are adduced in Table 7. The disability indices in second and third dose groups are significantly higher than the corresponding coefficients in first group (0-5 cGy). The fact is also worth attention that the index of disability of liquidators on the whole is 2.8-3.2 times as high as the index of all Russia.

2.7 Thyroid cancer among the population of the Bryansk and Kaluga regions

Against the background of general aggravation of health state, decrease of birth-rate and duration of life of Russians in the last 10 years, Chernobyl brought a strong additional factor of immediate and mediate effect of ionizing radiation on present and following generations.

The direct result of radiation influence on human organism - beside of acute and sub-acute radiation sickness - is the injury of thyroid tissue by iodine radionuclides and, as a result, impetuous growth of thyroid cancer cases among children and adolescents of both sexes and women of genital age.

In the process of screening of children and adolescents from south-western districts of the Bryansk region in 1991-1995, the primary clinico-laboratoy information on 25,000 persons was obtained including the examination of pediatrist, endocrinologist, ultrasonic investigation of thyroid, analysis of TTH, FT4 content in serum as well as of antibodies to thyroglobulin and microsomal fraction, and the data on ^{137}Cs content in organism.

It was stated that thyroid pathology in given groups of persons occupies the leading place in general morbidity structure. Out of all thyroid pathology, 75-80% fall on euthyroid goiter, 0.2-3.7% - on nodal formations in dependence of age group, 0.32-1.7% - on autoimmune thyroidites, 0.1% - on hypothyrosis with clinical manifestation and 5.0-7.8% - on that with subclinical course. As a result of screening, 14 cases of thyroid cancer were first discovered and confirmed histologically thereafter.

In total, 48 cases of thyroid cancer have been verified presently in the Bryansk region among children and adolescents who were children at the moment of the ChAPS accident. 33 girls and 15 boys are among them (Table 8).

Nearly 50% of children and adolescents with diagnosed thyroid cancer have lived on areas with pollution level as 15 and more Ci/km^2 for ^{137}Cs, i.e. in the resettlement zones.

Medical-dosimetric investigation is carried out concerning all cases of thyroid cancer. It has been found that the reconstructed individual dose on thyroid due to radioactive iodine depends on the zone of living and ranges from 1 to 270 cGy. Dose dependence was discovered of thyroid cancer incidence on the density of soil pollution with ^{137}Cs. 11.9 cases per 100,000 of children population were revealed on territories with pollution density from 0.1 to 1.0 Ci/km^2, 18.5 cases - on the territories with 1.0-5.0 Ci/km^2, 29.7 cases - on the territories with 15 and more Ci/km^2 [17].

2.8 Malignant neoplasm on territories polluted as a result of the ChAPS accident

Table 8. Number of cases of thyroid cancer in children and adolescents of Bryansk and Kaluga regions of Russian Federation [13]

Region	Year of diagnosing								
	1987	1988	1989	1990	1991	1992	1993	1994	Total
Bryansk region	1	-	-	4	4	8	12	19	48
Kaluga region	-	-	-	-	-	-	1	3	4
Russia	1	-	-	4	4	8	13	22	52

Table 9. Standardized indices of general oncological morbidity per 100,000 persons in different regions of Russian Federation [18]

Region	1994	Increase in 1994 compared with 1981, %
Bryansk	336.2	38.6
Kaluga	294.3	29.6
Orel	313.3	40.1
Tula	339.3	21.4
Ryazan	357.1	-
Kursk	300.0	-
Russian Federation	278.0	19.1

Moscow Research Oncological P. A. Gertsen Institute analysed the dynamics of onco-epidemiological situation in the six polluted regions by the Chernobyl accident: Bryansk, Kaluga, Orel, Tula, Ryazan, Kursk, in 1981-1994 period. Uninterrupted rise of malignant neoplasm incidence was registered in all territories and the whole Russian Federation as well. Since 1987, the levels of malignant neoplasm incidence were permanently higher in six mentioned regions than in Russian Federation (Table 9).

The structure of malignant neoplasm incidence did not change substantially in the post-accident period. On all areas, except for the Bryansk region, neoplasm of lungs, trachea, bronchi occupied the first place in the structure, and tumours of stomach - the second place. In the Bryansk region, the most frequent nosological form was cancer of stomach; and tumours of respiration system organs were on the second place. The malignant neoplasm of stomach, blood-forming and lymphatic tissue, thyroid gland, and larynx have a bigger specific weight in the morbidity structure of the Bryansk region than in that of Russian Federation. The share of malignant neoplasm of thyroid in morbidity structure of the Orel region is more significant than that in Russian Federation.

The dynamics of disease incidence among the population of studied territories with cancer of lungs, trachea, bronchi is characterized by positive trend. The highest levels of morbidity are characteristic of the Bryansk, Tula and Ryazan regions. The stomach cancer incidence which is higher than in Russian Federation was registered on radiocontaminated territories both in the pre- and the post-accident periods although the uninterrupted trend of decrease of this index is observed. In 1994, the Bryansk region occupied the second place in Russian Federation by the level of morbidity among men (index - 55.4; Russia - 40.3) and the third place among women. The incidence of malignant neoplasm of blood-forming and lymphatic tissue is higher in the Bryansk, Tula, Ryazan regions than that in Russian Federation. The highest indices in 1994 were registered in the Ryazan region: 18.0 for men and 13.5 for women. The rise of incidence of thyroid malignant neoplasm is observed on all radiocontaminated territories, and the pace of increase is much higher than in Russian Federation. The highest levels of thyroid cancer incidence in Russian Federation were registered in 1994 in the Bryansk, Orel and Ryazan regions; the indices constituted 7.8, 7.7, 7.7 per 100,000 of population respectively [18].

Conclusion

More than 10 years passed since the Chernobyl catastrophe. The biggest technogenic accident in mankind history attracted attention of the world society. However, the problem of assessment of total integral damages for life and health of the irradiated people is still extremely complicated. The negative influence of Chernobyl included the entire range of factors which are causing their mutual strengthening. In particular, neither theoretical models nor practical recommendations for the integral assessment of social and psycho-emotional factors by radiation catastrophes exist at present. From the other side, in order to rehabilitate efficiently the sufferers, it is needed to range and to determine objectively the contribution of both radiation and non-radiation components of influence. Therefore, it is of great practical value to continue many-years studies and to obtain new scientific data in the field of radiation epidemiology .

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