Research Activities about the Radiological Consequences of the Chernobyl NPS Accident and Social Activities to Assist the Sufferers by the Accident

Report of an International Collaborative Work under the Research Grant of the Toyota Foundation in 1995 - 1997

Edited by IMANAKA T.

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Preface

The 12^{th} anniversary is coming soon of the accident at the Chernobyl nuclear power station in the former USSR on April 26, 1986. Many issues are, however, still unresolved about the radiological impacts on the environment and people due to the Chernobyl accident.

This report contains the results of an international collaborative project about the radiological consequences of the Chernobyl accident, carried out from November 1995 to October 1997 under the research grant of the Toyota foundation. Our project team consisted of the following 9 members: T. Imanaka (leader, KURRI), H. Koide (KURRI), V. P. Matsko (Institute of Radiobiology, Academy of Sciences of Belarus), I. A. Ryabzev (Institute of Problems of Ecology and Evolution, Russian Academy of Sciences), O. Nasvit (Institute of Hydrobiology, National Academy of Sciences of Ukraine), A. Yaroshinskaya (Yaroshinskaya Charity Fund, Russia), M. V. Malko (Institute of Physical and Chemical Radiation Problems, Academy Sciences of Belarus), V. Tykhyi (Environmental Education and Information Center, Ukraine) and S. Sugiura (Japan Chernobyl Foundation, Minsk office).

Collaborative works were promoted along with the following 5 sub-themes:

- ✧ General description of research activities in Russia, Belarus and Ukraine concerning the radiological consequences of the accident.
- ✧ Investigation of the current situation of epidemiological studies about Chernobyl in each affected country.
- ✧ Investigation of acute radiation syndrome among inhabitants evacuated soon after the accident from the 30 km zone around the Chernobyl NPS.
- ✧ Overview of social activities to assist the sufferers by the accident in each affected country.
- ✧ Preparation of special reports of interesting studies being carried out in each affected country.

In this report, 32 papers prepared through the collaborative work are included. All members of the project team are sure that the contents of this report are useful not only to specialists, but also to all persons who have concern for the problem of nuclear energy.

We are grateful to the Toyota foundation for a high appreciation of our works, and to Research Reactor Institute, Kyoto University for various conveniences during the course of our collaborative project.

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March 1998

Title and Member List of the International Collaboration Study

✧ *November 1995 - October 1996*

Investigation of Research Activities about the Radiological Consequences of the Chernobyl Accident in Russia, Belarus and Ukraine after the Collapse of the USSR

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✧ *November 1996 - October 1997*

Investigation of Research Activities about the Radiological Consequences of the Chernobyl Accident and Social Activities to Assist Its Sufferers in Russia, Belarus and Ukraine

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Research Activities of the Nuclear Safety Research Group of KURRI with Belarussian, Russian and Ukrainian Colleagues about the Chernobyl Accident

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The 12th anniversary is coming soon since the Chernobyl accident on April 26, 1986, the worst accident in the history of the commercial use of nuclear energy. In Japan we say ″JUNEN HITO-MUKASHI″. It means that a period of ten years is one era. Literally, there happened a series of historical events during these 12 years which brought drastic changes in the world. The USSR, which had to take the primary responsibility for the Chernobyl accident, disappeared at the end of 1991. ″JUNEN HITO-MUKASHI″ also means that we tend to forget events in the past. The concern of the world to Chernobyl seems to become gradually diminishing as time goes on. However, a vast amount of contaminated territories remains and will remain regardless of the main events in the world (Table 1).

The sufferers by the Chernobyl accident are categorized into the followings:

- ✧ Staffs of the Chernobyl NPP and firemen directly involved in the accident: 1,000 - 2,000 persons
- ✧ Liquidators who worked for elimination of the consequences of the accident (including soldiers and workers for construction of so-called Sarcophagus, the containment of the destroyed reactor): 600,000 - 800,000 persons
- ✧ Evacuees from the 30-km zone during the first weeks after the accident: 135,000 persons
- ✧ People resettled from the contaminated areas: more than 115,000 persons
- ✧ Residents in the contaminated areas: over 6 million persons (Table 2)

In April 1996, at the time of the 10th anniversary of the Chernobyl accident, an international conference was held in Vienna by IAEA together with EC and WHO [6]. One of main purposes of the conference was announced to distinguish ′myths′ and ′speculations′ from scientific facts about the consequences of the Chernobyl accident. Conclusions of the conference can be summarized as follows.

<The only long-term health effect that could be observed so far due to the Chernobyl accident was the increase of thyroid cancer among inhabitants around Chernobyl. Other health effects were difficult to be observed even with following-up investigations of wide-scale. Reports indicating health deterioration of Chernobyl sufferers were made by scientists in the

Table 1. Areas contaminated with ^{137}Cs in three affected countries, km^2 [1].

	Level of ^{137}Cs density (Ci/km^2)				
	1 - 5	5 - 15	15 - 40	>40	>1 total
Russia	48,800	5,720	2,100	300	56,920
Belarus	29,900	10,200	4,200	2,200	46,500
Ukraine	37,200	3,200	900	600	41,900
Total	115,900	19,120	7,200	3,100	145,320

- According to Chernobyl laws in these countries, the contaminated territories are divided into the following categories depending on ^{137}Cs density: higher than 40 Ci/km^2 - zone of alienation, 15-40 Ci/km^2 - zone of obligatory resettlement, 5-15 Ci/km^2 - zone of guaranteed voluntary resettlement, 1-5 Ci/km^2 - zone of radiation control.

Table 2. Number of people living in the contaminated territory, thousands of persons.

Country (year of data)	Level of ^{137}Cs density (Ci/km^2)				
	1 - 5	5 - 15	15 - 40	>40	>1 total
Russia(1991.1.1) [2]	1,883	347	93	-	2,323
Belarus(1995) [3]	1,485	314	41	0.283	1,840
Ukraine(1995.1.1) [4]	1,732	653	19	-	2,404
Total	5,100	1,314	153	0.283	6,567

- According to the GOSPLAN report in 1990 [5], the numbers of residents in the area of 15-40 Ci/km^2 and over 40 Ci/km^2 were 234 thousands and 33.8 thousands, respectively. So, 115 thousands were at least resettled since 1990.

affected countries, but they were not reliable from the scientific point of view.>

We can interpret the above conclusion as follows: the health effects of the Chernobyl accident were very small except thyroid cancer, mortality of which is relatively low, although the Chernobyl accident was the worst one. The fact in 1991 at the conference of International Chernobyl Project by IAEA [7], however, should be remembered that experts of IAEA neglected protests of Belarussian and Ukrainian scientists insisting serious increase of child thyroid diseases around Chernobyl against the conclusion of the International Chernobyl Project that there was no health effect there. Five years later the same experts of IAEA had to recognize ′myth′ of thyroid diseases to be facts.

In this report of our international collaborative project, we have included reports and information that the experts of IAEA would see as ′myths′ or ′speculations′. The present author believes that there are ′myths′ reflecting the truth, and that one important task of science is to find out the truth hidden behind fragmentary information.

By the way, during these years the number of nuclear power plants in Japan increased to 53 reactors (total 45GWe) in January 1998 from 33 reactors (total 25 GWe) at the moment of the Chernobyl accident.

Activity of Japanese members before the collaborative project

The Nuclear Safety Research Group of Research Reactor Institute, Kyoto University (KURRI), to which the present author belongs, has been working on safety problems of nuclear facilities for more than 20 years. Main tasks of our group have been the followings: analyses of engineering problems of PWR and other reactors, assessment of radiological consequences by hypothetical severe accidents at nuclear power plants in Japan, measurements of radioactive contamination in the environment, investigation of the Three Mile Island NPP accident in March 1979 in the USA, etc. [8-11]. Through these works, our group has been providing the public with information about risks accompanied with the commercial use of nuclear energy.

It was quite natural for us, when the Chernobyl accident happened, to begin one more task to investigate its consequences from our point of view. We measured radioactivity from Chernobyl in Japan, collected information on all aspects of the accident including contamination data from all over the world, and made the assessment of radioactivities released by the accident [12-15].

By the end of 1986, we succeeded in making outline of radioactive contamination in the northern hemisphere except in the territory of the former USSR. Our estimates of irradiation dose in Japan due to fallouts from Chernobyl are shown in Table 3. Table 4 includes our assessment of released activities made in the first years after the accident. Although the results of our analysis, which was made based on small data presented in the 1986 USSR report on the accident [16], indicated a very high level of contamination in the territory of Belarus, we did not have measures to confirm it for several years. The fact should be kept in mind that there was a vacant period of information for about three years, when we retrospectively try to investigate the Chernobyl accident.

In the process of *perestroika* and *glasnost* within the USSR, the first detailed map of contamination was published in Belarus in February 1989 [17]. A vast amount of contaminated areas showed the validity of our assessment in the first years. We were also surprised to know that high levels of contamination extended even to 200 - 300 km from the Chernobyl site, which could not be supposed from our accident assessment for light water reactors.

Imanaka and his colleague Seo (deceased in 1994) made the first visit to the USSR in the summer of 1990 [18,19]. Through the visit to Moscow/Minsk/Kyiv, we knew that there were amounts of data about radioactive contamination taken by Soviet scientists at the initial stage of the

Table 3. Estimates of irradiation dose in Japan due to fallouts from Chernobyl for the 1st year after the accident [13].

Thyroid Organ Dose, μSv

	Path				Total
	Inhalation	Tap water	Leafy vegetable	Milk	
Children	60	14	290	43	~400
Adults	30	4	110	6	~150

Total Body Dose: μSv

	External		Internal				Total
	Cloud	Ground	Inhalation	Tap water	Leafy vegetable	Milk	
Children	0.02	3	0.2	0.07	0.7	1.2	~5
Adults	0.02	3	0.2	0.04	0.5	0.4	~4

Table 4. Estimates of released radioactivity of major nuclides by the Chernobyl accident.

Nuclide	Half life	Inventory, MCi	Estimated released radioactivity, MCi			
			USSR report [16] (1986)	Seo [14] (1988)	Dobrynin [21] (1993)	Imanaka 1993 [20]
I-131	8.05 d	36.5	7.3 (20)*	25.40	19.0	17.0
Cs-137	30.2 y	7.7	1.0 (13)	4.35	2.3	2.5
Ru-103	39.3 d	110	3.2 (2.9)	10.40	3.8	3.3
Zr-95	64 d	119	3.8 (3.2)	5.60	4.0	5.9
Ce-144	284 d	85.7	2.4 (2.8)	4.60	3.6	3.4

- All activities are decay-normalized to values on May 6, 1986.
- Values of reactor inventory are cited from the 1986 USSR report.

* Values in () are released percentage to inventory.

accident.

″Toyota″ project in 1993-1994

The collapse of the USSR at the end of 1991 changed the situation around Chernobyl problems. This allowed as a possibility to start a collaborative work with former USSR scientists.

In 1993, we succeeded in getting a research grant of the Toyota foundation for a collaborative project with Belarussian scientists under the title, ″Radioactivity Releases from the Chernobyl-4 Accident and Dose Estimates in Its Early Stage″ (leader Seo T.). The Japanese side consisted of 4 members of the Nuclear Safety Research Group. The Belarussian side includes 5 scientists of Academy of Sciences of Belarus, Belarussian State University and Hydrometeorology Committee. The Japanese side was going to refine the old analysis of contamination patterns around Chernobyl and reevaluate released activities on the basis of the new data that were obtained from the Belarussian side. In the course of this project, frankly speaking, the Japanese side met a lot of difficulties: differences in the tradition how to promote cooperative researches, difficulties to keep close communication (e-mail was not available, air mail was not a sure way, fax was relatively expensive), differences in the tradition how to manage the finance, etc. In addition, the team leader, Seo T. unexpectedly died of lung cancer during the project. In spite of these difficulties, some valuable results were obtained by this first project [20]. Our new estimates of released radioactivities are shown in Table 4 together with old values and by others. Our new estimates are consistent with the estimation by Dobrynin et.al. [21].

″Toyota″ project in 1995-1997

We have passed over the application to the Toyota foundation in 1994 and rearranged the frame of cooperation during this period. Considering the experiences through the first project, the base of collaboration was converted from a relation between groups of equal partnership into a network of personal relation coordinated by Imanaka. The way of working was also changed from face-to-face discussion between members to preparing reports by each member for his own themes.

In 1995 we received a new research grant under the title, ″Investigation of Research Activities about the Radiological Consequences of the Chernobyl Accident in Russia, Belarus and Ukraine after the Collapse of the USSR″. At the time of the application to the Toyota foundation, the members were limited to Imanaka and Matsko in Minsk in order to keep a flexibility of the project. Then, three members, Koide at KURRI, Ryabzev in Moscow and Nasvit in Kyiv joined the project. The members in CIS countries were expected to make their report concerning the situation of research activities in each country about the radiological consequences of the Chernobyl accident. In addition, Imanaka asked preparation of special reports for our project to several scientists who are engaged in interesting studies. Through the 1995 project, we succeeded in making 8 reports, including 4 special reports. Four of them were published in English or Japanese [22-25].

In 1996 we succeeded in extending our research grant under the title, ″Investigation of Research Activities about Radiological Consequences of the Chernobyl Accident and Social Activities to Assist Its Sufferers in Russia, Belarus and Ukraine″. A theme concerning social aspects of Chernobyl problems was added in this year. The following 4 new members joined the project; Malko in Minsk, Yaroshinskaya in Moscow, Tykhyi in Kyiv and Sugiura in Minsk. In January 1997, we had a meeting of all members in Moscow to discuss the contents of the project and decided the following 5 sub-themes (names of responsible member):

A. General description of research activities concerning the radiological consequences of the accident (Matsko, Ryabzev, Nasvit, Malko).
B. Investigation of the current situation of epidemiological studies in each country (Matsko, Ryabzev, Nasvit).
C. Investigation of acute radiation syndrome among inhabitants around Chernobyl (Yaroshinskaya,

Imanaka, Koide).

D. Overview of social activities to assist sufferers by the accident (Yaroshinskaya, Malko, Tykhyi, Sugiura).

E. Preparation of special reports of interesting studies (Imanaka and all others).

The 1996 project formally finished at the end of October 1997.

Here in this KURRI report we present 32 papers we could prepare through the collaborative works in 1995-1997. They are classified into the following categories by the report number in CONTENTS:

- Member reports in the 1995 project; 4, 5, 6 and 7,
- Special reports in the 1995 project; 8, 11, 22 and 25,
- Member reports in the 1996 project; 1, 2, 13, 14, 15, 16, 28, 29, 30 and 32,

Special reports in the 1996 project; 3, 9, 10, 12, 17, 18, 19, 20, 21, 23, 24, 26, 27 and 31.

Besides already mentioned, No. 19 by Sugenoya, No. 21 by Lazjuk and No.12 by Lupandin were published in Japanese [26-28]. No. 28 by Tykhyi will be published soon [29].

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Chernobyl Accident: the Crisis of the International Radiation Community

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Introduction

11 years passed since the Chernobyl accident. Within this period a lot of data have been established by the Belorussian, Russian and the Ukrainian specialists. These data clearly show that the Chernobyl accident is the most severe accident in the history of peaceful use of nuclear energy in the world. It has caused a heavy impact on the environment in Belarus, Russia and the Ukraine, significant worsening of the economic situation in these countries, disruption of social life in the affected areas, growing anxiety and fears among the people living in the contaminated territories, as well as significant biomedical effects on these people and on other categories of people.

At present there are no controversies about the ecological, economic, social and psychological consequences of the nuclear explosion at the Chernobyl NPP. At the same time there exist significant differences in the assessment of radiological consequences of this accident. Specialists in the affected republics of the former USSR had established a significant rise in the incidence of many somatic diseases soon after the accident. However, the international radiation community either denies such effects at all or rejects any link between the increase in the morbidity in general somatic diseases and the Chernobyl accident, and attempts to explain this increase on the basis of purely psychological factors and stresses. Such position of the international radiation community results from some political reasons and from the fact that it recognises only leukaemia, solid cancers, teratogen and genetic effects as late effects of radiation. At the same time even in the case of medical effects recognised by the international radiation community, it failed to make a correct assessment of thyroid cancers and hereditary malformations resulting from the Chernobyl accident. As well, it could not realise timely the real reasons of the Chernobyl facts. These implications may be considered as a sign of a crisis of the international radiation community. It could not assess the seriousness of the Chernobyl accident and its radiological consequences. Instead of taking an objective position in order to help the affected populations of the former USSR the international radiation community practically played a role of an advocate of the USSR government that tried to play down the consequences of this accident from the very beginning. These and other problems are discussed in the present report.

Official Assessment of Reasons and Consequences of the Chernobyl Accident

The Chernobyl accident is recognised by specialists as the worst nuclear accident in the history of peaceful use of nuclear energy. It had occurred on the 26th of April 1986 when the personnel of the fourth unit of the Chernobyl NPP attempted to test the capability of a turbogenerator to supply electrical energy for a short period of time in case of a station blackout. The accident completely destroyed the reactor and as a result large amounts of radioactive materials have been released to the environment. The Soviet authorities initially tried to conceal the fact of this accident. But as it was impossible they attempted to play down the radiological consequences of the accident.

Soon after the accident the IAEA and the USSR agreed to hold a Post-Accident Review Meeting in Vienna. This meeting took place on the 25th-29th of August 1986. At this meeting Soviet specialists presented false information on the accident and its radiological consequences [1].

According to the Soviet point of view, the main reason for the accident was a violation by the Chernobyl NPP personnel of the procedures of nuclear power reactor operation developed in the USSR. The Soviet specialists had also delivered their prognoses of the Chernobyl accident radiological consequences. They explained that deterministic effects were established only among the personnel and the firemen involved in the extermination of the accident. The Soviet specialists had excluded the possibility of deterministic effects among the population and forecasted only negligible stochastic effects. For example, their calculations based on the non-threshold hypothesis of the dose-effect relationship forecasted that the increase in the mortality rate had to be less than 0.05% of the spontaneous cancer mortality rate. This result covered the population in the European part of the USSR (about 75 mln. people).

The explanations presented by the Soviet part have been fully accepted by the participants of the meeting. This can be seen from the Summary Report of the Post-Accident Review Meeting in Vienna, published by the IAEA in September 1986 [2]. On page 28 of the above-mentioned report one can read the following:

> "The foregoing account is based on the Working Documents submitted and information volunteered

by the Soviet experts. On the basis of this information we have a plausible explanation for the sequence of events at Chernobyl Unit 4, and no attempt has been made to find alternative."

On page 17 of the Summary report of the IAEA it is stated that:

"The errors and violations of procedures were the major factors contributing to the accident."

The participants of the IAEA meeting have also agreed with the prognosis of radiological consequences suggested by the Soviet specialists. Such conclusion can be drawn on the basis of the following statement made on page 7 of the Summary Report of the Post-Accident Review Meeting:

"…. it appears that over the next 70 years, among the 135,000 evacuees, the spontaneous incidence of all cancers would not be likely to be increased by more than about 0.6%. The corresponding figure for the remaining population in most regions of the European part of the Soviet Union is not expected to exceed 0.15% but is likely to be lower, of the order of 0.03%. The relative increase in the mortality due to thyroid cancer could reach 1%" [2].

Such point of view was not changed by the international community until the present time.

The Post-Accident Review Meeting has delivered plausible explanations of the reasons of the Chernobyl accident and its radiological consequences accepted by the international radiation community. However, these explanations have either been erroneous, or incorrect. Today it is known that different drawbacks of the RBMK-type reactor project (four reactors of this type were in operation at the Chernobyl NPP) have been the real reasons of the accident [3] and not the mistakes of the personnel as it was stated in the Post-Accident Review Meeting in Vienna [2].

The most important of these shortages were [3]:

- large positive void coefficient;
- unstable operation at low reactor power;
- possibility of power excursion;
- imperfect construction of absorber rods (use of graphite water displacers linked with absorber rods).

One needs to notice that the IAEA had to correct its explanation of the direct reasons of the Chernobyl accident only 7 years after the Post-Accident Review Meeting in Vienna.

A question arises: why did the experts of western countries not even try look for other explanations of the reasons of the Chernobyl accident especially after the Soviet experts had told at the Vienna Meeting that remedial actions were planned to improve the safety of the RBMK reactors operation such as the increase of the full enrichment from 2.0% to 2.4% and installation of additional absorbers into the core (these two measures were developed to mitigate the problem of the positive void coefficient of the RBMK-type reactors - one of the main reasons of the accident)? The usage of fast shutdown system and some other systems had also been foreseen.

Two different explanations can be suggested for the fact that the participants of the Post-Accident Review Meeting in Vienna could not understand the real reasons of the accident. First is that the experts at this meeting did not understand the specific features of the RBMK-type reactors. Second is that they were unwilling to doubt the official Soviet point of view in order to save the image of nuclear energy. The first explanation is quite unreasonable because all remedial actions to improve the nuclear safety of reactors of the RBMK-type that were suggested by Soviet specialists at the Post-Accident Review Meeting in Vienna indicated clearly the project shortages of such reactors. It seems to us that the second explanation is more adequate and unpleasant because it means that the specialists in the field of nuclear safety are ready to conceal the real dangers of the peaceful use of nuclear energy.

The publication of the document [3] has practically put an end to the inadequate explanations of the reasons of the Chernobyl accident. However, a different situation remains in case of the radiological consequences of the accident. In fact, up to now the international radiation community insists that the radiological consequences of the Chernobyl accident are almost negligible. Only in 1995 did the international radiation community recognise the relation between irradiation and the high increase in the thyroid cancer incidence among children in Belarus, the Russian Federation, and the Ukraine [4]. All other effects established by the Belorussian, Russian and the Ukrainian specialists are completely rejected [5].

For example, the international radiation community does not recognise the data of Prof. G.Lazjuk and his colleagues [6,7] on hereditary malformation in the affected areas of Belarus. As well, nobody recognises the valuable statistical data on the significant increase in the morbidity rate in different somatic diseases, established soon after the Chernobyl accident in Belarus, the Russian Federation, and the Ukraine. As far as the radiological consequences of the Chernobyl accident are considered, the international radiation community continues to advocate the idea suggested by the Soviet specialists and accepted at the Post-Accident Review Meeting in Vienna that the radiological consequences of the Chernobyl accident cannot even be observed.

Such position of the international radiation community was of great importance for the Soviet authorities that have been trying from the very beginning to play down the Chernobyl radiological consequences. At the time of the accident the Soviet Union was in a state of a deep economic crisis and could not provide necessary assistance to the affected populations of Belarus, Russia and the Ukraine. The Soviet Union could provide only limited help to the affected population. Due to this reason all information related to the Chernobyl accident and its radiological consequences in the former USSR was concealed not only from the general public, but in many cases from the specialists in the field of radiation protection. For example, the data presented by the Soviet experts at the Post-Accident Review Meeting in August 1986 were closed in the USSR for a long time. The same happened to different documents regulating protective measures in the contaminated areas of the USSR.

Medical Effects on People Affected by the Chernobyl Accident

The ″350 mSv concept″

The complicated economic state of the USSR was possibly the main reason for elaboration of the so-called 350 mSv concept or the lifetime dose concept that established a limit of irradiation of the affected population. This concept was developed by the National Commission on Radiation Protection of the USSR (NCRP) in the late autumn 1988 [8].

The 350 mSv concept was based on the following assumptions:

- the sum of external and internal doses that can be delivered to a person as a result of the Chernobyl accident will not exceed 350 mSv within 70 years period beginning from the 26th of April 1986 in the majority of the contaminated areas of the USSR;
- an additional dose of radiation equal or less than 350 mSv accumulated within the whole lifetime on the contaminated territory will have no significant medical consequences for the people.

In accordance with these assumptions there was no necessity to carry out different protective measures including relocation practically in all areas of Belarus, Russia and the Ukraine affected as a result of the Chernobyl accident. It was foreseen to implement the 350 mSv concept beginning from the 1st January 1990. Along with its implementation all restrictions introduced in the contaminated areas after the accident had to be lifted.

The 350 mSv concept was based on prognoses of medical consequences made by the Soviet specialists in the summer 1986 [1], as well as on the basis of a revised assessment carried out under supervision of Prof. L.Ilyin in late 1988 [9]. The new predictions agreed very good with the old ones. However, they were incorrect as the previous ones. This is especially well seen in the case of thyroid cancer. According to the assessment [9], only 39 additional thyroid cancers would have been induced in children of Belarus as a result of the Chernobyl accident. They had to appear within the 30-year period after the latent period of 5 years. This means, that the first additional thyroid cancers could be registered by children in Belarus only in 1991.

This prognosis of Prof. L.Ilyin and his colleagues [9] was completely wrong. It can be seen from Table 1, where the data on the thyroid cancer incidence in Belarus [10] are given. Only 7 cases of children's thyroid cancer have been registered in Belarus within the 9-year period before the Chernobyl accident (1977-1985). This gives 1 thyroid cancer per year as a spontaneous morbidity rate of children in Belarus. Taking this value into consideration, one had to expect only 5 children's thyroid cancers in Belarus within the first 5 years after the Chernobyl accident. On the contrary, 47 cases of this cancer have been established over 1986-1990 which is 9 times more as compared to the expectations based on the assumptions by Prof. L.Ilyin and his colleagues [9].

The total number of children's thyroid cancers established in Belarus in 1986-1995, which is the first 10 years after the Chernobyl accident, reached 424 cases [11]. It exceeded 10 times the total number of children's thyroid cancers predicted by authors [9] for the 35-year period after the accident. As can be seen from the comparison of predicted and real data, the prognoses of the Soviet specialists [1,9] had underestimated to a great extent the children's thyroid cancer resulting from the Chernobyl accident. The

Table 1 Number of thyroid cancer of children and adults in Belarus [10].

Pre-accident period			Post-accident period		
Years	Adults	Children	Years	Adults	Children
1977	121	2	1986	162	2
1978	97	2	1987	202	4
1979	101	0	1988	207	5
1980	127	0	1989	226	7
1981	132	1	1990	289	29
1982	131	1	1991	340	59
1983	136	0	1992	416	66
1984	139	0	1993	512	79
1985	148	1	1994	553	82
Total	1131	7	Total	2907	333

same may be concluded in regard of the hereditary malformations in the contaminated areas of the former USSR. Predictions [1,9] excluded practically even the possibility of such effects being established. The incorrectness of this conclusion was shown by Prof. G.Lazjuk and his colleagues [6,7].

The mentioned facts are without doubt an indication of the serious underestimation of the radiological consequences of the Chernobyl accident made by the authors of the assessment [1,9]. This fact was evident for many specialists in the contaminated areas of Belarus, Russia and the Ukraine who had established a significant worsening in the health state of the affected population soon after the accident.

However, the results of the assessments [1,9] as well as the 350 mSv concept were considered by Soviet authorities and the international radiation community as valid. One needs to notice that the international radiation community had known in details the new Soviet assessment of the Chernobyl radiological consequences [9] and the 350 mSv concept. Soon after the Session of the USSR Academy of Medical Sciences, the report of Prof. L.Ilyin et al. [9] has been submitted to the World Health Organisation. Later it was published as a scientific article in a famous international journal [12]. The same happened to the 350 mSv concept. The report on the 350 mSv concept was delivered by Prof. L.Ilyin at the Thirty-eighth Session of the UNSCEAR that was held in Vienna 8-12 May 1989 [13]. The 350 mSv concept was also presented on the 12th of May 1989 at an informal meeting on the Chernobyl consequences organised by the Secretariat of the IAEA [14].

The new Soviet prediction did not cause any criticism from the part of the international radiation community. Such conclusion can be made from the fact that the contents of the article by Prof. L.Ilyin and his colleagues [12] did not significantly differ from the report [9], and from the fact of extensive help of the international radiation community to the Soviet government in its attempts to implement the 350 mSv concept.

Experts from WHO

This help was demonstrated by a visit of a group of the WHO experts to the Soviet Union in June 1989. This visit found place due to a request of the Soviet Government. The group of the WHO experts included the following specialists: Dr. D.Beninson, Chairman of the International Commission on Radiological Protection (ICRP), Director of License Department of Argentina Atomic Energy Commission; Prof. P.Pellerin, Chief of Radiation Protection Services of the French Health Ministry, member of the ICRP; Dr. P.J.Waight, Radiation Scientist of the WHO Division of Environmental Health [15].

The WHO experts attended a meeting of the USSR National Commission on Radiation Protection in Moscow, where they had taken part in a discussion of the principles and implementation of the 350 mSv concept. They had also taken part in meetings and discussions with other specialists of the affected Soviet republics and people from contaminated areas. In Minsk the WHO experts had visited a special meeting on Chernobyl problems held at the Academy of Sciences of Belarus. Such well-known specialists of the Ministry of Health Care of the USSR as Prof. L.Ilyin, Prof. L.Buldakov, Prof. A.Guskova and others had participated in that meeting.

At all of these meetings and discussions the WHO experts had completely approved of the official Soviet point of view that the Chernobyl accident could not cause significant health effects by the affected populations. They not only agreed upon the 350 mSv concept, but even volunteered the view that, had they been requested to set a level for the lifetime dose, they would have chosen a value of the order of two to three times higher than 350 mSv [15].

The WHO experts had also rejected any relation between radiation and the significant increase in the morbidity in many somatic diseases established in the affected areas of Belarus, Russia and the Ukraine soon after the accident. In regard to this problem they said in their report to the USSR government:

> "... scientists who are not well versed in radiation effects have attributed various biological and health effects to radiation exposure. These changes can not be attributed to radiation... and are much more likely to be due to psychological factors and stress. Attributing these effects to radiation only increases the psychological pressure in the population and provoke additional stress-related health problems, it also undermines confidence in the competence of the radiation specialists. This has in turn, led to doubts over the proposed values. Urgent consideration should be given to the institution of an education programme to overcome this mistrust by ensuring that the public and scientists in allied fields can properly appreciate the proposals to protect the population" [15].

The quotations given above from the report [15] clearly show that the WHO experts played a role of advocates of the Soviet authorities which tried to play down by any means the scale of the Chernobyl accident and its radiological consequences.

In January 1990 the special Mission of the League of the Red Crescent Societies also visited the affected areas of Belarus, Russia and the Ukraine [16]. This Mission comprised 6 members - qualified specialists in different branches of medicine from the United Kingdom, Sweden, the Netherlands, the Federal Republic of Germany and Japan. The experts of the Mission of the League of Red Cross and Red Crescent Societies were more careful in their assessment of the radiological situation in the affected areas. However, they too could not understand the real reasons for the worsening of the health state of the population affected by the Chernobyl accident. In the summary of their report compiled after returning from the affected areas, they had stated the following conclusions:

"Among the health problems reported it was felt that many of these, though perceived as radiation effects both by the public and by some doctors, were unrelated to radiation exposure. Little recognition appears to have been given to factors such as improved screening of the population and changed patterns of living and of dietary habits. In particular, psychological stress and anxiety, understandable in the current situation, cause physical symptoms and affect health in a variety of ways" [16].

Nevertheless, the Mission of the League of Red Cross and Red Crescent Societies was able to understand the seriousness of the situation in the affected areas of Belarus, Russia and the Ukraine. They had managed to come to the correct conclusion that in some cases relocation of people must have been accepted as one of the countermeasures. Taking this into account, they stated that the indications for relocation should be based not only on radiation doses, but on considerations of socio-economic conditions of inhabitants in the affected areas as well. This conclusion has been a very important one because the central authorities of the USSR were making all attempts to avoid the relocation as a measure of radiation protection.

International Chernobyl Project

In 1990 the International Chernobyl Project has been carried out under the aegis of the IAEA. It was initiated by the letter of the Soviet government sent on October 1989 [17]. The letter requested the IAEA to conduct an evaluation of the countermeasures taken in the USSR after the Chernobyl accident and of the future protective measures. Conclusions made on the basis of this evaluation were published in 1991 in a special report [17]. The report stated in regard of the biomedical consequences of the Chernobyl accident:

"There were significant non-radiation-related health disorders in the populations of both surveyed contaminated and surveyed control settlements studied under the Project, but no health disorders that could be attributed directly to radiation exposure. The accident had substantial negative psychological consequences in terms of anxiety and stress due to the continuing and high levels of uncertainty, the occurrence of which extended beyond the contaminated areas of concern. These were compounded by socio-economic and political changes occurring in the USSR.

The official data that were examined did not indicate a marked increase in the incidence of leukaemia or cancers. However, the data were not detailed enough to exclude the possibility of an increase in the incidence of some tumour types. Reported absorbed thyroid dose estimates in children are such that there may be a statistical increase in the incidence of thyroid tumours in the future.

On the basis of the doses estimated by the Project and currently accepted radiation risk estimates, future increases over the natural incidence of cancers or hereditary effects would be difficult to discern, even in large and well designed long term epidemiological studies" [17].

This abstract shows that the participants of the International Chernobyl Project practically repeated the conclusions of the official Soviet predictions presented at the Post-Accident Review Meeting in August 1986 in Vienna [1] as well as the conclusions of the documents [2] and [9].

The following conclusions were made in the Report of the participants of the International Chernobyl Project in relation to the increase in the morbidity in general somatic diseases that have been registered by medical specialists of Belarus, Russia and the Ukraine in the contaminated areas:

"Reported adverse health effects attributed to radiation have not been substantiated either by those local studies which were adequately performed or by the studies under the Project.

Many of the local clinical investigations of health effects had been done poorly, producing confusing often contradictory results. The reasons for these failures included: lack of well maintained equipment and supplies, poor information through lack of documentation and lack of access to scientific literature; and shortages of well trained specialists" [17].

In accord with these statements radiobiological consequences of the Chernobyl accident must have been relatively insignificant. However, such conclusion was wrong and that was proved just a couple of years after the International Chernobyl Project. Thus, one could wonder about the reasons for the experts participating in the International Chernobyl Project to be so optimistic in the evaluation of the radiological consequences of the Chernobyl accident. This question sounds especially justified in case one notices that practically all participants of this project had materials showing a picture contrary to their optimistic assessment.

It is known that the international experts who had taken part in the International Chernobyl Project were aware of the report by the Minster of the Ministry of Health Care of Belarus [18] delivered at an informal meeting arranged by the IAEA Secretariat on the 19th of December 1989 in Vienna. The Belorussian Minister reported about a significant increase in the morbidity of thyroid by children especially in heavily contaminated districts of the Gomel region. He also informed the participants of the meeting about an increase in the rate of hereditary malformations in new-born:

"The frequency of the birth of children with congenital developmental defects (with stricter recording) in the radionuclide-contaminated areas over recent years has increased somewhat more significantly than in remaining areas of the Republic (except the Grodno region). This index is 5.65 (per 1,000 newly born) for Byelorussia but 6.89 for the contaminated areas" [18].

In regard of the worsening of the general health state of the affected population the Minister stated:

"Among adults in 1988 there was a two- to fourfold increase, in comparison with preceding years, in the number of persons suffering from diabetes mellitus, chronic bronchitis, ischemic heart diseases, nerve diseases, ulcers and chronic bronchopulmonary diseases. There was also a noticeable rise in the proportion of children with various functional disorders, neurasthenic and anaemic syndromes, chronic diseases of the tonsils and nasopharynx, etc. At the same time, doctors of all specialities have noted a more difficult and more prolonged course of many diseases, a higher frequency of complications and an increase in adequate drug response" [18].

Despite of the official character of the information presented by the Belorussian Minister it was completely ignored and was not considered during implementation of the International Chernobyl Project. This disregard is often explained by the international radiation community by the low competence of the specialists working in the contaminated areas of Belarus, Russia and the Ukraine and by lack of reliable data on the morbidity in theses and clean areas.

Such explanation is not correct, at least in Belarus. For example, the monitoring of hereditary malformation of stricter recording has been carried out in Belarus since 1982 [6]. One needs to know that submission of data on hereditary malformations of stricter recording such as reduction of extremities, spina bifida, polydactyla, etc. to the national register is compulsory in Belarus. Such conditions allow to acquire reliable statistics related to the hereditary malformations.

Thyroid cancer in Belorussian children

The Belorussian specialists could also prove their high professional skills in the case of children's thyroid cancer. Different doubts were expressed by specialists of other countries after a group of Belorussian specialists had published their data on thyroid cancer of children in Belarus in the scientific journal "Nature" in September 1992 [19]. According to [20,21] a significant rise in the incidence of children's thyroid cancers in Belarus could be caused by the improved screening after the Chernobyl accident. Specialists of the World Health Organisation had suggested two rather exotic hypotheses [22]. According to the first, the growth in the thyroid cancer incidence in children of Belarus could have been caused by giving stable iodine preparates to children in the affected areas after the decay of radioactive iodine in order to prevent endemic goitre. The second hypothesis was based on the assumption that children's thyroid cancer in Belarus has been induced by chemical species (nitrates, etc.) in fruit and vegetables brought to the Republic from the Soviet Middle Asia where mineral fertilisers and pesticides are heavily used.

It is evident that these hypotheses are not plausible. The preparates of stable iodine were used in Belarus over a number of years before the Chernobyl accident because the soil in Belarus, especially in the Gomel and Brest regions is short of stable iodine. However, no increase in the thyroid cancer incidence had been registered in Belarus prior to the Chernobyl accident. On the other hand, the amounts of fruit and vegetables from the Soviet Middle Asia have not been large enough to be accessible to a significant number of children in Belarus.

The specialists of the WHO believed that their hypotheses could be valid because at the time of publishing of the paper [19] only a minor increase in the thyroid cancer incidence has been registered in the Ukraine and no increase at all in Russia. In reality, this difference in the morbidity in thyroid cancer in Belarus, Russia and the Ukraine had another cause. It is known [23], that the highest thyroid doses have been delivered to the affected children in Belarus and the lowest to the children in Russia. This fact explains the difference in the latent periods of the thyroid cancers in the affected republics of the former USSR.

Some specialists denied that radiation could have been the reason for the increase in the children's thyroid cancers in Belarus because of a very short latent period. Such specialists simply could not understand that the duration of the latent period depends strongly on the number of irradiated persons. It can be lessened if the number of exposed persons increases. This very important idea was suggested by a famous specialists in the field of radiation medicine, Prof. J.Gofman a long time before the Chernobyl accident. The Belorussian specialists have managed to prove the validity of this idea by Prof. J.Gofman in the case of thyroid cancer, thus making a significant contribution to the study of radiation effects on the organism. In 1993-1995 it was confirmed that their data have been correct [4, 25, 26].

Health statistics in the affected areas

Another very important contribution from the part of the Belorussian specialists is the establishment of a significant increase in the incidence of the general somatic diseases among the affected populations. Many specialists doubt that an increase in the incidence of general somatic diseases exists. The fact that such doubts have no serious grounds becomes evident from the data given in Tables 2 and 3 of this report. These data are the results of epidemiological studies carried out by Dr. P.Shidlovsky for the residents of the contaminated and control districts of the Brest region [27, 28].

As can be seen from the Tables 2 and 3, there had been a significant difference in the morbidity in many classes of general somatic diseases in adults and children living in the contaminated and clean areas of the Brest region. In the case of adults such difference may be observed in infections and parasitogenic diseases, diseases of the endocrine system, maldigestion, disorders of metabolism and immunity, psychic disorders, diseases of the circulatory system, cerebrovascular diseases, diseases of the respiratory system, diseases of digestive organs, etc [see Table 2]. In the case of children a significant difference was established in infections and parasitogenic diseases, diseases of the endocrine system, psychic disorders, disease of the nervous system, diseases of the sense organs, diseases of digestive organs, etc [see Table 3].

Dr. P.Shidlovsky surveyed a large number of persons in his studies of the contaminated and control districts. This provides a significant reliability of his results. For the cohort of residents of the contaminated districts he had used all residents of Luninets, Stolin and Pinsk districts of the Brest region.

The total number of people living in these districts constituted in 1990 approximately 182,900 persons. The average caesium-137 contamination is 37 to 185 kBq/m^2 (1-5 Ci/km^2) [27,28]. As the control cohort Dr. P.Shidlovsky used residents of Kamenetsk, Brest, Malorita, Zablinka and Pruzany districts of the Brest region with total number of 179,800 persons [27, 28].

Table 2 Indices of general morbidity of adults and adolescents in 3 contaminated and 5 control districts (rayons) of the Brest region in 1990 [27].

Diseases	Indices of the general morbidity (per 100,000 adults and adolescents)		P
	3 contaminated districts	5 control districts	
Altogether	62,023±113.48	48,479±117.9	0.99
Infections and parasitogenic diseases	3,251±41.5	2,119.8±34.0	0.99
Diseases of the endocrine system, maldigestion, metabolism disorders, immunity disorders,	2,340.6±35.4	1,506.7±28.7	0.99
including: thyrotoxicosis with and without goitre	74.4±6.4	29.5±4.0	0.99
Psychic disorders	2,936.0±39.5	2,604.0±37,6	0.99
Chronic otitis	249.9±11.7	166.3±9.6	0.99
Diseases of the circulatory system	12,060.7±76.2	9,300.4±68.5	0.99
including: hypertension,	3,318.2±41.9	2,394±36.1	0.99
: ischemic heart diseases	5,307.3±52.42	4,366.5±48.2	0.99
From the total number of patients suffering ischemic heart diseases:			
patients with acute myocardial infarction	53.6±5.4	41.7±4.8	0.99
patients with other acute and subacute forms of ischemic heart diseases	44.3	17.2	0.99
patients with stenocardia	1,328.6±26.8	594.5±18.1	0.99
Cerebrovascular diseases,	1,981.4±32.6	1,363.2±27.3	0.99
including: cerebral atherosclerosis	1,764.4±30.8	986.7±23.3	0.99
Diseases of the respiratory system,			
including: chronic diseases of tonsils and adenoids	597.0±18.0	278.1±12.4	0.99
: chronic bronchitis and unspecified bronchitis, emphysema	1.891.2±31.8	1,359.3±27.3	0.99
:suppurative and other chronic non-specific lung diseases	182.1±9.7	152.9±9.2	0.99
Diseases of digestive organs,	7,074.4±59.9	5,108.5±51.9	0.99
including: gastric ulcer, duodenal ulcer	1,895.0±31.8	1,225.7±25.9	0.99
: chronic gastritis (atopic)	1,468.6±28.1	765.3±20.5	0.99
: chololelitic disease, cholecystitis (without mentioning of gallstones)	1,147.1±24.9	658.5±19.1	0.99
Urogenital diseases,	3,415.6±42.5	1,995.6±33.0	0.99
including: nephritis, nephritic syndrome, neprosis	131.8±8.5	67.9±6.1	0.99
: kidneys infections	649.5±18.8	522.2±17.0	0.99
Female infertility	83.7±2.3	56.2±5.5	0.99
Skin diseases and diseases of the subcutaneous fat,	3,376.7±42.2	2,060.0±35.5	0.99
including: contact dermatitis and other forms of eczema	735.4±20.0	350.4±13.9	0.99
Diseases of the osteomuscular system and of the connective tissue	5,399.1±52.96	4,191.9±47.3	0.99
including: osteoarthrosis and salt arthropathyes	1,170.0±25.1	770.3±20.6	0.99
Poisoning with medicine preparates as well as with biological substances having mostly a non-medical character	135.6±3.8	28.9±4.1	0.99

These novel findings of the Belorussian scientist Dr. P.Shildlovsky were later confirmed by many other specialists of the CIS. In February 1993 the official magazine of the Ministry for Health Care of Belarus "Zdravookhranenie Belarusi" published results obtained by the Ukrainian epidemiologists [29]. They analysed the morbidity among 61,066 persons evacuated from the 30-km zone in 1986. The Ukrainian have found data similar to that of Dr. P.Shidlovsky for this category of people. Nearly the

Table 3 Indices of general morbidity of children in 3 contaminated and 5 control districts (rayons) of the Brest region in 1990 [27].

Diseases	Indices of the general morbidity (per 100,000 adults and adolescents)		P
	3 contaminated districts	5 control districts	
Altogether	68,725±188.5	59,974±203.3	0.99
Infections and parasitogenic diseases	7,096.5±104.4	4,010.1±80.6	0.99
Diseases of the endocrine system, maldigestion, metabolism disorders,	1,752.1±53.3	1,389.5±48.1	0.99
Psychic disorders	2,219.8±59.9	1,109.6±43,0	0.99
Diseases of the nervous system and of the sense organs	4,783.5±86.8	3,173.7±72.0	0.99
Chronic rheumatism	125.6±14,4	87.7±12,2	0.95
Chronic pharyngitis, nasopharyngitis, sinusitis	117.4±13.9	82.6±11.8	0.95
Diseases of digestive organs,	3,350.4±73.2	2,355.8±62.3	0.99
chronic gastritis (atopic)	128.9±14.6	40.5±8.3	0.99
chololelitic disease, cholecystitis (without mentioning of gallstones)	208.3±18.5	60.7±10.1	0.99
Atopic dermatitis	1,011.6±40.7	672.8±33.6	0.99
Diseases of the osteomuscular system and of the connective tissue	737.2±34.8	492.4±28.7	0.99
Congenital malformations	679.3±33.4	482.3±28.4	0.99
including: congenital malformations of the heart and of the circulatory system	305.8±22.4	242.8±20.2	0.95
Poisoning with medicine preparates as well as with biological substances having mostly a non-medical character	4.383.7±83.7	52.3±9.4	0.99

Table 4 Primary morbidity of adults and adolescents in Belarus (per 100,000 persons) [32].

Diseases	Year	Belarus	1st Group	2nd Group	3rd Group	4th Group
Diseases of the endocrine system, maldigestion, metabolism disorders, immunity depression	1993	631	2559	2528	1472	762
	1994	668	2862	2169	1636	909
	1995	584	3427	2368	1272	723
Diseases of the blood and blood-forming tissue	1993	62	322	293	292	132
	1994	91	339	283	254	114
	1995	74	304	279	175	101
Psychic disorders	1993	1014	1460	861	1416	930
	1994	1099	2439	1253	1579	1194
	1995	1125	3252	2317	1326	1115
Diseases of the nervous system and of the sense organs	1993	3939	5927	4880	4369	5270
	1994	4185	7250	4719	4789	5363
	1995	4120	8604	5812	3864	4769
including cataract						
	1993	136	301	355	226	190
	1994	146	420	425	366	196
	1995	147	463	443	321	194
Diseases of the circulatory system	1993	1626	4956	4969	3215	1732
	1994	1646	5975	5852	4827	1702
	1995	1630	7242	6293	4860	1524
Diseases of the digestive organs	1993	1938	5728	2653	3943	2170
	1994	1889	6411	3607	3942	2015
	1995	1817	7784	4216	3298	2283
Diseases of the osteomuscular system and of the connective tissue	1993	3148	4447	3611	4236	4432
	1994	3474	7095	4152	4404	4712
	1995	3720	8860	4419	5166	4196

Notices: Belarus — all adults and adolescents; 1st Group — liquidators; 2nd Group — evacuees from the 30-km zone; 3rd Group — residents of settlements in areas with caesium-137 contamination level higher than 555 kBq/m^2 (15 Ci/km^2); 4th Group — residents of settlements in areas with caesium-137 contamination level from 37 to 185 kBq/m^2 (from 1 to 5 Ci/km^2);

same results have been established for Belorussian and Russian liquidators [30, 31]. The studies [30, 31] established reliable data showing that the difference in the morbidity of liquidators and the general public increases with time. A similar increase is to be found in all other categories of the affected populations.

Table 4 compiled by the author of the present report on the basis of data of the National Medical Register published by authors [32] indicates this fact clearly. An analysis of Table 4 shows the existence of an evident correlation between doses of irradiation or levels of surface contamination and the morbidity of the affected populations. The highest incidence in somatic diseases in comparison to the total population of Belarus is to be found in liquidators and the people evacuated from the 30-km zone in 1986, the lowest — in the residents of the affected territories with caesium-137 contamination level less than 555 kBq/m^2 (15 Ci/km^2).

Comparison with Japanese data

One needs to stress a very interesting fact. Very often specialists who doubt of the significant increase in the number of non-specific somatic diseases in populations affected by the Chernobyl accident state that such an effect has not been observed in citizens of Hiroshima and Nagasaki which survived the atomic bombardment in August 1945. However, such statements are wrong. It was shown by specialists of the Hannan Chuo Hospital (Osaka, Japan) [33]. They examined 1,232 victims of the atomic bombardment within the period of 1985-1990. According to [33]:

> "Lumbago was 3.6 times more frequent, hypertension 1.7 times, eye diseases 5 times, neuralgia and myalgia 4.7 times, same tendencies for gastralgia, gastritis, etc.".

The data of Japanese specialists are presented in Fig. 1.

There are no data in Fig 1 for such diseases in Japanese general public as dental disease, headache arthritis, loss of physical strength, cervical spondyltitis because the authors [33] could not find them in "The Basic National Life Survey of Japan". Accordance in data established in people affected by the Chernobyl accident and the victims who had survived Hiroshima and Nagasaki gives a strong argument in favour of the assumption that the increase in the incidence in general somatic diseases established in Belarus, Russia and the Ukraine resulted from the accident, and not from pure psychological factors. This information indicates that at present there are no objective grounds for any scepticism often expressed by the international radiation community [5, 34] in relation to such phenomena as the increase in the incidence in general somatic diseases in all categories of people affected by the Chernobyl accident.

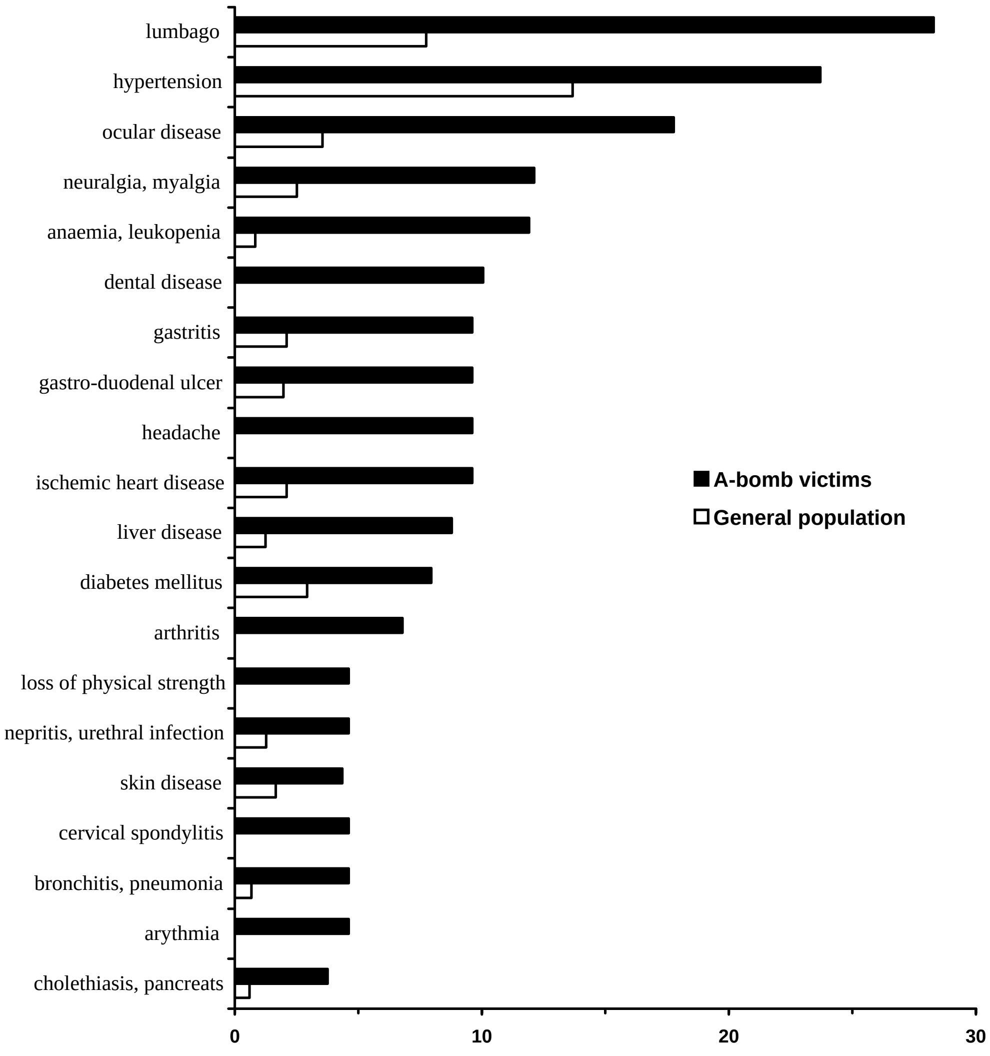

Fig. 1 Comparison of morbidity rates (%) of the A-bomb victims and of the general Japanese population [33].

One decade after Chernobyl

About 20 scientific papers describing various somatic effects in liquidators, adults and children exposed to radiation as a result of the Chernobyl accident have been presented at the International Conference "One

Decade after Chernobyl. Summing up the Consequences of the Accident" held in Vienna, Austria, 8-12 April 1996 [35, 56]. This conference was sponsored by the European Commission, the International Atomic Energy Agency and the World Health Organisation in co-operation with the United Nations Scientific Committee on the Effects of Atomic Radiation and other United Nations divisions, as well as with the Organisation for Economic Co-operation and Development (Nuclear Energy Agency). Practically all international organisations involved in peaceful use of nuclear energy took part in the preparation of this conference which was to become the most important step in the assessment of the Chernobyl accident and its radiological consequences. However, the conference could not fulfil the task of an objective analysis of this severest accident in the history of peaceful use of nuclear energy. Such conclusion may be drawn from the following statement of given in the conference summary:

"Increases in the frequency of a number of non-specific detrimental health effects other than cancer among exposed populations, and particularly liquidators, have been reported. It is difficult to interpret these findings because exposed populations undergo a much more intensive and active follow-up of their state of health than does the general population. Any such increases, if real, might also reflect effects of stress and anxiety" [5].

It is evident from the quotation that the participants of the conference "One Decade after Chernobyl. Summing up the Consequences of the Accident" who had prepared the most important document of the conference — the summary, doubted even the reality of the increase in the incidence of general somatic diseases in the affected areas of Belarus, Russia and the Ukraine. It seems very strange because, as was mentioned above, a number of scientific papers [35-56] have been presented at the conference that demonstrated the manifestation of this phenomena in all categories of people affected by the Chernobyl accident. The significant increase in the morbidity in different somatic diseases in the the affected population has been recognised by the author of the Background Paper 4 of the Conference [57] which explained this increase on the basis of psychological factors and stresses.

The conference also rejected the possibility of hereditary malformations in the affected areas of Belarus, Russia and the Ukraine as a result of the Chernobyl accident despite of the existence of reliable data on such effects. Practically it has not changed the conclusion of the international radiation community that the consequences of the Chernobyl accident are negligible. The only exception was made for the strong growth of the thyroid cancer morbidity. Possibly, because there are no more arguments to reject the reality in this case.

It seems that the international radiation community is more interested to save the image of the nuclear industry rather than to protect people from the effects of radiation. This can be determined by every objective specialist as a sign of a crisis if the international radiation community which rejects reliable information in order to support its own point of view about the negligible radiological consequences of the Chernobyl accident.

A very plausible explanation for the above attitude of the International Scientific Radiation Community has been given at the Session of the Permanent People's Tribunal by a famous specialist in the field of the radiation medicine Dr. Rosalie Bertell [58].

According to Dr. Rosalie Bertell, the harmful impact of radiation caused interest of the specialists and the military because of the possible use of nuclear weapons in wars. A very interesting problem for planners of such wars was how much enemies could have been killed by nuclear weapons. Due to this reasons specialists in the field of radiation biology, radiation medicine and radiation protection had worked since the very beginning mostly for the military purposes. Later they have switched to problems of nuclear reactors' use for electricity generation. As a result of such involvement in solving of military and industrial problems, specialists in radiobiology, radiation medicine and radiation protection did not pay attention to the problem to protect the health of public from the harmful influence of radiation. This is also a reason for the international radiation community not to consider any medical effect of radiation other than fatal cancers and leukaemia, some teratogen and genetic effects as consequence of irradiation.

Certainly, such way of assessment of the radiological consequences is not acceptable. The life standard, not the number of fatal cancers, should be considered in case of a radiological accident like the Chernobyl accident. Has not this to be the primary task of the international radiation community to protect the people exposed to ionizing radiation?

Summary

The information given in the present report about the Chernobyl accident and its radiological consequences indicates a serious crisis of the international radiation community. The following signs of this crises can be discerned:

- The international radiation community did not recognise the real reasons of the accident for a long time.
- It could not make a correct assessment of the damage to the thyroid of the affected populations of Belarus, Russia and the Ukraine.
- Up to present time it rejects the reliable data on hereditary malformations.

- It is not able to accept reliable data on the increase in the incidence in all categories of people affected by the Chernobyl accident.
- The international radiation community supported the Soviet authorities in their attempts to play down the radiological consequences of the Chernobyl accident for a long time.

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General Situation of the Radiological Consequences of the Chernobyl Accident in Ukraine

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Introduction

April 26, 1986, will go into history as the date when the 4th reactor of the Chernobyl Nuclear Power Station exploded causing radioactive contamination of a wide area practically in all Europe. The initial explosions and heat carried volatile radioactive materials up to 1.5 km height from where these materials were transported over large territories. Plumes containing numerous quantities of radionuclides moved with prevailing winds to the north, east, south and west, precipitating radioactive particles on areas thousands of miles away. Regions affected with the radionuclides from the Chernobyl's wrecked reactor included not only Ukraine itself but also Belarus, Russia, Poland, Sweden, Norway, Finland, Germany, Hungary, Slovenia, Lithuania, Greece, Bulgaria, Slovakia and many others. The volatile radioiodine, other radionuclides and small hot particles were detected in these countries on the very first days after the Accident. Crops, vegetables, grasses, fruits, milk, dairy products, meat and even eggs were sometimes so contaminated with radionuclides that they had to be abandoned.

The total amount of radioactivity released exceeded significantly 50 Mega Curies. On the roof of the destroyed reactor building, dose rate in May-June 1986 reached a very high level of 100,000 Roentgens per hour (1).

The main dose load on the Ukrainian population is caused by radionuclide contamination of the country territories located outside the alienated zone following the Chernobyl accident.

The territories contaminated with radionuclide ^{137}Cs in Ukraine are as follows (2,3):

Levels of surface contamination, Ci/km^2	Contaminated territories space, km^2
5-15	2,355
15-40	740
above 40	680
Total	3,775

Clearly the territory of agricultural use with a level of the surface contamination of an order of 1-5 Ci/km^2 is much more - 33,160 square km.

The radioactive materials from the reactor had been deposited along the north, west, east, south, south-east and south-west plumes. Much more than $2*10^{18}$ Bq of radionuclides were released from this unit and dispersed over wide areas (1).

The scale of radionuclide contamination of the territories is very significant. As we have shown, the area highly contaminated with ^{137}Cs in Ukraine occupies a space over 37 thousand sq. km. In consequence of the radionuclide contamination Ukraine lost tens of thousands sq. km of forest and arable land.

The surface contamination is extremely spotty. Spots of radioactive contamination have been formed after the trace of the plumes on very large territories. At the present time, we know well the spatial distribution of radioactivity in Ukraine. The spots differ in sizes having diameters from few meters to hundreds of km.

The population inhabiting the contaminated territories in Ukraine is as follows (1, 3):

Levels of surface contamination, Ci/km^2	Population, thousands of people
1-5	1,227.3
5-15	204.23
15-40	29.7
above 40	19.2
Total	1,480.4

The radionuclide contamination of the areas marked the beginning of a series of very dangerous radiological and radioecological consequences on a large scale and for a long time.

Ecological and radioecological consequences, economic burden, political pressure and speculation prevailing among politicians, and large moral and psychological symptoms affecting the Ukrainian population are linked together by that heavy chain which the Chernobyl accident had brought in Ukraine eleven years ago.

Radioecological Consequences

This main radioecological consequences of the Chernobyl accident are as follows:

1. The large activity of fission products escaped into the atmosphere and further into ecosystems. The radionuclides are migrating through all components of the ecosystems in the landscapes and, as a result, all living beings became radioactive;

microorganisms, mushrooms, plants, insects, other animals and human beings.

2. Radioactivity is moving to ground water and contaminating surface water.
3. Radionuclides come to the trophic chains and are moving to people. All things around people become radioactive as well as the bodies of adults and children. For one example, the radioactivity of leaves of some trees in the central Kiev's streets in 1986 varied from 70,000 to 400,000 Bq/kg (1, 4).
4. Dispersed radionuclides migrate in the biosphere and this process is accompanied by shaping of dose load on all living beings, including a large number of population. Exposure of population due to the fallout from the Chernobyl reactor accident occurs via three pathways: external irradiation from radioactive materials deposited on the ground, inhalation of airborne material, and ingestion of contaminated foodstuff. The contribution of ingestion of contaminated foods to the total irradiation dose is very high. It is worthy to note that internal irradiation is characterized by its much more higher biological effectiveness than external irradiation.
5. Excess of irradiation over the natural background could lead to manifestations of different kinds of diseases in people and deterioration in flora and fauna on the territories contaminated with radionuclides.

Plants being cultivated on soil contaminated with radionuclides uptake these radionuclides in proportion to their concentrations in soil solution and to biological significance of corresponding carriers. An example of radionuclide activity in sod-podzolic soil and some plants is shown in Table 1.

As evident from the data of Table 1, the uptake rate of radionuclides varies considerably depending on plant species. The radionuclide accumulation differs not only by the species of plants, but also significantly by the varieties within the same species. For varieties of winter rye, for example, the values of specific activity of dry masses varies from 14,900 to 1,100 Bq/kg for ^{137}Cs.

The coefficient of radionuclide accumulation by plants (CA) has been intensively investigated last years. Attention is drawn to the fact that the values of these coefficients are very variable being dependent on plants, physical-chemical state of radionuclides and their carriers in soil (1).

$$CA \left(\frac{\text{spcific activity of dry plant mass for a ceitain radionuclide}}{\text{specific activity of soil}} \right)$$

depends also on soil acidity. Typical values of CA for pea, corn, winter wheat, barley, sugar beet and cabbage range from 0.06 to 0.30.

The CA coefficients are much higher in salt-tolerant plants. This is apparent from Table 2.

The total reserves of radionuclides in different components of ecosystems and the rates of transfer of radionuclides to the food-stuffs (mainly milk, meat, mushrooms, fishes) set the extent of exposure of people to irradiation.

A very dangerous place within the 30 km zone around the destroyed reactor is the "Sarcophagus"

Table 1 Contents of radionuclides in soil and plants grown in the vicinity of the wrecked Reactor. July 1987 (4)

Object	Activity, Bq/kg of dry weight			
	^{137}Cs	^{144}Ce	^{106}Ru	$^{95}Zr/^{95}Nb$
Soil	51,800	296,000	92,200	40,700
Vetch	71,780	17,430	3,700	410
Clover	45,500	90,300	8,000	14,360
Melilo	9,770	9,200	1,400	1,400
Pea	4,400	1,500	330	150
Lupine	4,100	10,700	5,550	1,440
Alfalfa	1,800	2,150	1,400	70
Oats	330	520	150	75
Barley	260	330	40	40

Table 2 Coefficients of ^{90}Sr accumulation (CA) in some salt-tolerant plants (4)

Plant species	CA
Chenopodiacea	
Climacoptera salsa	2.38
Kochia scoparia	1.59
Kochia prostrata	2.03
Atriplex Fominii	1.59
Atriplex acuminata	1.06
Petrosimonia crassifolia	2.80
Salicornia europaea	1.70

protectively entombing the fourth unit. This entombment covers the monstrous ruin and radioactive remains spewed from the reactor core. The Sarcophagus remains a hazardous building because it contains about 200 tones of the fuel materials in the form of solidified lava with very high levels of radioactivity. In the contemporary state, the fuel-containing materials are sub-critical. But ingress of water into the Sarcophagus, earthquake, alteration of the Sarcophagus construction can change the sub-critical state of fuel into critical. The fate of the Sarcophagus as well as the fate of sedimentation in ponds and rivers within the contaminated region, and the radioactivity of the "Red Forest" which had died as a result of accumulation of large radioactivity are now hard to be forecast.

Assessment of Radiological Consequences

Since the very beginning of the accident, the information about the scale of the disaster has been misjudged and misleading. Even today the world opinion is far from truly elucidating the real scope of the impact of the Catastrophe on mankind. A sharply outlined controversy among specialists in the field of radiology exist till now about the medical consequences of the Chernobyl accident. Opinions differ as to the real causes of the increasing numerous diseases in the Ukrainian population after the Chernobyl accident. There are many supporters of a speculation that the morbidity augmentation after the Accident is due to psychological factors and no other. The term "radiophobia" was embedded in radiological literature. However, there is also a speculation that the morbidity is deeply allied to the radionuclide contamination in the environment. There are reliable data about the effects of low dose of irradiation and the health consequences of iodine influence on thyroid gland.

I would like to note that there are disgraceful and inhumane attempts to mendaciously diminish the consequences of the Chernobyl accident or even treat it as a thing of the past to be forgotten and erased from memory. This point of view come up mainly from prejudiced supporters of atomic energy, dignity of which has been suffering from the accident at the Chernobyl Nuclear Power Station. I believe, however, that this accident should not be forgotten. On the contrary, we should be very attentive to revealing of the consequences of the Accident because it is related to principally new aspects of radiation accidents ecologically dangerous in a large scale as follows.

Firstly, the conditions of combined irradiation by mixture of beta-, gamma- and alpha- rays are of rather high radiological effectiveness.

Secondly, the scope of people exposed to the action of ionizing radiation is unprecedentedly numerous.

Thirdly, the real levels of irradiation dose to people were much higher than we believed in the first years after the Catastrophe.

In such a situation we have no basis to apply the traditional radiological knowledge to elucidating, quantitatively evaluating and predicting the real threat of the Chernobyl radionuclide contamination.

The population living on the contaminated territories (above 0.5 Ci/km^2) exceeds five millions people. The victims of the Catastrophe can be logically classified into six groups according to conditions of irradiation. These groups are as follows:

1. people who took part in overcoming the accident consequences within the territory where the wrecked reactor is located. This territory represents a round area ringing the reactor. The radius of this area is equal to 30 km. It is named as the 30-km Zone or Alienation Zone. People having worked in this Zone are named Liquidators;
2. people evacuated from Prypyat' city and other settlements located within the 30-km Zone;
3. people evacuated from the territories contaminated with very high radioactivity;
4. people living on the highly contaminated territories;
5. children who had received high doses on thyroid gland from radioactive iodine;
6. children from irradiated parents.

I would like to show a sketchy description of the main factors of the radiological effects being formed in the territories contaminated with radionuclides.

Two general types of radiological effects are recognized: non-stochastic and stochastic effects.

Non-stochastic effects consist of somatic damages and deficiencies of the immune system. These effects induce the secondary diseases which can be manifested as illnesses mainly non-specific for radiation. At the same time, acute radiation sickness refers also to non-stochastic effects of irradiation. Manifestation of these effects depends on dose, dose-rate, types of radiation and the relationship between external and internal irradiation.

Stochastic effects are characterized by probabilistic nature of its manifestation. Cancernogenesis based on cell transformations, mutagenesis of somatic or gametes cells refer to stochastic effects of irradiation.

What is known at the present time about revealing of these effects in people?

It is very sad, but the state of people's health has been affected to a great extent during ten years after the Accident.

The main information basis to evaluate health of the people suffering from the Chernobyl Catastrophe is the National Register of victims. As for January 1995, the National Register in Ukraine included 432,543 persons. The Military Medical Register of the Ministry of Internal Affairs of Ukraine includes nearly 36,000 persons.

Table 3 Birth-rate and mortality after the Chernobyl accident in Ukraine (cases on one thousand of residents)

Year	Birth-rate	Mortality	Natural alteration of population
1990	12.7	12.1	0.6
1991	12.1	12.9	-0.8
1992	11.4	13.4	-2.0
1993	10.7	14.2	-3.5
1994	10.0	14.7	-4.7
1995	9.6	15.4	-5.8

Data of the Health Ministry of Ukraine, September 1996.

Table 4 Infantile mortality after the Chernobyl accident in Ukraine

Year	Number of cases in country	Number of cases per 1,000
1990	8,525	12.84
1991	8,831	13.90
1992	8,429	13.98
1993	8,431	14.93
1994	7,683	14.54
1995	7,314	14.68

Table 5 The main causes of infantile mortality in 1990-1995

Diseases	Number of cases per 10,000	Weight, %
Pathological states arisen during prenatal period	48.4	33.0
Inherent anomalies	42.6	29.0
Diseases of respiratory system	14.5	9.9
Infectious and parasitic diseases	11.2	7.6

Altogether over 3,200,000 people in Ukraine are considered to be ill owing to the Chernobyl Catastrophe. Almost 1,000,000 of them are children (5). A brief mention should be made on the health state of the people in Ukraine which has been heavily deteriorating last years. It can be seen from the next Tables (6).

From Table 3 we notice that the mortality rate exceeds the birth rate in Ukraine from 1991. The pace of the increase in infantile mortality is very high last years (Table 4). The main causes of the infantile mortality are identical to that for the population affected by the Chernobyl accident (Table 5). Mortality in the able-bodied residents in Ukraine has increased sufficiently last years particularly in men (Table 6).

Epidemiological investigations of the influence of the Chernobyl accident should be carried out with due regard for total deterioration of the state of health as a whole in Ukraine.

After the Chernobyl accident an annual increase of sickness incidence among the victims has been registered (5).

The alterations of a very general index of the state of people's health, namely percentage of practically healthy people, testify that there exists a sharp deterioration in the health state of adults, adolescents and children of the affected population (Table 7).

The percentage of healthy people decreases drastically with time in three groups of the Chernobyl's victims. Since 1987 the percentage of healthy population decreased from 80 % to 20 % and sometimes less. To site one example, in the Dubrowitzki district of the Riwno region there have been no healthy children last years. The high level of internal irradiation was observed in this place.

Health state of the participants of the liquidation of the Chernobyl accident consequences and of the people evacuated from the 30-km Zone (zone of alienation)

Territory of Ukraine was divided into zones depending on levels of radionuclide contamination in soil and values of average effective dose (1). There are the next four zones:

- Zone of alienation: the 30-km Zone around the Chernobyl Nuclear Power Station;
- Zone of obligatory settling out: level of a surface density of contamination with ^{137}Cs above 15 Ci/km^2, with ^{90}Sr above 3 Ci/km^2 or Pu above 0.1 Ci/km^2. In addition, the territories covered with the soils in which intensive migration of radionuclides occurs with a surface density of ^{137}Cs contamination of 5 - 15 Ci/km^2, with ^{90}Sr of 0.15 - 3 Ci/km^2, or Pu from 0.01 to 0.1 Ci/km^2 are also included in this category. The effective equivalent dose stands out above 5 mSv /yr.

Table 6 Mortality in the able-bodied residents (Number of cases on 100,000)

	Year				Increase compared to 1990, %
	1990	1992	1994	1995	
All causes of death:					
Men	697.7	826.9	942.8	1055.1	+51.2
Women	199.3	216.9	234.7	256.8	+28.9
Tumor:					
Men	226.5	279.9	312.0	349.7	+54.4
Women	41.2	49.3	54.1	60.2	+46.1
Diseases of blood circulation:					
Men	202.1	242.0	286.4	322.2	+59.4
Women	50.4	54.1	60.2	65.9	+30.1

Table 7 The index of practically healthy people , %

Year	The groups of victims		
	Liquidators	Evacuees from 30-km Zone	Children from irradiated parents
1987	82	59	86
1988	73	48	78
1989	66	38	72
1990	58	29	62
1991	43	25	53
1992	34	20	45
1993	25	16	38
1994	19	18	26

- Zone with the right for settling out: territories contaminated with ^{137}Cs in the range from 5 to 15 Ci/km^2, ^{90}Sr in the range from 0.15 to 3 Ci/km^2 or Pu in the range from 0.01 to 0.1 Ci/km^2. When the soils on territories are characterized by intensive uptake of radionuclides, the limits of the surface density are as follows: ^{137}Cs of 1 - 5 Ci/km^2; ^{90} Sr of 0.02 - 0.15 Ci/km^2 or Pu of 0.005 - 0.01 Ci/km^2. The effective equivalent dose should not exceed 1 mSv/yr over the pre-accident level of irradiation.
- Zone of residing with strict radiation control: territories contaminated with ^{137}Cs in the range from 1 to 5 Ci/km^2, ^{90}Sr from 0.02 to 0.15 Ci/km^2 or Pu from 0.005 to 0.01 Ci/km^2. When the soils on this territory are characterized by intensive uptake and migration of radionuclides, the limit of the surface density is ^{137}Cs of 0.2 - 1 Ci/km^2. The effective equivalent dose should not exceed 1 mSv/yr.

The victims of the Chernobyl accident in official documents are divided into four groups in the following way:

- The first group encloses the participants in the liquidation of the Chernobyl accident consequences. 245,587 persons fall in this group. Amongst this group, there are 223,908 men and 21,679 women.
- The second group embraces the people evacuated from the Zone of alienation and emigrants from the Zone of obligatory settling out. This group consists of 70,483 persons, among which there are 31,365 men and 39,128 women.
- The third group covers the residents who are living now or were living some years after the Accident in the Zone with strict radiation control. This group is very numerous, it consists of 2,096,000 persons (45.7% men and 54.3% women).
- The fourth group encompasses the children born from the parents of any one of the listed groups. This group consisted of more than 317,000 children in 1995.

The epidemiological data testify that the morbidity of the victims of the Chernobyl accident as a whole and by main classes of diseases is higher than the average values in Ukraine and has a very clearly defined tendency of increasing with time (7, 8). It can be seen from Table 8 that the index of morbidity is drastically grown with time. The data of morbidity about main diseases are shown in Table 9.

The number of patients among the participants of the liquidation of the Chernobyl accident consequences increased by 2.7 times in relation to 1987. Among the children of the fourth group, morbidity has been increased by 2.5 times last years. The number of patients increased by 56.3 % in the third group and by 33.6 % among people related to the second group.

Table 8 Index of morbidity of the victims by the Chernobyl accident (per 10,000)

Year	Groups of the victims	
	Adults and adolescents	Children (less than 14 yr)
1987	4,210	7,866
1994	12,559	16,026

Table 9 Index of morbidity in adults and adolescents of the suffering people (per 10,000)

Nosological forms	Year		Mean in population
	1987	1996	
Diseases of blood and hemopoetic system	12.7	30.5	12.6
Diseases of endocrinologic system	41.1	70.0	41.6
Neoplasia of the lymphatic and hemopoetic system	3.0	6.7	-

Table 10 Structure of morbidity in adults and adolescents of the victims in 1994

Nosological form	%
Diseases of respiration system	35.6
Diseases of nervous system	10.1
Diseases of blood circulation system	8.6
Diseases of digestion system	6.4
Diseases of osseous-muscular system	6.4
Genito-urinary diseases	6.1

Table 11 Index of morbidity in people living in territories of strict radiation control. (Data of 1996, per 10,000)

Nosological form	Victims	Mean for population of Ukraine
Diseases of hemopoetic system	30.2	12.6
Diseases of blood circulation system	430.4	294.0
Diseases of endocrinologic system	54.2	37.8
Diseases of digestion system	280.9	210.1
Diseases of osseous-muscular system	333.0	307.1

Table 12 Index of mortality in the groups of the victims in 1996

Groups of victims	Index (per 1,000)
Participants of the liquidation of the Chernobyl accident consequences	9.06
People evacuated from the Zone of alienation	11.60
Residents in the territories of strict radiological control	18.42
Able-bodied population in Ukraine	6.50
Mean for population of Ukraine	15.20

The structure of morbidity is specific for the victims of the Chernobyl accident. The pattern of the nosological forms is shown in Table 10. Diseases of blood and hemopoetic organs increased during last eight years by 3.9 times.

Morbidity in people living in the territories contaminated with radionuclides is well above the morbidity in the average in population of Ukraine. It is seen from the data of Table 11.

The mortality of adults and adolescents subjected to radiation exposure due to the Chernobyl accident essentially increased after 1987. It can be seen from Table 12.

The structure of the death causes of the Chernobyl victims is as follows:

- diseases of blood circulation system; 61.2 %,
- neoplasm; 13.2 %,

(incidence of death from malignant tumors in these case ranges up 98 .4 %);

- traumatism; 9.3 %,
- diseases of respiration organs; 6.7 %,
- diseases of digestion organs; 2.2 %.

The primary disablement in the suffering people has drastically increased last years. It can be seen from Table 13.

The data on the health state of the people who suffered from excess of irradiation confirm beyond any possible doubt that the environmental situation in the north part of Ukraine is unfavorable and inauspicious for people life.

Health state of children subjected to radiation exposure due to the Chernobyl accident

Increase of primary and total morbidity of children subjected to radiation exposure due to the Chernobyl accident was registered on the majority of disease classes for the period 1987 - 1996, as well as constant augmentation of the number of children with chronic pathologies. Table 14 gives the value of morbidity and prevalence of diseases in children of the regions affected by the Chernobyl accident.

It follows that the prevalence of diseases increased for 10 years by 2.1 times and the rate of morbidity increased by 2.5 times. It should be pointed out that the highest level of morbidity increase is registered for neoplasm, congenital defects and diseases of blood and hemopoetic organs. The highest level of morbidity is inherent to the children of the third group of victims (residents of the zone with strict radiation control). It should be mentioned that the morbidity of children in all Ukraine decreased by 20.8 % for the same period.

Thus, the morbidity of the suffering children exceeds significantly the all-Ukrainian level of children morbidity (7, 8). The structure of morbidity is shown in Table 15.

Morbidity of the suffering children by malignant tumors has noticeably increased as compared with the index of oncological morbidity of children in another parts of Ukraine. Oncological morbidity of children in the affected zones increased for ten years after 1987 by 3.6 times.

The rate of congenital defects increased for the same period by 5.7 times and morbidity of children by diseases of blood circulation system and hemopoetic organs increased by 5.4 times.

Along with the increase of the pregnancy pathology and confinement, there increases new born children mortality.

Mortality of children of 0 -14 years increased from 0.5 per 1000 in 1987 to 1.2 in 1994.

The children mortality increases at the expense of diseases of the nervous system and sense organs (augmentation by 5 times), congenital defects (increasing by 2.4 times) along with the infectious and parasitic diseases, and the diseases of blood circulation system.

Dynamics of the mortality by malignant tumors of various localization has no regular trend, but the level of oncological mortality of the suffering children is higher than this form mortality of the inhabitants in another parts of Ukraine.

Malignant thyroid tumor

It is now indisputable that the Chernobyl accident has influenced the increase of thyroid gland tumor morbidity. It is established that the growth of malignant thyroid tumor is connected with radionuclides of iodine released during the Accident from the damaged reactor unit. Before the Accident thyroid cancer was rare and characteristic mainly for elderly people. In children and adolescents an estimated annual incidence of thyroid cancer was around 0.2 to 0.4 cases per million children, representing around 3 % of all tumors. In 1981 -1985 there were only 25 cases of thyroid cancer in children in Ukraine.

The latency period between irradiation and cancer development varies with an average period around 8-10 years. There is no correlation between radiation dose and the length of the latency period. However, the increase of thyroid cancer morbidity began well before the time it was predicted, namely, after 4 years from the Accident and is continuing up to now.

The risk of thyroid cancer has sharply increased within the children subjected to irradiation at the age under 3 years old at the moment of the Accident. A

Table 13 Index of the primary disablement (per 10,000)

Year	Groups of people		Other
	Participants of the liquidation of the Chernobyl accident consequences	People evacuated from the Zone of alienation	
1987	9.6	20.5	5.4
1994	232.4	95.2	9.3

Table 14 Index of morbidity and prevalence of diseases in children of the affected regions (per 1,000)

Year	Index of morbidity	Index of prevalence of diseases
1987	455.4	786.6
1994	1138.5	1651.9

Table 15 Structure of morbidity of children of the suffered regions

Nosological forms	%
Diseases of respiration system	61.6
Diseases of nervous system	6.2
Diseases of digestion system	5.7
Diseases of blood and hemopoetic system	3.5
Diseases of endocrinologic system	1.2

characteristic feature is a high aggressiveness of thyroid cancer. In a half of cases the tumor goes outside of thyroid gland and grows into surrounding tissue and organs.

Number of the cases of childhood thyroid cancer is seen from the data of Table 16 (9).

The majority of cases of children thyroid carcinoma, 94 % are papillary forms.

It seems reasonable to say that the tendency to augmentation of manifestation of this cancer in children will continue many years. It appears this form of cancer did not peak yet.

Radiobiological appraisal of the radiological consequences

The real reasons responsible for the worsening of population health in Ukraine can be recognized from the radiobiological research carried out on the biological test-systems of different kinds. We used plant-systems to reveal the role of chronic irradiation at low doses on forming the stochastic and non-stochastic effects. Experiments have been carried out under the controlled conditions in the area influenced by the Chernobyl's radionuclides fallout.

The intimate linkage between the rate of the mitotic crossingover and irradiation has been proved in the mutant system of special plants. DNA repair processes in pollen cells were initially blocked or seriously reduced in accordance with the level of irradiation at Chernobyl (10). The present generations of pollen from trees exposed to continuous irradiation at Chernobyl fail to repair with fidelity the gene sequences in a series of experiments so far carried out. Epigenetic imprinting during morphogenesis showed a high sensitivity to internal irradiation and the hot particles located on the meristematic tissue (11). Alterations of mobility of some restriction fragments of DNA after chronic irradiation of cells bear witness to the significance of irradiation at low doses for stability of genom of somatic cells.

The results of fundamental radiobiological research should be considered in the attempts to understand the mechanism of the changes occurring in irradiated cells and of the augmentation of numerous diseases owing to the Chernobyl accident.

The results of radiobiological investigations carried out in the contaminated territories near the Chernobyl Nuclear Power Station have shown last time very important new facts.

The most important radiobiological effects related to irradiation at low doses have been revealed in the following:

1. Significant non-linearity in dose-dependent curves of radiobiological effects of irradiation at low doses.
2. Induction of genome instability under the influence of irradiation at low doses has come to light based on the chromatographic pattern of restricted DNA which has been studied in the experiments on different plant species growing in the soil contaminated with radionuclides.
3. Disruption of the position control owing to alteration of repeated sequences of DNA molecules is considered as a likely target at low doses.
4. Deterioration of the accuracy of DNA repair within cells. In our studies to date, by measuring unscheduled DNA synthesis, we have observed a complete failure of DNA repair in birch pollen in the first generation of pollen after the Chernobyl accident. Inhibition of unscheduled DNA synthesis in the next generation of birch pollen from the same site was less. However, later pollen from Chernobyl failed to achieve proper DNA repair, suggesting that a hidden damage still persisted in the overall mechanisms for DNA repair after chronic irradiation at low dose rates.

The data of these experiments are presented in Table 17. It is clear that the genotoxicity of irradiation from a mixture of radionuclides is much higher than similar doses from external gamma-irradiation only.

It was shown that the stochastic effects, like mutagenesis, was closely related to internal irradiation from accumulated radionuclides in cells. In this case the relative biological effectiveness of internal irradiation was much greater than under external irradiation. The waxy-mutation of barley and tests for pigment-mutants formation were used in these experiments under the controlled level of prolonged mutagenesis (12).

It is apparent that mutagenic effects in plant cells, in the case of radionuclide contamination of soil, could

Table 16 Number of cases of thyroid cancer in children in Ukraine after the Chernobyl accident (for contingent with age from 0 to 19 years when the accident occurred)

Year	Number of Cases	Cases per 100,000
1986	15	0.12
1987	18	0.14
1988	22	0.17
1989	36	0.28
1990	59	0.45
1991	61	0.47
1992	108	0.83
1993	113	0.87
1994	134	1.00
1995	166	1.30

not be extrapolated on the basis of measured dose. The yield of chromosome aberration is very high under chronic irradiation at low doses. This is supported by experimental results presented in Table 18.

The frequency of chlorophyll mutation is also increased by irradiation due to radionuclide contamination. The results of experiments on rye are tabulated in Table 19.

The data discussed above point to the conclusion that irradiation at low dose due to radionuclides incorporated by tissue is followed by strong genetic effects. It might be well to point out that the mechanisms of radiation mutagenesis and cell transformation are identical both for plant and animal cells. There is no question that irradiation owing its origin to radionuclides accumulated within cells is distinguished for its high biological effectiveness. The use of plant test systems which are capable of fast responding to irradiation at low dose holds beyond any reasonable doubt a great promise for the assessment of radiological risk.

Discussion

Following the Chernobyl Nuclear Accident on April 26,1986, epidemiological analyses of data point to impressive deterioration of health of the people affected by radionuclide contamination in the environment. This deterioration of population health embraces a broad spectrum of diseases.

Social psychological consequences of the Accident are also very impressive. Under the influence of what people has seen and heard from the first years after the Accident, the confidence in many things has been sometimes completely lost for a long time. But there is a tendency to consider the morbidity augmentation exclusively as a result having been associated with factors of non-radioactive origin (chemical compounds, heavy metals and mainly social-psychological syndrome development).

I should note that some specialists being mainly under ascendancy of the Nuclear Energy Authorities try to prove from the first days after the Accident that all deterioration in the health state of the people living on the territories contaminated with radionuclides as well as of Liquidators are not directly related to the impact of irradiation. Why are such doubts being cast upon existence of the relationship between irradiation and frequency of diseases in the victims of the Chernobyl catastrophe? Skeptics say that there are no reliable and sufficient proofs of these relationships. The evidences for this thinking are the following:

Table 17 Frequencies of waxy reversion in barley pollen as a result of 55 days of exposure to various levels of radionuclides released at Chernobyl and a pure gamma-field

Dose rate (μSv/h)	Total dose (mSv)	Total reversion	Radiation-induced
< Radionuclide contaminated conditions >			
Control (0.96)	1.3 ± 0.1	174	0
59	78 ± 50	226	52
320	422 ± 41	837	663
400	528 ± 47	1235	1061
515	680 ± 47	1705	1531
< Chronic gamma-irradiation >			
Background	0.1	82	0
5	3.0	145	63
50	29.6	150	68
500	296	198	116
5000	2960	192	110
50000	29600	292	210

Table 18 Yield of chromosome aberrations (%) by chronic irradiation in root apical meristems of different plant species (activity of substrate 70,000 $Bq.l^{-1}$) (4)

Plant species	Control	1986	1987	1988	1989
Lupinus alba	0.9	19.4	20.9	14.0	15.9
Pisum sativum	0.2	12.9	14.1	9.1	7.9
Secale cereale	0.7	14.9	18.7	17.1	17.4
Triticum aestivum	0.9	16.7	19.3	17.7	14.2
Hordeum vulgare	0.8	9.9	11.7	14.5	9.8

Table 19 Yield of albina chlorophyll mutation (%) in rye in the 30 km Zone (4, 11)

Variety of rye	Control	Contaminated soil (^{137}Cs, ^{137}Cs, ^{144}Ce, ^{106}Ru and others, 180,000 $Bq.kg^{-1}$)			
		1986	1987	1988	1989
Kiev-80	0.01	0.14	0.40	0.91	0.71
Kharkow-03	0.02	0.80	0.99	1.20	1.14

1. There are no plausible differences related to non-specific diseases between the people living on the contaminated territories and the control groups;
2. Techniques for diagnosis verification has become last years much better than ten years ago. Hence a comparison between epidemiological data obtained before and after the Accident is improper operation;
3. Deterioration of the state of health can be considered as a result of other affecting factors; a lowering of life conditions, including nutrition, and psychological stresses impact. As this takes place, so-called “radiophobia” attracts the largest notice.

I am sure that there are at least two means of approach to interpreting the epidemiological data in order to solve these contradictions.

In context of this assumption I would like to outline two considerations.

- The first consideration. Irradiated groups of people on contaminated territories are too numerous and they could not advantageously be compared with another groups. So it is difficult to find adequate groups for comparison. Actually let us see a map of total mortality of people in Ukraine. The contaminated territories are found in the regions where, before the Accident, mortality of people was well below than in many other regions of Ukraine. Hence it makes sense to consider the whole population of Ukraine as the control group for comparison of indexes of morbidity and mortality. The alternative is to use a comparative analysis of the tendencies for morbidity alteration.
- The second consideration. The data of radiobiological investigations should be used in analyzing real causes of health deterioration in people. Choosing correct controls in radiobiological experiments is fully possible and we know many biological test-systems particularly well suitable for evaluating the dose-dependence of the main cellular and molecular genetic processes which can be primary events of radiological effects.

Conclusion

Following the Chernobyl Nuclear Accident on April 26,1986, epidemiological analyses of data point to impressive deterioration of the health of the people affected by radionuclide contamination in the environment. This deterioration of population health embraces a broad spectrum of diseases. Epidemiological prediction of the rate of thyroid cancer in children near Chernobyl seems strikingly compatible with a real increase. But there is a tendency to consider the morbidity augmentation as a result having been associated with the factors of non-radioactive origin (chemical compounds, heavy metals and mainly social-psychological syndrome development).

The Chernobyl catastrophe has implied a heavy burden for Ukraine: pollution of air, water, soils and vegetation in all ecosystems, late radiological effects in the health of people, losses of arable land and forest, necessity of mass-evacuation from thousands of settlements in the contaminated regions, severe psychological shock for millions of people, and painful suffering of unexpected life tragedies.

Eleven years after, this tragic event with its causes and consequences brings one to very important conclusions concerning moral aspects of human relations within the nuclear society, as well as interactions between the society and the environment.

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Legislation and Research Activity in Belarus about the Radiological Consequences of the Chernobyl Accident: Historical Review and Present Situation

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I. Introduction

For nearly ten years since the April 26, 1986 explosion of the Chernobyl power plant nuclear reactor, the Republic of Belarus has subsequently been exposed to conditions of global radioactive contamination. That day ten years ago split the history of Belarus into two epochs - before and after Chernobyl. Judging by its scale, the Chernobyl accident was the biggest technogenious catastrophe that has ever occurred on this planet. Its radioactive cloud virtually covered the whole northern hemisphere, and resulted in the generation of a hitherto unknown mass of refugees, i.e. for ecological reasons, whose numbers only equal those produced by wars.

The most grave results of the accident were to be found in Belarus. Scientists are still arguing as to the exact amount of radionuclides released into the environment by the explosion. However, the most conservative estimate suggests it is equal to the effect of an explosion of twenty nuclear bombs. The damage caused to the Republic by the Chernobyl accident is estimated to be equal to 32 pre-accidental annual budgets. The scale of the accident demanded urgent countermeasures. During the initial stage of the post-accident period 24,700 people were evacuated. Up to the present, 130,000 people from the contaminated areas have been resettled.

Despite the fact that 10 years have passed since the accident, the problems resulting from it have not disappeared. Moreover, in some realms they have become even worse. This is tied to the high collective dosage of radiation absorbed by the population, to the difficulties in remote impact forecasting (especially against a background of our adverse ecological situation), as well as for other objective reasons.

The Republic, left practically alone to face the catastrophe's consequences, still faces a critical situation today. 1,840,951 people including 483,869 children below the age of 17, inhabit 3,221 villages and towns in the radioactively contaminated territories. The radiation dose in some of them is up to 5 mSv or higher per year. Socio-psychological tension is still very high, and there has been a steady increase in the incidence and prevalence of illness. In particular, concern has arisen over the growing number of thyroid pathologies, including thyroid gland cancer among children.

Aware of the global nature of the catastrophe, and of threatening implications for public health, the Supreme Soviet of Belarus declared the entire territory of the Republic to be a zone of ecological calamity.

II. Legislation and regulation in Belarus concerning Chernobyl

2.a. Legislation to assist people suffering due to the accident

The Republic of Belarus' "Social Protection of Citizens Affected by the Chernobyl APS Catastrophe" Law proposed on February 22, 1991 was approved on December 11, 1991 with amendments and additions. This law is designed to protect the rights and interests of citizens who took part in the liquidation of the Chernobyl accident, as well as those who were evacuated from the radioactively polluted territories, and those who still live on these territories. This law provides that citizens living or working on the territory of the Republic of Belarus who experienced damage to their health or property due to the Chernobyl APS accident are guaranteed certain rights and compensation by the State.

The basic criterion used to evaluate the areas in which the living and working conditions of the population do not face any restriction is an effective equivalent dose of living population which does not exceed 1 mSv (0.1 rem) per year. According to the stipulations of the Republic of Belarus' "Legal Status of Territories Exposed to Radioactive Pollution as a Result of the Chernobyl APS Catastrophe" Law, following zones are designated on the polluted territory:

- zone of evacuation (alienation);
- zone of first-place resettlement;
- zone of subsequent resettlement;
- zone with the right of resettlement;
- zone having periodic radiation control.

This law guarantees the right of Belarus citizens to obtain complete, timely, and verifiable information about the level of radioactive pollution of the territory, the degree of radionuclide contamination of food products and other consumable commodities, and the requirements of the radiation safety regime. This law considers workers who participated in the liquidation of the Chernobyl accident as people affected by the catastrophe. Also covered are citizens of Belarus who took part in the liquidation or were affected by other accidents and their consequences at other nuclear installations, whether civil or military.

It foresees considerable privileges for those who participated in the liquidation of Chernobyl and for those others who were affected by the accident (free receipt of medicines upon physician prescriptions, free annual treatment in sanatoria and health resorts, 50-percent off lodging payments, a 50-percent reduction in heating, water, gas, and electricity payments, income tax exemption, increase in annual holidays, etc.). The people affected by the Chernobyl catastrophe have the right to receive pensions before the age proscribed by law. Pensions will also be in full irrespective of the salary received. This law also determines duty of the military to keep watch on the polluted territories.

A Decree of A. G. Lukashenko, President of the Republic of Belarus, on September 1, 1995, attempted to suspend the action of a number of articles of this law relating to the privileges of citizens affected by the Chernobyl catastrophe. However, the Constitutional Court canceled that presidential decree.

2.b. Legislation and regulation pertaining to the radiation dose limit

After agreeing with Academician L. A. Il'in, the President of the National Committee on Radiation Protection (NCRP) at the Ministry of Health of the USSR, A. I. Kondrusev, the Chief State Sanitarian of the USSR, upon the presentation of his deputy A. I. Zajchenko, approved on November 22, 1988, a limit on the individual dose per life for the population of controlled areas of Russia, Belarus and Ukraine which were radioactively polluted as a result of the Chernobyl accident. This is a 1-page document with 6 pages of explication grounding a 35 rem per life limit as the basic concept for "safe living" of population (Letter of NCRP No. 51-2-10/4212 of July 25, 1989). After this, there began discussion of the concept at the Congress of People's Deputies, evaluations of the situation by scientists of the Academy of Sciences of Byelorussian SSR, the Ministry of Education, the Gosagroprom, the Ministry of Health and the Ministry of Social Security of BSSR. After the discussion in the Academy of Sciences of BSSR in July of 1989 with the participation of WHO experts who supported the concepts, the Presidium of the Academy of Sciences of BSSR decided to disagree with the proposed concept of safe living and the opinion of invited foreign scientists. The principal remarks made by the Byelorussian scientists were based on the following deficiencies in the proposed concept (35 rem per life):

- there was no system to control the dose commitment formation, nor any concrete measure to provide safe living and working environment for separate districts, categories of population, etc.;
- the data on the "dose-effect" dependence for long-term (70 years) irradiation were not adduced;
- a risk assessment of stochastic effects was not made relating to the present situation;
- radiation effects were not evaluated against a scenario of the joint action of a multitude of irrational factors;
- there was no analysis of data on the irradiation of different population categories in the first period after the accident when people lived without any restrictions and iodine prophylaxy was not carried out (, which undoubtedly will have future repercussions);
- the endemicity of separate territories relating to iodine and related health disturbances were not taken into account;
- the separate accumulation of plutonium, strontium, "hot" particles in the lungs and strontium in bone, etc. was not considered; however, it may become the leading factor in development of pathologies;
- there was no "risk-profit" assessment, etc.

These and other remarks were considered during a session of a number of scientific councils in the Academy of Sciences of the USSR in May of 1989, and on September 15, 1989 during a session of the State Council at the Presidium of the Academy of Sciences of the USSR. Representatives of the USSR Ministry of Health, NCRP, Academy of Sciences of Ukrainian SSR et al. participated. The most important conclusions arrived at were as follows:

1). Taking into account the generally accepted concept of a non-threshold "dose-effect" dependence, any dose can not be considered as absolutely safe. This means, the concept of safe living on polluted territory requires revision and additional grounding.
2). According to available data, it is impossible to assess correctly the expected risk for the effect of chronic low (from 0 to 100 rem per life) radiation doses.
3). The "35 rem per life" dose must be considered as the limit, overstepping of which or the risk of overstepping of which is unacceptable. In the case of territories where the people receive less than the 35 rem limit, each case must be decided by means of a complex approach and optimization "input-output" analysis. Moreover, if the safety of the people can not be guaranteed by countermeasures, then resettlement is mandated.
4). The people must be fully informed about the consequences of living on polluted territories, the

planned governmental activities, and then have the opportunity to voluntarily decide whether or not to continue living on polluted territories.

As a result of these conclusions, the "Concept of People's Living in Regions Affected by the Chernobyl APS Catastrophe" was developed. It was proposed in this Concept:

1). To define an additionally acceptable irradiation limit not higher than 0.1 rem (1 mSv) per year for the living and working conditions of the population. This irradiation limit can be reached by stages: 1991 - 0.5 rem (5 mSv) per year, 1993 - 0.3 rem (3 mSv) per year, 1995 - 0.2 rem (2 mSv) per year, 1998 - 0.1 rem (1 mSv) per year.

2). To divide all the territories into zones according to the density of radionuclide pollution:

- zone of alienation - zone of resettlement in 1986, adjacent to the Chernobyl APS territory;
- zone of obligatory resettlement - zone with a density of soils polluted with Cesium-137, Strontium-90 and plutonium - 1480, 111 and 3.7 kBq/m^2, respectively;
- zone of resettlement - territory with a density of soils polluted with Cesium-137 , Strontium-90 and plutonium, respectively, from 555 to 1480, from 74 to 111 and 1.85 to 3.7 kBq/m^2 where the irradiation dose of a person may exceed 0.5 rem (5 mSv) per year;
- zone with the right of resettlement - territory with a density of soils polluted with Cesium-137, Strontium-90 and plutonium, respectively, from 185 to 555, from 18.5 to 74 and 0.37 to 1.85 kBq/m^2, where the acceptable limit of population irradiation is higher than 0.1 rem (1 mSv) per year;
- zone of living under periodical control - territory with a density of soils polluted with Cesium-137 - from 37 to 185 kBq/m^2, where the acceptable limit

Table 1. Tentative acceptable levels (TAL) and republican control levels (RCL) of Cesium-137 and Strontium-90 content in food products and potable water, defined in connection with the Chernobyl APS accident

	Name of food product	TAL-86 Bq/kg,l	TAL-88 Bq/kg.l	TAL-91 Bq/kg,l	RCL-90 Bq/kg,l
	For Cs-137				
1	Potable water	370	18.5	18.5	18.5
2	Milk	370	370	370	185
3	Lactic products, sour cream, curds	3700	370	370	185
4	Milk powder	18500	1850	1850	740
5	Butter, condensed milk	7400	1100	1100	370
6	Meat (pork, mutton), poultry, fish, eggs, meat and fish products	3700	1850	740	592
7	Beef and beef products	3700	2960	740	592
8	Vegetable and animal fats, margarine	7400	370	185	185
9	Potatoes, verdure	3700	740	600	592
10	Vegetables, orchard fruits and berries	3700	740	600	185
11	Bread and bread products, grains, oats, flour, sugar	-	370	370	370
12	Canned fruit and vegetables, juices, honey	-	740	600	185
13	Infant food	-	1850	185	37
14	Fresh berries (forest and orchard)	-	-	1480	185
15	Fresh mushrooms	-	-	1480	370
16	Dried fruits, mushrooms and forest berries	-	11100	7400	3700
17	Medicinal plants, tea	-	-	7400	1850
18	Other food products and additives	-	-	-	592
	For Sr-90				
1	Potable water	-	-	3.7	0.37
2	Milk and milk products	-	-	37	3.7
3	Milk powder	-	-	185	18.5
4	Condensed milk	-	-	111	3.7
5	Concentrated milk, butter	-	-	-	3.7
6	Meat (beef, pork, mutton), poultry, fish, eggs, meat and fish products, vegetable and animal fats, margarine	-	-	-	18.5
7	Potatoes	-	-	37	-
8	All types of infant food (ready to be consumed)	-	-	3.7	1.85
9	Bread and bread products, grains, oats, flour, sugar	-	-	37	3.7

of population irradiation is not higher than 0.1 rem (1 mSv) per year.

The Council of Ministers of Belarus makes decisions on the resettlement and providing for acceptable living conditions. This Concept was approved on December 19, 1990 by the Bureau of the Presidium of the Academy of Sciences of Belarus and became the basis of the above- mentioned “Social protection of citizens affected by the Chernobyl APS catastrophe” Law. The “Legal Status of Territories Exposed to the Radioactive Pollution as a Result of the Chernobyl APS Catastrophe” Law was adopted by the Supreme Soviet on November 12, 1991.

In order to fulfill the protective and other measures indicated by these laws, since 1991, the Ministry of Health has calculated, updated, and filled out the “Catalogue of Doses of Republic of Belarus Populations Living in Settlements with a Level of Cs-137 Pollution Higher Than 37 kBq/m^2”.

2.c. Legislation and regulation concerning radioactivity levels in foods, water and air

The basic principles for limitations and prohibitions on agricultural production and consumption of agricultural products, as well as the harvest and storage of forest food products, wildfowl, and fish, are laid down in articles 21-25 of the “Legal Status of Territories Exposed to the Radioactive Pollution as a Result of the Chernobyl APS Catastrophe” Law and are differentiated according to the division of polluted territories defined by this law.

On the basis of emergency dose limits (the first year after the catastrophe - 10 rem, 1987 - 5 rem, 1988 - 3 rem, 1989 - 3 rem, 1990 - 0.5 rem; 50% - external irradiation, 50% - internal one), the Ministry of Health of the former USSR defined in 1986, 1988, and 1991, the tentative acceptable levels (TAL) of Cesium-137 radionuclide content in food products and potable water. TAL-88 were adopted, most likely, on the basis of the concept of “safe living” with an absorbed dose limit of 35 rem per life, which was adopted in the same year by the Ministry of Health of the former USSR.

In 1990, the Republic of Belarus “Social Protection of Citizens Affected by the Chernobyl APS Catastrophe” Law was prepared. Since August 1, 1990, the Government of Belarus has put in force the republican control levels (RCL-90) of acceptable radionuclide content in water and food products. The RCL-90 enforced for two years until June of 1992. The RCL-90 rates predicted that for a constant radionuclide intake from food products, the annual dose of internal irradiation of the critical population group would consist of not more than 0.17 rem. The RCL-90 first included the control levels of Strontium-90 in potable water and food products. In the beginning of 1991, the Ministry of Health of the former USSR began to enforce the new TAL of Cesium-137 and Strontium-90 content in potable water and food products. Values of TAL-86, TAL-88, TAL-91 and RCL-90 are shown in Table 1.

At present, the republican acceptable levels (RAL-92) remain in force for cesium and strontium radionuclide content in food products and potable water, which were approved on October 21, 1992 by the Chief State Sanitarian of the Republic of Belarus. RAL-92 assume that radionuclide intake by humans on such a level will comprise an effective equivalent dose not higher than 1 mSv per year (Table 2).

Table 2. Fixed values (RAL-92)

	Name of food product	Bq/l.kg
a) for cesium radionuclides		
1	Potable water	18.5
2	Milk and milk products	111
3	Milk powder	740
4	Meat and meat products	600
5	Potatoes and root vegetables	370
6	Bread and bread products	185
7	Flour, grains, oats, sugar, honey	370
8	Vegetable and animal fats, margarine	185
9	Vegetables, orchard fruits and berries, forest berries	185
10	Canned vegetables, orchard fruits and berries	185
11	Dried mushrooms	3700
12	All types of infant food (ready to be consumed)	37
13	Other food products (ready to be consumed)	370
b) for strontium radionuclides		
1	Potable water	0.37
2	Milk and milk products	3.7
3	Bread and bread products	3.7
4	Potatoes	3.7
5	All types of infant food (ready to be consumed)	1.85

III. Activity of governmental organization concerning Chernobyl

3.a. Basic governmental policy

The activity of the Belarus Government concerning the mitigation of the Chernobyl catastrophe may be divided conditionally into two periods (before and after the collapse of the USSR) and 5 stages. In the first period, the government of the Republic, recuperating after the shock, made policy determined principally by the Central Committee of the CPSU (Communist Party of the Soviet Union) and the USSR Government. After the collapse of the USSR, when the hope to obtain help from other republics of the former USSR (predominantly Russia) was lost, the Belarus Government began to make independent policy concerning Chernobyl.

During the first stage (April-May 1986), the socio-economic conditions in the Republic favored pursuing various directions in spite of their inconsistencies. The greatest error of that period was that the population was not informed about the danger of radiation. The opinion that panic would arise was not grounded. Due to the secrecy surrounding the scale of the disaster, only about 170,000 people received iodine prophylaxy instead of the entire populations of four regions: Mogilev, Gomel, Brest and Minsk. Regarding the objective difficulties of solving the primary prophylaxy and decontaminaton tasks, the insufficiency of portable equipment, medications, and portable sanitation installations should be taken into account.

In the second stage (June-December 1986), more than 25 different decrees and instructions were promulgated by the Council of Ministers of the Byelorussian SSR and the Central Committee of the CPB (Communist Party of Belarus). Incidentally, their principal activity was directed to the financial support of affected citizens, as well as to the privileges and donations to population living in areas with a pollution density higher than 1,480 kBq/m^2. Those acts were conditioned mainly by the massive departure of population from the most polluted areas of the Gomel region and, a little later, the Mogilev region. At the same time, there were not clear enough recommendations regarding the production of “clean” agricultural products. Practically all the yield of 1986 was processed to be consumed, except for the yield from the 30-km zone. In this stage, a negative practice was begun to restrain the population from leaving the area by offering financial incentives, even though the resettlement of people from especially affected areas was needed.

The third stage (1987-1988) is characterized by socio-economic and political instability. Unnecessary products were produced in polluted areas. The number of cases of diseases caused by small radiation doses increased. Meetings and demonstrations began to occur, which were the result of contradictions in the development of concept of safe living between the central government and Republican’s scientific and economic bodies. The Republic still supplied animal and plant products to the USSR fund in full-volume. Activity was mainly directed towards decontamination and agrotechnical works on lowering the radioactive pollution levels. In polluted settlements with a level of pollution higher than 555 kBq/m^2, pipelines for gas heating, schools, and polyclinics were built. Later, those territories were transformed to a regime of strong control, and all social and economic activities were halted.

In the fourth stage (1989), it became obvious that it was impossible to solve all of the complex problems related to the consequences of the accident without adopting a clear overall program. Such a program was developed and adopted, but it was late in many respects. Adequate material resources were not provided to carry out the program tasks. The 5-year program implementation plan became strategically obsolete. The fact that solving the problems of the population would take five years did not gain the approval of the people.

The fifth stage (1990-) is characterized by a dramatic shift from instructions and decrees to the elaboration of legislative acts: the “Social Protection of Citizens Affected by the Chernobyl APS Catastrophe” Law and “Legal Status of Territories Exposed to the Radioactive Pollution as a result of the Chernobyl APS Catastrophe” Law were elaborated and adopted. The State Committee on the Problems of the Chernobyl APS Accident was created at the Council of Ministers of the BSSR. Governmental activities included all aspects of the liquidation of the accident’s consequences and were oriented towards:

- the resettlement of inhabitants of the most polluted regions;
- the provision of medical assistance to sufferers ;
- the construction of new dwellings and opening of new jobs for the migrants;
- the creation of radiation control system;
- the isolation of the most polluted areas;
- the sanitarian-ecological planning of settlements in polluted zones;
- the organization of scientific investigations of the consequences of the accident, etc.

3.b. Ministry activity concerning Chernobyl

Primarily, all the decisions concerning Chernobyl were made in Belarus by the Commission on the Liquidation of the Consequences of the Chernobyl APS Accident at the Bureau of the Central Committee of the CPB and the Council of Ministers of the BSSR.

According to a decision by the Supreme Soviet in 1991, the State Committee on the Problems of the Chernobyl APS Accident was formed. The President of the Committee had a position equal to the Vice-President of the Council of Ministers. In 1994, the State Committee on the Problems of the Chernobyl APS Accident became the Ministry on Emergencies and Protection of the Population from the Consequences of the Chernobyl APS Catastrophe.

The realization of state policy in protecting the population, in addition to coordinating and controlling the activities of ministries and other central bodies in this direction are the principal tasks of the Ministry in terms of mitigating the consequences of the Chernobyl APS accident. There are subdivisions within the Ministry which control the direction of certain activities toward mitigating the consequences of the catastrophe and in making decisions to be implemented by various branch ministries and institutions, as well as local administrations. For example, the Department of Science and International Relations of the Ministry controls the scale, the nature, and the development of research in the field of Chernobyl-related problems conducted by the Academy of Sciences, universities, and institutes of branch ministries. The Ministry orders and finances these research projects.

3.c. Parliament

In October of 1989, the Supreme Soviet of the Republic of Belarus adopted the "State Program Mitigating the Consequences of the Chernobyl APS Catastrophe for 1990-1995". Since its adoption, all activity concerning protecting the people from radiation factors, production of "clean" food products, decontamination, and agrochemical works has become more complex and systematic. The tasks foreseen in the Republic's program were partially induced in the "State Union-Republican Program of Emergent Measures on Liquidation of After-Effects of the Chernobyl APS Accident for 1990-1992" which was adopted by the USSR Supreme Soviet. It was expected that, after the implementation of this program, the union-republican long-term program on mitigating the consequences of the Chernobyl APS accident for 1993-1995 and until 2000 would be formulated. However, due to the collapse of the Soviet Union, it was not adopted.

In 1990, a session of the Belarus Supreme Soviet defined the Chernobyl problem as a national, nodal, which causes political, social, demographic, and economic tension in the Republic, and thereby declared Belarus a zone of ecological disaster. Making up for lost time, the parliament adopted a number of important acts in the short-term. In February of 1991, the "Social Protection of Citizens Affected by the Chernobyl APS Catastrophe" Law was adopted, as well as instructions for a "Complex Special Program of Prophylaxy of Genetic Consequences Influenced by the Chernobyl APS Catastrophe", and a "Complex Special Program of BSSR 'Defense of Maternity and Childhood in the Conditions of Influence of Consequences of the Chernobyl APS Catastrophe' for 1991-1995". The "Legal Status of Territories Exposed to the Radioactive Pollution as a Result of the Chernobyl APS Catastrophe" Law was adopted in November of 1991.

The Permanent Commission of the Supreme Soviet on the Problems of the Chernobyl APS Catastrophe also controls the activity of executive bodies and local administrations on the mitigation of the accident consequences.

IV. Academy of sciences

After the Chernobyl APS accident, a number of complicated problems arose in the fields of ecology, medicine, agriculture, law, demography, etc. All the Republic's specialists with corresponding profiles were engaged in the solution of them. In the first stage of the liquidating the accident consequences, work was carried out under the direction of a working group of the Council of Ministers headed by A. A. Petrov. After determining the scale of the disaster, a Governmental Commission was formed, headed by V. G. Evtukh, the First Vice-President of the Council of Ministers of the Republic. The Science-Technical Council was created for the scientific provision of works as well as the Operative Group - at the Presidium of the Academy of Sciences.

An assessment of the radiation situation and an elaboration of urgent measures to lower the negative effects of radiation on human beings were the principal tasks during the first stage after the accident. Scientists and specialists from the Academy of Sciences, the Ministry of Health, the Ministry of Higher Education, Gosagroprom and other Belarus institutions took part in solving these questions. The research results enabled an assessment of the general characteristics of the radiation situation in the accident zone and adjacent areas and facilitated the creation of maps of radionuclide pollution in the Republic. The data obtained by scientists and specialists from different institutions became the basis for making decisions on additional resettlement of inhabitants of contaminated districts, construction of new dwellings, and norms of radiation safety for industrial activity in polluted zones.

However, it was obvious that in addition to the urgent first-priority activities, the adoption of long-term scientifically grounded measures were also needed in order to fully liquidate the consequences of the accident. It was impossible to elaborate clear recommendations for solutions to these problems based on past international experience of liquidating the consequences of nuclear accidents. Therefore, in July of 1986, according to a proposal made by directive bodies and scientists of Belarus, a complex program of investigations into the problems of liquidating the consequences of the Chernobyl catastrophe was jointly developed in cooperation with Ukraine and Moldova and approved for 1986-1990. This program induced research and experimental and technological works in four principal directions:

- study of radioactive pollution of ecological systems; genetic, physiological, and biochemical assessment of its possible consequences;
- development of technology and methods of agricultural production in the case of pollution of the environment with radionuclides;
- study of the effects of radiation on functional systems of organisms, occurrence and course of

human diseases, the development of methods of diagnosis and treatment of radiation injuries;
- development of technologies to decrease radiation pollution of the environment and other separate objects, methods and means of radiometric and dosimetric control.

Specialized scientific institutes and structural subdivisions were created in a number of the Republic’s ministries and institutions for the implementation of this program, and corresponding tasks were assigned to them. First of all, created were the Institute of Radiobiology of the Academy of Sciences of Belarus (Minsk), the Research Institute of Radiation Medicine (Minsk), Vitebsk, Gomel and Mogilev filial branches of the Research Institute of Radiation Medicine, the Belarus Research Institute of Agricultural Radiology (Gomel). Practically all of the scientific institutions and centers of higher education possessing corresponding specialists and equipment participated in solving the problems which arose. In particular, involved were the Institute of Nuclear Energy of the Academy of Sciences (the Institute of Radioecological Problems later originated from this institute), the Belarus State University, the Belarus Research Institute of Soil Science and Agrochemistry, the Belarus Research Institute of Haematology and Blood Transfusion, the Institute of Oncology and Medical Radiology, and many others. The majority of scientific groups addressed these problems without receiving salaries.

The coordination of efforts by scientific institutions within the program facilitated the fulfillment of operative tasks in the systematically planned studies of accident consequences, with the goal to elaborate measures for their liquidation. Co-ordination was provided by the Inter-republican Scientific Board consisting of Belarus, Ukrainian and Moldavian sections. The academician E. F. Konoplya became the Co-chairman of the Inter-republican Board and the Chairman of the Belarus section. The program tasks were fulfilled by 18 institutes of the Academy of Sciences and more than 20 scientific and educational centers of the Ministry of Health, Gosagroprom, the Ministry of Higher Education and other organizations in the Republic.

In Belarus, every year plans for research within the program were designed and then approved by the Academy of Sciences and the Commission of Council of Ministers of the Republic. The course and results of the research were discussed in special republican and international seminars, sessions and conferences, and the conclusions and proposals made by scientists were submitted to the Government. Simultaneously, the program of monitoring and forecasting the radiation situation in the Republic was created and approved.

As a result of implementing research projects within these programs, a complex assessment of the radioecological situation in the Republic was made. The forms of radionuclides present in different ecosystems were determined, as well as their basic ways of migration. The first results were obtained in the study of the effect of the present situation on functional systems of organisms and the rate of disease in the population. A number of prophylactic medical activities took place; a number of recommendations about agricultural production on polluted territories and the rational use of nature was elaborated; methods of decontamination and cleaning radionuclides from environmental objects were proposed; a forecast of radioactive pollution dynamics in the Belarus territory for the coming years was made.

The results obtained became the basis for a number of protective measures taken by directive bodies, including: the resettlement of inhabitants of the most polluted areas, the selection of places for construction of new settlements, the confirmation of stricter norms on radionuclide content in food products and potable water, the prohibition or limitation of various kinds of economic activity on affected territories.

The significant negative consequences of the accident on a large territory of the Republic which were revealed in 1986-1989, became the reason for elaborating a state program of liquidation of accident consequences for 1990-1995. This program was approved by the XII Session of the Supreme Soviet of Belarus on October 26, 1989. In the state program there is a special section which addresses the scientific provision of works, which is headed by the Institute of Radiobiology of the Academy of Sciences of Belarus. The Coordinative Council was formed in order to coordinate the research and was approved on December 13, 1989 by the Commission on the Questions of Science-Technical Progress of the Council of Ministers of Belarus. Research within the state program is carried out based upon a complex arrangement of assignments in the following areas:

- medical consequences of the Chernobyl accident and prognosis of the state of population’s health, elaboration of methods of diagnosis, treatment and prophylaxy of diseases of different categories of sufferers (head organization: the Research Institute of Radiation Medicine of the Ministry of Health of Belarus);
- carrying out of agricultural production on contaminated territories, forecasting and working out of protective measures (head organization: the Belarus Research Institute of Soil Science and Agrochemistry of the Ministry of Agriculture and Food of Belarus);

- regularities of changes in the radioecological situation and the effects on the life of organisms in various ecosystems, long-term prognosis of the radioecological situation in the Republic (head organization: the Institute of Radiobiology of the Academy of Sciences of Belarus);
- decontamination, processing, disposal and storage of radioactive wastes and products of decontamination (head organization: the Institute of Radioecological Problems of the Academy of Sciences of Belarus);
- social and economic development of territories affected by the Chernobyl APS catastrophe (head organization: the Institute of Economy of the Academy of Sciences of Belarus);
- problems of social adaptation and social and psychological support of population (head organization: the Institute of Philosophy and Law of the Academy of Sciences of Belarus);
- research and testing of new preparations, compounds and food additives, development of recipes and technologies to produce them (head organization: the Belarus Sanitarian-Hygienical Institute of the Ministry of Health of Belarus);
- design and production of equipment to provide radiometric and dosimetric control (head organization: Belarus State University);
- effects of small irradiation doses (head organization: the Institute of Radiobiology of the Academy of Sciences of Belarus);
- combined effect of ionizing radiation and other injuring factors (head organization: the Research Institute of Radiation Medicine of the Ministry of Health of Belarus);
- rehabilitation of polluted territories (head organization: the Belarus Research Institute of Agricultural Radiology of the Ministry of Agriculture and Food of Belarus);
- provision of information-analysis of scientific issues of the state program (head organization: the Institute of Radiobiology of the Academy of Sciences of Belarus).

The specialized national program approved by the Supreme Soviet of the Republic of Belarus are elements of the state program on liquidation of the consequences of the Chernobyl APS accident. They are as follows:

- prophylaxy of genetic consequences conditioned by the Chernobyl accident (head organization: the Research Institute of Hereditary and Congenital Diseases of the Ministry of Health of Belarus);
- defense of maternity and childhood in areas suffering from the Chernobyl APS accident (head organization: the Belarus Research Institute of Defense of Maternity and Childhood of the Ministry of Health of Belarus).

With the goal to create a radiometric and dosimetric basis in the Republic, instead of issuing a scientific program aimed at creating an equipment basis, the government of Republic adopted an independent republican scientific-technical program on design and production of equipment to provide radiometric and dosimetric control on December 21, 1990.

There are councils of experts within every head organization, who evaluate the projects submitted for inclusion into the state program, provide the expertise for them, draw up annual plans and reports on corresponding branches, and submit them to the Coordinative Council. The Coordinative Council considers the plans and reports of these head organizations, and with the participation of independent experts, prepares reports compiled within the program plans and submits them for confirmation to the Department of Science of the Ministry on Emergencies and Protection of Population from the Consequences of the Chernobyl APS Catastrophe.

The research implemented within the state program allows for an objective assessment of the ecological, medical, economic and social consequences of the accident, in order to propose a number of measures oriented to their mitigation. The financial support of such research significantly enhanced their efficiency. The structure and assignment of scientific matters in the state program are constantly being improved according to the demands of addressing practical tasks.

V. List of scientific organization working on Chernobyl

5.a. Physical processes and radioactivity released during the accident

- *sequences and causes of the accident:*

The study of the course and causes of the catastrophe falls within the scope of the Institute of Nuclear Energy (currently, the Institute of Problems of Energy of the Academy of Sciences of Belarus) and the scientific center “Belrad.”

- *behavior of radioactivity release into the atmosphere:*

The Institute of Radiobiology (V. P. Mironov, Ph. D.) and the Center of Radiation Control and Environmental Monitoring of the Committee on Hydrometeorology of Republic of Belarus study the distribution of radioactivity released into the atmosphere during the accident.

- *dispersion and deposition of radioactivity in the atmosphere:*

The dispersion and migration of radioactivity in the atmosphere and its deposition onto the ground are the subject of studies by the Institute of Radiobiology (V. P. Mironov, Ph. D.), Belarus State University (Professor E. P. Petryaev), and the above-mentioned

Center of Radiation Control by which the monitoring of atmosphere pollution is being conducted.

5.b. Radioactivity contamination and monitoring

- *contamination data in the early stage after the accident:*

The data on exposure doses during the early stage after the accident are kept in the Center of Radiation Control and Environmental Monitoring and in the State Committee on Civil Defense.

The data on soil pollution are kept in the Center of Radiation Control as the Republic's data bank on the cesium, strontium and plutonium radionuclide content in soils throughout Belarus during post-Chernobyl years. The Institute of Soil Science and Agrochemistry and the Institute of Radiobiology are also occupied with this question.

The data on food pollution are gathered at the Ministry of Agriculture and Food, the center "Belrad," and sanitation stations in settlements.

- *recent contamination data:*

The Center of Radiation Control and Environmental Monitoring of the Committee on Hydrometeorology of Republic of Belarus is the center where recent contamination data are kept.

5.c. Dose estimation

The reconstruction of thyroid dose is the subject of research by V. F. Minenko, Ph. D. (Head of the Laboratory of Radiation Situation Assessment and Dosimetry at the Research Institute of Radiation Medicine). The research is headed by Ya. Eh. Kenigsberg, D. M., Deputy Director of the Institute of Radiation Medicine. They are also involved in the reconstruction of external and internal doses at the early stage after the accident, as well as the prediction of radiation doses. The forecast of the dynamics of doses and radiation risk also fall within the scope of studies by the Laboratory of Radiation Monitoring at the Institute of Radiobiology (Head - V. A. Knatko, Ph. D.). The rise of thyroid cancer in children dependent on the absorbed dose is the theme of a study by the group handling thyroid morphology research at the Central Research Laboratory of Minsk Medical Institute (Head - Professor E. D. Cherstvoj), as well as by the group on tumorous thyroid pathology (Head - Professor E. P. Demidchik).

5.d. Medical care for people suffering from the accident

The Ministry of Health of the Republic of Belarus and, more exactly, the Department of Medical Protection from the Consequences of the Chernobyl APS Catastrophe and Emergencies (Head - V. A. Stezhko) directs the medical care for the people suffering from the accident. The Department of Radiation Hygiene (Head - V. V. Grin) and the Section of Radiation Safety Control on the Economical Objects (Head - A. F. Kardash) are also involved. Immediate medical care is provided by district, town, and regional health departments, in addition to hospitals, polyclinics, and other institutions. The clinic and dispensary of radiation medicine of the Ministry of Health of Belarus is the head medical base.

5.e. Epidemiological study

The program of registering liquidators, evacuees, and inhabitants of contaminated areas is conducted by the Belarus State Register of citizens subjected to radiation action as a result of the Chernobyl APS catastrophe (a Decree by the Council of Ministers No. 283 of 5/5/1993 determined its status and functions). The Belarus Center of Medical Technologies (Director Professor A. E. Okeanov) is the responsible executive. The Laboratory of Analysis and Control of Data (Head - S. I. Antipova) is occupied directly with these questions (medicine). Software is provided by the Department of Population Registers Automation (Head - S. M. Polyakov). In addition, the state of health of the population subjected to radiation action is studied by the Laboratory of Epidemiology of Radiation Actions (Head - K. V. Moshchik) at the Research Institute of Radiation Medicine and the Laboratory of Epidemiology and Forecast of the Population's Health of the Belarus Center of Medical Technologies.

VI. Short description of lead organizations

- Institute of Radiobiology, Academy of Sciences of Belarus

a. History and aims of the foundation

The Institute was organized in 1987 upon a decree by the Government to be a head organization in the Republic in solving problems caused by Chernobyl.

b. Structure and number of staff in the organization

10 laboratories, 2 departments, 1 group. 85 scientists.

c. Research activities relating to Chernobyl

Principal scientific activities:

- study of radionuclide behavior in environmental components: soil, water, air, and plants;
- study of the effects of ionizing radiation on the most important organism's systems: endocrine, immune, cardiovascular, sex, etc.;
- forecast of the dynamics of the radioecological situation and doses of external irradiation;
- study of the effects of small irradiation doses;
- research for compounds of natural or artificial origin with radioprotective properties.

- Research Institute of Radiation Medicine, Ministry of Health

a. The Institute was organized in 1987 upon a decree by the Government in order to study the medical consequences of the Chernobyl APS catastrophe and to search for ways to mitigate them.

b. 14 laboratories. 89 scientists. 3 affiliated branches in Gomel, Mogilev and Vitebsk.

c. Principal scientific activities:

- dosimetry, doses prognosis, determination of ration components contributing to the formation of internal doses;
- endocrinologic investigations, primarily, thyroid pathology;
- immunological, cytogenetical, epidemiological investigations;
- study of combined effect of radiation and non-radiation factors;
- study of efficiency of sanitation and treatment in sanatoria and resorts.

- Belarus Center of Medical Technologies, Information, Direction and Economy of Public Health

a. The Center was organized in 1992 upon a decree by the Government in order to analyze the state of health of the population, to forecast the further development of a public health system, to create data banks and registers of the health state of the population, especially of those affected by the Chernobyl APS accident and those involved with the liquidation.

b. 2 laboratories (15 scientists) are occupied with Chernobyl problems.

c. Principal scientific activities:

- epidemiology of malignant neoplasm in the Republic before and after the accident;
- study of the health state of different categories of sufferers based on the State Register of citizens subjected to the effects of radiation as a result of the Chernobyl accident, including liquidators, evacuees, inhabitants of polluted areas, as well as their children.

- Institute of Radioecological Problems, Academy of Sciences of Belarus

a. The Institute was organized in 1991, based on part of the former Institute of Nuclear Energy of the Academy of Sciences of Belarus in order to solve problems connected with decontamination, utilization, and burying of radioactive wastes.

b. 8 laboratories. 48 scientists.

c. Principal scientific activities:

- elaboration of methods and means of decontamination and protection of the environment from pollution with decontamination products and buried radioactive wastes;
- elaboration of methods to protect the population from radiation and protective countermeasures, and an evaluation of their efficiency.

-Research Institute of Hereditary and Congenital Diseases, Ministry of Health

a. The Institute was organized in 1988 based on affiliated branch of the Institute of Medical Genetics of the Academy of Medical Sciences of the USSR, in order to elaborate methods of prophylaxy and diagnosis of hereditary and congenital diseases.

b. 2 laboratories, 1 department and 2 groups (total: 20 scientists) are engaged in solving Chernobyl problems.

c. Principal scientific activities:

- biological indication of radiation injury to human hereditary structures;
- monitoring of human hereditary pathology, medico-genetic consultation;
- prenatal diagnosis and prophylaxy of hereditary and congenital diseases of fetus.

- Institute of Genetics and Cytology, Academy of Sciences of Belarus

a. The Institute was organized in 1965 to develop genetic studies of vegetable, microbial, and animal objects in Belarus. After the Chernobyl catastrophe, it was partially re-oriented to study the effect of radioactive contamination of the environment on genetic structures.

b. 2 laboratories, 3 groups, 1 department (total: 34 scientists) are engaged in solving Chernobyl problems.

c. Principal scientific activities:

- study of mutations on the molecular level by feeding experimental animals with contaminated feeds;
- analysis and prognosis of genetic after-effects of the Chernobyl catastrophe on animals and man;
- genetic observation of children living in contaminated areas;
- study of genetically determined rise of tumors in people living in polluted areas;
- elaboration of radioprotective preparations and sensitive methods of bioindication of environmental pollution.

- Research Institute of Haematology and Blood Transfusion, Ministry of Health

a. The Institute was organized in 1932 as the head republican science-medical organization addressing problems of haematology and blood service. In 1986, the Institute was partially re-oriented to Chernobyl problems.

b. 5 laboratories (25 scientists) are engaged in the solution of problems related to Chernobyl.

c. Principal scientific activities:

- analysis of the reaction of haematopoietic and immunocompetent cells to the action of ionizing radiation, primarily, in people affected by the Chernobyl APS catastrophe;
- study of phenotypical and functional disturbances of immunocompetent cells in liquidators;

- study of the incidence of haematological diseases in Belarus relating to the Chernobyl accident;
- study of clinical characteristics of leukoses, anemia, and haemostasiopathies in adult patients, and the definition of peculiarities in clinical treatment of diseases arising as a result of small irradiation doses.

VII. List of principal scientific conference held on Chernobyl in Belarus

1. Republican Science-Practical Conference on Radiobiology and Radioecology, December 22-23, 1988, Minsk.
2. 1st Science-Practical Conference, December 26-27, 1989, Minsk.
3. Republican Science-Practical Conference on Radiobiology and Radioecology, December 20-21, 1990, Minsk.
4. 2nd Science-Practical Conference "Science-Practical Aspects of Preservation of Health of People Exposed to Radiation Action as a Result of Chernobyl APS Catastrophe", March 12-14, 1991, Minsk.
5. Belarus Republican Science-Practical Conference "Psychological Consequences of Chernobyl APS Accident", June 26, 1991, Minsk.
6. International Symposium (with the participation of an international working group on Chernobyl problems) "Man, Ecology, Symmetry", October 9-11,1991, Minsk.
7. All-Union Conference "Radiobiological Consequences of the Chernobyl APS Accident", October 30 - November 1, 1991, Minsk.
8. 3rd Science-Practical Conference, April 15-17, 1992, Gomel.
9. International Practical Seminar "Agrotechnical Methods of Improvement on Soils Polluted with Radionuclides", September 1992, Minsk.
10. International Symposium "Effect of Radiation on Thyroid", October 27-30, 1992, Minsk.
11. Belarus Republican Science-Production Conference "Principal Directions of Obtaining Ecologically Clean Plant Production", 1992, Gorki.
12. Science-Practical Conference on Problems of Social and Psychological Rehabilitation and Social-Legal Protection of Children and Adolescents Affected by the Chernobyl APS Accident, April 23-24, 1992, Gomel.
13. 2nd Belarus-German Symposium on Problems of Infant Oncohaematology, April 24-27, 1992, Minsk.
14. International Symposium "Consequences of Nuclear Catastrophes: Chernobyl, Hiroshima, Nagasaki", June 29 - July 1, 1992, Minsk.
15. Science-Practical Conference on Problems of Safe Living in the Zone, Wastes Management, Ecological Control, 1992, Gomel.
16. Belarus Republican Science-Practical Conference "Natural and Economical Complexes of Belarus Palesse in Extreme Conditions", May 14-15, 1992, Gomel.
17. Belarus Republican Science-Practical Conference "Psychological Consequences of the Chernobyl APS Accident", June 26, 1992, Minsk.
18. International Symposium "Chernobyl and Health of Children", June 1-5, 1992, Mogilev.
19. International Conference "Science and Medicine for Chernobyl", November 10-13, 1993, Minsk.
20. Conference "Defense of Maternity and Childhood in Conditions of the Chernobyl APS Catastrophe Consequences", January 10-12, 1994, Minsk.
21. 4th Science-Practical Conference "Science-Practical Aspects of Preservation of Health of People Exposed to Radiation Action as a Result of the Chernobyl APS Accident", April 11-13, 1994, Mogilev.
22. 2nd International Congress "World After Chernobyl", April 18-22, 1994, Minsk.
23. Republican Seminar "State and Perspectives of Development of Medico-Genetic Service in Post-Chernobyl Period", June 7-8, 1994, Minsk.
24. Belarus-Japan Symposium "Acute and Late Consequences of Nuclear Catastrophes: Hiroshima-Nagasaki and Chernobyl", October 3-5, 1994, Minsk.
25. International Task-Force Meeting "Ecological Status of Territories Polluted with Radionuclides", April 19-20, 1995, Minsk.
26. Science Conference "Ten Years after the Chernobyl Catastrophe (Scientific Aspects of Problem)", February 28-29, 1996, Minsk.
27. 1st International Conference "Radiological Consequences of Chernobyl Catastrophe", March 18-22, 1996, Minsk.

VIII. List of important publication by Belarussian scientists on Chernobyl

1. Avramenko T. A., Drozdovich V. V., Minenko V. F., Tretiakevich S. S. Radiation, "Dose Catalogue of Inhabitants in Settlements on the Republic of Belarus", Minsk, 1992 (in Russian).
2. Astakhova L.N., Polyanskaya O. N., Drozd V. M. et al., "Functional State of Pituitary-Thyroid System in Children and Adolescents", Zdravookhranenie Belarusi. 1993, No.2, pp.4-7 (in Russian).
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BSSR. Seryya fizika-ehnergetychnykh navuk. 1991, No.4, pp.58-64 (in Russian).
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11. Knatko V. A., Sivakov I. V., “Calculation of Dynamics of Exposure Dose of Cs-134 and Cs-137 Gamma-Radiation with Migration in Soil”, Vestsi ANB. Seryya fizika-matehmatychnykh navuk. 1995, No.2, pp.93-96 (in Russian).
12. Kuznetsov V. A., Kol’nenkov V. P., Shagalova Eh. D. et al., “Plutonium-238, 239, 240 in River Deposits on the Territory of the North-East Trace of the Chernobyl Radioactive Pollution”, Doklady ANB. 1993, Vol.37, No.6, pp.104-107 (in Russian).
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Legislation and Research Activity in Russia about the Radiological Consequences of the Chernobyl Accident

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I INTRODUCTION

One of the principal problems in liquidating the after-effects of the Chernobyl APS accident in the first weeks and months after it occurred was to protect people from external irradiation and internal intake of radioactive products through the consumption of local food stuffs. To solve this problem, evacuation of the population and livestock from a 30-km zone around the APS was carried out in the first days after the catastrophe. In the following period, assessment of the pollution of agricultural products in areas adjacent to the Chernobyl APS became one of the primary tasks, as was a general assessment and forecast of the ecological consequences of the environmental pollution both in natural and agricultural ecosystems.

The approach to solve these problems assumed:

1. Detailed study of the radiation characteristics of surface contamination, i.e. spatial distribution, composition and density of pollution by released radionuclides, dose of external γ-radiation in different landscape-ecological conditions, including surface waters.
2. Study of migration and penetration of the most dangerous (long-lived) radionuclides into the soil, their solubility and potential for root intake in different soil-geographical conditions.
3. Study of the initial aerial pollution of wild and agricultural vegetation. Later, assessment of accumulation coefficients of dangerous radionuclides by the biomass of wild and agricultural plants at the root intake to address the problem of how to use the yield economically.
4. Study of the accumulation of dangerous radionuclides in milk and organs of agricultural animals to solve the problem of animal products' use.
5. Assessment of direct effects and prognosis of long-term (genetic) effects of radioactive contamination on functional parameters of natural ecosystems, animals and human beings.

Many of these research directions had been developed during the study of environmental pollution by radioactive products formed during nuclear weapons tests, as well as accidents at nuclear power installations. However, the simple application of previous radioecological and radiobiological knowledge to the Chernobyl catastrophe could lead and did actually result in a number of significant errors due to the specificity of this case. Among the specific features of the Chernobyl accident, it is necessary to note the following:

1. The complex composition of radionuclides polluting the environment, which changes in a variety of ways depending on the direction and distance from the source.
2. Physico-chemical properties (dispersibility, solubility etc.) of radioactive precipitation, which also change over a wide range.
3. The diversity of natural and meteorological conditions which influence redistribution and migration of radionuclides in ecosystems.
4. The vast territory of radioactive pollution and the sheer number of people living under conditions of chronic ionizing radiation of small doses.

Owing to the above-mentioned circumstances, large-scale and systematic studies of the ecological and radiobiological effects of radioactive contamination in areas adjacent to the Chernobyl APS were started in the first weeks after the accident.

II LEGISLATION AND REGULATION IN THE USSR AND RUSSIA CONCERNING CHERNOBYL

2.a. Legislation and regulation pertaining to radiation dose limit

In April and May of 1986, the Governmental Commission of the Council of Ministers of the USSR and the Ministry of Health of the USSR directed implementation of protective activities and the liquidation of the consequences of the Chernobyl APS catastrophe. The first decision concerning limiting the irradiation dose of the population was to evacuate the population from a zone where the exposure dose rate exceeded 25 mR/h (a level observed approximately at a radial distance of 10 km from the Chernobyl APS). Then a decision was made to lower this limit to 5 mR/h corresponding to a zone with a 30 km radius.

Among other decisions made on the level of ministries and institutions of the USSR, it is necessary to mention the following:

- On May 12, 1986, the National Committee on Radiation Protection of the USSR (NCRP) determined to limit the irradiation dose for the population to 500 mSv/year, and for children under 14, pregnant women and nurses to 100 mSv/year.

- On May 22, 1986, a dose limit of 100 mSv/year was determined for the entire population.
- In 1987, NCRP approved norms of radiation safety (NRS-76/87). These norms gave the Ministry of Health the right to establish dose limits for the population irradiated as a result of the accident. A limit of 30 mSv was established for 1987, with a level of 25 mSv established for 1988 and 1989.

According to decree No. 1452-1 of the Supreme Soviet of the USSR made April 25, 1990, “About the Unique Program for Liquidating the Consequences of the Chernobyl APS Accident and the Situation Related to this Accident” and decree No. 645 of the Council of Ministers of the USSR made June 30, 1990, about this problem, a concept was developed concerning living in the areas affected by the Chernobyl APS accident. The objective of this concept was to formulate principles and criteria to justify the practical measures aimed at maximizing the mitigation of possible negative after-effects of the Chernobyl APS accident relating to human health and compensation of losses.

The basic principles and criteria are as follows:

1. Each person living on the territory polluted with radionuclides or having lived there for at least the established minimum period has a right to compensation for losses in the form of legal privileges, and guaranties of social and medical protection.
2. The irradiation dose resulting from radioactivity due to the Chernobyl APS accident is the principal criterion for making decisions about the necessity of protective measures, their content and scale, and the compensation for losses.
3. Overexposure (above the level of the natural and technogenic background for a given locality) of the average annual effective equivalent dose not higher than 1 mSv (0.1 rem) from the radioactive precipitation as a result of the Chernobyl APS accident is considered acceptable and does not require any intervention.
4. It is mandatory to carry out resettlement of people from the populated areas registered on the official list, by taking into consideration the established intervention levels and socio-economic conditions.
5. Besides radiation protection, the following countermeasures must be taken:

- improved medical service, including special medical observation of groups at increased risk, treatment in sanatoria and sanitation in resorts;
- provision of nutrition at full value including additional microelements, vitamins;
- measures to lower socio-psychological tension;

6. Each person living on the territory polluted with radionuclides has the right to make the decision independently about whether to continue living on a given territory or choosing resettlement to another place, on the basis of the objective information presented to him (her) about the radiation situation, irradiation dose and possible health effects.

Based on the above concept, a law of the USSR, "On Social Protection of Citizens Affected by the Irradiation as a Result of the Chernobyl APS Catastrophe" was written up and approved in May of 1991. This law established the rights of citizens who took part in the liquidation of the catastrophe, those resettled to new places, and those who still live in the given territories.

After the collapse of the USSR, the Russian Federation succeeded to addressing the tasks of coping with the consequences of the Chernobyl catastrophe. At present, there is an elaborated concept of radiation, medical and social protection and rehabilitation of the Russian Federation population who were irradiated due to the accident. It contains a concrete list of recommended measures for radiation protection of people who still live in situations vulnerable to the accident consequences. Those territories where people have a possibility to receive the annual effective dose exceeding 1 mSv are recognized now as being polluted. They are categorized in the following manner:

- zone of obligatory resettlement: areas where soil densities of Caesium-137, Strontium-90 and Plutonium are 1480, 111 and 3.7 kBq/m^2 or higher, respectively.
- zone of limited inhabitancy: areas where the annual dose of the people may exceed 5 mSv (Caesium-137 density from 555 to 1480 kBq/m^2).
- zone with the right to resettlement: areas where the annual dose is higher than 1 mSv (Caesium-137 density from 185 to 555 kBq/m^2).
- zone of living under periodical control: areas where the annual dose should not exceed 1 mSv (Caesium-137 density from 37 to 185 kBq/m^2).

Within this concept, those who have received a dosage of more than 50 mSv of acute and 70 mSv of chronic irradiation are recognized as ‘irradiated’, and as ‘affected’ are those who have developed a disease whose occurrence has been proven to be as a result of irradiation from the accidents. All of the people referred to are being included in the national radiation-epidemiological register.

A program of medical assistance and rehabilitation has been developed for all those ‘irradiated’ and ‘affected’. Special attention is being paid to the ‘affected’ people and groups at increased risk among the ‘irradiated’. In the system of medical protection and rehabilitation of the population, activities are foreseen to raise the resistance to and protect irradiated people from cancer, as well as for limiting the influence of injurious factors of a non-radiation nature. Psychological support and rehabilitation of the population are aimed to limit and prevent the development of stress among people living in the polluted territories. In order to do so, efforts are

Table 1 Temporary acceptable level of Caesium and Strontium contents in food products (TAL-94)

Name of food	Concentration (Bq/kg, l)	
	Caesium-134, 137	Strontium-90
1. Milk and milk products, bread and bread products, grains, flour, sugar, vegetable and animal fats, margarine	370	37
2. All types of infant foods (ready to be consumed)	185	3.7
3. Other food products	600	100

expected to raise the level of people's knowledge about irradiation effects, to provide convincing information about the radiation situation, and to create psychological support services in polluted areas.

In accordance with this concept, certain amendments and changes were introduced into the law of the Russian Federation, "On Social Protection of Citizens Affected by Radiation as a Result of the Chernobyl APS Catastrophe," which was approved by the State Duma of the Russian Federation on July 12, 1995.

2.b. Legislation and regulation concerning radioactivity levels in foods, water and air

Before the Chernobyl APS accident, limits on radionuclide intake with food, water and inhaled air by humans, as well as permissible levels of radioactive contamination of different surfaces, were defined in the "Norms of Radiation Safety" (NRS-76) and the "Principal Sanitarian Rules of Working with Radioactive Substances and Other Ionizing Radiation Sources" (PSR-72/80). Complying with these documents was obligatory for all state and cooperative enterprises, institutions and organizations throughout the USSR. After the Chernobyl APS accident, however, they could not be complied with across a vast territory. Therefore, starting May 3, 1986, the USSR's NCRP established a temporary acceptable level of radioactive iodine of 3.7 kBq/l,kg for drinking water and food products. It was then revised on May 30, 1986, by the USSR Ministry of Health to add standards for Caesium-137 and -134. These standards were calculated to not exceed 50 mSv of the internal dose permissible for the first year after the accident.

Meanwhile, on May 7, 1986, the USSR Ministry of Health approved temporary permissible levels of surface contamination of land, vehicles, clothing, skin, etc., which were then reduced on October 26, 1986.

The temporary acceptable levels of pollution of food products and water with cesium isotopes were introduced in 1988 (TAL-88) in order to limit the internal irradiation dose. TAL-91 were then established in 1991, and TAL-94 (Table 1) in 1994. The acceptable levels of pollution of food products and drinking water decreased gradually, and in the last document the levels correspond to those in the majority of European countries and the USA.

Also, in 1987, the new "Norms of Radiation Safety" (NRS-76/87) and "Principal Sanitarian Rules of Work with Radioactive Substances and Other Ionizing Radiation Sources" (PSR-72/87) were approved. They defined more precisely some standards about the influence of ionizing radiation on human beings. The experience gained in radiation control and prophylactic activities in corresponding institutions and the environment was reflected in them, including the knowledge gained from the liquidation of the Chernobyl after-effects. PSR-72/87 was valid on the USSR territory and, after its collapse, on the territory of Russia until recently. At present, they have been revised, amended and corrected, and in the shortest time are to become obligatory to apply the entire Russian territory.

In addition to the principal laws and regulations mentioned above**,** a number of instructions, recommendations and rules were published. They were oriented to decreasing the dose commitment and radionuclide intake by people living on polluted territories and those working in various spheres of the economy. For example: "Instruction on Protection of Population from Accidents Which Release Radioactive Substances into the Environment," "Instruction on Radiation Safety for the 30-km Zone around the Chernobyl APS," "Provisional Instruction on Forestry Regulations and Radiation Safety under the Condition of Radioactive Pollution," "Recommendations on the Agro-industrial Complex Activities under the Condition of Radioactive Pollution of Territories," "Recommendations to the Population about Behavior on Territories Polluted with Radionuclides" and so on.

III GOVERNMENTAL ORGANIZATION CONCERNING CHERNOBYL

The principal policy of the government was made in two directions:

- to carry out restoration and decontamination activities aimed at decreasing radioactive pollution of the territories;
- to provide social guaranties to the sufferers, first of all, their resettlement away from polluted zones, supply of clean food products and organization of medical service.

Since the time of the accident, the following organizations have been in charge of handling the consequences of the accident in the former USSR and then in the Russian Federation:

- Since May 1986 - Governmental Commission of the Council of Ministers of the USSR,
- Since 1989 - State Commission on Emergencies of the USSR Council of Ministers,
- Since 1990 - State Committee of Russian Federation on the Liquidation of Consequences of the Chernobyl APS Accident.
- Since 1994 - Ministry of Russian Federation on Civil Defense, Emergencies and Liquidation of Consequences of Natural Disasters.

Besides the above, almost all of the union and republican ministries and institutions have been involved in the liquidation of the Chernobyl consequences and the activities to help the affected population right from the first years after the accident. Currently, the ministries below fulfill these functions in the Russian Federation:

- Ministry on Civil Defense, Emergencies and Liquidation of Consequences of Natural Disasters;
- Ministry of Health;
- Ministry of Social Protection;
- Ministry of Agriculture;
- Ministry of Forestry;
- Ministry of Atomic Energy and Industry;
- Ministry of Chemical Industry;

The Ministry of Health and the Ministry on Emergencies are responsible for medical assistance to the people affected by the Chernobyl APS accident. In the period after the accident, the material-technical base of health services was improved significantly in several areas. Necessary scientific methods were developed to examine and treat adults and children. Practical medical activities were undertaken; all of these activities acted to preserve the health and, sometimes, the lives of thousands of people.

IV ACTIVITY OF THE ACADEMY OF SCIENCES

Immediately after the Chernobyl APS catastrophe, scientists of the Academy of Sciences and the Academy of Medical Sciences simultaneously started functional and expeditionary investigation.

In 1986, the "Coordinative Council on Scientific Problems Related to the Ecological Aftermath of New Technologic Systems" was created at the Presidium of the Academy of Sciences of the USSR and headed by Academician ALEKSANDROV A. P. The "All-Union Science-Technical Program on the Liquidation of Chernobyl APS Accident Consequences for 1986-1990" was worked out under the support of this Council. The program consisted of major six foci:

1. Geophysical aspects of radioactive pollution.
2. Agro-industrial aspects of radioactive pollution.
3. Ecological aspects of radioactive pollution.
4. Biomedical aspects of radioactive pollution.
5. Decontamination bases.
6. Methodological and instrumental provision of control for the radiation situation.

Leading scientists of the USSR entered into the Coordinative Council, and scientists from various ministries, institutions and academies were charged with implementation of this program.

The "State Union-Republican Program on the Liquidation of the Consequences of the Chernobyl APS Accident for 1990-1995" was worked out later on, as were legislative acts regulating different aspects of activity in the post-accident period.

However, it must be pointed out that both research and socio-economical programs for 1992-1995 were not implemented. The principal reason for this is that only 16% of the scheduled funds were provided for this period. In this case of unsatisfactory financial provision, only selected activities were implemented, disregarding the integrated approach. Thus, the planned objectives were not met and the indices of people's lives did not improve. This period, moreover, coincided with a general socio-economical crisis in Russia, the rapid decline in industrial and agricultural production, the appearance of unemployment and impoverishment of the population. All of these processes exerted negative effects on the health and birth-rate of the country. The mortality rate increased, and the population in the Russian Federation began to decrease.

It is also necessary to note that the pre-Chernobyl radiobiological science in the USSR was oriented mainly to the study of the effects of high irradiation dose on cellular, tissue and organisms of living things. When the Chernobyl catastrophe took place, experts found themselves in a complicated situation. The classic texts of radiobiology asserted that effects of small-dose irradiation in people should not be that extensive. Therefore, such terms as 'radiophobia', 'acute psychological stress' and so on were often used by the officials to describe the situation.

Other than mentioned above, a very important biological concept of the non-proportionally strong effects of small doses of radiation on biological objects has been developed. It was formulated in the 1960's by Professor BURLAKOVA E. B. (and, independently, in the 1970's by Canadian researcher, PETKO A.). This concept requires to the revision of many commonly accepted theories concerning 'dose-effect' dependence, not only for ionizing radiation but for all physico-chemical influences on living organisms. Therefore, before making optimistic predictions, it is necessary to understand the regularities of the effects of small doses of radiation and carry out extensive investigation into this field.

The results of research concerning the effects of Chernobyl radioactive contamination on human health were reported at the World Health Organization's conference in Geneva in November 1995. They can be formulated as follows:

1. Thyroid cancer incidence among children and adolescents is several tens of times as high as was prognosticated by medical officials. Obviously, the rate of other types of cancer has begun to increase in recent years.
2. (As compared with children in similar socio-economic conditions living on “clean” territories) more than half of the children born on the contaminated territories show a delay in mental development (psycho-linguistic and other forms).
3. Immunological and cytogenetic disturbances has been found in people living on territories polluted with radionuclides and those who worked at the Chernobyl APS after the explosion of the 4th block.
4. Incidence of cataract, cardiovascular diseases, diseases of the gastrointestinal tract, respiratory and urogenous systems are increasing.

V ACTIVITY OF NON-GOVERNMENTAL ORGANIZATION ABOUT CHERNOBYL

The Union “Chernobyl” is the biggest and most ramified public organization uniting the participants in the liquidation of the Chernobyl APS accident. Its brief history follows:

1. August 1988 - an initiative group was created of those who worked in 1986 on the cleaning of the 3rd and 4th blocks of the Chernobyl APS and who were still working in the zone.
2. December 1988 - the first version of the union’s Statutes was written up.
3. April 5-11, 1989 - the first four primary organizations of the future Union were created.
4. April 12, 1989 - the uniting session took place, thus making the date of birth of the Union.
5. May 13, 1989 - 1st Conference of Union “Chernobyl” took place at the Zeleny Mys settlement in the Kiev region. The Statutes were approved, the final name of the Union was approved, the Board was elected, and a declaration to all “liquidators” and to the public organizations and movements of the USSR was composed.
6. April 14- the broadcast from the all-Union radio station “Mayak” of a program about the organization, its aims, and the tasks of the “Chernobyl” union.

In different cities and regions of the USSR, organizations, societies and associations of “Chernobyl” people began to appear independently, and already in October 1989, the All-Union Conference of the “Chernobyl” Union was held in Kiev. 344 persons from 11 republics of the USSR participated in it.

The Union “Chernobyl” took the great tasks upon itself. Firstly, protection of the interests of the Union members, their families, and the people affected by the Chernobyl APS accident. Secondly, discovery of the truth relating to Chernobyl and an objective analysis of what took place and what has continued until the present time. Thirdly, organization of social-patriotic activity based on the experience having worked at Chernobyl.

At present in Russia, besides the Union “Chernobyl”, there are many regional public organizations made up of Chernobyl invalids. Charitable funds (e.g. A. Yaroshinskaya Fund) also do what they can to help the people affected by Chernobyl.

VI LIST OF SCIENTIFIC ORGANIZATIONS WORKING ON CHERNOBYL

6.a. Physical processes and radioactivity release dynamics

The following organizations have been involved in investigating the physical processes and the dynamics of radioactivity release during the course of the Chernobyl accident:

- Russian Scientific Centre “Kurchatovskij Institut”, Moscow
- All-union Scientific Research Institute for Nuclear Power Plant Operation (VNIIAES), Moscow
- Scientific Research and Design Institute for Power Technology, Moscow
- Institute of Problems of Safe Development of Atomic Energy of RAS (Russian Academy of Sciences), Moscow
- Science-Production Corporation “V. G. Khlyupin Radievyj Institut”, St. Petersburg
- L. Ya. Karpov Research Institute of Physical Chemistry of RAS, Moscow
- Ministry of Defense of the USSR

6.b. Radioactivity contamination and radiation monitoring

- Institute of Experimental Meteorology of Science-Production Corporation “Tajfun”, Obninsk
- State Committee of the Russian Federation on Sanitarian-Epidemiological Control, Moscow
- All-Russia Research Institute of Agricultural Radiology and Agroecology, Obninsk
- Radiation Hygiene Research Institute, St. Petersburg
- V. I. Vernadskij Institute of Geochemistry and Analytical Chemistry of RAS, Moscow
- Science-Production Corporation “V. G. Khlyupin Radievyj Institut”, St. Petersburg
- Institute of Problems of Safe Development of Atomic Energy of RAS, Moscow
- Institute of Applied Geophysics, Moscow
- Moscow M. V. Lomonosov State University, Moscow
- A. N. Severtsov Institute of Evolution and Ecology of RAS, Moscow

CBGD: Since 1991, efforts to create a Central Bank of Generalized Data (CBGD) started at the Institute of Problems of Safe Development of Atomic

Energy of RAS. The information for CBGD was supplied by tens of organizations participating in the liquidation of the consequences of the Chernobyl APS accident, including those mentioned above. The total volume of accumulated data is over 1 Gbyte. At present, CBGD consists of more than 20 sub-banks which include the following:

- data bank on the radiation-hygienic situation in settlements (nearly 10 thousand settlements in Russia, up to 150 indices about every settlement);
- data bank on the radioactive pollution of agricultural and forest lands, and agricultural products;
- data bank on the demography (sex-age distribution and sex-age mortality due to different causes from 1982 to the present in the majority of Russian regions);
- data bank on the population's migration in the zones of radioactive contamination;
- data bank on the chemical pollution of atmosphere, surface waters, agricultural lands and agricultural products;
- data bank on socio-psychological status of population;
- data bank on legislative acts, directive documents, and reference information concerning the problem of liquidating the consequences of radiation accidents and catastrophes;
- data bank of electronic maps of Russian territories polluted with radionuclides with a scale of 1:500,000;
- data bank on the registration of persons affected by Chernobyl or other radiation catastrophes.

An integrated computer system has been elaborated for analyzing and processing the CBGD data. It can be used in different analyses and in creating prognostication systems to support decision-making by officials at the time of radiation accidents. 'Model Bank' is a part of the integrated system and consists of:

- models of atmospheric transfer of radioactive admixture;
- models of migration of radionuclides in soil and in water systems;
- models of radionuclides transfer within food-chains;
- models for analysis and processing of spatially distributed radioecological data;
- models for calculating the radiation field and equivalent dose in human organs from sources with various geometrical forms.
- models for calculation of equivalent doses in 25 organs and tissues of persons of different ages in cases of radioactive substances intake through inhaled air, food, or direct injection into the blood;
- models of risk calculation.

The system presupposes a wide choice of sources, radionuclides and materials which are frequently used in calculation. The formation of the data bank, model bank, and development of methods of data processing and analysis, as well as the means to interpret them by computer, enable carrying out systematic analysis and predictions of radiation situation on polluted areas with an acceptable level of precision and validity. There is no analog of this set of models in terms of the scale and computer technology.

6.c. Dose estimation

Thyroid dose: The Medical Radiological Scientific Centre (MRSC, Obninsk) of RAMS (Russian Academy of Medical Sciences) and the Radiation Hygiene Research Institute (St. Petersburg) have been working from the first weeks after the accident to reconstruct thyroid doses received by the population of Russia as a result of the Chernobyl APS accident. In the first weeks after the accident, the personnel of these institutions measured the Iodine-131 content in the thyroid of approximately 31,000 persons. The results of these direct measurements were used to develop a dose reconstruction model which allowed the carrying out of a retrospective assessment of individual and average thyroid doses in settlements.

External dose: The State Scientific Centre of the Russian Federation - the Institute of Biophysics, Moscow, has been involved in reconstructing the dose of external β- and γ-irradiation received by those who worked in the zone of the Chernobyl accident. The lack of individual dosemeters in the months just after the accident and their virtual absence among the military servicemen and clean-up workers made such studies necessary. In order to improve the verifiability of the available information about γ-irradiation doses, all 'liquidators' were divided into 10 cohorts with different quantities: Chernobyl APS personnel, 'Sarcophagus' builders, military liquidators and so on. The distribution of individual doses of γ-irradiation was determined for all cohorts, as well as the statistical parameters including the average and maximum values for each cohort. Doses of β-irradiation of skin and crystalline lens received in the first months after the accident were assessed using the β/γ ratio, and, starting in July 1986, they were measured in a sample of the liquidators using the multilayer dosemeters developed at the Institute of Biophysics. The Medical Radiological Scientific Centre (Obninsk) is concerned with a retrospective assessment of individual accumulated doses among the population of the central part of Russia after the Chernobyl APS accident using the 'EPR' method (spectrometry of dental enamel). Dental clinics collected extracted decayed teeth. More than 2,000 samples of individual accumulated doses have been measured until now.

Internal dose: To reconstruct the internal irradiation dose, special methods were developed at the Institute of Biophysics of the Ministry of Health and the RSC "Kurchatovskij Institut." These methods are based on the results of measurements of Chernobyl radionuclide content in organs and tissues of those who took part in the liquidation of the accident consequences. The Radiation Hygiene Research Institute (St. Petersburg, filial branch - Novozybkov) carried out individual surveys of the cesium radionuclides content in the organ of more than 90,000 people living on territories having a density of Caesium-137 pollution over 550 kBq/m^2. For the purpose of effectively using the information obtained, a data bank to reconstruct individual irradiation doses is being developed at the institute. It includes primary data of the radiometric surveys of the population, the data on the radiation situation and social factors determining irradiation conditions, as well as software for verifying data and processing information.

In addition to the above, efforts to reconstruct the equivalent irradiation dose are being held in the Laboratory of Radiation Genetics of the N. I. Vavilov Institute of General Genetics, Moscow, by means of the FISH method - fluorescence analysis of chromosomes after in-situ hybridization of DNA samples with specific reagents for certain chromosomes. It is noteworthy that the dose defined by this method does not always coincide with the official dosimetric data.

Institute of Problems of Safe Development of Atomic Energy of RAS are occupied with the long-term prospective assessment of dose.

6.d. Epidemiological study

In 1986, immediately after the Chernobyl APS accident, the USSR Ministry of Health approved a large-scaled program creating the All-Union Distributed Register of irradiated persons. All republics of the former Soviet Union were involved in the creation of this Register as were a significant number of scientific and other institutions.

Presently, the National Radiation-Epidemiological Register (NRER) exists in Russia. The Ministry on Emergencies of Russia is the general sponsor of the work carried out within the Register. The head organization is the Medical Radiological Scientific Centre of RAMS which collects primary medical and dosimetric data through 24 regional centers.

The Register includes three subsystems of principal medical-dosimetric information:

1. Registration list of the people affected by irradiation divided according to special dosimetric categories (Southern Urals, Altai, Chernobyl and other regions),
2. All-Russia State Medical-Dosimetric Register (RSMDR, so-called Chernobyl Register, created in 1986).
3. Registry of expert councils.

Presently, the creation of the Chernobyl register in Russia is practically over. At the end of 1994, the data base of RSMDR contained information on 370,120 persons including 159,027 liquidators (43.0%), 8,091 evacuees (2.2%), 185,912 inhabitants of Russian contaminated territories (50.2%), 16,226 children of liquidators of 1986-1987 (4.4%), 864 resettled people (0.2%). In 1993, there were registered 8,006 invalids among the liquidators (2.2% - 1st class, 58.6% - 2nd class, 32.9% - 3rd class). Incidentally, malignant neoplasms constitute 3.61% within the structure of disablement, while diseases of the nervous system and sensory organs - 26.39%, mental disorders - 15.12%.

Therefore, one of the most real and complicated problems in determining the socio-medical after-effects of the Chernobyl catastrophe is to conduct a complex (integral) evaluation of the damage to liquidators' health, including both direct radiation effects and other factors relating to participation in the liquidating work of Chernobyl.

6.e. Other scientific organizations related to Chernobyl

Besides the above-mentioned, the following Russian institutes have also played a role in solving various problems related to the Chernobyl APS accident:

- Hematological Scientific Centre of RAMS.
- Endocrine Scientific Centre of RAMS.
- Medico-Genetic Scientific Centre of RAMS.
- Oncological Scientific Centre of RAMS.
- Moscow P. A. Gertsen Research Oncological Institute.
- Research Institute of Neurology of RAMS.
- V. P. Serbskij State Scientific Centre of Social and Juridical Psychiatry.
- Institute of Psychology of RAS.
- Moscow Research Institute of Psychiatry.
- Department of Psychology of Moscow State University.
- All-Russia Centre of Ecological Medicine.
- Research Institute of Experimental Veterinary.
- Republican Science-Production Veterinary Radiological Laboratory
- Institute of Biology of Komi Scientific Centre of Ural Section of RAS.
- All-Russia Research Institute of Chemical Production of Forestry.
- State Research Institute of Lake and River Fishery.
- Institute of Ecology of the International Engineering Academy.
- Institute of Chemical Physics of RAS.
- Science-Production Corporation "Radon".
- State Scientific Centre VNII NM of Academician A. A. Bochvar.
- Kaluga Institute of Sociology.
- Institute of Economics of RAS.
- Institute of Physical Chemistry of RAS.
- Institute of Parasitology of RAS.
- Laboratory of Forest Science of RAS.
- Institute of Epidemiology of the Ministry of Health.

This list is far from complete.

VII DESCRIPTION OF SOME LEADING ORGANIZATIONS

a) Medical Radiological Scientific Centre (MRSC) of RAMS was established based on the Research Institute of Medical Radiology created in 1962 in Obninsk. An academician, TSYB A. F., the chairman of Russia Scientific Commission on Radiation Protection, is the director of MRSC.

MRSC is a research and medical institution concerned with fundamental and clinical radiobiology, experimental radiology, radiopharmaceutics, radiation diagnostics, radiation epidemiology, and radiooncology.

MRSC consists of 10 departments uniting 32 laboratories and sections as well as 11 independent scientific units. The Center's clinic has 400 beds.

The Center's staff numbers over 1900 including 350 scientists (25 professors, 51 Drs. and 174 candidates of Dr.).

From the first days after the Chernobyl APS catastrophe in 1986, scientists and specialists of MRSC have been engaged actively in efforts concerning the estimation of possible medical consequences of the accident and the elaboration of measures to mitigate their influence on human health. At present, MRSC conducts studies of the biological effects of small doses of radiation, reconstruction of irradiation doses using cytogenetic methods and EPR-spectrometry, epidemiological investigations of the Russian population. Regular investigations are carried out in Kaluga, Bryansk and other regions. As described before, the Chernobyl Registry (RSMDR) is maintained by MRSC.

In addressing the Chernobyl-related scientific and medical problems, MRSC collaborates fruitfully with WHO, IAEA, Commission of European Community, scientists from Japan, Germany, USA, Great Britain, Finland, France and other countries.

b) Russian Scientific Center "Kurchatovskij Institut" was organized in November of 1991 based on the Kurchatov Institute of Atomic Energy. The former Kurchatov Institute was established during World War II for special military purposes. After quick success in achieving its first task, the Kurchatov Institute began to work in a wide range of scientific fields not only for military, but for peaceful, practical and fundamental purposes. The scope of the Institute gradually widened to where it has contained practically every field of the natural sciences.

At present, the main activities of the Institute are related to the development of safe and clean nuclear energy (power reactor and fuel cycle), control of thermo-fusion and plasma processes, and research for nuclear physics of low and medium energy, solid physics and superconductivity.

The institute employs 8,500 staff in total: with the number of scientific staff at 3,048, technicians -2,562, workers - 2,198 and other specialists - 692. There are 13 Academicians of RAS, and 900 Drs. and Cds. of Dr. Academician VELIKHOV E.P. is the director of the Institute.

c) Institute of Biophysics was established in 1946 to investigate the effects of ionizing radiation on living organisms and the methods to ensure radiation safety of persons working in the nuclear industry. It belonged at first to the Academy of Medical Sciences of the USSR and then was moved under the Ministry of Health of the USSR. Since 1995, it has been called the State Scientific Center of Russian Federation - Institute of Biophysics.

The principal activities of the Institute are research in the fields of radiobiology in animals and man, medical cures for radiation syndrome and protection of individuals from various sources of radiation. Standards for radiation safety in the USSR have been developed based on the results of this research. Radiation dosemeters, various instruments and medicines have also been invented to protect the people from radiation.

There are 5 Academicians and one associate Academician in the Institute. There are now 64 Drs. and 215 Cds. of Dr. Since 1968, Academician IL'IN L.A. has been the director of the Institute

VIII INTERNATIONAL COOPERATION RELATED TO CHERNOBYL

8.a. Cooperation within the framework of the 4-side agreement among CEC, Russia, Ukraine and the Republic of Belarus

The long-term and structural help began after concluding an agreement on June 23, 1992, between the Commission of European Community, the Republic of Belarus, Russia and Ukraine on overcoming the consequences of the Chernobyl catastrophe. This agreement permitted the involvement of the leading scientific institutions in the fields of radioecology and radiation medicine of the different EC countries into direct cooperation with those institutes of the former USSR which since the first stage in 1986 had worked actively on the accident liquidation.

The first step within the framework of this CEC-CIS agreement was the organization of 7 experimental and research projects in 1992. In 1994, the number of projects was increased to 16. Presently, specialists of 30 Russia institutes participate in them. The EC partners are represented by nearly all leading institutes of CEC countries.

Implementation of these projects is not humanitarian aid, but rather presupposes the equivalent participation of the 4 sides. From the side of CEC, financial support is given according to items of the agreement: equipment, exchange of scientists and local support. Thus, from 1992 to 1995, within the framework of agreement the CEC side provided nearly 2 million ECU. This is quite a significant contribution to support the intellectual part of the program - to provide help to Russian scientists. It was a considerable help in purchasing up-to-date scientific equipment. The sum used to procure equipment for the years of the collaboration reached more than 0.5 million US dollars.

In 1993, the Coordinative Council decided to create national secretariats in each participating republic in order to support cooperation and to solve practical problems. It was worthy to note that high-ranking officials of Ministries on Emergencies of Russia, Belarus, of Minchernobyl of Ukraine and the XII Directorate of EC entered into the Coordinative Council. In 1994, the structure of project coordination was perfected, and the Directive Group was created. The mission of the Directive Group was to guarantee the implementation of projects according to the policy of the Coordinative Council, as well as to prepare reports on project implementation for the Coordinative Council.

Russians had close contacts not only with the representatives of western laboratories, but also with Ukrainian and Belarussian scientists. The experience gained by this collaboration is very important to establish partnerships on all levels of executive power across the CIS.

The Minsk Conference about this work (March 18-22, 1996) may serve as a good example of successful cooperation. The complex approach of international groups to solving the task of how to overcome the greatest nuclear accident of the XX century is reflected in its proceedings.

8.b. Cooperation with the Commission of European Community within the framework of TASIS program

Cooperation between the Ministry on Emergencies of the Russian Federation and CEC within the framework of the TASIS program has been less successful. This is due to the fact that there is not a capable infrastructure in Russia to permit the planning and implementation of the project, and that Russian specialists, mainly from the affected regions, are not closely involved with the work.

In 1995, within the framework of the TASIS program, it was planned to start a project costing about 400,000 ECU to train medical personnel in thyroid cancer therapy.

This program is expected in total to complete 3-4 projects concerning Chernobyl.

8.c. Cooperation with the International Union of Radioecologists

At the end of 1995, a protocol of agreement was signed between the Ministry on Emergencies of Russian Federation and the International Union of Radioecologists about a project of Program of Independent International Expertise called the “Assessment of the Actual State and Ecological Safety of the Alienation Zone and Influence to the Adjacent Zone.”

This project (costing 900,000 ECU) is being carried out by the initiative of Ukrainian Minchernobyl with the participation of the Ministry on Emergencies of Belarus and that of Russia.

The Ministry on Emergencies supports the cooperation of Ukrainian and Belarussian scientists and will assist with the Program.

8.d. Cooperation with UNESCO

The program of cooperation between the USSR and UNESCO surrounding Chernobyl problems was established in June of 1990.

According to the “UNESCO-Chernobyl” Program, 235,000 US dollars were provided for purchase of equipment, reconstruction of buildings, and training of specialists-psychologists for three centers of socio-psychological rehabilitation being created in Uzlovaya (Tula region), Nikolskaya Sloboda (Bryansk region) and Bolkhov (Orel region).

Additionally, UNESCO gave 12,000 US dollars for equipment to be used of the childhood sport schools in Novozybkov, the Bryansk region.

In its first stage, the “UNESCO-Chernobyl” Program foresaw implementation of 70 projects on the territories of Russia, Ukraine and Belarus concerning the liquidation of the Chernobyl APS accident consequences. Taking into consideration certain priorities, 30 projects were selected for realization including 9 on the Russian territory. In order to oversee their implementation, the Coordinative Council was created consisting of representatives of Belarus, Russia, Ukraine and UNESCO. The projects listed below are being carried out successfully:

- Project No. 1 “Language Support” has been carried out from 1992 until the present.
- Project No. 18 “Associated Schools”; within its framework the spread of knowledge is expected among pupils about prophylactic measures in case they stay in the areas affected by the Chernobyl APS accident.
- Project No. 32-33 “Creation of Zones of Socio-Economical Development”. Such zones will be created in Gagarin, the Smolensk region.
- Project No. 42-45 “Culture” has been in place since 1993. The exchange of art exhibitions, musicians has been taking place. The International Seminar “Children of Chernobyl” was held in France in 1994.
- Project No. 79 “Sport Equipment” was conducted in Novozybkov, the Bryansk region.

8.e. Cooperation with the World Health Organization (WHO)

From 1991 to 1994, 6 projects of WHO's program were carried out in Russia: "Medical Aspects of the Chernobyl Accident" IPHECA, "Thyroid", "Hematology", "Epidemiological Register", "Sustaining Activity (Biological and Physiological Dosimetry)" and "Pre-Natal Injury of Brain". The Bryansk and Kaluga regions of Russia, which are the most polluted with radionuclides, were covered by these projects.

The IPHECA (International Program on the Health Effects of the Chernobyl Accident) program's budget for three affected countries constituted 20 million US dollars received by WHO mainly from the government of Japan. Russia received unique diagnostic and dosimetric equipment through this program, as well as hardware costing a total of nearly 6.5 million US dollars. The use and operation of the equipment purchased are under the supervision of WHO.

51 Russian specialists were trained in foreign centers which accounts for part of the IPHECA program's budget. 16 Russian medical specialists visited Japan (Hiroshima and Nagasaki) in 1992-1994 at WHO's expense to participate in a one-month training course on medical equipment.

The IPHECA program is oriented to diagnosis of diseases and analysis of their possible relationship with irradiation factors. Regretfully, medical assistance to the people who revealed pathology is not included within the framework of this program.

In 1994, the budget of the IPHECA program was exhausted. The results of the implemented studies were generalized in a report "Medico-Radiological Research in Prior Directions" published by WHO at the end of 1995. The pilot project "Thyroid" has become a permanent project. It is also planned to continue research on the "Dosimetry" project. A new project "Liquidator" has also been formulated and approved.

8.f. Cooperation within the Russian-German Dosimetry Program

In 1991-1993, the Russian-German Dosimetry Program was carried out successfully to solve the problem of how to define radiation burden on the population and environment of the territories of the Russian Federation affected as a result of the Chernobyl catastrophe. The German side gave to Russia 4 movable research laboratories equipped with whole body counters, devices to measure radioactivity of environmental samples, and two camping-vans. The total cost of the equipment was 1.25 million German marks. Nearly 200,000 people living on polluted areas of Russia were observed as a result of this joint project.

8.g. Cooperation with the USA

According to a treaty between the government of the Russian Federation and the government of United States of America, an agreement was concluded about collaboration in the field of studying radiation effects in order to minimize the influences of radiation pollution on human health and the environment. The planned budget of this program is 1 million US dollars. The projects are planned to look at the radiation consequences of the activity of the production corporation "Mayak" in the South Ural. The cooperation plans in the future to include projects related to the consequences of the Chernobyl APS accident and nuclear weapons tests at the Semipalatinsk testing ground.

8.h. Cooperation with France

The French public organization "Rotary Club" supplied, as humanitarian aid, an immuno-pharmic laboratory costing 162,000 francs to the All-Russia Centre of Radioecological Medicine (St. Petersburg), and trained service personnel. Besides this, the organization provided technical maintenance for two years.

On June 23, 1993, according to a commission of the Russian Government, an agreement was concluded with the Medical Committee on Nuclear Safety of the French Republic about a cooperation in the field of studying the consequences of radiation accidents and exchanging knowledge of how to control post-accident situations. At present, works on implementing this agreement is being continued.

8.i. Cooperation with Japan

Cooperation with Japan at an official level started in 1990 based on an agreement between the Japanese government and the USSR. Within the framework of this cooperation, Japanese scientists of the Radiation Effect Research Foundation (RERF), National Institute of Radiological Sciences (NIRS), University of Hiroshima, University of Nagasaki and others have been involved. The experience in Japan of overcoming the after-effects of the atomic bombing of Hiroshima-Nagasaki provided valuable information to the USSR, later the CIS, scientists to cope with the consequences of the Chernobyl catastrophe. Other than the official level, the Sasakawa Memorial Health Foundation launched the "Chernobyl Sasakawa Project" in 1991 to provide medical services financed at 5 billion yen over five years. They created 5 clinical centers and have examined more than 130,000 children around the contaminated territories in Russia, Belarus and Ukraine. There are also many other NGOs in Japan carrying out humanitarian activity to help the sufferers of the Chernobyl catastrophe.

IX LIST OF IMPORTANT PUBLICATIONS BY RUSSIAN SCIENTISTS ON CHERNOBYL

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4. "Problems of Ecological Monitoring", Scientific-practical Conference, Bryansk, 1991 (in Russian).
5. KRISHEVA I.I. ed., "Radioecological Consequences of the Chernobyl Accident", USSR Nuclear Society, 1991 (in Russian).
6. "Radioecological, Medical and Social-Economical Consequences of the Chernobyl Accident: Rehabilitation of Territories and Inhabitants", All-Russian Conference, 1995 (in Russian).
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Legislation in Ukraine about the Radiological Consequences of the Chernobyl Accident

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1. Principal laws aimed at liquidating the consequences of the Chernobyl accident

1.1. Basic concept

The description of the Ukrainian system of laws concerning the problem of the Chernobyl catastrophe should be started from a document of general character, *"Concept of population residence on the territories of Ukrainian SSR with increased levels of radioactive contamination as a result of the Chernobyl accident."* This document, small in volume, was adopted by the Supreme Soviet of Ukrainian SSR on February 27, 1991. It was planned that this Concept would provide decrease of negative influences of the Chernobyl accident on public health. Implementation of the principles of the Concept should be based on the following two Ukrainian laws; *"On the legal status of the territory subjected to radioactive contamination as a result of the Chernobyl catastrophe"* and *"On the status and social protection of the citizens who suffered as a result of the Chernobyl catastrophe."*

The main principle of the Concept is as follows: for the critical group of population - children born in 1986 - the effective exposure dose due to the Chernobyl accident should not exceed 1 mSv (0.1 rem) per year and 70 mSv (7 rem) for the life period in any specific environment.

The Concept states that "the situation on the contaminated territories demonstrates low effectiveness of countermeasures aimed at eliminating harmful effects of radiation on the health of people" , and, therefore, "evacuation of people from these territories is of particular importance". In the Concept, the soil density of radioactive contamination (deposition) is considered to be a temporary (until individual effective dose is identified) criterion to make decision on resettlement. As it is impossible to resettle a great number of people simultaneously, the Concept presumes as follows: "a principle of differentiated step-by-step resettlement:

- I stage - obligatory resettlement - is practiced on the territories with cesium deposition above 15 Ci/km^2 or above 3 Ci/km^2 with strontium deposition, or 0.1 Ci/km^2 with plutonium, where residence of people in excising conditions can cause additional effective exposure dose exceeding 5 mSv (0.5 rem) per year, which is dangerous for health.
- II stage - guaranteed voluntary resettlement - is practiced on the territories with cesium deposition from 5 to 15 Ci/km^2, or with strontium from 0.15 to 3 Ci/km^2, or with plutonium from 0.01 to 0.1 Ci/km^2, where residence of population in existing conditions can cause additional effective exposure dose exceeding 1 mSv (0.1 rem) per year, which is dangerous for health".

On these territories it is necessary to apply the system of countermeasures to protect population from radiation (which was considered non-efficient in the first part of the Concept, O.N.). Also, some additional criteria are established there to make decisions on resettlement. These criteria relate to the possibility of growing radiologically "clean" agricultural products.

A very important aspect of the Concept is the statement that "after the Chernobyl accident the conditions for the combined effect of radioactive exposure and factors of non-radioactive origin (synergism) were formed. This greatly increases negative influences of low radiation doses on the population health status, especially that of children. In this situation the extent of synergism is an additional criteria for making decision on introducing any counter-radiation measures."

On the territories with contamination density of cesium isotope below 5 Ci/km^2, or strontium below 0.15 Ci/km^2, or plutonium to 0.01 Ci/km^2, residence is allowed only with enhanced control and on a condition that the additional effective dose from the Chernobyl accident does not exceed 1 mSv (0.1 rem) per year. If this condition is not observed, the population should be given the possibility to resettle to radioecologically "clean" areas.

On the whole, the Concept lacks consistent logic and is even of contradictory nature. At first, it states low effectiveness of protective measures (though it is not clear what specific measures are meant) on the territories with higher levels of contamination. This provides a basis for psychological orientation toward resettlement. Then, in the latter part, the necessity of countermeasures is proposed on the territories with lower contamination levels, although specialists know very well that countermeasures are more effective on the territories with higher contamination levels, i.e. implementation of ineffective measures is proposed.

A similar problem is with synergism. According to the Concept, the people are totally resettled from the areas with higher contamination levels. Consequently, synergism should be eliminated on the territories with lower contamination levels. It is recommended to take measures to lower exposure doses (which was considered to be ineffective), while nothing is said about elimination of non-radiation origin factors which cause synergism, and about improvement of general ecological conditions of life.

1.2. Basic laws aimed at liquidating the accident consequences

The Ukrainian Law, *"On the legal status of the territory subjected to radioactive contamination as a result of the Chernobyl catastrophe"* was adopted by the Supreme Soviet of Ukrainian SSR on the February 27, 1991, and is effective since July 1, 1991. Changes and additions have been introduced by laws of Ukraine (by Verkhovna Rada, i.e. Ukrainian parliament) of 17.12.91, 01.07.92, 28.04.95, 22.12.95, 17.12.96, 04.04.97; by a decree of the Cabinet of Ministers of Ukraine of 26.12.92

This Law is aimed at regulating "problems of territories classification by zones in accordance to the levels of contamination; the regime of territories utilization and security; conditions of living and work of the population; production, research and other types of activities in these zones".

This Law consists of 6 chapters:

I. General
II. Legal status of exclusion zone and zone of obligatory resettlement
III. Legal status of guaranteed voluntary resettlement zone
IV. Legal status of the zone of enhanced radioecological control
V. Control of the legal status in the zones subjected to radioactive contamination after the Chernobyl catastrophe
VI. Liability for the violation of the legal status in the zones subjected to radioactive contamination after the Chernobyl catastrophe

Article 1 of the Law gives the definition of the territories subjected to radioactive contamination as a result of the Chernobyl catastrophe - these are the territories where "the persistent contamination of the environment with radioactive substances exceeding the level before the accident...can cause population irradiation above 1mSv/year...". On these territories special measures should be introduced in order to provide radiation protection and normal life activity of the population.

Article 2 defines the categories of the zones of contaminated territories. Following Table 1 presents the summary of criteria for identification of zones of radioactive contamination as a result of the Chernobyl catastrophe. As it can be easily seen, the zone of enhanced radioecological control (monitoring), defined as Zone-4 in Table 1, should not be related to the territories subjected to radioactive contamination as a result of the Chernobyl catastrophe (see Article 1), but it is.

The criteria of zones identification are set by the National Commission of Radiation Protection of Ukrainian Population (NCRPU). The zone borders are identified by the Cabinet of Ministers of Ukraine proceeding from the expert conclusions of NCRPU, National Academy of Sciences of Ukraine (NASU), Ministry of Health, Ministry of Chernobyl Affairs, Ministry of Agriculture, Ministry of Ecological Safety, State Hydrometeorological Committee, and on the representation of the Regional deputy councils. According to the additions to the Law, adopted by Verkhovna Rada (Ukrainian parliament) in 1996, no changes could be done to the zone borders without approval by Verkhovna Rada.

Article 7 of the Law in its initial edition provided the release from taxation for enterprises, organizations, collective and state farms, located in the zones of voluntary guaranteed resettlement and enhanced radioecological control, except payments to the local budgets. At the end of 1992 the release from profits tax was canceled, and from January 1996 the release from taxes, customs and excises on imported excisable goods was canceled.

I cite the next article, as it is of special interest for

Table 1. Criteria for identifying the zones of radioactive contamination

No	Zones	Deposition, Ci/km^2			Calculated dose, mSv·y^{-1}
		^{137}Cs	^{90}Sr	Pu	
1	Exclusion	n.d.	n.d.	n.d.	n.d.
2	Obligatory resettlement	>15	>3	>0.1	can exceed 5
3	Guaranteed voluntary resettlement	5-15	0.15-3	0.01-0.1	can exceed 1
4	Enhanced radioecological control (monitoring)	1-5	0.02 - 0.15	0.005-0.01	exceeds 0.5

n.d.: not determined

exclusion zone - the territory from which the people were evacuated in 1986 everybody involved in scientific research concerning Chernobyl:

"*Article 11. Property on the results of scientific research, connected with Chernobyl catastrophe.* All scientific information and results of research, obtained in the zones of radioactive contamination, is the property of Ukraine, and can be used only on the permission of the Cabinet of Ministers of Ukraine"

The Law prescribes limitations of types of economic activities in the contaminated zones, aiming at decreasing radiological and other toxic effects on the people living and working there, as well as at preventing radionuclides transport outside the borders of the zones.

The article on the measures to reduce disease risk is very important from the point of view of population protection. In accordance to this article, the state has to guarantee:

- annual medical check of the population and early prophylactic of diseases;
- supply of the population with necessary amount of medicines, potable water, clean foodstuffs;
- provision of gas supply for the settlements, construction of roads with concrete cover, etc.

Article 21 of the Law identifies responsibilities among the Ministries and Departments concerning radiation monitoring and provides the notion about monitoring structure and location of the data. The following Table 2 summarizes the contents of Article 21.

The law of Ukraine, *"On the status and social protection of the citizens who suffered as a result of the Chernobyl catastrophe"* was adopted by the Supreme Council of Ukraine on February 28, 1991 and is effective since July 1 1991. Changes and additions were introduced by laws of Ukraine (by Verkhovna Rada) of 19.12.91, 01.07.92, 05.05.93, 17.06.93, 06.04.95, 22.12.95, 22.03.96, 06.06.96, 11.12.96, 27.06.97; and decrees of the Cabinet of Ministers of Ukraine of 26.12.92, 26.03.93 and 30.04.93.

"The Law is aimed at protection of the citizens who suffered as a result of the Chernobyl catastrophe, and at solving the problems of medical and social character, which arose as a result of radioactive contamination of the territories" (Article 1).

The Law consists of the following 10 Chapters

I. General
II. Status of persons who suffered as a result of the Chernobyl catastrophe
III. Unified system of registration and medical care for the persons who suffered as a result of the Chernobyl catastrophe
IV. Social protection of the citizens affected by the Chernobyl catastrophe, general compensations and benefits
V. Protection of the children who suffered as a result of the Chernobyl catastrophe
VI. Protection of the population affected by the Chernobyl catastrophe
VII. Peculiarities of labor regulation for the citizens who work on the territories with radioactive contamination.
VIII. Pensions and compensations for the persons related to categories 1, 2, 3. 4
IX. Public associations of the persons who suffered as a result of the Chernobyl catastrophe
X. Final statement

Article 2 provides the definition of the zones of radioactive contamination (in fact, it is the same as

Table 2. Responsibilities among the Ministries and Departments concerning radiation monitoring.

Type of activity and control	Responsible Ministries
Prognostic estimates of the total human irradiation dose and control of the radiation safety standards	-Ministry of Health
General assessment of radiological situation on the territories of the zones, radioecological monitoring, methodical supervision and coordination of works on identifying the radiological situation	-Ministry of Chernobyl Affairs
Control of radioactive contamination levels of:	
-farmlands	-Ministry of Food and Agriculture
-water resources	-State Water Resources Committee
-subsurface waters and minerals	-State Geology Committee
-atmosphere on the territory of contaminated settlements	-State Hydrometeorological Committee
-agricultural products and foodstuffs	-Ministry of Food and Agriculture
-vehicles and their parts	-Ministries and committees on transportation means and Ministry of Internal Affairs -State Sanitary Control
-Household belongings, tools and construction materials during the transportation outside contaminated areas during evacuation	-Civil Defense
domestic animals during the evacuation	-State Veterinary Control
Control of reliability and objectivity of the data of radiation control services	-State Sanitary Control
Metrology control of radiation control services	-State Committee of Standard
Radiation control of the products	-enterprises, organizations-manufacturers

Article 2 of the previous law), and in Article 3 it is stated that "the condition of living and working without limitations, considering radiation factor, is additional irradiation dose which does not exceed 1 mSv per year". Thus, the contradiction between Articles 1 and Article 2 of the previous law can be found also in this Law. In these Laws it is defined first that the contaminated territory is the area where additional irradiation due to the accident can be over 1 mSv per year, and then, when the contaminated zones are identified, the territories are included where this additional irradiation dose is less than 1 mSv, e.g. from 0.5 mSv and more.

Further, the Law sets limitations for entering in the radioactively contaminated territories for permanent residence, and states necessary and sufficient conditions for resettlement of the people. In particular, the right for self-resettlement (before the conditions for resettlement are ready) is given to the people whose individual effective dose exceeds 70 mSv for life period, in reality, only to those who received this dose by the present time because there is no method of dose prognosis confirmed by competent authorities. A very important, but also a very disputable statement is that "the population in the zone of obligatory resettlement is to be resettled without fail."

The Law defines that the values of acceptable levels of radionuclides content in foodstuffs and agricultural products are approved and putted into practice by the Health Ministry of Ukraine on approval of the National Commission on Radiological Protection of Ukraine.

The Cabinet of Ministers of Ukraine is responsible for the reliability, completeness and timeliness of the information on radioactive contamination levels of the environment and foodstuffs, as well as for the requirements and conditions of radiation safety.

According to the Law, the people who suffered from the Chernobyl catastrophe include those who participated in the liquidation of its consequences and residents, including children, who were affected by irradiation as a result of the Chernobyl catastrophe. The Law defines 4 categories of the people affected by the Chernobyl catastrophe (Table 3). The amount of all compensations and benefits depends on the category of the person and status of the territory of their residence and work.

The State should compensate the followings:

1) health damage or loss of working ability of the people caused by the Chernobyl catastrophe;
2) supporter loss of children if his death is caused by the Chernobyl catastrophe;
3) material loss of the people and their families caused by the Chernobyl catastrophe.

The State is responsible to provide medical examination to the people affected by the Chernobyl catastrophe. Of great importance is the statement in the Law that "the causal relation between the deterioration of health status, disease... loss of ability to work of the people who suffered from the Chernobyl catastrophe, and the Chernobyl catastrophe is identified

Table 3. Definition of categories of people who suffered from the Chernobyl catastrophe

Categories	Description
I	Invalids, belonging to liquidators and affected residents, for whom the causal relation between their disability and the Chernobyl catastrophe was proved; Persons who got radiation syndrome as a result of the Chernobyl catastrophe.
II	Liquidators who worked in the exclusion zone: - since the accident to July, 1, 1986: independently of length of working days; - since July,1, 1986 to December, 31, 1986: not less than 5 days; - in 1987: not less than 14 days; Affected residents: - evacuated from the exclusion zone in 1986; - permanently lived in the zone of obligatory resettlement since the accident to the moment of adoption of the decree on resettlement.
III	Liquidators who worked: - in the exclusion zone since July,1, 1986 to December, 31, 1986: from 1 to 5 days; - in the exclusion zone in 1987: from 1 to 14 days; - in the exclusion zone in 1988-1990: not less than 30 days; - on sanitary treatment of people and decontamination of equipment or on construction of these stations; Affected residents (not referred to category II), who: - permanently lived on the territory of zones of obligatory resettlement and guarantee voluntary resettlement on the day of accident, or by the January, 1, 1993, provided that they spent not less than two years in the zone of obligatory resettlement, or three years in the zone of guarantee voluntary resettlement, and were resettled from these territories; - permanently living, or permanently working, or permanently studying in the zones of obligatory resettlement and guarantee voluntary resettlement, provided that by January, 1, 1993 they spent not less than two years in the zone of obligatory resettlement, or three years in the zone of guarantee voluntary resettlement.
IV	Affected residents who permanently living, or permanently working, or permanently studying in the zone of enhanced radioecological control (monitoring), provided that by January, 1, 1993 they spent not less than 4 years in this zone.

(independently of whether the dosimetry results are available or not) unless the authorized medical institution confirms the absence of such relation".

"For the purpose of effective fulfillment of the task of medical and social care of the citizens who suffered from the Chernobyl catastrophe, the State Register of Ukraine (general information system) is organized. It includes sociological, dosimetry and medical sub-registers". The basic task of the register is "to control health status, and to study immediate and remote medical consequences" of the affected people. Organs of the state administration, executive committees of the local councils, and social organizations should send complete information about the affected people to the State Register of Ukraine. Confidentiality of the information in the register is guaranteed.

Medical supplies and equipment, imported on the territories of radioactive contamination, are exempt from customs and tax.

Further in the Law, compensations and benefits are specified for the citizens who suffered as a result of the Chernobyl catastrophe. The list of all the benefits and compensations occupies 11 pages. Benefits and compensations can be both of single-time character, e.g. free supply with dwellings and compensation of the lost property (houses, vehicles, domestic animals and fruit plants), as well as of permanent character, e.g. free medicines, free treatment in sanatoriums, additions to the salary, additional payment for enhanced foot, increased pensions, free use of city transport, and earlier retirement age.

The Law states that the citizens who suffered as a result of the Chernobyl catastrophe have advantage in applying to job and advantage in preserving their working places during reduction of staffs on enterprises and organizations. This creates conflict situations, as it causes the dissatisfaction and anger of more experienced and qualified workers. The Law declares that the local councils should allocate 15% of all built dwellings annually in order to provide for the benefits envisaged by the Law. This situation also creates a basis for conflict, because, despite the allocation of special funds, the queue of those waiting for dwelling is very long.

Rather strange is the statement in the Law that "the salary of the workers on enterprises, organizations and institutions, who work on the construction of the objects within the program of the liquidation of the Chernobyl accident consequences, should be 20% above the standard rate."

The Law provides the definition of the children considered as affected by the Chernobyl catastrophe and identifies the following benefits and compensations for such children and their parents: total state insurance of the children before they reach school age; annual free treatment in sanatoriums and resorts for the period to 2 months; increase of the salary for one of the parents; prolonged maternity leave for women who suffered as a result of the Chernobyl catastrophe - 180 paid days, etc.

The expenses related to the implementation of this Law are financed from the State budget. The Cabinet of Ministers of Ukraine is responsible for the clarification of the scheme of Law implementation.

2. Laws and regulations of Ukraine on radiation protection

The legislation of Ukraine on radiation protection of people consists of the following laws: *"On radiation protection of people"* (being considered by the Parliament), *"On radioactive wastes disposal"*, *"On the use of nuclear energy and radiation safety"*, as well as other legal documents.

2.1. Laws and regulations on dose limits.

The basic document on radiation protection on the territory of the former USSR is the *Standards of Radiation Safety SRS-76/87 (Нормы радиационной безопасности НРБ-76/87)*, which are still effective in Ukraine until new national norms are adopted. According to this document, three categories of irradiated persons are identified:

- Category A, staff - persons directly working with the sources of ionizing radiation (SIR)
- Category B, certain part of population - persons who are not working directly with SIR, but by living conditions (*this made essential difference with the international standards* !!!) or by the location of working places may be affected by radioactive substances or other SIR.
- Category C, population - population of the country, region, etc.

For category A and B, dose limits are identified to be 50 mSv per year and 5 mSv per year, respectively. For category C, however, dose limit is not determined, but there is only a requirement for implementing measures to restrict irradiation of population. In a case of radiation

Table 4. Dose limits for total (internal and external) irradiation ($mSv \cdot y^{-1}$)

Dose limits	Category of irradiated persons		
	A	B	C
Effective dose limit	20*	2	1
Equivalent dose limits:			
for crystalline lens	150	15	15
for skin	500	50	50
for hands and feet	500	50	-

Remark: * - in average for any 5 consecutive years, but not more than 50 mSv for separate year.

accident, "depending on the scale and character of an accident, the Ministry of Health can establish temporary dose limits and permissible levels for the population".

The Law of Ukraine, *"On radiation protection of people"* (still being considered at the Parliament) defines dose limits for categories A and B to be 50 mSv and 5 mSv per year, respectively. The same law establishes dose limit for category C (population) - "on the condition of normal operation of nuclear installations and sources of ionizing radiation", effective dose should not exceed 1 mSv per year. "Real or expected doses of irradiation for individuals of any critical group should not exceed the determined dose limits, independently on the number of pathways for the formation of this dose."

In 1997 the Ministry of Health of Ukraine adopted new *Standards of Radiation Safety of Ukraine SRSU-97*, mainly based on international safety standards (1). This document presents a different definition for category B of irradiated persons: "category B, staff - persons, which are not working directly with the SIR, but by the location of working places may be affected by radioactive substances or other SIR". SRSU-97 will be introduced into practice from 1998. The following Table 4 presents main dose limits established by SRSU-97.

Table 5. Local control levels of ^{137}Cs concentration in food and agricultural products brought into use in different regions since 1994, Bq/l, Bq/kg.

	Foodstuff	Regions		
		Kyiv	Volyn'	Zhytomyr
1.	Drinking water	-	4	4
2.	Milk	74	74	74
3.	Different milk products	74-148	74	75
4.	Milk powder	-	185	-
5.	Pork, beef, mutton, poultry	74-148	276	740
6.	Fish	185-296	296	-
7.	Potato	60	-	-
8.	Root vegetables	60	-	-
9.	Leafy vegetables, fruits, berries	60	-	185
10.	Bread, grain products	-	-	185
11.	Mushrooms fresh	-	740	740
12.	dry	-	1850	1850
13.	Eggs	74	296	-
14.	Infants foodstuff	-	37	-

Table 6. Values of acceptable levels for ^{137}Cs and ^{90}Sr in foodstuff and potable water (AL-97), Bq/kg, Bq/l.

	Name of the product	^{137}Cs	^{90}Sr
1.	Bread and bread products	20	5
2.	Potato	60	20
3.	Vegetables (root, leafy)	40	20
4.	Fruits	70	10
5.	Meat and meat products	200	20
6.	Fish and fish products	150	35
7.	Milk and milk products	100	20
8.	Eggs (per piece)	6	2
9.	Water	2	2*)
10.	Milk concentrate	300	60
11.	Milk powder	500	100
12.	Fresh wild berries and mushrooms	500	50
13.	Dried wild berries and mushrooms	2500	250
14.	Drug plants	600	200
15.	Others	600	200
16.	Special infants foodstuff	40	5

*) Remark: 4 Bq/l until 01.01.1999

2.2. Laws and regulations on radioactivity levels of food, water and air.

For the category B, the permissible concentrations of radionuclides (PC_B) in water and air are presented in the Standards of Radiation Safety (Table 8.1 of SRS-76/87). Its values were calculated with the assumption that if a person constantly inhales air with radionuclide concentration equal to PC_B, or if a person constantly consumes water with radionuclide concentration equal to PC_B, then human irradiation dose will be 5 mSv per year from each radionuclide of either route of intake (inhalation or ingestion). In certain situations that persons receive irradiation from both pathways, derived permissible levels should be determined, taking into account existing ratios of radionuclides in water and air.

In Ukraine there are no standards for radionuclides content in the air for the category C. After the Chernobyl accident in accordance with Soviet regulations the Ministry of Health of the USSR defined in 1986, 1988 and 1991 the tentative acceptable levels (TAL) for radionuclides in foodstuff and potable water. In 1993 the National Commission on Radiological Protection of Ukraine issued the TAL-93 document. But, since different Ukrainian Ministries did not come to an agreement about the figures of this document, it was not approved by the Ministry of Health. So, TAL-91 continued to be actual in Ukraine up to 1997. The main problem of TAL-93 was groundlessness of its figures. Since 1994, however, local authorities of the contaminated regions brought into use local control levels (LCL) of radionuclides in food and agricultural products, mainly based on the TAL-93 figures, and also taking into account local conditions (Table 5). According to local laws, exceeding of LCL is a subject of investigation and, if necessary, elaboration and implementation of countermeasures. In fact, only several percents of products, obtained from collective farms, exceeded LCL values in 1995-1996. In private sector of agriculture, however, this happens more often.

In 1997 the Ukrainian Ministry of Health approved acceptable levels for ^{137}Cs and ^{90}Sr in foodstuff and potable water (AL-97). This document will be introduced into practice from January 1, 1998. If a person of critical groups constantly consumes a reference ration composed of all products containing ^{137}Cs and ^{90}Sr at the levels presented in Table 6, he will receive 1 mSv per year separately from ^{137}Cs and ^{90}Sr. A product is considered to be accepted for consumption if the sum of ratios of actual concentrations of ^{137}Cs and ^{90}Sr to their acceptable levels dose not exceed 1. Introduction of AL-97 provides guarantee that annual individual effective dose of internal irradiation due to consumption of food products does not exceed 1 mSv for any person.

Final remarks.

1. The system of Chernobyl Laws in Ukraine reflects rather good intentions of Ukrainian authorities to help the people who suffered from the Chernobyl catastrophe, than scientifically justified recommendations. Firstly (in 1991) it was planned to receive funds for implementation of the Laws from the budget of the Soviet Union. After the Soviet Union decay it was found that the Laws were overloaded with social payments and compensations and became impracticable taking into account the state of economy of independent Ukraine. Annual income to the Chernobyl fund is about 70-80% of what is prescribed by the Laws for their implementation.

A number of changes and additions to the Laws reflects the special attention to the Chernobyl problem of Verkhovna Rada deputies and public in general. This is being exploited by politicians, and Chernobyl issues became the field of political struggle between pragmatists and populists. In this situation, radiological aspects of the problem stepped aside.

Radiological survey system in Ukraine provides necessary information on annual doses to population of each settlement on the contaminated territories. Despite of clearly observed reduction of doses on most territories, allocation of settlements to the categories of contaminated zones has not been reviewed since 1991. According to the monitoring data, the level of irradiation dose of about 50% of all settlements does not correspond to their present status (relation to their zones).

What is very impotent in the present situation is to stop compulsory resettlement (senseless after 11 years have gone since the accident) and drive resources to the reconstruction of people's life on the contaminated territories. It is necessary to stop to pay compensations for production of radioactively contaminated food products and introduce a system of benefits to those, who produce pure products on contaminated territories.

These elements of new approach to the Chernobyl problem as well as many others are presented in the new "*Concept of protection of population in connection with the Chernobyl catastrophe*" elaborated together by MinChernobyl and NCRPU. This document was submitted to the Cabinet of Ministers and approved by it in Autumn 1997. It is expected that on approval of Verkhovna Rada it will become a new basis for reviewing of the Chernobyl Laws.

2. Laws and regulations of Ukraine on radiation protection are on the way to meet international basic safety standards. But there is no experience in the world of dealing with the consequences (especially long-term ones) of such a wide-scale radiation catastrophe. Taking into account that a certain part of the Ukrainian population have to live permanently on the radioactively contaminated territories, the contamination on this territories is not considered as accidental (people can not live permanently in accidental conditions), but rather as environmental factor like natural radioactivity. This provides somewhat different approach to setting acceptable levels of radionuclides in foodstuff and explains the differences in figures between AL-97 and international recommendations (2).

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Research and Managing Institutions in Ukraine concerning the Radiological Consequences of the Chernobyl Accident

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1. National Academy of Sciences of Ukraine and governmental organizations

First of all it should be mentioned that during the time of the Soviet Union all researches and investigations connected with different aspects of nuclear energy and industry were secret and, as a rule, carried out by all-union organizations which had their main offices in Russia. National (republican) institutions had only restricted access to this kind of information and scientific activity. After the Chernobyl accident even the Minister of Ministry of Health of the Ukrainian SSR was not provided with comprehensive actual information on the problem for a long time and had to content himself with pieces of information obtained from his Moscow colleagues by personal communications.

On the basis of above-mentioned circumstances, the National Academy of Sciences of Ukraine (NASU) started its activity on liquidation of the accident consequences (LAC) from the first days after the accident. On May 3, 1986 the Operational Commission of NASU (which later was renamed into the Permanent Acting Commission of the Presidium of NASU) was created. Being the acting body of the Presidium, this commission was managing the activity of institutions and enterprises of NASU, accomplishing scientific examination of proposals on LAC, providing communication and coordination of NASU activities with ministries and departments, and preparing proposals to directive bodies and Governmental commission. The head of this commission was Academician of NASU, V.I.Trefilov, and his deputies were Academicians of NASU, V.G.Barjakhtar and V.P.Kukhar.

During the first days after the accident a large scale rearrangement of financial and technical resources was made to provide solution of immediate tasks of LAC. For example, since May 3 teams of scientific workers from various Institutes of NASU (among them the Institute of Nuclear Research, the Institute of Physics and the Institute of Metallophysics) carried out twenty-four-hour radiological control on milk-treating factories in Kyiv. This permitted to reduce the strength of iodine shock on Kyiv citizens.

A special attention was paid to the diagnostics of the destroyed unit 4 reactor. Unique technical solutions to monitor physical parameters in the destroyed reactor were developed and implemented by staffs of the Institute of Nuclear Research of NASU.

In October 1986 a special modeling system to describe and predict the behavior of radionuclides in the Dnieper reservoirs cascade was developed at the Institute of Cybernetics in collaboration with other institutes of NASU. This system provided an instrument of reliable prediction of the radioactive contamination in Dnieper water, which was proved by the actual monitoring data. In December 1986 the first prediction of radioactive contamination in subsurface water was performed at the Institutes of Geological Sciences and of Cybernetics together with Ministry of Geology of Ukraine. Scientists of NASU took part in elaboration of contamination maps, and in developing of technologies and techniques of decontamination and radioactive dust reduction (suppression).

Some part of proposals of Ukrainian scientists was rejected in Governmental bodies of the USSR. For example, this happened to a plan, developed by NASU and Ministry of Water Resources Management of Ukraine, to change the Pripyat river stream and to drive it to the Dnieper river round about the Chernobyl site.

After the acute period of the accident has passed, institutions of NASU concentrated their efforts on investigations and elaboration of measures to mitigate consequences, taking into account their long-term character. This activity was carried out from 1987 within all-union programs, and from 1992 within republican ones.

In 1990 a special executive body, the State Committee of Chernobyl Affairs was established in Ukraine to manage the whole activity to overcome the Chernobyl problems. In 1991 it was rearranged into the Ministry of Chernobyl Affairs (MinChernobyl). In 1996 a new Ministry of Ukraine on Emergencies and Affairs of Population Protection from the Consequences of Chernobyl Catastrophe (MEA) was found on the basis of both MinChernobyl and Headquarters Staff of Civil Defence. Officially MEA is the main coordinator of all scientific research related to Chernobyl.

Since 1992 to 1995 financing of Chernobyl-related NASU activities was being distributed through the Presidium of NASU using the Chernobyl fund of the state budget. This scheme of financing did not permit effective usage and comprehensive control of the Chernobyl fund. In 1996, therefore, MEA introduced a system of direct contracts between MEA as the customer and leading institutions of NASU as executors of research work. MEA elaborates a program of scientific research and experimental design aimed at elimination of negative effects of the Chernobyl accident. Then direct contracts are made with different institutions of MEA. Specialists of MEA check implementation and results of the works.

Several principal directions were defined within the program and respective institutions of NASU were nominated as head organizations. Among them are:

- Institute of Nuclear Research (I.Vyshnevsky),
- Institute of Magnetism (V.Barjakhtar),
- State Scientific Center of Environmental Radio-geochemistry (E.Sobotovich),
- Scientific Engineering Center of Radiohydro-geoecological Field Research (V.Shestopalov).

The Permanent Acting Commission of the Presidium of NASU is responsible for coordination of Chernobyl-related research activity within NASU (head of the Commission is Academician V.Shestopalv, his deputies are Academicians E.Sobotovich and I.Vishnevsky, members are Academicians D.Grodzinsky, V.Kukhar and others) and the First Vice-president of NASU V.Barjakhtar is the supervisor of this activity.

The following governmental organizations are also directly involved in the activities on the elimination of the Chernobyl accident consequences:

- Ministry of Health of Ukraine
- Ministry of Agricultural-Industrial Complex of Ukraine;
- State Water Resource Committee of Ukraine
- State Hydrometeorology Committee of Ukraine;
- State Geology Committee of Ukraine

Ministry of Health, Ministry of Agricultural-Industrial Complex and State Water Resources Committee have special departments which deal with Chernobyl-related problems. The activity of these departments is funded by the MEA. A certain amount of finance to implement works concerning the Chernobyl problems is allocated to the Ministries and organizations directly from the state budget, and in this case MEA has no possibility to provide effective control of the use of funds, topics and quality of research.

The structure of Regional administration of all regions with contaminated territories includes departments for Chernobyl affairs (the size of which depends on the contaminated area and the number of inhabitants). These departments are subordinate to the Regional administrations and MEA, i.e. these are the departments of double subordination. The same situation is on district (rayon) level. The major work to help people is being done on the level of Regional (Oblast), District (Rayon) and City state administrations by their Chernobyl departments.

The National Commission on Radiological Protection of Ukraine (NCRPU) belongs to the Parliament (Verkhovna Rada) structure. Being the body of the Parliament, NCRPU is responsible for approval of radiological safety standards and derived regulations. Very often the regulations approved by NCRPU are stricter than the respective international recommendations.

There is an essential lack of attention within the Parliament deputies to the activity of NCRPU. It operates in the frame of the temporary Statute, the full-scale permanent Statute of NCRPU was submitted two years ago to the Parliament for approval, but has not been considered yet.

The head of NCRPU is Academician of NASU, Dmytro Grodzinsky. Total number of Commission members is 25, but only two of them (deputy head, Yu.Bezdrobny and scientific secretary, V. Kalyna) have full-time occupation within the Commission. Others are working in different research institutions and ministries of Ukraine.

2. Medical care system and the State Registry of the Chernobyl sufferers.

Ministry of Health is responsible for all kinds of medical care for the people suffering from the Chernobyl catastrophe. In order to provide permanent medical service, a nation-wide scheme has been worked out based on 4 hierarchy levels of medical institution:

- the first level - medical assistants' and obstetric clinics and District hospitals,
- the second level - Central District and Numbered hospitals,
- the third level - Regional Specialized Medical Dispensaries of Radiological Protection of Population and other specialized medical institutions,
- the fourth level - Ukrainian Scientific Centre of Radiation Medicine and other central scientific research institutes.

Network of these medical institutions (about 300) was approved by instructions of regional and state administrations. Every year MEA (earlier MinChernobyl) develops and approves *"Programme of Measures on Special Medical Support to the People Who Suffered from the Chernobyl Catastrophe"*. This Programme is aimed at providing support and additional financing to medical institutions which belong to the network of permanent and continuous medical assistance to those suffering from the catastrophe.

The State Register

Right after the Chernobyl accident, the USSR

Ministry of Health started a program on creating the All-Union Distributed Register of irradiated persons. After decay of the USSR, Ukraine inherited some uncoordinated parts of this register and had to develop its own system aimed to provide effective medical-social security for those suffering from the Chernobyl catastrophe. The respective statements were included into the Article 16 (Organisation of the united state registration of the persons who suffered from the Chernobyl catastrophe) of the Law of Ukraine, "*On the Status and Social Protection of the People Who Suffered from the Chernobyl Catastrophe*". Ministry of Health is nominated to be responsible for implementation of this task. Formally the State Register was created, but due to lack of coordination and shortage of funds it did not provide the really united registration system. It is expected that this situation will change on approval of *"Regulations on Organizing and Functioning of the State Register of Ukraine of the Persons Who Suffered from the Consequences of the Chernobyl Catastrophe"* (approved by the Decree of the Cabinet of Ministers of Ukraine on June, 9, 1997 No. 571).

The population size of principal groups in the State Register is shown in Table 1. The State Register also includes medical, dosimetric and sociological subregisters. <Medical subregister> provides the data of special purpose clinical examination and medical care for suffering people. <Dosimetric subregister> provides the data of measured and reconstructed doses of irradiation. <Sociological subregister> is formed on the basis of selected groups belonging to all categories of suffering people which are included to the State register. The Ukrainian Military Register, units of which are managed by Ministry of Defence, Ministry of Internal Affairs and Security Service of Ukraine, is also a part of the State Register.

Organizational structure of the State Register has following levels of managing:

a) state level - Ukrainian Centre of Medical Information Technologies and National Register of Ministry of Health of Ukraine, respective special units of Ministry of Defence, Ministry of Internal Affairs and Security Service of Ukraine, special departments of scientific research institutes of the Academy of Medical Sciences and National Academy of Sciences of Ukraine;
b) region and city level - regional or city hospital (center or dispensary);
c) district level - central district hospital.

The basic elements to collect medical data within this medical scheme are district hospitals. In principle, there are instructions in order to provide certain basis for proper data collection. It is recognized, however, by international medical scientific experts that lack of knowledge about the actual mechanisms of data collection and the quality of basic epidemiological statistics, such as mortality and cancer incidence, are limitation factors in Ukraine for epidemiological investigations of international standards.

Managing and financing of the activity of State Register are coordinated by MEA. Finances for creating and maintenance of the State Register are provided from the Chernobyl fund of the state budget.

3. Description of leading research organizations about the Chernobyl problems

3.1. Scientific Centre for Radiation Medicine of the Academy of Medical Sciences of Ukraine

Scientific Centre for Radiation Medicine (SCRM) is the leading scientific institute of the Academy of Medical Sciences of Ukraine and Ministry of Health of Ukraine, which works on the medical problems of the Chernobyl accident.

The total number of personnel of the Center as of 01.01.1995 was 1,254 persons, including 236 scientists (30 doctors, 90 candidates)

The structure of SCRM comprises three institutes:

- Institute of clinical radiology with the clinic for 300 beds;
- Institute of epidemiology and prophylactics of X-ray diseases;
- Institute of experimental radiology and outpatient's clinic of radiation registration.

The SCRM performs fundamental and applied research. The main trends of research are:

- investigation and assessment of radiation and non-radiation factors of the Chernobyl accident, as well as of other sources of ionizing radiation, which affect the health of people;
- investigation of the health status of the population

Table 1. The structure of the State Register of persons who suffered from the Chernobyl catastrophe (persons, 01.01.1996)

	Group 1	Group 2	Group 3	Group 4	Total
	Liquidators	Evacuees and resettlers	Residents in the contaminated areas	Children born with parents of Group1-3	
Adults	184,672	53,866	161,611	-	400,149
Children	-	8,845	27,907	37,194	73,946
Total	184,672	62,711	189,518	37,194	474,095

origin- Ten Years after the Accident at the Chernobyl NPP: National Report of Ukraine, MinChernobyl, 1996.

which suffered from the Chernobyl accident, and those of other categories which receive additional irradiation doses;
- scientific grounds and support of medical measures on the protection of population form negative effects of the Chernobyl accident and other sources of radiation;
- scientific support, generalization of the data, presented by the national State Register, about the persons who suffered from the Chernobyl accident;
- study of the mechanism of ionizing radiation effect and negative factors influencing on human organism, development of prophylactic, diagnostics, treatment and rehabilitation methods.

Reconstruction of thyroid dose for 12 regions and the city of Kyiv due to the Chernobyl accident has been carried out at the Department of Dosimetry and Radiation Hygiene of SCRM (Dr. I.Kairo). Results for 7 regions and the city of Kyiv were approved by Ministry of Health and presented to the Ukrainian government as Thyroid Dosimetric Passports. Ministry of Emergencies (MEA) supports this work and is planning to provide the passportisation of the whole Ukrainian territory until the end of 1999.

Works on reconstruction of external and internal dose at the early stage after the accident have being carried out at also this Department (Drs. V.Repin, V Chumak, V.Berkovsky, O.Bondarenko) in cooperation with staffs from other institutes. This Department is leaded by Prof. I.Likhtarev.

3.2. State Scientific Center of Environmental Radiogeochemistry of NASU and MEA

State Scientific Center of Environmental Radiogeochemistry (SSCER) was created in 1996 on the basis of two departments of the Institute of Geochemistry, Mineralogy and Ore Forming: Department of Environmental Radiogeochemistry and Department of Metallogenesis.

Center was created in order to improve coordination and managing of scientific researches on the behavior of artificial and natural radionuclides and chemical substances in the environment, creation of data basis of scientific works on this subject, preparation of recommendations on restoration of the environment, including questions of decontamination and rehabilitation of the exclusion zone of the Chernobyl NPP and other territories, subjected to harmful influence of technogenic and natural catastrophes; scientific supervising over the development of uranium industry and radioactive waste treatment, including preservation, disposal and deposition in deep geological formations.

SSCER has the following 9 scientific sections:

- section of nuclear geochemistry and cosmochemistry (E.Sobotovich);
- section of radiogeochemistry of ecosystems (G.Bondarenko);
- section of ecological geology (V.Bukharev);
- section of geochemistry of technogenesis (B.Gorlytsky);
- section of cosmoecology and cosmic mineralogy (V.Semenenko);
- section of problems of ecological safety (Ju.Melnyk);
- section of metalogenesis and mineral resources (Eu.Kulish);
- section of geology of uranium and attendant metals (V.Koval);
- section of complex problems of uranium deposits (B.Zankevych).

Total number of staff members is 200 persons, including 72 - scientific workers, among the last - 1 academician of NASU, 3 correspondent-members of NASU, 15 - doctors of science, 47 - candidates (Ph.D).

The main directions and subjects of investigations:

- geochemical fundamentals of noosphere forming;
- technogenic-ecological safety and rehabilitation of contaminated territories;
- treatment, preservation, disposal and deposition (burial) of radioactive and toxic wastes;
- ecological assessment and forecasting of the environment status;
- complex problems of ecological safety and forecasting of emergencies.

3.3. Chernobyl Scientific-Technical Center for International Research

Chernobyl Scientific-Technical Center for International Research (ChSCIR) was created in March 1996 on the basis of Scientific-Technical Center (STC) that existed within the structure of Research-Industrial Association (RIA) “Pripyat” and research infrastructure of Chernobyl Center for International Research (CheCIR). The last organization was up-to-date equipped for radioecological study and carried out associated investigations with CEC within the frame of ECP-JSP projects in 1993-1995.

ChSCIR is headed by the director, Prof. N.Arkhipov and includes 7 sections:

- section of analysis and research work organization (A.Makhno);
- section of study of radionuclides spreading (V.Nadvorsky);
- section of radiology and recultivation (L.Loginova);
- section of forest radioecology (M.Kuchma);
- section of radiobiology and medicine (M.Alesina);
- section of international analytical research (V.Libman);
- production-technical section (G.Mykhailyuk);

and special experimental farm (M.Novopashen).

ChSCIR has 159 staff members, among them 80 graduate specialists, 4 doctors of science, 15 candidates (Ph.D).

Directions of research work:

- elaboration and implementation of radioecological monitoring system of radioactively contaminated territories;
- complex investigations, analysis and forecast of space distribution and migration of radionuclides in the environment and food chains;
- study of radiogeochemical status of the exclusion zone on the basis of geochemical and hydrogeological observations;
- radiobiological and medical-biological consequences of the Chernobyl accident;
- study of the influence of radioactive contamination upon forest ecosystems and development of special forestry system;
- elaboration, examination and implementation of countermeasures to reduce radionuclide transfer from soil to plant and through the food chains, and methods for rehabilitation of radioactively contaminated agricultural lands;
- study of the influence of microbiological agents upon transformation and migration of radionuclides and their compounds (including initial fallouts);
- elaboration and implementation of geographical information-modeling systems;
- forecast of ecological and radioecological status of the exclusion zone;
- making informational provision of research work, elaboration of standardizing basic documents, elaboration of united informational data bank on scientific research works, standardizing technical documents, working materials of conferences, workshops etc.

ChSCIR has well-equipped laboratories and experimental field stations located in a distance of 3-15 km from ChNPP and experienced in sampling of soils, waters and biological objects. Laboratories and vivariums, greenhouses and field stations are suited to carry out various radiobiological and radioecological investigations. Spectrometric and radiochemical laboratories, natural experimental fields, cooling pond of ChNPP with special fish-breeding farm, vivariums for about 2 thousands laboratory rats and mice are also opened to those who want to carry out radioecological and radiobiological studies.

3.4. Ukrainian Scientific Hygienic Center of Ministry of Health of Ukraine

Ukrainian Scientific Hygienic Center (USHC) was created in 1989 and included two institutions:

- Scientific Research Institute of General and Communal Hygiene named after O.M.Marzeev
- Ukrainian Scientific Center for Medical Genetics.

USHC is a leading scientific institution in Ukraine in the fields of environmental hygiene, hygiene of children and adolescents, medical genetics, assessment of ecological-hygienic safety of population, medical aspects of liquidation of the consequences of the ChNPP accident.

Activity of USHC is being carried out within the frame of complex programs of Ministry of Health; “Environmental hygiene” and “Medical genetics” and aimed at:

- protection of health and geno-fund of population from hazardous environmental agents, including anthropogenic;
- elaboration of scientifically grounded practical measures of health protection for present and future generations, improving conditions of the environment;
- coordination of research work within the state scientific-technical programs “Protection of Ukrainian population geno-fund” and “Problems of ecological safety of Ukraine”;
- preparation of research personnel on hygiene, ecology and genetics.

The next scientific topics were accomplished or being studied in USHC since the Chernobyl accident:

1. Hygienic aspects of the consequences of the Chernobyl NPP accident, 1986-1990.
   - Hygienic assessment of the natural and artificial sources of ionizing radiation on the territory of Ukraine;
   - Analysis of health status of children population, subjected to radiation as a result of the ChNPP accident;
   - Developing of organizational questions of sanitary-epidemiological stations work in the conditions of radiation accident.
2. Analysis of radionuclides of ^{90}Sr and ^{238,239}Pu in soils of some contaminated districts of Ukrainian SSR, 1990.
3. Study of the radiation-hygienic situation in some districts of the Rivne region, 1991-1994.
4. Study of the migration of artificial and natural radionuclides through ecological paths in particular geochemical provinces of the republic and to develop hygienic recommendations for provision of safe living conditions for population, 1991-1992.
5. Ecological-hygienic assessment of the environment in controlled regions of Kyiv, Zhytomyr, Rivne, Chernigiv, Cherkasy regions in relation to the ChNPP accident and development of prophylactic measures, 1991-1992.
6. Study of the mechanisms of migration of ^{137}Cs, ^{90}Sr, Pu radionuclides through the ecological paths taking into account their state and forms present in soils, 1992-1995.

7. Hygienic assessment of the 30-km zone of the Chernobyl NPP and elaboration of network of medical sanitary measures for optimization of conditions for staying in the zone, 1991-1994.
8. Evaluation of the contribution of water path of radionuclides migration through food chains to dose forming to population of Dnieper river basin, 1992.
9. Ecological-hygienic monitoring and assessment of environment and population health quality on the radioactively contaminated territories, 1993-1995.
10. Study of the influence of doses due to presence of ^{137}Cs and ^{90}Sr in organisms on children's health in different regions of Ukraine, 1993-1995.
11. Radiological-hygienic assessment of working conditions of forest workers, carrying out different works in the exclusion zone, 1993-1994.
12. Study of the forming of microbiocenoses of waters and soils in the regions of enhanced radioactive contamination and their role in remedial processes in the environment, 1994-1996.
13. Radioecological studies of the consequences of the Chernobyl catastrophe on the Dnieper reservoirs cascade (determination of plutonium), 1994.
14. Study of the influence of magnetic field of industrial frequency in combination with ionizing radiation upon organism and development of hygienic measures to protect humans from unfavorable effects of these factors, 1995-1999.
15. Radiological-hygienic grounding of the diet- and phyto-therapeutic measures for improving of health and rehabilitation of persons, subjected to irradiation, 1995-1997.
16. Elaboration of acceptable levels of radioactive contamination of objects in the exclusion zone of the Chernobyl NPP, 1996.
17. Study of sanitary-hygienic characteristics of the environment on the territories contaminated by radionuclides, and their influence on health status, 1996-1998.

The reports on accomplished topics were presented to Ministry of Health of Ukraine.

4. Major publications on Chernobyl by Ukrainian scientists

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2. Radioactive and Chemical Pollution of Dnieper River and It's Reservoirs After the Chernobyl NPP Accident. / Romanenko V.D., Kuzmenko M.I, Evtushenko N.Yu. et al. - Kyiv: Naukova Dumka, 1992. - 196 P. (Rus)
3. Post-Accidental Encephalopathy: Experimental Studies and Clinical Observations/ Red. Romodanov A.P. - Kyiv, Ukr SRI Neurosurgery, 1993. (Ukr)
4. Serkiz Ya.I., Pinchuk V.G., Pinchuk L.B. et al. Radiobiological Aspects of Chernobyl NPP Accident. - Kyiv: Naukova Dumka, 1992. - 172 P. (Rus)
5. Frantsevych L.I., Gaichenko V.A., Kryzhanovsky V.I. Animals in Radioactive Zone. - Kyiv: Naukova Dumka, 1991. - 128 P. (Rus)
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Assessment of the Chernobyl Radiological Consequences

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INTRODUCTION

The Chernobyl accident has been the worst accident in the history of peaceful use of nuclear energy. The nuclear explosion and the following 10 days graphite fire have not only completely destroyed the fourth unit's reactor of the Chernobyl NPP but, as well, resulted in the release of a large amount of radioactive species into the environment. This accident caused radioactive contamination in a lot countries of the Northern hemisphere, even in countries many thousand kilometers away from Chernobyl. For example, the deposition of different radionuclides has been found even in Japan [1-3].

The Belorussian Republic was affected by the Chernobyl accident much more than any other country in the world [4]. Twenty three percent of its territory were contaminated by caesium-137 with 1 Ci/km^2 and higher. As a result of the accident at the Chernobyl NPP, large territories in the Russian Federation and in the Ukraine have been contaminated as well [5-7].

Experts of different countries and international organizations are unanimous in the opinion that the Chernobyl accident has caused enormous socio-economic consequences in Belarus, the Russian Federation, and the Ukraine [4, 7-9]. It is also recognized that residents of the affected areas of the former USSR have been subject to various psychological burdens soon after the Chernobyl accident [4, 7-11].

However, there exists a significant controversy among specialists about the medical consequences (other than psychic) of the Chernobyl accident. For example, according to the assessment of J. Gofman [12] this accident will result in additional 475,000 fatal solid cancers, 19,500 leukemia and additional 475,000 non-fatal solid cancers. The abovementioned data were evaluated by J. Gofman [12] for all countries of the Northern hemisphere affected by the Chernobyl accident. Significant medical consequences, especially additional thyroid cancers and leukemia, have been as well predicted by E. Ivanov [13].

The whole International Radiation Community, on the contrary, rejected the possibility of serious medical consequences other than psychic stresses and feeling of anxiety suffered by the residents of the affected areas [8-11, 14-16]. Such controversy is unbelievable in the light of the reliable data established in the affected regions of the former USSR [4,7,17].

One of the reasons for such controversy has been explained by J. Gofman [18]. He managed to show that the abovementioned discrepancies in prognosis of medical consequences of the Chernobyl accident arose due to the incorrect risk coefficient of ionizing radiation employed by some specialists to forecast additional number of solid cancers and leukemia induced by Chernobyl radiation.

Another incorrectness that can seriously influence the forecasting of biomedical consequences of the Chernobyl accident is related to the collective dose estimation. It is well known, that assessments of authors [8, 12-16] have been made on the basis of data of nuclides release into the environment established soon after the accident [19, 20]. During the last years, however, more accurate data were established on the total discharge of radioactive species due to the Chernobyl accident, as well as more accurate data on deposition of different radionuclides in the affected areas of the former USSR [5-7].

The facts discussed above justify any independent analysis of possible medical consequences of the Chernobyl accident. This paper presents our attempt to assess the pure radiological consequences of the accident at the Chernobyl NPP.

The following limitations were taken into consideration in our assessment. First, we have restricted our analysis to stochastic effects of ionizing radiation only, such as solid cancers and leukemia. Second, we have also excluded from our analysis members of the personnel of the Chernobyl NPP and the cohort of liquidators. It means that our study was concentrated only on the population of areas affected by the Chernobyl accident. Third, our assessment was based on the use of simplified model of collective dose estimation very similar to the models used by authors [13-16,20]. The first step in collective dose assessment is the calculation of the exposition dose in air on the basis of experimental data on radionuclide deposition on the ground. The results of our assessment are given below.

METHOD OF THE COLLECTIVE DOSE ASSESSMENT

The collective irradiation dose within some time **τ**, H_{τ}^{coll}, can be estimated as:

$$H_\tau^{coll} = N \cdot \overline{H}_\tau \qquad (1)$$

where,

N = number of irradiated people,

$\overline{H}_\tau$ = mean individual effective equivalent dose accumulated within the time τ.

The value of $\overline{H}_\tau$ is estimated as a sum of external, $\overline{H}_{\tau,\,ext}$, and internal, $\overline{H}_{\tau,\,int}$, doses:

$$\overline{H}_\tau = \overline{H}_{\tau,\,ext} + \overline{H}_{\tau,\,int} \qquad (2)$$

On the basis of data given in the Catalogue of doses [21] we have estimated that average contributions of external and internal irradiation to the equivalent doses delivered to inhabitants of the affected areas of Belarus in 1991-1992 were 60 and 40 percent respectively.

Assuming that the same contribution of external and internal radiation will be sustained at any time within a period of time τ we can write:

$$\overline{H}_\tau = \frac{\overline{H}_{\tau,ext}}{0.6}, \qquad (3)$$

$$\overline{H}_\tau = \frac{\overline{H}_{\tau,\,int}}{0.4}. \qquad (4)$$

Any of these expressions can be used for assessment of the collective equivalent dose delivered to the Belorussian population.

We shall base our investigation on the equation (3) because the procedure of assessment of $\overline{H}_{\tau,\,ext}$ is much easier than that of $\overline{H}_{\tau,\,int}$. The mean external equivalent dose, $\overline{H}_{\tau,\,ext}$, can be determined by means of the equation:

$$\overline{H}_{\tau,\,ext} = \overline{H}^*_{\tau,\,ext} \cdot \overline{A}^0_s\,(^{137}Cs) \qquad (5)$$

where

$\overline{H}^*_{\tau,\,ext}$ = mean external individual equivalent dose of inhabitants living in areas with initial contamination level by ^{137}Cs equal to 1 Ci/km^2,

$\overline{A}^0_s\,(^{137}Cs)$ = average initial deposition level of ^{137} determined for the total area of contaminated territories.

Thus, the value of $\overline{A}^0_s\,(^{137}Cs)$ is given by:

$$\overline{A}^0_s\,(^{137}Cs) = \frac{Q_0}{S} \qquad (6)$$

where

Q_0 = total amount of ^{137}Cs deposited on all affected territories (source term)

S = total area of contaminated territories

As can be seen from the equation given above the task of the collective equivalent dose assessment results in values: $\overline{H}^*_{\tau,\,ext}$, Q_0 and S_Σ. The mean individual equivalent dose of external irradiation normalized to the initial level of ^{137}Cs contamination equal to 1 Ci/km^2, $\overline{H}^*_{\tau,\,ind}$, can be determined on the basis of measured or calculated exposition dose rates in contaminated areas. By means of exposition dose rates integration for the period of time τ one can then compute the exposition dose P_τ. This value can be transformed to the air-absorbed dose D_τ by:

$$D_\tau = C_1 \cdot P_\tau \qquad (7)$$

where

C_1 = conversion factor equal to 0.873 $\frac{rad}{R}$ [22].

By means of another conversion factor C_2 which is determined in $\frac{rem}{rad}$ one can later estimate the required equivalent irradiation dose:

$$H_\tau = C_2 \cdot D_\tau \qquad (8)$$

DOSE RATE AND DOSE IN AIR RECONSTRUCTION

There are only sparse measurement data on exposition dose rates in different areas of Belarus affected by the Chernobyl accident. Thus, one needs to assess these values by means of some computational methods and data on contamination of the soil.

The most simple model which can be used for computation of dose rates is based on the so-called model of infinite half-space source geometry at a reference height of 1 m. According to this model the exposition rate of external radiation at the time **t** is given by:

$$\dot{R}_\gamma(t) = \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma^0_i \cdot \exp\left(-\frac{0.693}{T^i_{1/2}} \cdot t\right) \cdot K_{i,L}(t) \qquad (9)$$

where

n = number of nuclides contributing to the total exposition dose rate,

$K_{i,\gamma}$ = conversion factor of *ith* nuclide per unit deposition, $(mR/hr)/(Ci/km^2)$,

σ^0_i = initial surface contamination with *ith* nuclide normalized to initial surface contamination equal to 1 Ci/km^2 of ^{137}Cs,

$T^i_{1/2}$ = half-life of *ith* nuclide,

$K_{i,L}(t)$ = shielding factor of *ith* nuclide originated from its penetration into the soil (function of time).

Computation of $\dot{R}(t)$ is usually carried out on the basis of the assumption, that all nuclides have the same shielding factor $K_L(t)$. Then the equation (9) can be written in the form:

$$\dot{R}_\gamma\ (t) = K_L(t)\cdot\sum_{i=1}^{n} K_{i,\gamma}\cdot\ \sigma_i^0\cdot\exp\ (-\frac{0.693}{T_{1/2}^i}\cdot t), \quad (10)$$

Integration of the equation (10) from **t**=0 up to **t**=**τ** gives the exposition dose of external radiation accumulated within the period of time **τ**:

$$P_\tau = \int_0^\tau K_L(t)\cdot\sum_{i=1}^{n} K_{i,\gamma}\cdot\ \sigma_i^0\cdot\exp\ (-\frac{0.693}{T_{1/2}^i}\cdot t)dt. \quad (11)$$

Data on exposition dose rates and doses calculated on the basis of the equations (10) and (11) for different areas of Belarus are given in Fig. 1 and in Tables 1, 2 and 3. In computing these data experimental data on deposition of radionuclides as a result of the Chernobyl accident given in the book [5] were used (see Table 4). Table 5 consists of values of half-lives of gamma-emitting nuclides considered by calculation of $\dot{R}_\gamma$ and P_τ. The shielding factor K_L was calculated for the exponential model as it was done by T. Imanaka, T. Seo and H. Koide [23]:

$$K_L = a_1\cdot\exp(-l_1\cdot t) + a_2\cdot\exp(-l_2\cdot t), \quad (12)$$

where

a_1 and a_2 = fractions of fast and slow migration of radionuclides into the soil

l_1 and l_2 = constants of vertical migrations into the soil

Values of these fractions and constants for different periods of time after the Chernobyl accident are given in Table 6. They were determined from experimental data on vertical migration of radionuclides into the soil measured by specialists of Goshydromet of the former USSR [5]. They measured the vertical migration of radionuclides in the undisturbed soil for different kind of soils. We used data given in [5] for the sod-podsolic soil as more characteristic for contaminated territories of Belarus.

Figure 1 shows the change in exposition dose rates of external radiation in different areas of Belarus within the first weeks after the nuclear explosion at the Chernobyl NPP.

One can see that as a result of different composition or radionuclides deposited on the ground, roofs and walls of houses and other buildings the exposition dose rate in air in different contaminated areas of Belarus can differ by factor 3 even at the same ^{137}Cs contamination level.

The highest exposition dose rate had to be in the Northern sector of the so-called "nearest zone". This zone is a not very broad stripe that is extended in the Northern direction up to 100 kilometers from the Chernobyl NPP.

The lowest exposition dose rate had to be in the so-called "caesium spots", which are characterized by relative enrichment of radioactive deposition by caesium isotopes.

The difference in exposition dose rates diminished very quickly because of a radioactive decay of short-lived isotopes. At the end of the first month after the explosion at the Chernobyl NPP the exposition dose rates at different areas of Belarus were quite similar.

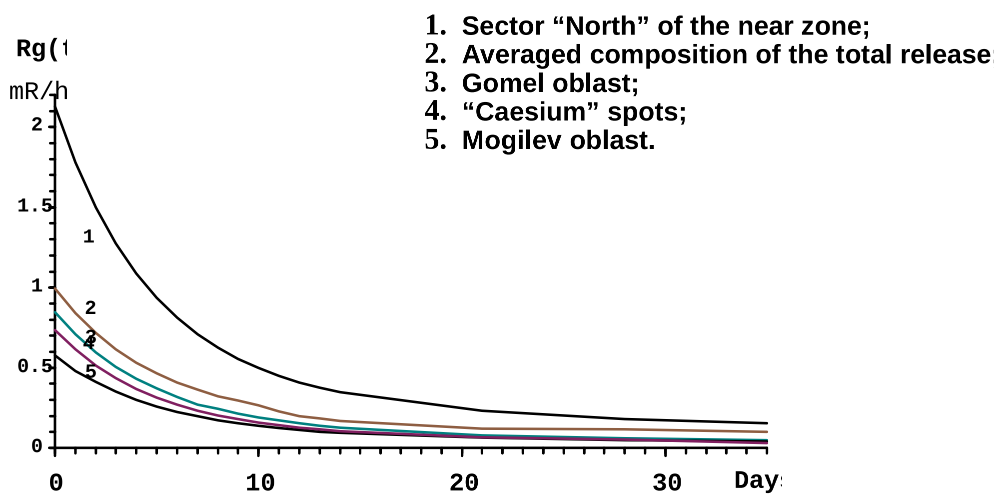

Fig. 1 Exposition dose rates in air at a height of 1 m during the first weeks after the Chernobyl accident in different areas of Belarus (normalized to the contamination level of caesium-137 equal to 1 Ci/km^2).

Table 1. Free air gamma exposition doses at a height of 1 m accumulated in different contaminated areas of Belarus within the period from 26.04.1986 to 26.04.2056 (normalized to the level of ^{137}Cs contamination of 1 Ci/km^2, mR).

Year	Vetka rayon of Gomel oblast	Krasnopolje rayon of Mogilev oblast	"Caesium spot"	Sector "North" of the near zone	Average composition of the total release
1986	258.0	212.7	225.1	622.5	369.1
1987	414.0	358.8	366.7	815.1	517.6
1988	531.7	471.9	476.8	947.9	628.0
1989	623.4	561.4	564.2	1048.6	715.5
1990	698.0	635.0	636.2	1128.8	787.5
1991	760.8	697.2	697.4	1195.1	848.7
1992	815.2	751.4	750.8	1251.7	902.1
1993	863.2	799.3	798.2	1301.3	949.5
1994	906.5	842.6	841.1	1345.7	992.4
1995	946.2	882.2	880.5	1386.1	1031.8
1996	983.0	919.1	917.2	1423.4	1068.5
1997	1017.4	953.4	951.4	1458.1	1102.7
1998	1049.8	985.8	983.8	1490.2	1135.0
1999	1080.5	1016.6	1014.4	1521.5	1165.7
2000	1109.9	1046.0	1043.8	1551.1	1195.1
2001	1138.0	1074.0	1071.8	1579.2	1223.1
2002	1164.9	1101.0	1098.7	1606.3	1250.0
2003	1191.1	1127.3	1125.1	1632.4	1276.3
2004	1216.3	1152.4	1150.1	1657.4	1301.4
2005	1240.3	1176.4	1174.1	1681.3	1325.4
2006	1263.2	1199.3	1197.1	1704.2	1348.3
2016	1447.8	1383.9	1381.6	1888.8	1532.8
2026	1573.8	1509.9	1507.6	2014.7	1658.7
2036	1660.8	1596.9	1594.6	2101.8	1745.7
2046	1721.1	1657.2	1654.9	2162.1	1806.0
2056	1760.4	1696.6	1694.3	2201.4	1845.3

Table 2. Contribution of different radionuclides to the summary free air gamma exposition dose, accumulated within the period from 26.04.1986 to 31.08.1986 in contaminated areas of Belarus.

Radionuclide	D_i / D, %				
	Vetka rayon of Gomel oblast	Krasnopolje rayon of Mogilev oblast	"Caesium spot"	Sector "North" of the near zone	Average composition of the total release
^{239}Np	0	0	0	0.9	0.8
^{99}Mo	0	0	0	0.2	0.1
^{132}Te	25.3	21.6	26.9	22.1	19.5
^{131}I	12.6	10.7	10.5	6.6	7.3
^{140}Ba	9.1	7.6	6.5	11.3	16.6
^{141}Ce	0	0	0	0.8	0.5
^{103}Ru	10.0	11.1	11.6	10.2	5.2
^{95}Zr	0	0	1.4	27.8	25.0
^{110m}Ag	0	0	0	0	0
^{144}Ce	0	0	0	0.7	0.7
^{106}Ru	6.8	3.3	4.0	3.7	2.0
^{134}Cs	21.1	26.7	22.1	9.9	12.6
^{125}Sb	0	0	0	0	0
^{137}Cs	15.1	19.0	17.0	5.8	9.7

According to [7], there are places in the 30 kilometers zone with level of contamination by ^{137}Cs as high as many hundred Ci/km^2. It means that soon after the explosion the exposition dose rate in air could reach in such places many hundred millirentgen per hour and therefore exceed many hundred thousand times the exposition dose rate in air before the Chernobyl accident.

According to our calculation nuclides with half-lives shorter than 1 year played an important role during the first months after the Chernobyl accident.

It can be seen from Table 3, where individual contributions to the total exposition dose of external radiation of different nuclides at different areas of Belarus are given.

Data presented in Table 2 show that short-lived

Table 3. Contribution of different radionuclides to the summary free air gamma exposition dose, accumulated within the period from 26.04.1986 to 31.04.2056 in contaminated areas of Belarus.

Radionuclide	D_i / D, %			
	Vetka rayon of Gomel oblast	Krasnopolje rayon of Mogilev oblast	"Caesium spot"	Sector "North" of the near zone
^{239}Np	0	0	0	0.2
^{99}Mo	0	0	0	0
^{132}Te	2.7	1.9	2.5	5.1
^{131}I	1.3	0.9	1.0	1.5
^{140}Ba	1.0	0.7	0.6	2.6
^{141}Ce	0	0	0	0.2
^{103}Ru	1.2	1.1	1.2	2.6
^{95}Zr	0	0	0.2	8.3
^{110m}Ag	0	0	0	0
^{144}Ce	0	0	0	0.6
^{106}Ru	3.0	1.2	1.6	3.4
^{134}Cs	16.4	17.0	15.5	16.0
^{125}Sb	0	0	0	0
^{137}Cs	74.4	77.2	77.4	59.5

Table 4. Composition of nuclide deposition in the affected areas of Belarus (normalized to the activity of 137-Cs) [5]

Radionuclide	D_i / D, %				
	Vetka rayon of Gomel oblast	Krasnopolje rayon of Mogilev oblast	"Caesium spot"	Sector "North" of the near zone	Average composition of the total release
^{239}Np				33.33	6.67
^{99}Mo				3.33	3.33
^{132}Te	14.13	9.5	12.78	33.3	16.7
^{131}I	14.13	9.5	10.0	20.0	16.7
^{140}Ba	1.086	0.714	0.67	3.67	3.33
^{141}Ce				3.67	3.67
^{103}Ru	1.957	1.714	1.994	5.33	2.67
^{95}Zr			0.056	3.33	3.33
^{110m}Ag					0.01
^{144}Ce				2.00	2.33
^{106}Ru	1.413	0.55	0.722	2.00	1.0
^{134}Cs	0.545	0.545	0.5	0.67	0.5
^{125}Sb					0.02
^{137}Cs	1.00	1.00	1.00	1.00	1.0

nuclides determined more than 50 percent of the total exposition dose in air delivered within the first months after the accident.

In case of the Northern sector of the so-called "near zone" (Bragin district is settled in this zone) short-lived nuclides gave about 85 percent of the total exposition dose.

It is clear that one needs to consider the total spectrum of the deposited radionuclides in the assessment of the possibility of direct effects of radiation on inhabitants of 30 kilometers zone, that were evacuated within the first months after the Chernobyl accident.

The total contribution of short-lived nuclides to the exposition dose of external radiation which can be delivered within quite a long period is not very large. Such conclusion may be drawn on the basis of data given in Table 3. In this table results of the exposition doses calculated for different areas of Belarus for the period of time from 26.04.1986 to 26.04.2056 (70 years period) are presented.

As can be seen from this table nuclides with half-life shorter than the half-life of isotope ^{134}Cs, give together only about 7% of the total exposition dose in air delivered during the 70 years after the Chernobyl accident.

It means that caesium isotopes determine practically the total exposition dose of external radiation delivered during a rather long period of time after the Chernobyl accident.

So, in the assessment of the total collective irradiation dose one does not have even to take into consideration nuclides other than caesium isotopes and concentrate the efforts on accuracy of

Table 5. Half lives and conversion factors of radionuclides deposited in the areas affected by the Chernobyl accident [5].

Nuclide	Half life, $T_{1/2}$, days	Conversion* factor, $K_{i,8}$
^{239}Np	2.35	2.9
^{99}Mo	2.73	5.1
^{132}Te	3.27	45.9
^{131}I	8.04	7.3
^{140}Ba	12.6	41.5
^{141}Ce	32.5	1.2
^{103}Ru	39	8.9
^{95}Zr	64	28.3
^{110m}Ag	250	50.3
^{144}Ce	284	0.8
^{106}Ru	368	3.8
^{134}Cs	755.6	29.1
^{125}Sb	985.5	7.9
^{137}Cs	11023	10.7

* Note: Conversion factors are given in units $\frac{mR/H}{Ci/km^2}$

Table 6. Parameters of nuclide vertical migration in soil.

Period of time, years	a_1 —	l_1 $year^{-1}$	a_2 —	l_2 $year^{-1}$
$0 \le t \le 1$ year	0.61	1.25	0.39	- 0.4
$0.5 \le t \le 16.5$ years	0.4407	0.18	0.4068	$2.75 \bullet 10^{-3}$
$16.5 \le t \le 100$ years	0.5345	0.18	0.4934	$1.375 \bullet 10^{-2}$

computational models and accuracy of data on contamination levels of caesium isotopes.

Only in case of the Northern sector of the “near zone” the contribution of nuclides other than caesium isotopes to the total exposition dose in air delivered over the 70 after the Chernobyl accident has reached about 25%.

It is well known, that radioactive contamination of the soil in the major part of the affected territories of Belarus, the Russian Federation and the Ukraine is similar to contamination in “caesium spots”.

This fact simplifies the assessment of collective irradiation doses of the affected population in Belarus, Russia and the Ukraine because it allows to use some uniform data that transform data on the initial surface contamination of the soil to external exposition doses.

According to the data given in Table 1, the total exposition dose of external radiation in air at a reference height of 1 m delivered over the 70 years after the Chernobyl accident in an area with ^{137}Cs isotope contamination equal to 1 Ci/km^2 is about 1,700 mR.

The contribution of the ^{137}Cs isotope to the total exposition dose is about 1,311 mR or 77.4 percent within the 70 years period.

DOSE RATES AND DOSES IN SETTLEMENTS ENVIRONMENT

It is clear that the data established for the areas with undisturbed soil can not be used for assessment of the collective irradiation doses delivered by external radiation because only a small fraction of population affected by the Chernobyl accident has a regular access to such areas.

For example it was established by the Ukrainian specialists [7] that children at the age of 7 years and under living in contaminated areas spend only 13 percent of the day outside the houses and other buildings. This means automatically that such children forming the most sensitive subpopulation to irradiation spend 87 percent of day inside the buildings and at least 87 percent of their time in settlements.

Children and teenagers at the age of 7-18 years according to the Ukrainian National Report [7] (see Table 4.1.3 on pages 4.18) spend about 18 percent of their time outside the buildings and this means about 82 percent inside the buildings.

The largest fraction of time outside the buildings spend pensioners. It reaches 36 percent of the day.

These data show that the inhabitants of contaminated areas spend about 20 percent of their time outside the buildings and 80 percent of time inside the buildings.

Table 7. Mean exposition dose rates in different areas of Bryansk oblast in autumn 1990 at a height of 1 m (μR/h) [24].

Settlement	Mean level of contamination, Ci/km^2	Street	Bench	Yard	Bed	Garden	House
Fedorovka	2.2	19	18	19	20	21	14
Glinnoe	5.2	27	23	27	28	28	15
Klintsy	5.9	20	19	19	21	22	14
Veliki Topol	7.1	28	28	27	30	32	16
Lopatni	8.1	32	30	31	34	34	17
Unoshevo	10.8	35	39	39	45	48	17
Lesnovka	15.9	54	51	49	61	73	26
Novo-zybkov	18.5	53	52	49	58	62	19
Gordeevka	21.6	50	65	67	79	84	25
Zlynka	28.4	106	85	90	87	100	25
Vyshkov	29.6	82	85	89	100	109	47
Mirnyi	32.6	58	65	78	109	113	22
Staryi Vyshkov	33.9	145	132	108	112	143	32

Table 8. Mean exposition dose rates outside and inside the buildings in contaminated areas of Bryansk oblast in autumn 1990 at a height of 1 m (μR/h).

Settlement	Mean level of contamination, Ci/km^2	Outside the building	Inside the building
Fedorovka	2.2	19.4	14
Glinnoe	5.2	26.6	15
Klintsy	5.9	20.2	14
Veliki Topol	7.1	29	16
Lopatni	8.1	32.2	17
Unoshevo	10.8	41.2	17
Lesnovka	15.9	57.6	26
Novozybkov	18.5	54.8	19
Gordeevka	21.6	69	25
Zlynka	28.4	93.6	25
Vyshkov	29.6	93	47
Mirnyi	32.6	84.6	22
Staryi Vyshkov	33.9	128	32

These values show that at least 80 percent of time the inhabitants of contaminated areas spend in settlements or areas with disturbed soil.

Therefore, use of the data calculated for areas with undisturbed soil for the assessment of the collective dose will cause a significant overestimation of the collective doses.

In order to avoid this mistake one needs to correct the equations (10) and (11) by introducing an additional correcting factor K_S , which is determined as a ratio of the exposition dose rate in air measured in settlements to the exposition dose rate in air over the undisturbed soil measured at the same level of radioactive contamination.

The equations (10) and (11) can be then rewritten as follows:

$$\dot{R}_\gamma^*(t) = K_S \cdot K_L(t) \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma_i^0 \cdot \exp\left(-\frac{0.693}{T_{1/2}^i} \cdot t\right), \quad (13)$$

$$P_\tau^* = K_S \cdot \int_0^\tau K_L(t) \cdot \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma_i^0 \cdot \exp\left(-\frac{0.693}{T_{1/2}^i} \cdot t\right) \quad (14)$$

where:

$\dot{R}_\gamma^*($ = exposition dose rate at a reference height of 1 m in the settlements environment.

P_τ^* = exposition dose of external radiation in air at a reference height of 1 m in the settlements environment delivered over a period of time τ

We describe here a very simple method that allows to consider the differences in external radiation in settlements and in areas with the undisturbed soil. It is based on experimental data on exposition dose rates measured by specialists of the scientific organization "Typhoon" of the Goshydromet of the former USSR

[24].

Specialists of this organization have carried out extensive measurements of dose rates in autumn 1990 in different contaminated settlements of the Bryansk oblast.

They performed measurements of exposition dose rates in the streets, yards, on benches, over beds of kitchen gardens, in gardens and inside the houses as well. Dose rates measured in the course of this investigation and averaged for each studied settlement are given in Table 7.

On the basis of data given in columns 3-7 of Table 7 we can estimate the mean arithmetic dose rates outside the buildings, $\dot{R}_\gamma(t)_{\text{out}}$, by:

$$\dot{R}_\gamma(t)_{\text{out}} = \frac{\dot{R}_\gamma(t)_{\text{str.}} + \dot{R}_\gamma(t)_{\text{bn.}} + \dot{R}_\gamma(t)_y + \dot{R}_\gamma(t)_b + \dot{R}_\gamma(t)_g}{5} \quad \textbf{(15)}$$

where:

$\dot{R}_\gamma(t)_{\text{str.}}$ = exposition dose rates measured in the streets,

$\dot{R}_\gamma(t)_{\text{bn.}}$ = exposition dose rates measured at benches,

$\dot{R}_\gamma(t)_y$ = exposition dose rates measured in yards,

$\dot{R}_\gamma(t)_b$ = exposition dose rates measured over beds of kitchen gardens,

$\dot{R}_\gamma(t)_g$ = exposition dose rates measured in gardens.

Values of $\dot{R}_\gamma(t)_{\text{out}}$ determined this way are presented in the third column of Table 8. Here are also given the values of exposition dose rates measured by [24] inside the houses for comparison (see the fourth column of Table 8).

Values of $\dot{R}_\gamma(t)_{\text{out}}$ as a function of effective contamination levels, A*eff*, are also shown in Fig. 2. Here A*eff* is estimated by:

$$Aeff = \frac{1}{K_\gamma(^{137}Cs)} \cdot \sum_{i=1}^{n} K_{i,\gamma} \cdot A_i^0 \cdot \exp(-\frac{0.693}{T_{1/2}^i} t), \quad \textbf{(16)}$$

where:

$K_\gamma(^{137}Cs)$ = conversion factor of ^{137}Cs per unit deposition, (μR/h)/(Ci/km^2),

A_i^0 = initial surface contamination of the soil by *ith* nuclide.

Figure 2 shows the existence of a strong dependence of $\dot{R}_\gamma(t)_{\text{out}}$ from the effective contamination levels *Aeff* that can be described on the basis of the linear function:

$$\dot{R}_\gamma(t)_{\text{out}} = A + B \cdot Aeff, \quad \textbf{(17)}$$

where *A* and *B* are some constants.

They have a very easy meaning. As can be seen from (17), at *Aeff*→0 $\dot{R}_\gamma(t)_{\text{out}}$→*A*. It means that *A* is the exposition dose rate on territory not contaminated by the Chernobyl accident or the exposition dose rate of the background radiation. The constant *B* in the equation (17) is the exposition dose rate in autumn 1990 per unit of the effective contamination *Aeff*, (μR/h)/(Ci/km^2).

On the basis of the standard LSM procedure we have established the following values of *A* and *B*: *A*=8.555 μR/hr, *B* = 2.381 (μR/h)/ (Ci/km^2).

Substitution of quantities *A* and *B* into the equation (18) transforms it to:

$$\dot{R}_\gamma(t)_{\text{out}} = 8.555 + 2.381 \cdot Aeff, \quad \textbf{(18)}$$

where $\dot{R}_\gamma(t)_{\text{out}}$ is expressed in μR/h.

The solid line in Fig. 2 was drawn on the basis of the equation (18).

We have performed the same procedure with the data on measured exposition dose rates established by [24] inside the houses of settlements of the Bryansk oblast (see column 8 of Table 7 or column 4 of Table 8).

For the exposition dose rates inside the buildings $\dot{R}_\gamma(t)_{\text{in}}$, we have established the following formula:

$$\dot{R}_\gamma(t)_{\text{in}} = 11.814 + 0.505 \cdot Aeff \quad \textbf{(19)}$$

The solid line in Fig. 3 was calculated by means of the equation (19). One needs to notice much larger scattering of measured data from the solid line in Fig. 3 in comparison to Fig. 2.

This phenomenon has an easy explanation. Conditions of irradiation outside the houses and other buildings in different settlements of the Bryansk oblast do not differ very much. On the contrary - conditions of irradiation inside the houses and other buildings can differ very significantly. It is known that in rural settlement houses and other buildings are mostly constructed of wood that has much lower attenuation capability than brick or concrete used as a construction materials in urban settlements. Therefore, the exposition dose rates inside the urban buildings are lesser than in rural settlements even if the exposition dose rates outside the buildings are the same. This is a reason of much larger scattering of experimental points from solid line in Fig. 3 than in Fig. 2.

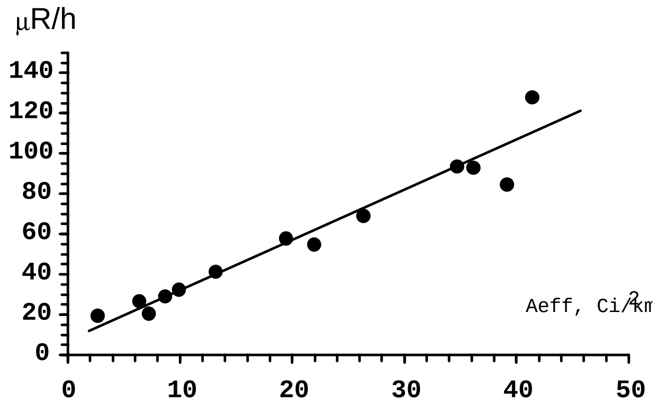

Fig. 2. Exposition gamma dose rates at a height of 1 m outside the buildings as a function of Aeff

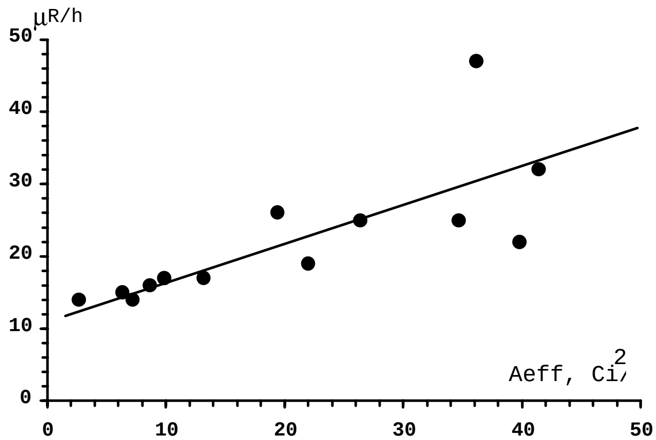

Fig. 3. Exposition gamma dose rates at a height of 1 m inside buildings as a function of Aeff

One needs to remember that the equations (18) and (19) can be used only for calculation of exposition dose rates outside and inside buildings in settlements environment in autumn 1990.

They can be transformed to such equations that will allow the assessment of the exposition dose rates at any arbitrary time *t*.

Let us rewrite the equation (16) in the following form:

$$Aeff\,(t) = \frac{A^0\,(^{137}Cs)}{K_\gamma\,(^{137}Cs)} \cdot F\,(t), \qquad \textbf{(20)}$$

where:

$A^0\,(^{137}Cs)$ = initial surface contamination by the nuclide ^{137}Cs,

$F\,(t)$ = some function of time.

This function is given by:

$$F\,(t) = \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma_i^0 \cdot \exp(-\frac{0.693}{T^i_{1/2}} \cdot t). \qquad \textbf{(21)}$$

On the basis of the equation (20) one can estimate $F\,(t)$ as:

$$F\,(t) = \frac{K\gamma\,(^{137}Cs)}{A^0\,(^{137}Cs)} \cdot A\,eff\,(t). \qquad \textbf{(22)}$$

Then the equation (13) can be rewritten as:

$$R_\gamma^*\,(t) = K_S \cdot K_L\,(t) \cdot \frac{K_\gamma\,(^{137}Cs)}{A^0\,(^{137}Cs)} \cdot Aeff\,(t). \qquad \textbf{(23)}$$

The value of $R_\gamma^*(t)$ in 1990 $R_\gamma^*(90)$, can be calculated from the following formula:

$$R_\gamma^*\,(90) = K_S \cdot K_L\,(90) \cdot \frac{K_\gamma\,(^{137}Cs)}{A^0\,(^{137}Cs)} \cdot Aeff\,(90), \qquad \textbf{(24)}$$

where:

$K_L\,(90)$ = numeric value of shielding factor originated from natural vertical migration of nuclides into the soil,

$Aeff\,(90)$ = effective contamination of the soil in 1990.

On the other hand the equation (18) can be written as:

$$\dot{R}_\gamma(90)_{out} = \dot{R}_{\gamma,bgr.} + \dot{R}_\gamma(90)_{ch}, \quad \textbf{(25)}$$

where:

$\dot{R}_\gamma(90)_{out}$	= exposition dose rate outside the building in settlements environment in autumn 1990,
$\dot{R}_{\gamma,bgr.}$	= exposition dose rate of background radiation; does not depend on time,
$\dot{R}_\gamma(90)_{ch}$	= contribution of Chernobyl nuclides to the exposition dose rate.

Comparison of the equations (18) and (25) gives:

$$\dot{R}_\gamma(90)_{ch} = 2.381 \cdot Aeff(90) \quad \textbf{(26)}$$

Let us transform the last equation by dividing its left and right parts by $A^0(^{137}Cs)$:

$$\frac{\dot{R}_\gamma(90)_{ch}}{A^0(^{137}Cs)} = 2.381 \frac{Aeff(90)}{A^0(^{137}Cs)}. \quad \textbf{(27)}$$

The left part of this the equation can be denoted as $\dot{R}^*_\gamma(90)_{ch}$. It is the exposition dose rate of external radiation normalized to the initial surface contamination by ^{137}Cs.

It is clear that:

$$\dot{R}^*_\gamma(90)_{ch} = \dot{R}^*_\gamma(90)_{ch}. \quad \textbf{(28)}$$

Combining the equations (24), (27) and (28) gives the following equation:

$$K_s \cdot K_L(90) \cdot \frac{K_\gamma(^{137}Cs)}{A^0(^{137}Cs)} \cdot Aeff(90) = 2.381 \cdot \frac{Aeff(90)}{A^0(^{137}Cs)}. \quad \textbf{(29)}$$

From here:

$$K_s \cdot K_L(90) \cdot K_\gamma(^{137}Cs) = 2.381. \quad \textbf{(30)}$$

The equation (30) can be rewritten as follows:

$$K_s = \frac{2.381}{K_L(90) \cdot K_\gamma(^{137}Cs)}. \quad \textbf{(31)}$$

Let us insert the correcting factor K_S determined by the equation (31) into the equation (23). After some changes this gives the following:

$$\dot{R}^*_\gamma(t) = \frac{2.381}{K_L(90)} \cdot \frac{1}{A^0(^{137}Cs)} \cdot Aeff^*(t), \quad \textbf{(32)}$$

where $Aeff^*(t)$ is determined by:

$$Aeff^*(t) = K_L(t) \cdot Aeff(t). \quad \textbf{(33)}$$

Multiplication of the left and right parts of the equation (32) by $A^0(^{137}Cs)$ gives:

$$\dot{R}(t)_{ch} = \frac{2.381}{K_L(90)} \cdot Aeff^*(t), \quad \textbf{(34)}$$

where:

$\dot{R}(t)_{ch}$	= exposition dose rate of external radiation at the time *t* at the initial surface contamination with ^{137}Cs originated from the Chernobyl accident equal to $A^0(^{137}Cs)$.

The numeric value of $K_L(90)$ can be estimated by means of the equation (12). It gives K_L = 0.604. Insertion of this value into the equation (34) transforms it into:

$$\dot{R}(t)_{ch} = 3.944 \cdot Aeff^*(t), \quad \textbf{(35)}$$

where:

3.944	= exposition dose rate in air per unit of the effective contamination expressed in (µR/h)/ (Ci/km^2).

The total exposition dose rate outside the buildings expressed in µR/h can be described by the following equation:

$$\dot{R}(t)_{out} = 8.555 + 3.944 \cdot Aeff^*(t). \quad \textbf{(36)}$$

The same procedure allows to develop the equation for calculation exposition dose rates in air inside the buildings (expressed in µR/h):

$$\dot{R}(t)_{ins} = 11.814 + 0.836 \cdot Aeff^*(t) \quad \textbf{(37)}$$

Here the numeric constant 11.814 in the part of the equation (37) determines the average exposition dose rate inside buildings, originated from the background radiation. The second member of the right part of this equation gives the contribution of the Chernobyl nuclides to the total exposition dose rate inside buildings, $\dot{R}(t)_{ch}$ (expressed in µR/h):

$$\dot{R}(t)_{ch} = 0.836 \cdot Aeff^*(t). \quad \textbf{(38)}$$

There are some arguments allowing to state that the equations (35)-(38) can be used for the assessment of the collective doses not only in settlements of the Bryansk oblast but outside of this area. These arguments are discussed below.

Data on measurements of exposition dose rates in air outside and inside were measured by specialists of the “Typhoon” in settlements of the Bryansk oblast that borders the Gomel oblast. That allows the supposition that (35)-(38) are also valid for contaminated territories in the Gomel oblast.

One also needs to consider that the major part of the total deposition of radioactive species in the

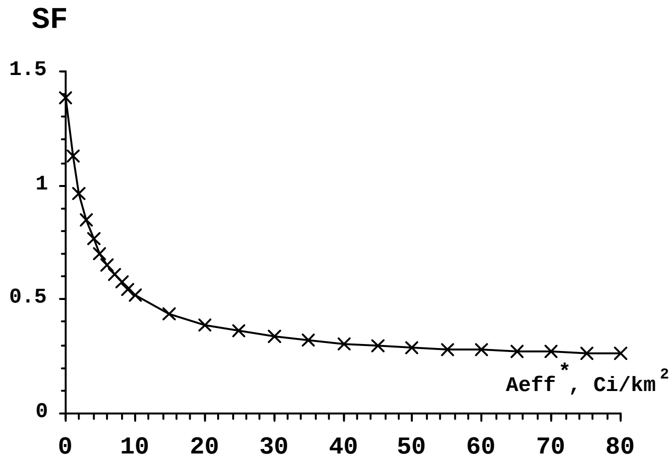

Fig. 4 Shielding factors as a function of contamination levels

former USSR lies in the Belarussian-Ukrainian Woodland with quite uniform geochemical characteristics. Moreover, urban and rural settlements in the affected areas of Belarus, Russia and the Ukraine are very similar as well as are the life-style and occupational activities of their inhabitants.

Our assumption on the similarity of irradiation of the Bryansk oblast inhabitants and inhabitants of other affected areas of the former USSR is also supported by the data on the natural radiation background in Belarus prior to the Chernobyl accident [25].

So according to the publication [25], the average exposure dose rate in air in 1981-1982 was 10.6 μR/h in urban areas of Minsk, Borisov, Vitebsk, Soligorsk and 9 μR/h in rural areas of Minsk rayon. These values very well agree with the dose rate of background radiation (~ 8.6 μR/h) that we have estimated for the settlements environment in the Bryansk oblast.

An additional evidence of justified application of the equations (18), (19) and (35)-(38) for assessment of exposition dose rates and doses in the settlements environment outside of the Bryansk oblast gives also a very good agreement between the shielding factors of buildings SF, calculated on the basis of the equations (18), (19) or (36), (37) and estimated on the basis of experimental data.

The shielding factors of buildings are expressed as a ratio of the exposition dose rates inside and outside the buildings.

They can be calculated on the basis of the equations (18), (19) or (35)-(38).

Figure 4 shows the shielding factor estimated by the following equation:

$$SF = \frac{11.814 + 0.836 \cdot Aeff^{*}}{8.555 + 3.944 \cdot Aeff^{*}}. \qquad \textbf{(39)}$$

As can be seen from Fig. 4 this factor decreases with the increase of the $Aeff^{*}$. Its value changes from about 1.4 at $Aeff^{*}$ = 0 (noncontaminated territory) to 0.4-0.3 in the interval of $Aeff^{*}$ from 20 to 80 Ci/km^2.

Table 9 demonstrates the data on the exposition dose rates in air outside of buildings that were calculated for different periods of time on the basis of the equation (35). Here are shown separately individual contributions of short-lived nuclides, isotopes of caesium as well as the total exposition dose rates. Data of Tables 1 and 3 have been also used by calculation of data given in Table 9.

On the basis of Table 9 we have calculated the air-absorbed doses inferred only by ^{137}Cs in settlements environment accumulated over different periods of time τ after the Chernobyl accident. Results of this calculation are presented in Table 10. There are also our estimates on the air-absorbed doses in areas of "caesium spots" with the undisturbed soil. They were calculated on the basis of data presented in Table 1 and 3 of our report.

We have also included in Table 10 the data estimated on the basis of data of Miller et al [27] and data used by J. Gofman [12] in his assessment of the Chernobyl consequences.

As it is known, J. Gofman [12] did not carry out a study for estimation of the air-absorbed doses inferred by the isotope ^{137}Cs. He had based his assessment on investigations conducted by H. Beck and G. de Planque [28] and recommendations of UNSCEAR [29].

Data in Table 10 shows that there is very good agreement between our values of air-absorbed doses estimated for areas with undisturbed soil and values of air-absorbed doses delivered in forest that we estimated on the basis of data [27]. Our doses calculated for areas with undisturbed soil as well very good agree with data estimated on the basis of data used by J. Gofman [12]. On the other hand, our results for settlements environment fall into intervals formed by data of Miller et al [27] estimated for plowed lands with depth plowing of 15 and 30 cm respectively.

It is also necessary to notice that our air-absorbed doses estimated for settlements environment practically coincide with the arithmetic mean values calculated on the basis of data [27] estimated for different depth of plowing.

For example, air-absorbed doses that we have estimated by use of data of Miller et al [27] for the period of time τ=70 years are 0.559 rad for the plowed land with depth plowing of 15 cm and 0.348 rad for depth plowing of 30 cm (see Table 10).

The arithmetic mean of these values is 0.453 rad. The last value is only about 7 percent higher than the value of air-absorbed dose that we have calculated for the settlements environment (0.425).

This agreement is surprising, especially, if one remembers that our estimations are based on experimental data of [24] established in areas of the Bryansk oblast affected by the Chernobyl accident and contaminated by ^{137}Cs to very high levels.

On the contrary, the data of K. Miller et al [27] have been established in course of experimental investigations of ^{137}Cs soil-penetration due to global fallout from atmospheric nuclear weapons tests. Moreover, these investigations have been carried out in the USA, which means in areas many thousand kilometers away from the contaminated territories of the Bryansk oblast.

Taking into consideration all arguments given above one can conclude that our method of dose rates estimation and doses described in this part of our report gives quite correct data.

One can also agree with our statement that the assessment of the collective doses delivered to the population affected by the Chernobyl accident has to be based on results estimated for the settlements environment. The use of data established for undisturbed soil for this purpose will cause an overestimation of the collective dose at least by factor 3. Taking in account this conclusion we shall carry out our further calculation on the basis of data given in Table 9.

The value of the mean equivalent dose of external radiation normalized to the level of contamination by ^{137}Cs equal to 1 Ci/km^2 can be estimated by use of data from Table 9 on the basis of the equation:

$$\overline{H^{*}_{\tau,ext}} = C_1 \cdot C_2 \cdot F_1 (F_2 + (1 - F_2) F_3) \cdot P_\tau , \qquad \textbf{(40)}$$

where:

- C_1 = conversion factor from exposition dose to tissue-absorbed dose (rad/R),
- C_2 = conversion factor from tissue-absorbed dose to equivalent dose (rem/rad),
- F_1 = correction factor (considers different factor that can influence the exposition dose in air, for example snow cover, etc.),

Table 9. Exposition doses in air at a height of 1 m in "caesium spots", accumulated during different periods of time after the Chernobyl accident (normalized to 1 Ci/km^2 of ^{137}Cs), in mR.

Periods of time, years	Short lived isotopes	^{134}Cs	^{137}Cs	All nuclides together
50	45.4	98.6	449	593
70	45.4	98.6	486.6	630.6
90	45.4	98.6	508.6	652.6

Table 10. Calculated doses of caesium-137 in air at a height of 1 m accumulated during different periods of time after deposition (given in rads) normalized to 1 Ci/km^2

Place	Period of time, years				Source of information
	50	70	90	Infinite time	
Forest	1.195	1.365	1.495	—	Kevin M. Miller et all [27]
Undisturbed field	0.707	0.807	0.866	—	Kevin M. Miller et all [27]
Plowed land (to 15 cm depth)	0.481	0.559	0.625	—	Kevin M. Miller et all [27]
Plowed land (to 30 cm depth)	0.296	0.348	0.370	—	Kevin M. Miller et all [27]
Undisturbed field	1.058	1.145	1.193	—	M.Malko, this paper
Settlement, outside the buildings	0.392	0.425	0.444	—	M.Malko, this paper
Used for assessment of the Chernobyl consequences	1.15*	1.25**		1.44	J.Gofman [12]

Notice: * this value is evaluated by multiplication of the value 1.44 rad per km^2 by factor 0.80;
** this value is evaluated by multiplication of the value 1.15 rad per km^2 by factor 0.425/0.392.

F_2 = occupancy factor (fraction of time spent outside the buildings, dimensionless),
F_3 = shielding factor of buildings (dimensionless).
P_τ = exposition dose in air (R).

By carrying out the calculations of $\overline{H^*_{\tau,ext}}$ we used the following numeric values of these factors: C_1=0.93 rad/R; C_2=0.72 rem/rad; F_1=1; F_2=0.2 [20], F_3=0.211.
We estimated the value of factor F_3 by use of the equations (35) and (38). Therefore: F_3 is determined by the equation:

$$F_3 = \frac{0.836 \cdot Aeff^*}{3.944 \cdot Aeff^*} = \frac{0.836}{3.944} = 0{,}212 \quad \textbf{(41)}$$

As can be seen from the equation (41), the shielding factor of buildings F_3 does not depend on the effective contamination level $Aeff^*$. It means that F3 is an uniform factor for all contaminated areas. The differences in shielding factors of buildings (39) and (41) arises from the fact, that the equation (39) determines the shielding effect of buildings from combined action of background radiation and Chernobyl nuclides. On the contrary, the equation (41) describes only the shielding effect against radiation caused by nuclides deposited on the ground as a result of the Chernobyl accident. As the task of our study is the assessment of the consequences of the Chernobyl accident we need to separate the influence of background radiation and radiation caused by the accident.

Insertion of the numeric values of the factors C_1, C_2, F_1, F_2 and F_3 into the equation (40) results in the following formula:

$$\overline{H^*_{\tau,\mathrm{ext}}} = 0.247 \cdot P_\tau . \quad \textbf{(42)}$$

The next step is estimation of the total mean equivalent dose $\overline{H^*_{\tau,ext}}$ normalized to the initial surface contamination by ^{137}Cs equal to 1 Ci/km^2.
On analogy to the equation (3) one can write:

$$\overline{H^*_\tau} = \frac{\overline{H^*_{\tau,\mathrm{ext}}}}{0.6} . \quad \textbf{(43)}$$

Combination of the two last equations gives:

$$\overline{H^*_\tau} = 0.412 \cdot P_\tau . \quad \textbf{(44)}$$

Application of the equation (44) to a 70 years period of time yields the following value of the normalized mean equivalent dose: $\overline{H^*_\tau}$ = 0.26 rem / 1 Ci/km^2. The last value was calculated by use of the value $P_\tau = 0{,}631 \cdot R$ given in Table 9.

SOURCE TERM

The total release of nuclides to the environment (source term) is an important parameter in any radiological accident because it determines the scale of this accident. Soon after the Chernobyl accident the Soviet specialists had suggested their data on the amounts of radionuclides that escaped from the destroyed Chernobyl reactor [19]. In this paper these data are presented in Table 11.

According to the estimations of the Soviet specialists about 100 MCi of different nuclides including 50 MCi of radioactive inert gases came into the environment over the 10 days after the first explosion at the reactor of the fourth unit of the Chernobyl NPP.

Later it was recognized that the data published in [19] were underestimated. For example, the UNSCEAR had shown in its report published in 1988 [20], that the total release of ^{137}Cs into the environment as a result of the Chernobyl accident had been in reality 2 times higher than claimed by the Soviet specialists.

According to the Ukrainian specialists [7] the total release of all radioactive isotopes during the accident at the Chernobyl NPP reached 10,813 PBq (about 296 MCi). This value is about factor 3 higher than the estimations of the specialists of the former USSR in 1986. The data of the Ukrainian specialists on the total release of nuclides from the Chernobyl reactor are presented in this paper in Table 12.

CAESIUM DEPOSITION IN BELARUS, RUSSIA AND THE UKRAINE.

Over the years that passed since the Chernobyl accident extensive measurements of contamination levels by ^{137}Cs have been undertaken in Belarus, Russia and the Ukraine. Results of these measurements allowed to establish the mean contamination levels by ^{137}Cs in many thousand settlements in these countries.

The total area of contaminated territories with initial levels of contamination by ^{137}Cs that change from some minimal value $A^0_{s,\min}$ to some maximal value $A^0_{s,\max}$ has also been determined.

As a rule 6 different intervals for characterizing of areas of contamination were established:

0.27-0.54 Ci/km^2 (10-20 kBq/m^2);
0.54-1.0 Ci/km^2 (20-37 kBq/m^2);
1-5 Ci/km^2 (37-185 kBq/m^2);
5-15 Ci/km^2 (185-555 kBq/m^2);
15-40 Ci/km^2 (555-1480 kBq/m^2);
and higher than 40 Ci/km^2 (> 1480 kBq/m^2).

Table 11. Radionuclide composition of discharge from damaged unit of Chernobyl nuclear power plant* [19]

Nuclide***	Activity of discharge, MCi 25.04.86	06.05.86**	Fraction of activity discharge from reactor on 6 May 1986, %
^{133}Xe	5	45	Possibly up to 100
^{85m}Kr	0.15	—	- " -
^{85}Kr	—	0.5	- " -
^{131}I	4.5	7.3	20
^{132}Te	4	1.3	15
^{134}Cs	0.15	0.5	10
^{137}Cs	0.3	1	13
^{99}Mo	0.45	3	2.3
^{95}Zr	0.45	3.8	3.2
^{103}Ru	0.6	3.2	2.9
^{106}Ru	0.2	1.6	2.9
^{140}Ba	0.5	4.3	5.6
^{141}Ce	0.4	2.8	2.3
^{144}Ce	0.45	2.4	2.8
^{89}Sr	0.25	2.2	4.0
^{90}Sr	0.015	0.22	4.0
^{239}Np	2.7	1.2	3.2
^{238}Pu	$0.1 \bullet 10^{-3}$	$0.8 \bullet 10^{-3}$	3%
^{239}Pu	$0.1 \bullet 10^{-3}$	$0.7 \bullet 10^{-3}$	- " -
^{240}Pu	$0.2 \bullet 10^{-3}$	$1 \bullet 10^{-3}$	- " -
^{241}Pu	0.02	0.14	- " -
^{242}Pu	$0.3 \bullet 10^{-6}$	$2 \bullet 10^{-6}$	- " -
^{242}Cm	$3 \bullet 10^{-3}$	$2.1 \bullet 10^{-2}$	- " -

*) Error of estimate ± 50%

**) Total discharge up to 6 May 1986

***) The data presented relate to the activity of the main radionuclides measured on radiometric analyses

Table 12. Radionuclide composition in the active core before the accident and in the total discharge recalculated on 26.04.1986 [7].

Inventory of the active core before the accident (26.04.1986)			Total discharge recalculated on (26.04.1986)	
Nuclide	Half life	Activity (PBq)	Released fraction of inventory, %	Activity (PBq)
^{133}Xe	5.3 d	6 500	100	6500
^{131}I	8.0 d	2 300	50-60	-1760
^{134}Cs	2.0 a	180	20-40	-54
^{137}Cs	30.0 a	280	20-40	-85
^{132}Te	78.0 h	2 700	25-60	-1150
^{89}Sr	52.0 d	2 300	4-6	-115
^{90}Sr	28.0 a	200	4-6	-10
^{140}Ba	12.8 d	4 800	4-6	-240
^{95}Zr	1.4 h	5 600	3.5	196
^{99}Mo	67.0 h	4 800	> 3.5	> 168
^{103}Ru	39.6 d	4 800	> 3.5	> 168
^{106}Ru	1.0 a	2 100	> 3.5	> 73
^{141}Ce	33.0 d	5 600	3.5	196
^{144}Ce	285.0 d	3 300	3.5	-116
^{239}Np	2.4 d	27 000	3.5	-95
^{238}Pu	86.0 a	1	3.5	0.035
^{239}Pu	24 400.0 a	0.85	3.5	0.03
^{240}Pu	6 580.0 a	1.2	3.5	0.042
^{241}Pu	13.2 a	170	3.5	-6
^{242}Cm	163.0 d	26	3.5	-0.9
Total		73559.05		-10933.007

Notice: The discharge activity recalculated on 6 May 1986 is about 2000 PBq

The data on the total area of contaminated territories of Belarus, Russia and the Ukraine characterized by these intervals of contamination levels by ^{137}Cs are presented in Tables 13-16.

The data given there allow to estimate the minimal amounts of ^{137}Cs deposited in Belarus, Russia and the Ukraine by means of the following equation:

$$Q^{i}_{min} = A^{0,i}_{s,min} \cdot S_i , \qquad (45)$$

where:

Q^{i}_{min} = the minimal amounts of ^{137}Cs deposited on the area with the initial contamination by ^{137}Cs equal to $A^{0,i}_{s,min}$ (Ci);

S_i = the area of territories contaminated by ^{137}Cs at the level $A^{0,i}_{s,min}$ (km^2).

The results of our calculation on the basis of the equation (45) are given in Table 17. In case of Belarus this method gives $Q^{i}_{min} = 260{,}000$ Ci.

Division of this minimal deposition value of ^{137}Cs, Q^{i}_{min} by the total area of Belarus (207.6 thousand square kilometers) gives the following minimal average contamination of the total territory of Belarus by ^{137}Cs:

$$A_{s,min} \approx 1.25 \text{ Ci / km}^2 \text{ or } 46.3 \text{ kBq / m}^2 .$$

It is interesting to notice that the UNSCEAR performed its assessment of the collective irradiation doses originated from the Chernobyl accident by the average contamination of Belarus equal to 39 kBq/m^2 [20]. This value is about 20 percent lower than the value 46.3 kBq/m^2 which was calculated on the basis of the equation (45).

It is clear that the real average contamination of Belarus by ^{137}Cs has to be higher than 1.25 Ci/km^2. We have developed a simple method for estimation of more correct data on the total contamination of Belarus by ^{137}Cs.

The corrected amount of the deposited ^{137}Cs, Q_{tot}, as a result of the Chernobyl accident can be calculated by the following equation:

$$Q_0 = \sum_{i=1}^{N} \overline{A^{0}_{s,i}} \cdot \Delta S_i \qquad (46)$$

Table 13. Contaminated areas in Belarus with the level of caesium-137 equal to 1 Ci/km^2 or higher (square kilometers) [31].

Oblast	Level of contamination, Ci/km^2			
	1-5	5-15	15-40	> 40
Brest	3800	470		
Vitebsk	35			
Gomel	16870	6740	2760	1625
Grodno	1690	12		
Minsk	2030	48		
Mogilev	5490	2900	1450	525
Total	29915	10170	4210	2150

Table 14. Contaminated areas in the Russian Federation with the level of caesium-137 equal to 1 Ci/km^2 or higher (square kilometers) [31].

Oblast	Level of contamination, Ci/km^2			
	1-5	5-15	15-40	> 40
Belgorod	1620			
Bryansk	6750	2628	2130	310
Voronezh	1320			
Kaluga	3500	1419		
Kursk	1220			
Lipetsk	1690			
Leningrad	850			
Nizhni Novgorod	15			
Orel	8840	132		
Penza	4130			
Ryazan	5210			
Saratov	150			
Smolensk	100			
Tambov	510			
Tula	10320	1271		
Uljanovsk	1060			
Total	48915	5450	2130	310

where:

N = number of all contaminated settlements;

$\overline{A^0_{s,i}}$ = the average level of initial surface contamination by ^{137}Cs in *i*th settlement, (Ci/km^2);

ΔS_i = area of the territory that belonged to *i*th settlement (km^2).

The equation (46) can be simplified in order to make the estimation of the value Q easier.

It is known that there is no significant difference in the population density in the affected regions of Belarus. The same conclusion can be made in relation to Russia as the Ukraine. It is also known that the majority of settlements in the affected regions have quite similar number of inhabitants.

Considering the abovementioned facts we can estimate the value of ΔS_i by:

$$\Delta S_i \approx \frac{S}{N}, \qquad (47)$$

where:

S = the total area of all contaminated territories.

Combination of the equations (46) and (47) gives:

$$Q_0 \approx S \cdot \sum_{i=1}^{N} \frac{\overline{A^0_{s,i}}}{N} = S \cdot \overline{A^0_s}, \qquad (48)$$

where:

$\overline{A^0_s}$ = contamination level by ^{137}Cs averaged over the total contaminated area (Ci/km^2).

As can be seen from the equation (48) the value of $\overline{A^0_s}$ is determined by the equation:

$$\overline{A^0_s} = \sum_{i=1}^{N} \frac{\overline{A^0_{s,i}}}{N}. \qquad (49)$$

The last equation was used for the calculation of the averaged levels for areas with the level of contamination $A^0_s \geq 1 Ci/km^2$. Results of the calculation performed on the basis of the experimental data on $\overline{A^0_{s,i}}$ presented in the publication [32] are given in Table 18. There are also the averaged levels of contamination by ^{137}Cs at levels of contamination $A^0_s \leq 1 Ci/km^2$. In this case the following equation was used:

Table 15. Contaminated areas in the Ukraine with the level of caesium-137 contamination equal to 1 Ci/km^2 (square kilometers) [31].

Oblast	Level of contamination, Ci/km^2			
	1-5	5-15	15-40	> 40
Vinnitsy	1944	38		
Volyn	582			
Dnepropetrovsk	38			
Donetsk	410			
Zhitomir	9192	1780	336	154
Ivano-Frankovsk	606			
Kiev	7695	957	546	417
Kirovograd	219			
Nikolaev	24			
Odessa	27			
Rovno	9332	181		
Sumy	491			
Ternopol	357			
Cherkasy	3233	72		
Chernigov	2221	135		
Chernovtsy	500	14		
Kharkov	31.4	16		
Chmelnitsk	319			
Total	37205	3177	882	571

Table 16. Caesium-137 contaminated areas in Belarus, the Russian federation and the Ukraine with level 10-37 kBq/m^2 [6].

Countries	Area (in 1000 km^2) contaminated above specified levels	
	10-20	20-37
Belarus	60	30
Russia	300	100
Ukraine	150	65

Table 17. Minimal deposition of caesium-137 on territories of Belarus, the Russia Federation and the Ukraine

Range of contamination, Ci/km^2	Q, Ci		
	Belarus	Russia	Ukraine
0.27-0.54 (10-20 kBq/m^2)	16200	81000	40500
0.54-1 (20-37 kBq/m^2)	16200	54000	35100
1-5	29915	48915	37205
5-15	50850	27250	15885
15-40	63150	31950	13230
> 40	86000	12400	22840
Total deposition	262315	255515	164760
Rounded total deposition, Ci	260000	255000	165000

Table 18. Calculated average contamination levels in different affected areas of Belarus.

Range of contamination levels, Ci/km^2	Average contamination level, Ci/km^2
0.27-0.54 (10-20 kBq/m^2)	0.405
0.54-1.0 (20-37 kBq/m^2)	0.77
1-5	2.98
5-15	8.58
15-40	24.30
> 40	52.7

Table 19. Total deposition of caesium-137 on territories of Belarus, the Russian Federation and the Ukraine.

Range of contamination levels, Ci/km^2	Q, Ci		
	Belarus	Russia	Ukraine
0.27-0.54 (10-20 kBq/m^2)	24300	121622	60810
0.54-1 (20-37 kBq/m^2)	23100	77027	50066
1-5	89147	145767	110871
5-15	87259	46761	27259
15-40	102305	51759	21433
> 40	113305	16337	30092
Total deposition, Ci	439414	459273	300531
Rounded total deposition, Ci	440000	460000	300000

$$\overline{A_s^0} = \frac{A^0_{s,\min} + A^0_{s,\max}}{2}. \qquad \textbf{(50)}$$

By use of the data given in Tables 13-16 and 18 data on the initial contamination of the affected areas in Belarus, Russia and the Ukraine were calculated. Table 19 shows the results of this calculation. The data given in Tables 17 and 19 show that the described method of calculation has given increased amounts of deposited 137Cs in Belarus, Russia and the Ukraine by factor 1.7 (Belarus) -1.8 (Russia, Ukraine) estimations made on the basis of the equation (45).

One needs to notice that the amount of ^{137}Cs deposited in the Ukraine which is shown in Table 19 does not include big amounts of this isotope in the 30 kilometer zone. According to the Ukrainian National Report [7] there is about 470 thousand Ci of ^{137}Cs in temporary storages of radioactive materials, in the soil, in hydrosystems, etc.

By taking into account this value and the data on the deposition of ^{137}Cs in Belarus, Russia and the Ukraine given in Table 19 as well as the data on the deposition of this isotope outside of the former USSR (1.2 MCi [20]) one can assess the approximate amounts of ^{137}Cs that was discharged from the destroyed Chernobyl reactor. It reaches 2.87 MCi. Summing up this number with the amounts of ^{137}Cs deposited in the Baltic States and Countries of the CIS other than Russia, Belarus and the Ukraine one can assess the total discharge of ^{137}Cs to the environment as a result of the Chernobyl accident equal to about 3 MCi of the core inventory of this nuclide before the accident. The last figure coincides with upper limit of the estimations given in publication [7].

COLLECTIVE DOSE ASSESSMENT

As it was shown earlier, the collective irradiation dose can be calculated by means of the equation (1). It is possible to use for this purpose the equation:

$$H_\tau^{coll} = N \cdot \overline{H_\tau^*} \cdot \overline{A_S^0} \qquad \textbf{(51)}$$

Insertion of the value A_S given by (6) into the equation (51) gives the following:

$$H_{\tau}^{coll} = N \cdot \overline{H_{\tau}^{*}} \cdot \frac{Q^{0}}{S} \quad \textbf{(52)}$$

The total number of the inhabitants of the affected areas N can be estimated by the following:

$$N = \overline{\rho} \cdot S, \quad \textbf{(53)}$$

where:

$\overline{\rho}$ = the average population density in contaminated areas (man/km^2).

The combination of equations (52) and (53) gives:

$$H_{\tau}^{coll} = \rho \cdot H_{\tau}^{*} \cdot Q^{0} \quad \textbf{(54)}$$

Results of the collective equivalent doses calculation that can be delivered to affected population of Belarus, Russia and the Ukraine within the period of 70 years after the Chernobyl accident are obtained on the basis of the equation (54) and are given in Table 20. This table also contains data on the total deposition of the isotope ^{137}Cs in Belarus, Russia and the Ukraine, the total areas of contaminated territories of these states as well as the data on the mean contamination levels, mean population density and mean dose delivered over 70 years on a territory with the contamination level by ^{137}Cs equal to 1 Ci/km^2.

The data on population density presented in Table 20 were calculated for 1986 on the basis of data of the statistical handbook of the USSR [33]. Analysis of data given in Table 20 shows that the highest equivalent irradiation dose has to be delivered to the Ukrainian population. It can be estimated as $6.6 \cdot 10^4$ man·Sv over 70 years. The collective equivalent irradiation doses of inhabitants of the affected areas of Belarus and Russia according to our estimation are $5.5 \cdot 10^4$ and $4.4 \cdot 10^4$ man·Sv respectively. At the same time the highest mean individual equivalent dose can be delivered to inhabitants of the contaminated territories of Belarus. It is practically 3 times higher than the respective values estimated for Russia and the Ukraine.

ASSESSMENT OF COLLECTIVE THYROID DOSES

The assessment of collective thyroid doses delivered to the population of Belarus, Russia and the Ukraine can be performed on the basis of the data established in the course of extensive studies by V. Stepanenko, A. Tsyb, Yu. Gavrilin et al. [34].

By use of the experimental data on [31] accumulation in thyroid measured within the first days after the nuclear explosion at the Chernobyl accident these Russian specialists estimated the collective thyroid dose of 3,674,000 residents of contaminated territories of 7 oblasts of Russia (Bryansk, Tula, Kaluga, Orel, Riasan, Kursk, Leningrad) as 234,000 person·Gy. [34]. This value can be used for the estimation of the factor q_{th} that determines the collective thyroid dose commitment per unit deposition of ^{131}I.

In order to fulfill this task one needs to determine the total deposition of ^{131}I in “7 oblasts” of the Russian Federation. It can be done by means of the equation:

$$Q_{7}^{0}(^{131}I) = \psi \cdot Q_{7}^{0}, \quad \textbf{(55)}$$

where:

$Q_7^0(^{131}I)$ = total deposition of ^{131}I in 7 oblasts of Russia,

Q_7^0 = total deposition of ^{137}Cs in 7 oblasts of Russia,

ψ = correlation factor averaged over the total area of contaminated territories of “7 oblasts” expressed as a ratio of surface contamination level by ^{131}I to surface contamination by ^{137}Cs

Experimental values of the factor ψ at 23.05.1986 measured in different settlements of Belarus and Russia [35] are given in Table 21 of this report.

Table 22 shows the values of the factor ψ recalculated to 26.04.1986. On the basis of these values we have estimated the mean values of factor ψ

Table 20. Collective equivalent irradiation doses of populations of Belarus, the Russian Federation and the Ukraine.

Parameter	**Belarus**	**Russia**	**Ukraine**
Total deposition of caesium-137, Ci	440000	460000	300000
Total area of contaminated territories with level of caesium-137 ≥ 0.27 Ci/km^2 (10 KBq/m^2), in k m^2	136445	348915	256835
Mean contamination level, Ci/ km^2	3.225	1.318	1.168
Mean dose equivalent commitment during 70 years after the accident (normalized to 1 Ci/ km^2), rem	0.26	0.26	0.26
Mean population density, person/km^2	48.2	36.6	84.5
Total number of people living in contaminated areas	6576649	12770289	21702558
Collective dose, manrem	5514520	4376123	6590633
Collective dose in man Sv, rounded	5.5•10^4	4.4•10^4	6.6•10^4
Mean individual dose, rem	0.84	0.26	0.30

Table 21. Ratios of nuclide activities to Cs-137 activity in soil of different contaminated areas of Belarus and the Russian Federation by 23.05.1986 [35].

Settlement	^{131}I	^{103}Ru	^{134}Cs	^{95}Zr + ^{95}Nb	^{140}La + ^{140}Ba	^{90}Sr
Belarus						
Gomel	3.48	1.74	0.42	4.54	1.97	0.17
Mozyr	1.16	1.0	0.39	1.06	1.06	0.13
Pinsk	5.68	1.98	0.58	2.28	1.0	—
Zhitkovichi	1.78	3.89	0.53	2.22	1.67	—
Khoiniki	1.62	3.49	0.56	11.2	4.6	0.07
Jurovichi	1.47	2.50	0.43	6.47	2.21	0.06
Russia, Bryansk oblast						
Barsuki	0.64	0.86	0.54	0.13	0.30	0.11
Makarichi	0.74	0.93	0.4	0.08	0.39	—
Novozybkov	0.88	0.85	0.46	0.07	0.38	—
Nikolaevka	0.82	0.83	0.55	0.09	0.36	0.008
Berezovka	2.05	1.58	0.55	0.14	0.34	0.008
Svjatsk	1.17	1.11	0.56	0.13	0.31	0.03
Bartolomeevka	0.68	1.0	0.63	0.14	0.06	0.04
Russia,Kaluga oblast						
Zhisdra	0.91	1.0	0.52	0.03	0.25	—
Mileevo	0.95	0.85	0.53	0.1	0.37	—
Kolodjassy	0.95	1.01	0.56	0.07	0.31	—
RussiaTula oblast						
Belev	1.03	1.34	0.54	0.06	0.23	—
Plavsk	0.55	0.69	0.53	0.06	0.45	—
Dubovka	0.63	1.02	0.54	0.14	0.14	—
Uzlovaja	1.26	2.55	0.45	0.05	0.26	—

Table 22. Calculated values of I-131/Cs-137 activity ratio in contaminated areas of Belarus and the Russian Federation by 26.04.1986.

Settlement	I-131 / Cs-137 (23.05.86)	I-131 / Cs-137 (26.04.86)
Belarus		
Gomel	3.48	38.9
Mozyr	1.16	12.96
Pinsk	5.68	63.45
Zhitkovichi	1.78	19.9
Khoiniki	1.62	18.1
Jurovichi	1.47	16.4
Russia, Bryansk oblast		
Barsuki	0.64	7.15
Makarichi	0.74	8.27
Novozybkov	0.88	9.83
Nikolaevka	0.82	9.16
Berezovka	2.05	22.9
Svjatsk	1.17	13.1
Bartolomeevka	0.68	7.60
Russia, Kaluga oblast		
Zhisdra	0.91	10.2
Mileevo	0.95	10.6
Kolodjassy	0.95	10.6
Russia, Tula oblast		
Belev	1.03	11.7
Plavsk	0.55	6.14
Dubovka	0.63	7.04
Uzlovaja	1.26	14.1

for Russia and Belarus as 10 and 20 respectively.

By use of factor ψ=10 and the data given in Tables 14 and 18 we have calculated the total deposition of ^{131}I in "7 oblasts" of Russia as 2.24 MCi. By estimation of this value we did not take into consideration the contaminated territories in "7

Table 23. Collective thyroid dose of the affected populations in Belarus, the Russian Federation and the Ukraine.

Parameter	**Belarus**	**Russia**	**Ukraine**
Total deposition, Ci	8800000	4600000	6000000
Total area of contaminated territories, km^2	136445	456805	256835
Mean population density, person/km^2	48.2	36.6	84.5
Collective thyroid dose equivalent commitment per unit release, man.Sv/Bq	$3.90 \cdot 10^{-12}$	$2.95 \cdot 10^{-12}$	$6.80 \cdot 10^{-12}$
Thyroid collective dose, man.Sv	$12.7 \cdot 10^{5}$	$5.0 \cdot 10^{5}$	$15.0 \cdot 10^{5}$
Collective effective dose equivalent resulted from thyroid irradiation, man.Sv	$6.35 \cdot 10^{4}$	$2.5 \cdot 10^{4}$	$7.5 \cdot 10^{4}$
Mean individual dose of thyroid irradiation, rem	19.3	3.0	6.9

Table 24. Contributions of different nuclides to collective effective equivalent doses of irradiation during the period of 70 years after the Chernobyl accident.

Nuclide	**Belarus**	**Russia**	**Ukraine**
Short lived isotopes other than ^{131}I, man.Sv	$0.4 \cdot 10^{4}$	$0.38 \cdot 10^{4}$	$0.48 \cdot 10^{4}$
^{134}Cs, man.Sv	$0.86 \cdot 10^{4}$	$0.68 \cdot 10^{4}$	$1.03 \cdot 10^{4}$
^{137}Cs, man.Sv	$4.24 \cdot 10^{4}$	$3.34 \cdot 10^{4}$	$5.09 \cdot 10^{4}$
^{131}I, man.Sv	$6.35 \cdot 10^{4}$	$2.5 \cdot 10^{4}$	$7.5 \cdot 10^{4}$
Total collective effective equivalent dose, man.Sv	$11.85 \cdot 10^{4}$	$6.9 \cdot 10^{4}$	$14.1 \cdot 10^{4}$

*) Notice: these values were estimated by multiplication of collective thyroid doses by organ weighting factor 0.05 [36].

Table 25. Collective effective dose equivalent commitments per unit release of caesium and iodine nuclides.

Country, organization	Period of time, years	^{134}Cs	^{137}Cs	^{131}I
		man.Sv		
Belarus	50	$1.06 \cdot 10^{-12}$	$2.42 \cdot 10^{-12}$	$1.95 \cdot 10^{-13}$
	70	$1.06 \cdot 10^{-12}$	$2.61 \cdot 10^{-12}$	$1.95 \cdot 10^{-13}$
Russia	50	$8.04 \cdot 10^{-13}$	$1.82 \cdot 10^{-12}$	$1.47 \cdot 10^{-13}$
	70	$8.04 \cdot 10^{-13}$	$1.96 \cdot 10^{-12}$	$1.47 \cdot 10^{-13}$
Ukraine	50	$1.86 \cdot 10^{-12}$	$4.23 \cdot 10^{-12}$	$3.38 \cdot 10^{-13}$
	70	$1.86 \cdot 10^{-12}$	$4.59 \cdot 10^{-12}$	$3.38 \cdot 10^{-13}$
UNSCEAR, 1988	50	$3 \cdot 10^{-12}$	$6 \cdot 10^{-12}$	$1 \cdot 10^{-13}$

oblasts” of Russia with the contamination levels by ^{137}Cs less than 1 Ci/km^2.

Division of the collective thyroid dose established by V. Stepanenko, A. Tsyb, Yu. Gavrilin et al [34] for the residents of “7 oblasts” by the assessed deposition of ^{131}I one can obtain the value of q_{th} factor equal to $2.82 \cdot 10^{-12} \cdot Gy/Bq$ or approximately $2.82 \cdot 10^{-12} \cdot Sv/Bq$.

In order to emphasize the fact that the numerical values of q_{th} given above have been estimated on the basis of the data established by [34] for residents of “7 oblasts” we shall describe it as $q_{th,7}$.

Multiplication of $q_{th,7}$ by the thyroid weighting factor 0.05 [36] converts it to the collective effective dose equivalent commitment per unit release of ^{131}I equal to $1.41 \cdot 10^{-13}$ man·Sv/Bq. The last value only insignificantly differs from the collective effective dose equivalent commitment per unit release of ^{131}I estimated in 1988 by UNSCEAR in its assessment of the Chernobyl accident consequences. This surprising agreement is a very important evidence of sound scientific backgrounds of the methods used by UNSCEAR [20] and by V. Stepanenko, A. Tsyb, Yu. Gavrilin et al in estimation of collective thyroid doses resulted from the Chernobyl accident. It also states that the numeric value of $q_{th,7} = 2.82 \cdot 10^{-12}$ man·Sv/Bq can be used as the reference value of this factor. It is necessary to notice that the factor $q_{th,7}$ is a function of population density. Therefore, one needs to correct the numeric value of $q_{th,7}$ in case of population density ρ that differs from the average population density in “7 oblasts” of the Russian Federation. It can be made by means of the following equation:

$$q_{th} = q_{th,7} \cdot \frac{\rho}{\rho_7}, \qquad (56)$$

where:

q_{th} = the collective thyroid dose commitment per unit of ^{131}I deposition (man·Sv/Bq) by arbitrary population density,

$q_{th,7}$ = the collective thyroid dose commitment per unit of ^{131}I deposition (man·Sv/Bq) established on the basis of “7 oblasts” data,

ρ = population density in contaminated area (persons per km^2),

ρ_7 = population density in contaminated areas of "7 oblasts" of the Russian Federation.

Table 23 presents the data on the collective thyroid doses estimated for population of Belarus, Russia and the Ukraine by means of factor q_{th} calculated on the basis of the equation (56).

These data can be possibly considered as upper limits of collective thyroid doses delivered to the populations of Belarus, Russia and Ukraine.

The total amounts of ^{131}I deposited in these countries were calculated by means of the data on ^{137}Cs deposition presented in Table 19 as well as the following numeric values of factor ψ: 10 for Russia and 20 for Belarus and the Ukraine.

As can be concluded from the above-discussed facts, the correctness of the collective thyroid dose estimations is fully determined by the correctness of ^{131}I depositions. This means that each improvement in the estimation of the total amounts of ^{131}I deposited in areas affected by the Chernobyl accident will improve estimation of the collective thyroid doses.

The results of our estimations given in Table 23 show that the highest collective thyroid dose was delivered to the Ukrainian population and the lowest to the population of Russia. On the contrary, as can be seen from Table 23, the highest mean individual thyroid dose was estimated for the residents of the contaminated territories of Belarus. It is higher by factor 6.4 than the mean individual thyroid dose in Russia and by factor 2.8 than the mean individual thyroid dose in the Ukraine.

Table 23 as well contains the data on the collective effective dose equivalents resulted from irradiation of people by ^{131}I in Belarus, Russia and the Ukraine. Table 24 shows the individual contributions of different isotopes to the total collective effective equivalent doses calculated on the basis of data given in the tables 20 and 23. The collective effective dose equivalent commitments per unit release of caesium and iodine nuclides are shown in Table 25.

LIFETIME MORTALITY RISK FROM SOLID CANCERS AND LEUKEMIA

The latest estimations of the risk coefficient of radiation induced solid cancers and leukemia are shown in the Table 26. In our prognosis of delayed radiological effects we have used the data of the UNSCEAR 94 [37] that are 2-fold less than the data estimated in 1994 by J. Gofman [38].

We preferred the UNSCEAR 1994 risk coefficient of radiation-induced solid cancers due to the following reason. It is well known that the risk coefficient of solid cancers induced by radiation is proportional to the frequency of spontaneous cancers which is a function of the life expectancy. J. Gofman [38] had obtained his value on the basis of the Vital Tables of the USA population. However, the life expectancy of the American population is 10-15 years higher than the life expectancy in Belarus, Russia and the Ukraine [33, 39].

So, even in case the UNSCEAR will in future increase its estimations of the risk coefficient of radiation-induced solid cancers one needs to remember that estimations of the UNSCEAR are based on the data established for the atomic bomb survivors that have been living in a country with a very high life expectancy in comparison to the life expectancy of the people in Belarus, Russia and the Ukraine. One also needs to remember that in contrast to the USA, Japan and other developed countries characterized by a permanent increase of life expectancy, Belarus, Russia and the Ukraine have a permanent decrease of life expectancy.

PROGNOSIS OF STOCHASTIC EFFECTS

The estimations of the possible stochastic effects in the effected areas of Belarus, Russia and the Ukraine are given in Table 27. The data on morbidity and mortality from radiation-induced thyroid cancers were calculated by use of the data on the collective thyroid doses presented in Table 23 and the risk coefficients $160 \cdot 10^{-4} Sv^{-1}$ and $16 \cdot 10^{-4} Sv^{-1}$, respectively. The latter coefficients were estimated by the following method. According to the data given in the Table B-17 of ICRP Publication 60 [36] (see p.132 of Publication 60) the risk coefficient of fatal thyroid cancer for low dose, low dose rate and Low LET radiation (DDREF is equal 2) is $8 \cdot 10^{-4} Sv^{-1}$. For the case of an acute or quasi-acute irradiation (Chernobyl case) one needs to use as a risk coefficient of fatal thyroid cancer a value 2 fold higher or $16 \cdot 10^{-4} Sv^{-1}$ (DDREF=1). From here one can receive the lifetime morbidity risk coefficient $160 \cdot 10^{-4} Sv^{-1}$ as used for calculation of data shown in Table 27.

The data on mortality from solid cancers other than thyroid cancer were used on the basis of the risk coefficient from solid cancers estimated in 1994 by the UNSCEAR and "corrected" for fatal thyroid cancers. The "correction" was in reality a subtraction of the value $16 \cdot 10^{-4} Sv^{-1}$ from the value $1{,}090 \cdot 10^{-4} Sv^{-1}$ estimated by the UNSCEAR. One can receive on this simplified way the value $1{,}074 \cdot 10^{-4} Sv^{-1}$ as a risk coefficient for fatal solid cancers other than thyroid cancers. Such "corrected" risk coefficient was used in assessment of fatal cancers in Belarus, Russia and the Ukraine resulted from the Chernobyl accident.

By the calculation of leukaemia mortality we used the value $110 \cdot 10^{-4} Sv^{-1}$ determined by the UNSCEAR in 1994 [37].

According to our estimations the Chernobyl accident will cause about 20,000 additional thyroid cancers among children and adults of the affected areas of Belarus. About 10 per cent of this number can be fatal (2,000 fatal thyroid cancers). We have estimated the number of radiation-induced thyroid cancers in Russia as 8,000 (800 fatal thyroid cancers). For the Ukraine we predicted 24,000 additional thyroid cancers (2,400 fatal thyroid cancers). Considering our method of collective thyroid doses assessment one can believe that these data on the number of additional thyroid cancers are upper limits of possible thyroid cancers.

As can be seen from this Table, the numbers of additional fatal thyroid cancers in each state is similar to the numbers of additional leukaemia and about 10 times less than the numbers of additional fatal solid cancers other than thyroid cancer.

We have assessed the total number of radiation-induced fatal cancers and leukaemia in Belarus, Russia and the Ukraine, as a result of the Chernobyl accident as about 44,000 with 16,030 cases in Belarus, 8,960 in Russia and 19,050 in the Ukraine.

As it was said above we have carried out our assessment only for populations living in the contaminated areas of these countries. We have estimated the total deposition of ^{137}Cs in these areas as 1.2 MCi (total deposition of ^{134}Cs about 0.6 MCi). The same amount of ^{137}Cs deposited in the countries outside the former USSR. If we assume that the number of radiation-induced cancers and leukaemia outside the former USSR caused by the Chernobyl accident will be the same as the total number of solid cancers and leukaemia in Belarus, Russia and the Ukraine because of similar deposition of ^{137}Cs, we will also obtain about 44,000 additional cancers and leukaemia for the countries outside the former USSR and about 90,000 fatal cancers for all the countries of the world including the former USSR. This assumption means that the Chernobyl accident will

Table 26. Lifetime solid cancers and leukemia mortality risk following acute whole body exposure to 1 Sv.

Projection method	Lifetime risk, %	Data source
Solid cancers		
Constant relative risk	10.9	[37]
Decline to risk for age at exposure 50 years	9.2	[37]
Decline to zero risk at age 90 years	7.5	[37]
Constant relative risk (UNSCEAR 1988)	9.7	[20]
Whole body Cancer Dose (J. Gofman - 1981)	37.31	[12]
Whole body Cancer Dose (J. Gofman - 1990)	26.64* 25.56**	[18] [18]
Whole Body Cancer Dose (J. Gofman - 1994)	23.37* 22.35**	[38] [38]
Leukemia		
Linear-quadratic dose response model	1.1	[37]
Constant relative risk (UNSCEAR 1988)	1.0	[20]

Notice: *) values determined by using T65DR dosimetric data of the RERF
**) values determined by using DS86 dosimetric data of the RERF

Table 27. Forecast of stochastic effects in Belarus, the Russian Federation, and the Ukraine as a result of the Chernobyl accident (DDREF = 1).

Effect	**Belarus**	**Russia**	**Ukraine**
Thyroid cancer (morbidity)	20300	8000	24000
Thyroid cancer (mortality)	2030	800	2400
Leukemia (mortality)	1300	760	1550
Solid cancers other than thyroid cancer (mortality)	12700	7400	15100
All cancers and leukemia (mortality)	16030	8960	19050

Table 28. Forecast of stochastic effects in Belarus, the Russian Federation, and the Ukraine as a result of the Chernobyl accident (DDREF = 2).

Effect	**Belarus**	**Russia**	**Ukraine**
Thyroid cancer (morbidity)	10150	4000	12000
Thyroid cancer (mortality)	1010	400	1200
Leukemia (mortality)	650	380	775
Solid cancers other than thyroid cancer (mortality)	6350	3700	7550
All cancers and leukemia (mortality)	8010	4480	9525

cause in the affected countries the number of fatal cancers and leukaemia which is similar to the death numbers resulted from atomic bombardment of Hiroshima or Nagasaki.

One may also assume that the total number of potential victims in case of such accident in a country with very high life expectancy and high population density, for example in Japan, will be much higher as in the case of the Chernobyl accident.

The data discussed above have been estimated by use of the factor DDREF=1, which is recommended by the ICRP for the case of acute irradiation by high doses and dose rates [36]. For chronic irradiation of the population by low doses the ICRP recommends the value of the reduction factor DDREFF equal to 2.

In the light of new data [37, 40, 41] it seems that even in cases of low doses and dose rates this factor is very close to 1 for solid cancers. But for leukaemia the DDREF factor is about 2.5 or even higher [37, 41]. For comparison only we have also carried out the estimations of additional stochastic effects assuming that DDREF=2. The results of such estimation are presented in Table 28.

We understand that the results of our assessment have rather qualitative than quantitative character because of many limitations in our study. For example we did not consider the possible interaction of radiation and chemical contamination in the affected areas of Belarus, Russia, and the Ukraine. This can be a reason for the very significant difference in predicted and manifested stochastic effects among the people affected by the Chernobyl accident. However, at present, there is no such quantitative information that could be used in assessment of radiological consequences of this accident in the areas having a very strong chemical contamination. Because of a lack of necessary information we also did not consider deterministic effects that could be even more important as radiological consequences in comparison with stochastic effects as well as genetic affects and effects of a very strong increase in the incidence of general somatic diseases in the affected areas established by Belorussian, Russian and the Ukrainian specialists soon after the accident. At the same time we believe that our data are quite accurate for solving of some problems that arose due to the Chernobyl accident. It is well known, that the reliable data on the increase of the morbidity on thyroid cancer among children of the affected areas of Belarus were established already at the end of the 80's [42,43]. Now, practically all specialists in the field of radiation biology and medicine recognise that this increase is the result of the Chernobyl accident [44]. However, at the end of 80's no such increase in the morbidity on thyroid cancer was established in Russia or in the Ukraine. This fact was considered by specialists of many countries as an evidence of incorrectly assessed data.

The difference in the change of the morbidity on thyroid cancer can be explained very easy on the basis of the data shown in Table 23. As it was said earlier, the highest mean individual thyroid doses were delivered by the Chernobyl accident to the residents of the affected areas of Belarus and the lowest to the Russian population. It is known that the latent periods of stochastic effects induced by the radiation depend from the irradiation doses. The lower the irradiation dose is, the longer is the latent period. This is an explanation why marked increase in the thyroid cancer incidence was registered first in Belarus and then in the Ukraine and later in Russia.

Our data can also answer the question why there are no reliable data on additional leukaemia among the residents of the affected areas of Belarus, Russia and the Ukraine up to present time [45-47]. This contrasts the data established among the Hiroshima and Nagasaki inhabitants that survived the atomic bombardment. Additional cases of leukaemia among them were registered firstly, and only then the radiation-induced solid cancer.

We suggest the following explanation for these differences in the manifestation of stochastic effects among the irradiated populations of Belarus, Russia, the Ukraine and the residents of Hiroshima and Nagasaki.

The survivors of the atomic bombardment of these Japanese cities received practically the same doses on bone marrow (the whole body dose) and on thyroid. The more earlier manifestation of leukaemia than thyroid cancers by inhabitants of Hiroshima and Nagasaki indicates that the latent period of leukaemia is shorter than the latent period of thyroid cancers when doses on bone marrow and thyroid are equal. Another situation arises in the case when thyroid doses are much higher than doses on bone marrow. Such situation has place by the people affected by the Chernobyl accident. Tables 20 and 23 demonstrate clearly that thyroid doses among the affected populations of Belarus, Russia and the Ukraine are practically one order in magnitude higher than doses on the whole body. This is according to our point view the reason of earlier manifestation of solid cancer (thyroid cancer) than leukaemia in Belarus, Russia and the Ukraine.

SUMMARY

An assessment of radiological consequences (stochastic effects) caused by the Chernobyl accident in Belarus, Russia and the Ukraine on the basis of experimental data on ^{131}I and ^{137}Cs in these countries has been carried out.

Results of this assessment show that the Chernobyl accident can be considered a real disaster. It can cause about 44,000 additional fatal cancers and leukaemia

among the affected populations of Belarus, Russia and the Ukraine.

On the basis of the data established in the course of this study explanations of some contradictions in manifestation of stochastic effects as a result of the Chernobyl accident have been suggested.

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Relationship between ^{131}I and ^{137}Cs Deposition on Soil in the Territory of Belarus after the Chernobyl Accident.

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As a result of the Chernobyl accident a large part of territory of Belarus had been contaminated with radioactive fallout. One of important radionuclides was ^{131}I which caused significant thyroid exposure in the most affected areas. Direct measurements of ^{131}I activity in thyroid and determination of ^{131}I concentration in foodstuffs and air were performed only in limited areas regions of the contaminated territory. Therefore, reconstruction of thyroid doses resulting from ^{131}I intake is important problem solution of which needs information of ^{131}I deposition on soil [1].

Izrael [2] noted expediency of using an isotope ratio of ^{131}I to ^{137}Cs content in soil for assessment of ^{131}I deposition in the areas where measured data on ^{131}I are absent or limited. The relationship between ^{131}I and ^{137}Cs deposition had been obtained by Mahonko et.al. [3] on the basis of data on ^{131}I and ^{137}Cs activity concentration in more than one hundred soil samples taken in the area located between cities Kiev (Ukraine) and Tula (Russia) (north-eastern direction from Chernobyl). The regression function derived by Mahonko et.al. [3] predicts an approximately linear increase of ^{131}I content in soil with a growth of ^{137}Cs deposition ($^{131}I \sim [^{137}Cs]^{0.85}$).

The analysis of measured data performed by Orlov et.al. [4] shows that the ^{131}I/^{137}Cs isotope deposition ratio R on soil in the European part of the former USSR increases in western regions. In particular the ratio R in the western part of Belarus is larger by 4-5 times than in the eastern part. The inhomogeneous deposition of radioactive dispersed materials makes it necessary to take a regional approach to dose reconstruction. In this connection the relationship between ^{131}I and ^{137}Cs content in deposition on soil in various contaminated areas of Belarus is studied in the present paper.

The data for the analysis of ^{131}I and ^{137}Cs activity concentration in soil have been taken from the report by Slizov et.al. [5]. Their samples were collected in the southern and the eastern parts of the territory of Belarus during May-June 1986. The location of the areas where samples were taken is shown in Fig. 1. Radionuclide activity was determined by gamma-ray spectrometer with semiconductor Ge(Li)-detector at the Institute of Nuclear Energy of Belarus Academy of Sciences (Minsk). All results of the measurements were given as values of activity on 10th May 1986. The numbers of soil samples taken in the southern and the eastern areas were 139 and 213, respectively.

The southern area includes five administrative districts of the Gomel region. The distance of the farthest west point of this area is about 190 km from Chernobyl. The eastern area is located in the territory of the Gomel and the Mogilev regions, including 6 and

Fig. 1 Location (shaded) wher soil samples had been taken in the Belarus territory: the southern area and the eastern area.

5 administrative districts, respectively. The extent of the eastern area from the south end to the north end is about 110 km. The level of ^{137}Cs contamination in soil of the studied areas varies from tens to thousands of kilo-becquerels per square meters and the distribution of ^{137}Cs deposition is highly non-uniform. The wide variability of deposition provides an opportunity to investigate the relationship between ^{131}I and ^{137}Cs content in soil over a wide range of contamination.

Relative frequency distributions of ^{131}I and ^{137}Cs activity concentration in soil of areas under consideration are presented in Figs. 2 and 3. The results of performed calculations show that empirical data can be described by log-normal distribution

$$f(x) = \left(\sqrt{2\pi}ax\right)^{-1} \exp\left[-(\ln x - b)^2 / 2a^2\right] \quad (1)$$

The parameter a in (1) characterizes skewness of the distribution and is defined as

$$a = \left[2(\ln E - \ln M)\right]^{1/2},$$

where E is the mean value, and M=e^b is the median of the distribution.

According to estimated parameters, the ^{137}Cs mean value characterizing the distribution of data obtained for the southern area (westward radioactive trace from Chernobyl - WRT) is larger by two times than the mean value in the case of the eastern area (northern radioactive trace — NRT) (see Figs. 2 and 3). At the same time the ^{131}I data obtained in the southern and the eastern areas are characterized by similar mean values. The observed behavior of parameters means that the isotope ratio of ^{131}I/^{137}Cs in deposition on soil in the studied areas can be characteristically different.

The empirical data presented in Figs. 2 and 3 were used to derive the relationships between ^{131}I and ^{137}Cs deposition on soil in the studied areas. It is noted that ^{131}I and ^{137}Cs activity concentration in soil are strongly variable. To minimize this variability and elucidate the relationship between ^{131}I and ^{137}Cs concentration, the empirical data were ln-transformed. As the ^{131}I and ^{137}Cs data follow the log-normal distribution, the ln-transformed quantities will obey the normal distribution which is more convenient for statistical treatment. Calculation of the relationship between ^{131}I and ^{137}Cs activity concentration have been performed without regard to the contribution of ^{137}Cs global fallout which is comparably small (~0.06 Ci/km^2) and has not remarkable influence on results. The relationships between ^{131}I and ^{137}Cs deposition are given in Fig. 4. The corresponding regression functions describing dependence of ^{131}I concentration on ^{137}Cs contamination level in soil of the southern and the eastern areas are written as

$$^{131}I = 14.58 \cdot \left(^{137}Cs\right)^{0.605} \qquad (2)$$

and

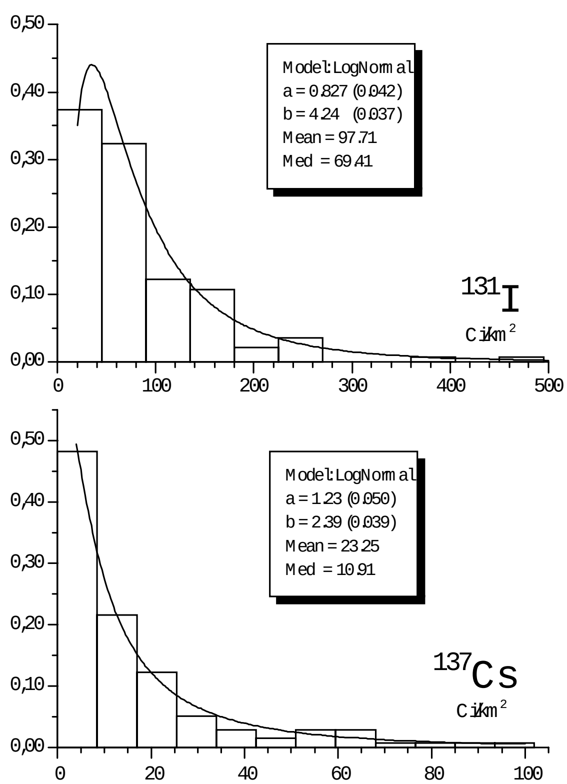

Fig. 2 Distribution of ^{131}I and ^{137}Cs activity concentration in soil of the southern area of Belarus.

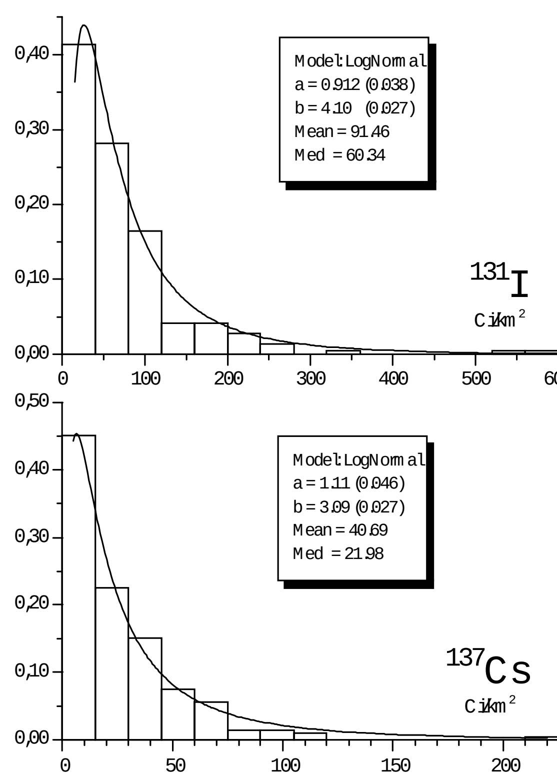

Fig. 3 Distribution of ^{131}I and ^{137}Cs activity concentration in soil of the eastern area of Belarus.

$$^{131}I = 8.85 \cdot \left(^{137}Cs\right)^{0.627} \qquad (3)$$

respectively, where levels of contamination are expressed with activity (Ci/km^2) on 10th May 1986.

The similar function was derived from analysis of the joined set of data including measurements for both studied areas (see Fig. 5). In this case the obtained regression equation is

$$^{131}I = 11.47 \cdot \left(^{137}Cs\right)^{0.591}. \qquad (4)$$

Using the regression equations (2), (3) and (4), the isotopic ratio R can be taken to be

$$R = C \cdot \left(^{137}Cs\right)^{-0.40}, \qquad (5)$$

where the coefficient C is equal 14.15, 8.85 and 11.47 for the southern, the eastern and the joined (southern + eastern) areas, respectively. According to coefficient C values, the isotope ratio R in deposition on soil in the southern area is larger by 1.6 times than in the eastern one.

The relationship (5) predicts that R values increase by a factor of about 4.8 with decreasing ^{137}Cs content of soil from 50 to 1 Ci/km^2. The observed behavior is in agreement with the data of Orlov et al. [4] who show that R values obtained in the western regions of Belarus where the level of soil contamination with ^{137}Cs is low (1-5 Ci/km^2) are higher by 3-5 times than in the strongly contaminated areas of the south-eastern and the eastern parts of Belarus.

Thus the results of the present study performed for a wide range of soil contamination with ^{137}Cs predicts non-linear behavior of ^{131}I/^{137}Cs isotope ratio in the studied areas of Belarus. Use of the obtained non-linear relationship between ^{131}I and ^{137}Cs content in soil may provide a more realistic regional estimation of ^{131}I deposition and help to improve radiological assessments.

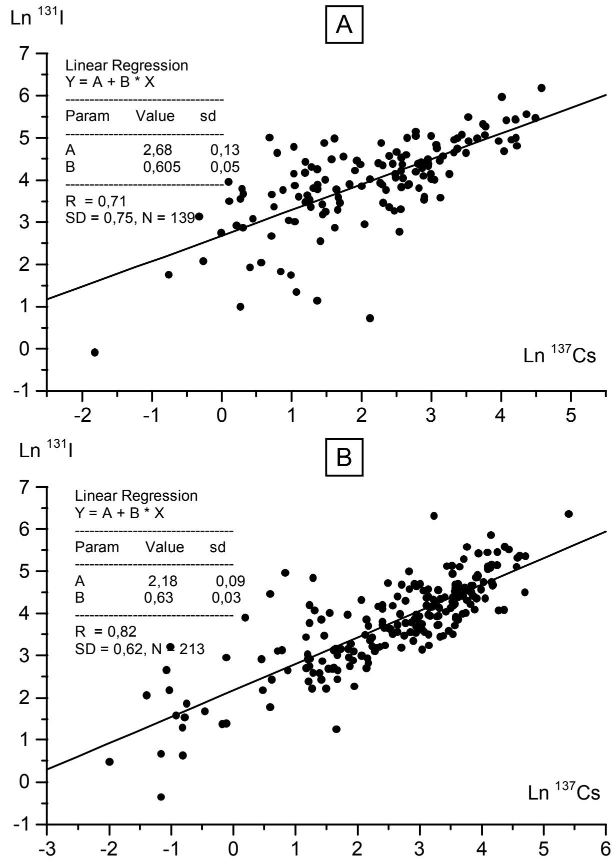

Fig. 4 Relationship between ^{131}I and ^{137}Cs activity concentration (Ci/km^2) in soil of the southern (A) and the eastern (B) areas of Belarus.

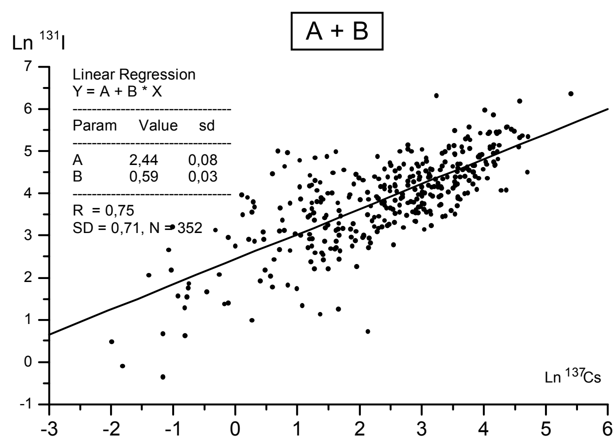

Fig. 5 Relationship between ^{131}I and ^{137}Cs activity concentration (Ci/km^2) in soil of the Belarus territory including both the southern (A) and the eastern (B) areas.

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Isotope Fractionation of Uranium in the Process of Leaching of Nuclides of Dispersed Fuel of RBMK of the Chernobyl NPP

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SUMMARY

The particles of fragmented nuclear fuel containing uranium of different degree of oxidation were found as the parts of conglomerates in the premises of the IV unit and in soils of the Chernobyl NPP Industrial site. When leaching uranium from contaminated soils, fractionation of the nuclides of ^{235}U and ^{238}U between solid and liquid phases may take place. Fractionation was not indicated in leaching of uranium from the particles patched into graphite fragments.

Fractionation of uranium nuclides is due to difference in energies of these nuclides bonds in crystal lattice of solid phase of the products of fuel fragmentation. Two hypotheses are accepted. The first one supposes heterogeneous composition of nuclear fuel of RBMK reactor consisting of fractions with different enrichment by ^{235}U, uranium isotopes of the more enriched fraction having higher mobility due to features of preparation technology. Another hypothesis bases on the assumption of selective loosening of bonds of separate ^{235}U atoms takes place in the solid body under action of slow neutrons.

INTRODUCTION

Works on study of uranium isotopic composition in the products of accidental ejection from the Chernobyl NPP by its scope take up rather modest place among other studies on consequences of 1986 accident in spite of obvious connection between ^{235}U distribution in the process of fuel destruction and nuclear safety of Sarcophagus. Studies on the uranium isotopes distribution in dissolution, leaching of dispersed fuel gave discrepancy results: some experiments showed ^{235}U enrichment of uranium in water solutions relative to the solid phase [1,2], others showed an identity of the isotopic composition of the both of phases [2-4]. The results were explained by the heterogeneous composition of fuel component of Chernobyl ejection. Detailed analysis of the performed studies has enabled to establish the regular connection between the possibility of uranium isotopes fractionation and conditions of dispersed fuel formation and to propose the version of rise of weakening of ^{235}U bond in the solid phase of fragmentation products of fuel.

1. Fuel-containing products of accident on the IV unit core of Chernobyl NPP.

Unit cores of the Chernobyl NPP are equipped with reactors of channel type (RBMK), that use graphite as reaction moderator and light water as heat-carrier. Reactor core is an vertical cylinder 11.8 m in diameter and 7 m in height. It contains fuel assemblies, moderator, heat-carrier, technological channels, neutron absorber rods. Graphite brickwork makes up vertical columns with through holes for placement of technological and control channels. Graphite density is 1.65 g/cm^3. Fuel assembly consists of two sequentially connected sections 3.5 m each in length. Each section includes central tube from zirconium alloy, steel distanced grid, 18 fuel rods.

Initial enrichment of fuel is 2%. If the design burn-up is taken as 18.6 MW/ton, then nuclide contents are: ^{235}U — 4.1; ^{236}U — 2.1; ^{238}U — 969.3; ^{239}Pu — 2.4; ^{240}Pu — 1.7; ^{241}Pu — 0.5; and ^{242}Pu — 0.3 kg per tone of initial uranium [5]. So spent nuclear fuel should contain 0.42 % of ^{235}U.

On the moment of the accident the reactor active zone of IV block of the Chernobyl NPP contained 1659 fuel assemblies (FA). Their nuclear fuel total mass was 190.2 tons [4]. The bulk of the FA was enclosed in the first charge cassettes with the burn-up of 11 to 15 MW·day/kg of U. Some amount of "fresh" nuclear fuel was in the active zone too. Calculations of mass and activity of fission products and transuranium elements that took account of factors of irregularity of the field of energy emission in RBMK-1000 were carried out for each cassette. The total mass of each accumulated nuclide was estimated by summing over all fuel assemblies in the reactor core. According to these estimates ^{235}U content conformed to effective enrichment of 1.1% [2]. Plutonium nuclides contents were estimated in: ^{239}Pu — 2.166, ^{240}Pu — 0.925, ^{241}Pu — 0.257, and ^{242}Pu — 0.074 kg per ton of uranium [8].

More than 180 tons of nuclear fuel are considered to be enclosed in the object "Ukrytiye" ("Sarcophagus"). Irradiated fuel inside "Sarcophagus" has the following modifications:

- fragments of the reactor core - fuel tablets, fuel assemblies and their fragments, radioactive graphite, fragments of technologic channels;

- finely dispersed fuel - "hot" fuel particles that were the main radioactive components of dispersed phase of aerosols and solid precipitates on different surfaces;
- lava-like masses containing nuclear fuel;
- crystalline nova-formations that are bright-yellow spots and figures;
- water solutions.

Finely dispersed fuel of micron dimensions was characterized form of accidental ejection of the Chernobyl NPP into the environment. In the early months and years after the accident they were the objects of numerous studies. "Hot" particles were sampled in the premises of the IV unit, in close proximity to the Chernobyl NPP, on the area of the Chernobyl NPP industrial site and sanitary zone, on the territories of Ukraine, Byelaruss as well as Scandinavian countries, Central and West Europe.

The most of works were limited by studies of radionuclide content of particles. Studies concerning with radionuclide state in particles are not numerous. Works on study of chemical and structural composition of particles, on kinetics of dissolution and leaching of radionuclides, and on distribution of radionuclides in the system "solid phase - solution" [1-3, 12-14] are among them.

2. Elemental and structural composition of hot particles.

Some particles contained radioactive substances that had low boiling temperature (^{131}I, ^{137}Cs and ^{134}Ñs), others contained radionuclides with rather high boiling temperature (isotopes of Sr, Ce, Zr, Pu, Am, Cu, Np etc.) as the parts of uranium matrix [3]. At morphology fibre-like and spherical microconglomerates and that of irregular habitus. Density of the heaviest of the particles reached 8 g/cm^3 [2, 6].

In one of samplings hot particles of two varieties - 30 µm and 1 to 2 µm in size - predominated. Particles of the first variety were identified as fuel ones, those of the second variety were recognized to be condensational particles formed during burning of graphite. In the sampling of particles that deposited in the premises of "Sarcophagus" maximum of dimension distribution was in the region of 15-20 µm [6].

At a distance of more than 1 km from the accident unit, separate hot particles were found on the surface of the earth, buildings and constructions as the parts of conglomerates of particles of different substantial composition. Oxides of U(IV) and U(VI) as well as blobs of carbonaceous matter, small fragments of quartz, aluminosilicate matter, ferrous minerals, rounded titanic fragments were detected in these conglomerates by the methods of microscope probing and X-ray-structural analysis [19].

Sampling of hot particles from the soils in the floodplain of the Prypiat (5-7 km distant from the unit) and those from soddy-podzolic soils from st.Yanov (2-3 km from the unit) was presented by microconglomerates and fragments of reactor graphite [2]. Several types of particles can be separated by their composition and structure:

- quartz-feldspar, clastogeneous, having grains predominantly of sharp-angle profile cemented by micaceous-kaolinic mass;
- clastogeneous substantially micaceous-silicate, consisting of entangled fibrous aggregates of sheet crystals;
- condensation-clastogeneous, consisting of microgeodes, spherules of condensation genesis with admixture of clastogeneous matter.

Predomination of small sharp-angle clastic fragments, cementation, presence of implanted uranium particles, condensation formations have enabled to assume that the microconglomerates as the radioactivity carriers were formed mainly in result of agglutination of particles of fluid materials used during fire fighting, dispersed materials of reactor unit constructions, fuel and graphite at high temperatures [10, 12, 15].

One of the fragments, 2x3 mm in size, sampled in the premise of the IV unit consisted of grains of graphite and small fragments of concrete. Grains of quartz and microcline were cemented with fine Ca-containing material. Particles with high atomic mass that had substantially uranium composition were found in that fragments by vision of preparates in reverse reflected electrons. Uranium particles of 1-50 µm in size were placed on the surface of graphite aggregates or were slightly implanted into them.

Two types of particles were separated by the morphology:

- shperules and their fragments of 3-90 µm,
- irregular-shaped particles, predominantly sheet-shaped, with dimensions of fractions of micron to 50 µm.

Spherical particles showed microdifraction picture corresponding to UO_2 structure with diminished parameter of elemental cell ($\grave{a}_0 = 0.535 \pm 0.005$ nm). It was attributed to the partial oxidation of U(IV) to U(VI), that increased number of defects in crystals and decreased effective dimensions of blocks of coherent scattering of electrons. Mixture of uranium dioxide and elemental uranium was identified by characteristic X-ray emission in number of plate-shaped particles. Hypothesized process of UO_2 sublimation at high temperatures in the authors view could be accompanied by formation of pre-stoichiometric oxide $UO_{2-\tilde{o}}$ and following disproportionation to UO_2 and U.

Among the synthesized uranium oxides used as a nuclear fuel in the modern energetic units the series of phases were established that transfer one into another from UÎ$_2$ to UÎ$_3$ gradually or abruptly as uranium oxidation occurred from U(IV) to U(V) and U(VI).

Synthetic UÎ$_2$ oxide has cubic crystal structure with elemental cell dimension of 0.548 nm. As uranium oxidation occurs, at first diminishing of this dimension that is recognized as a result of isomorphous replacement of U(IV) (ion radius is 0.1 nm) by U(VI) (r=0.08 nm), and than decreasing of oxide symmetry to tetragonal U$_4$Î$_9$ are observed. More oxidized phase U$_3$Î$_8$ is known to have two polymorphous modifications (rhombic and hexagonal), maximally oxidized phase UÎ$_3$ - five modifications, one of them is amorphous. Oxidation series consists of the next discrete phases:

UÎ$_2$ — U$_4$Î$_9$ — U$_3$Î$_7$ — U$_2$Î$_5$ — U$_3$Î$_8$ — UÎ$_3$.

In the sampling of particles aspirated from the aerosols from the object "Sarcophagus" about 10% of the total activity were contained in fraction < 1 μm, about 70% of it - in fraction 1-5 μm, and about 20% of activity were concentrated in the rough-dispersed fraction. The main input into activity of the dispersed matter deposited on the surfaces fraction 1-10 μm has made (~70%), rough-dispersed fraction (>10 μm) contained about 20% of the total activity, fine-dispersed one - about 10% [8]. The finest particles sampled from the soils of the south Byelaruss had the highest specific activity [15].

All the long-lived products of nuclear fuel fission were detected in the dispersed phase of aerosols. ^{238}Pu and $^{239+240}$Pu were found in all the separated fractions of dispersed phase of aerosols. ^{238}Pu /$^{239+240}$Pu ratios were close to those of the "mean" nuclear fuel of the IV unit. There was no correlation between ^{144}Ce and ^{241}Am [4,7]. Activities of ^{144}Ce in the separate particles of the sampling of 17 to 55 μm in dimension were (8.1 - 9.6) $\times 10^9$ Bq/g that was close to "mean" radionuclide content in the fuel at the moment of the accident.

Rather large-sized spherical particles up to several millimeters in diameter were collected on the surfaces of steam-dumping valves in the steam-distributing premise of the accidental unit [6]. Study of radionuclide distribution with depth in these particles showed the maximal contents of plutonium as well as radioactive isotopes of Sr and Cs in the outer layers and decreasing of their activities up to the centers of particles. Plutonium contents in the upper layers of spherical particles were from 1×10^5 to 1.5×10^5 Bq/g when mass concentrations of uranium were of 0.5 to 7.5%. Plutonium contents in other layers of the particles were less by some factors and in some cases by several orders of magnitudes. ^{238}Pu/ $^{239+240}$Pu ratios were stable in all these cases and corresponded to those of the "mean" nuclear fuel of the IV unit.

Above-mentioned data testify that the processes of high-temperature atomizing of elements and subsequent spontaneous solid condensation of vapour resulted in the formation of spherical particles, proceeded in the active stage of the accident at least in some point of the IV unit. Recrystallization of the nuclear fuel material accompanied with establishing of contents of Pu, ^{144}Ñe, ^{241}Am, ^{90}Sr, and U in different layers of spherical particles that rather differed by their ratios from the "mean" nuclear fuel of the IV unit. The growth of fiber-like particles proceeded obviously in the active stage of the accident too from the gas phase at the temperatures higher than 3,000 ^{0}Ñ.

3. Leaching of fission products from hot particles in soils.

Radioactivity of soils in the industrial site of the Chernobyl NPP was attributed to fallout of irradiated fuel in the next principal forms:

1) fragmented fuel of different grain size; its particles differed in their degree of oxidation, due to interaction between the heated fuel and oxygen in the course of explosive release. The U(VI)/U(IV) ratios in the fuel fallouts of near-field zone varied from 0.6 to 1.7;
2) fuel-graphite conglomerates; the main part of fragmentary nuclides in the near-field zone was attributed to these fallouts. According to the X-ray microanalytical data, a spatial association between uranium and carbon was found for many particles;
3) nuclear fuel embedded into the matrices of construction materials (iron, zirconium, copper);
4) extremely fine (≤ 1 μm) hot particles of aluminosilicate composition, as a rule with a regular

Table 1. Vertical distribution of plutonium and ^{238}U/^{235}U atomic ratios in total uranium in the soils of the nearest zone of the Chernobyl NPP.

Index	$^{239(240)}$Pu contents in layers, %					^{238}U/^{235}U atomic ratios				
	0-1cm	1-2 cm	2-3 cm	3-4 cm	4-5 cm	0-1 cm	1-2 cm	2-3 cm	3-4 cm	4-5 cm
1	92.0	7.4	0.4	0.2	-	79.9	128.2	134.7	137.4	137.6
2	91.2	7.9	0.6	0.2	0.1	80.3	129.6	129.6	137.3	137.7
3	95.9	3.8	0.3	-	-	89.6	135.8	137.3	137.8	137.8
4	96.7	2.9	0.3	0.1	-	96.1	126.7	134.8	137.1	137.6
5	91.8	7.8	0.3	0.1	-	98.4	131.5	136.9	137.8	137.8
6	96.0	3.4	0.4	0.1	0.1	103.5	132.9	137.1	137.6	137.6

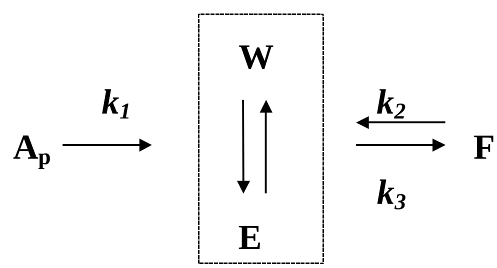
carbon admixture;

5) so-called condensation particles enriched with volatile nuclides, foremost by ^{137}Ñs and ^{134}Ñs, more characterized for the distant zone.

In the first months after the accident more than 99% of uranium and plutonium radionuclides were accumulated in the upper 2 cm-layer of the soil in the nearest zone of the Chernobyl NPP (Table 1).

Vertical distribution of the fission products in the first weeks and months after the accident was the same. Their activity was localized in form of hot particles, that was confirmed by the autoradiography data [15].

In soils hot particles are exposed to destruction due to effects of soil solutions and products of bacteria action. In the result of leaching of radionuclides and dissolution of matrix, products of uranium fission were carried out from the particles and their water-soluble compounds were formed. This process and following transformations of radionuclide forms can be presented by processes of mobilization, immobilization, remobilization of radionuclides:



$$A_0 = A_p + W + E + F$$

where : À$_0$ is bulk radionuclide activity; À$_p$ - part of radionuclide in solid-phase particles; W - part of radionuclide in water-soluble form; Å - part of radionuclide in ion-exchangeable form; F - part of radionuclide in fixed form.

Mobilization is identified with carry-out of radionuclides from solid-phase particles and formation of water-soluble and ion-exchangeable forms of radionuclides that are subjected to water migration. Immobilization is connected with formation of relatively conservative (fixed) forms of radionuclides. Remobilization is an opposite process to immobilization.

According to deterministic kinetic model of transformation [14], activity of the mobile form of radionuclide (A_M) is :

$$A_M = A_0 \left\{ \frac{k_1 - k_3}{-k_1 + k_2 + k_3} [(exp(-k_1 t) - exp(-k_2 - k_3)t] + \frac{k_3}{k_2 + k_3} [1 - exp(-k_2 - k_3)t] \right\}$$

where A_M and A_0 - activities of radionuclide mobile and initial forms, k_n - constants of rate of mobilization, immobilization, and remobilization of radionuclides sequentially.

The constant of radionuclide mobilization rate k_1 is a characteristic of the resistance of solid-phase fallout in the soil. Its value first of all depends on the solid-phase particles qualities (material composition, degree of dispersion, way of formation) as well as on physical-chemical characteristics of the soil. The constants of radionuclide immobilization rate k_2 and remobilization rate k_3 are determined by radionuclide chemical properties, and for each radionuclide they essentially depend on physical-chemical characteristics of the soil. Numerical values of constants of transformation rates of ^{90}Sr and ^{137}Ñs forms were estimated by calculations on the base of comparison of the data on radionuclides forms in the soils in the different moments of post-accidental period.

The kinetic curves of ^{90}Sr and ^{137}Ñs mobile forms accumulation in soddy-podzolic soils in the Chernobyl exclusion zone as well as experimental data on their contents are presented in Figs. 1 and 2.

In the first years after the accident, sharp increasing of ^{90}Sr mobile forms content took place, and then their stabilization was observed. So immobilization was not substantial in ^{90}Sr forms transformation. Dynamics of changes of ^{137}Cs mobile forms activities in soddy-podzolic soils was characterized by maximum that was observed in 1987-1988 and subsequent decreasing of ion-exchangeable form content at the expense of advancing immobilization.

The mean value of constant of radionuclide mobilization rate was evaluated in 0.195 year^{-1} with variations of 0.12 to 0.30 year^{-1}. Hot particles that were in the air-dry state preserved fission products in their compound for a much longer time.

4. Mobility of uranium isotopes in the soils containing hot particles.

The radionuclide status in solid substances is commonly studied by leaching procedure and research of its distribution between different phases and chemical forms. Solutions that don't dissolve matrix matter are used. So admixtures elements residing out of nodes of crystal lattice are leached. Nuclides of daughter radioactive elements are leached from uranium and thorium minerals. Atoms resided inside a crystal or in the narrow capillaries migrate to the crystal surface in the result of diffusion over vacancies, internodes and capillaries. Desorption of the element from the surface depends on the concentration of displacing element in the solution and proceeds to attainment of equilibrium. Parent radionuclides move into solution only in the result of destruction of crystal lattice, i.e. dissolution of the matrix matter.

Mobility of uranium isotopes and fission products in soils contaminated by solid-phase accidental fallouts

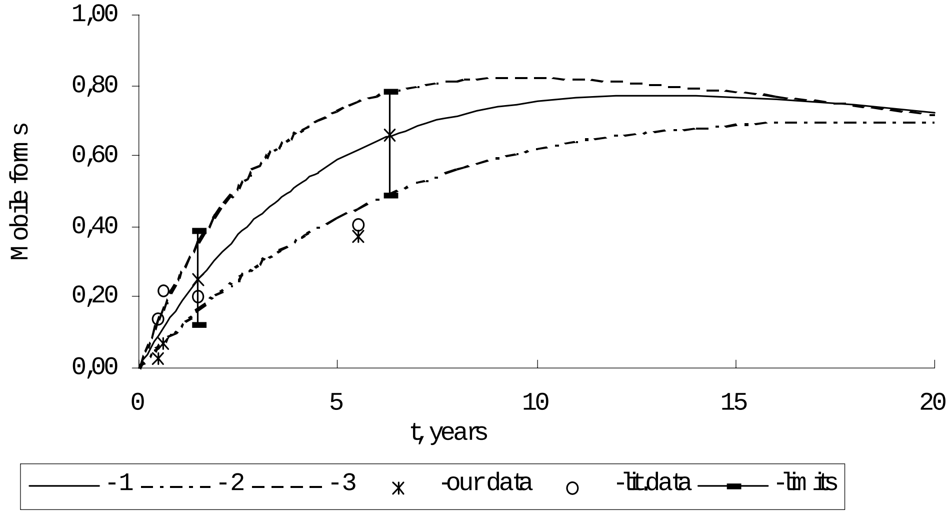


Fig. 1. Kinetic curves of ^{90}Sr mobile forms accumulation in soddy-podzolic soils in the exclusion zone: 1 - $k_1 = 0.195$, $k_2 = 0.02$; 2 - $k_1 = 0.12$, $k_2 = 0.02$; 3 - $k_1 = 0.30$, $k_2 = 0.02$ year^{-1}.

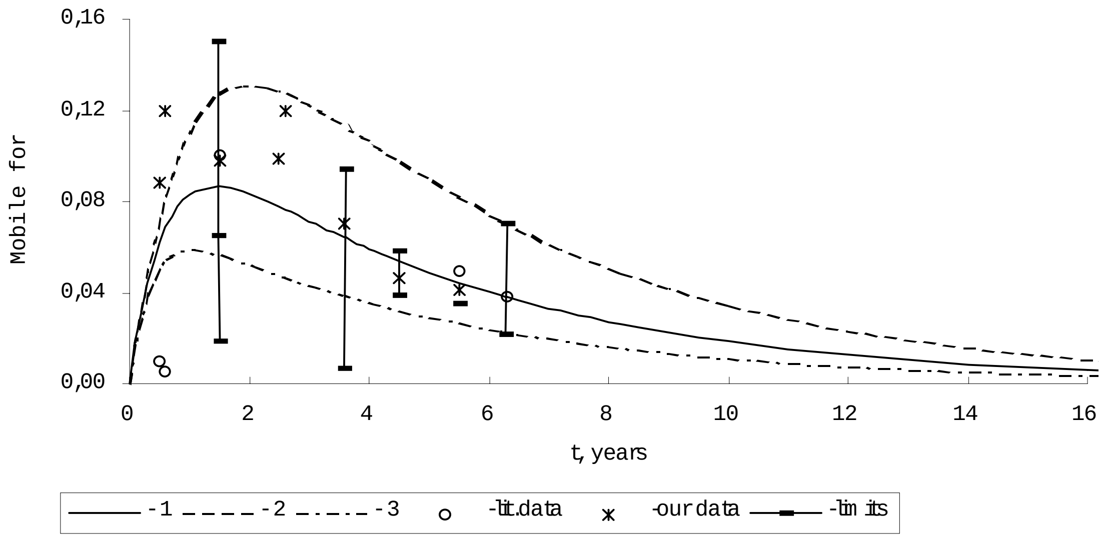


Fig. 2. Kinetic curves of ^{137}Cs mobile forms accumulation in soddy-podzolic soils in the exclusion zone: 1 - $k_1 = 0.195$, $k_2 = 1.7$; 2 - $k_1 = 0.195$, $k_2 = 1.0$; 3 - $k_1 = 0.195$, $k_2 = 2.7$ year^{-1}.

was evaluated by leaching method in series of works [1-3, 14, 15]. For these purposes sequential leaching of nuclides from solid phase by water solutions of salts and acids was performed.

Experiments on leaching of uranium isotopes from the top layer soils, which contained hot particles, were carried out at the laboratory of transuranium elements geochemistry of Department of Environmental Radiogeochemistry of Institute of Geochemistry and Physics of Minerals [14]. Soils were sampled in 1986 mainly at the industrial site of Chernobyl. Determinations of atomic (mass) ratios such as ^{238}U/^{235}U and ^{235}U/^{236}U were carried out by the MI-1320 and MI-1201T mass-spectrometers with 0.2% limiting relative error. Alpha-spectrometric determinations of ^{234}U/^{238}U activity ratios as well as plutonium activity were carried out with Si (Au) - detector within a 2% error. Content of uranium in the soil was estimated by the mass-spectrometric isotopic dilution method within a 0.8% error. Standard ^{235}U solution with ^{238}U/^{235}U isotope ratio equal to 0.1022 was used as an isotopic label. Limiting relative errors for all the experimental measurements were estimated within 95% confidence interval.

To check of the obtained ^{238}U/^{235}U ratios, a series of duplicate analyses were performed at the mass-spectrometric laboratory by Prof. N.P.Tsherback, which confirmed validity of the previous results.

Extraction of uranium from the soils was carried out in these experiments with concentrated hydrochloric acid. After solid phase separation isolation of the uranium from the solution and its preparation to

Table 2. Uranium isotopic composition and content in soils in the near-field zone of the Chernobyl NPP [1].

No	Soil sampling point	$^{238}U/^{235}U$ *	$^{235}U/^{236}U$ *	$^{234}U/^{238}U$ **	^{238}U (μg/g)	^{235}U,%
1	Site of the IV unit	39.68	16.08	3.06	1.38	2.46
2	North-western part of the cooling pond	44.82	26.12	2.75	0.796	2.18
3	Vicinity of Yanov railway bridge	51.21	14. 28	2.38	1.173	1.92
4	Left bank of the Prypiat	53.3	8.16	2.00	0.745	1.84
5	Yanov railway station	52.6	13.05	3.96	0.910	1.87
6	Red forest	57.8	26.77	2.32	0.848	1.70
7	v. Yanov	62.8	35.72	2.57	0.764	1.57
8	v. Leliv	77.5	83.2	2.39	1.092	1.27
9	Paryshev channel	93.8	140. 3	3.22	0.632	1.06
10	v. Burakivka	102.4	47.26	2.18	0.826	0.97
11	v. Tolsty Lis	106.3	76.6	1.94	0.911	0.93
12	town of Prypiat	108.4	92.4	1.82	2.14	0.91
13	Chernobyl	112.9	103.7	1.86	0.948	0.88
14	v. Cherevach	126.3	194.8	1.69	1.013	0.79

* Ratios between mass concentrations of uranium isotopes;

** Ratios between activities of uranium isotopes.

Table 3. Isotopic composition of uranium in leachate solutions before and after oxidation of uranium.

No	Sampling point	Leaching agent	Soil		Solution without oxidation		Oxidized solution	
			$^{238}U/^{235}U$	^{235}U, %	$^{238}U/^{235}U$	^{235}U, %	$^{238}U/^{235}U$	^{235}U, %
1	Cooling pond	8 Ì HNO_3	44.82	2.18 %	28.42	3.4 %	11.74	7.85 %
2	Yanov railway station	2 Ì HNO_3	52.6	1.86 %	40.61	2.4 %	12.17	7.6 %
3	v. Yanov	6 Ì HNO_3	62.8	1.57 %	48.4	2.02 %	20.32	4.69 %
4	v. Leliv	7 Ì HCl	77.5	1.27 %	47.9	2.04 %	23.68	4.05 %
5	v. Leliv	2 Ì HNO_3	77.5	1.27 %	51.1	1.92 %	31.22	3.1 %
6	Paryshev channel	7 Ì HCl	93.8	1.05 %	15.64	6.0 %	2.744	27 %
7	Paryshev channel	8 Ì HNO_3	95.4	1.04 %	61.4	1.6 %	18.93	5.0 %

mass-spectrometric analysis was performed. Experimental data on isotopic composition of uranium and its content in liquid phase are presented in Table 2.

Obtained data on the uranium contents in soils did not exceed the Clark values varying from 0.632 to 2.14 μg/g. This testified at least to comparability of technogeneous uranium content in soils to the natural one. The $^{238}U/^{235}U$ ratio in the uranium extracted from the soils varied from 44.82 to 126.3; $^{235}U/^{236}U$ ratio varied at more greater extent. Shifts in the isotopic composition relative to natural and even to technogeneous uranium were pronounced: $^{238}U/^{235}U$ isotopic ratios for some leachate-solutions were found to be considerably lower than that of the initial fuel.

Besides, dependence of uranium isotopic composition in soils upon their distance from the source was observed: uranium enrichment by ^{235}U isotope increased with approaching to the IV unit, i.e. with enrichment of soils by technogeneous (fuel) uranium.

Mobility of uranium isotopes in the solid phase was evaluated by the method of their sequential leaching in the variable physico-chemical conditions: different acids with admixtures were used (Table 3). It was found that the $^{238}U/^{235}U$ ratio for the first leachates ranged from 15.6 to 61.4, whereas in the case of more complete extraction of uranium from the same soils it varied from 44.8 to 93.8. On these grounds the authors of the work assumed that the reduction in the $^{238}U/^{235}U$ isotopic ratio in solutions might be explained by the fact that the technogeneous fuel uranium (or at least some part of it) differed from the natural one in its higher ability to leaching. Dependence on the $^{238}U/^{235}U$ ratio value on leaching conditions testified that the mobile uranium both of natural and fuel origin is not completely transferred into a solution. In such a case a dynamic equilibrium should be established between the solid and liquid phases of the system. Subject to the changes in the physico-chemical leaching conditions such an equilibrium should be disturbed resulting in changes in the uranium isotopic composition of the leachate solution.

To estimate an effect of oxidation of the liquid phase upon the displacement of uranium isotopic composition oxidation of the aliquot part of the leachate solution was performed with persulphuric ammonium in presence of Ag^+ cations. When uranium was leached from the soil by hydrochloric acid, evaporation of the solution aliquot, conversion of the salt residual into NO_3-form (removing of Cl^- ion traces) and its dissolution in 1 *M* HNO_3 preceded to the oxidation operation.

Values of $^{238}U/^{235}U$ ratio in leachate solutions before and after oxidation of uranium are presented in Table 3. In the case of oxidation of the solution uranium in the leachate solution was more enriched with ^{235}U isotope in comparison with unoxidized solution. The minimal detected $^{238}U/^{235}U$ ratio reached 2.7, that corresponded to ~27% enrichment by ^{235}U.

Experiments to estimate the contents of uranium valency forms in the leachate solutions were also carried out. U(VI)/U(IV) ratios were found to vary from 0.6 to 1.7 [2].

In the experiments on absorption of uranium from hydrochloric acid solutions by the anion-exchange resin AV-17, the authors of the work [2] have found the anionic form that is characterized to U(V1) to be enriched by ^{235}U isotope relatively to U (1V) form.

In the other series of experiments, processes of leaching of fragmented radionuclides as well as fuel uranium from the contaminated soils from left-bank flood-plain of the Prypiat river were studied. Soils were sampled in the right bank of Murovka channel on 20.03.91. By this moment solid-phase fallouts underwent destruction to some extent. (see Part 3).

The levels of surface contamination by ^{90}Sr in the sampling site were from 3.7 to 7.4 MBq/m^2. Radionuclide compositions of the studied samples are presented in Table 4.

Gamma-spectrometric analysis and radiochemical determination of ^{90}Sr content were carried out from the same sample. Then the samples were sequentially treated by water with natural hydrochemical composition, 1M solution of ammonium acetate, and concentrated acid solutions. ^{90}Sr and uranium contents and uranium isotopic composition were determined in each of leachate-solutions. Solid to liquid phases ratio was 1:1, the mixture was stirred for 24 hours, then separation of the phases on the Buchner funnel with membrane filters of 0.2 μm in diameter was carried out. Acid leaching was carried out in teflon dishes under light heating and periodical stirring during 24 hours.

Stringent regime of acid leaching resulted in dissolution of uranium matrix and in partial or complete breakdown of natural uranium-containing minerals, but, because of low uranium concentrations, the applied procedure did not make available determination of its content in a number of leachate-solutions (Table 5). High ^{235}U contents were found in water, salt and acid leachate-solutions. Insoluble residue from the sample 2 after mineral breakdown by hydrofluoric acid was the mixture of accessories (mainly zircon-rutile) and graphite particles. Presence of ^{90}Sr pointed to the definite influence of graphite fuel-containing particles on the uranium isotopic composition.

In the leachate-solution from the mineral concentrate [15], sampled at the cooling-pond bank, mass contents of heavy nuclides were determined by the mass-spectrometer "Plasma Quad" ("VG Instruments") with ionization of the material in inductively connected plasma. The relative contents of masses from 233 to 242 were the next: 233 – 6.29; 234 – 45.1; 235 – 2712.2; 236 –455.69; 237 – 5.54; 238 – 237999; 239 – 112.61; 240 – 9.68; 241 – 9.11; 242 – 8.38. Ratio of mass of 235 to 238 corresponded here to the enrichment of uranium with ^{235}U isotope up to 1.126%, that is close to "mean" composition of ejected

Table 4. Radionuclide composition of soil samples from left-bank flood-plain of the Prypiat on 20.04.91 [3].

Sample	Radionuclide content, kBq/kg				
	^{144}Ce	^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr
1	57.4	18.1	134	13.7	154
2	8.5	2.5	18.2	1.82	15.7
3	16.2	3.0	34.6	3.57	38.3

Table 5. Uranium isotopes in the leachate-solutions from the soils [3].

Agent	Sample 1			Sample 2			Sample 3		
	$^{238}U/^{235}U$	U, μg/g	^{90}Sr, %*	$^{238}U/^{235}U$	U, μg/g	^{90}Sr, %*	$^{238}U/^{235}U$	U, μg/g	^{90}Sr, %*
H_2O	10 (9.1%)	-	3.0	-	-	1.7	22 (4.3%)	-	1.9
NH_4Ac	1.4 (41.6%)	-	4.2	22 (4.3%)	$5.4 \cdot 10^{-4}$	4.5	3.3(23.2%)	-	3.3
6N HNO_3	36 (2.7%)	0.39	91.7	110(0.9%)	-	91.4	30 (3.2%)	0.015	84
HNO_3+ HCl	45 (2.17%)	0.11	1.05						
HNO_3+ HF						2.4			
6N HNO_3									9.9

* ^{90}Sr content is given as percentage of bulk activity in the soil

Table 6. Extent of radionuclides leaching from the graphite hot particles in the experiment with subsequent treatment with water and mineral acids [3].

Treatment	Time of exposition, hours		Total leaching, %		
	total	for separate fraction	^{90}Sr	^{137}Cs	U
Water 1	1	1	32.7	75.7	69.0
Water 2	4	3	52.9	89.3	69.1
Water 3	7	3	66.4	92.4	69.2
Water 4	13	6	75.1	93.5	79.6
Water 5	23	10	85.7	94.5	80.3
Water 6	40	17	90.5	95.6	80.5
Water 7	67	27	94.3	96.0	-
HNO_3	**	**	**	**	99.1
HF	**	**	**	**	99.75
HCl	**	**	**	**	99.98

** Has not been controled

Table 7. Uranium isotopic composition in water leachate-solutions from the graphite hot particles [3].

Conditions of leaching		Isotope ratios			
Time, hours	Leaching agent	^{235}U, %	^{234}U/^{238}U	^{238}U/^{235}U	^{236}U/^{238}U
1	H_2O	1.078	$1.6 \cdot 10^{-4}$	91.70	$1.8 \cdot 10^{-3}$
3	H_2O	1.088	$2.3 \cdot 10^{-4}$	90.91	$1.8 \cdot 10^{-3}$
6	H_2O	1.107	$1.6 \cdot 10^{-4}$	89.29	$1.9 \cdot 10^{-3}$
10	H_2O	1.068	$1.5 \cdot 10^{-4}$	92.60	$1.8 \cdot 10^{-3}$
17	H_2O	1.099	$1.4 \cdot 10^{-4}$	89.96	$1.9 \cdot 10^{-3}$
27	H_2O	1.088	$2.5 \cdot 10^{-4}$	90.91	$1.6 \cdot 10^{-3}$
	HNO_3	1.010	$1.5 \cdot 10^{-4}$	97.96	$1.6 \cdot 10^{-3}$
	HF	1.906	$2.6 \cdot 10^{-4}$	51.47	$1.7 \cdot 10^{-3}$
	HCl	1.986	$2.4 \cdot 10^{-4}$	49.36	$1.7 \cdot 10^{-3}$
Natural uranium		0.721	$6 \cdot 10^{-5}$	138.6	$<2 \cdot 10^{-6}$

(*) Table was drawn up after [3], % ^{235}U was calculated for the convenience of discussion.

fuel. In groundwater in the "Red Forest" near the Chernobyl NPP, the presence of uranium with mass ratios ^{238}U/^{235}U from 50 to 54 was fixed in 1987 [16]. It corresponds to 1.8-2.0% enrichment of the fuel.

Comparison of the data from the cited works makes it evident that the intervals of variations of uranium isotopic composition in water phase in its leaching from soils in natural conditions and in the laboratory are actually identical.

5. Leaching of nuclides from dispersed fuel of graphite composition.

Ability of uranium and fission products to leaching from hot particles of predominantly graphite composition sampled in the premises of the "Sarcophagus" was studied in the work [3]. Radionuclide composition of sampled particles varied noticeably. ^{90}Sr content in some particles varied from 37 to 814 kBq/g, that of ^{137}Cs - from 2 to 12 MBq/g. Radioactivity of a number of particles was caused exclusively by nuclides of ^{134}Cs and ^{137}Ñs. These data testified predominantly condensation genesis of the particles.

Leaching of radionuclides from graphite particles was carried out in the hermetically sealed vessels under continuous stirring. After set time expiration solid phase was separated on the membrane filter of 0.2 μm in diameter and then was treated by the water or acid solution again to continue the process of leaching. Sequential effect of mineral acids HF and HCl in different conditions, including under high temperature (200 ^{0}Ñ) was carried out in the hermetically sealed teflon cylinder.

Nuclide composition of leachate-solutions from graphite hot particles was determined by mass-spectrometer "PlasmaQuad" ("VG Instruments"). Solution of the natural uranium has a strictly constant ^{238}U/^{235}U ratio equal to 137.88. A series of 10 measurements showed the ^{238}U/^{235}U ratio in 138.6 ± 2.0 when the time of the single measurement was 3 min. Uranium content and its isotopic composition were determined in the experimental leachate solutions from hot particles.

Experimental results are presented in the Tables 6 and 7. Experimental results testify the difference in the rates of dissolution of strontium, cesium, and uranium nuclides in the process of their leaching from graphite particles and their independence (Fig. 3). It is explained by authors by the distinctions of formation of uranium-containing particles: recrystallization of uranium compounds following the "release" of fragment radionuclides took place under conditions of effects of high temperatures and interaction between construction materials and air oxygen.

Isotopic composition of uranium in sequential water leachate-solutions from graphite particles was uniform varying in ranges of 1.07-1.11% enrichment, which was rather close to calculated values for the bulk mass of the fuel. Only insignificant part of it, i.e. the most resistant to dissolution, corresponded to 2% enrichment.

Authors of the work [3] distinguish two groups of uranium-containing phases in graphite particles by their resistance to action of leaching agents:

- depleted fuel with ^{235}U content about 1%; it constitutes the main mass (~99%) of uranium that is contained in the particles and dissolves readily in the water and nitric acid;
- uranium-containing phase with $^{238}U/^{235}U$ isotopes ratio corresponded to that of the "fresh" 2% reactor fuel; its content is quite insignificant, and its dissolution requires high temperature and pressure.

The both phases contain ^{236}U, formed in result of nuclear processes.

6. Hypothesis for fractionation of uranium nuclides in its leaching from fuel-containing soils.

Heterogeneous composition of uranium-containing compounds should be taken into account in an attempt to explain the results of determination of uranium isotopic composition in the soils contaminated by solid-phase radioactive fallouts. The contaminated soils may be expected to contain the next uranium-containing compounds:

- natural minerals and soil compounds, containing uranium with composition of about 0.7 % ^{235}U;
- technogeneous fuel-containing particles with uranium of about 1.1% ^{235}U composition;
- technogeneous fuel-containing particles containing uranium of fresh fuel charged immediately before the accident and enriched up to 2% of ^{235}U; statistical expected contribution of that particles is less than 1% of technogeneous uranium.

Relationship between technogeneous and natural uranium in the studied soils increases with approaching near the source (Chernobyl NPP Industrial site) up to their comparable contents [1, 15]. ^{235}U contents could not exceed in the most contaminated samples 1.1% ($^{238}U/^{235}U$ ratio was about 89.5). Part of ^{235}U in slightly contaminated soils should be close to 0.7%.

According to work [1] $^{238}U/^{235}U$ ratio in the water phase after extraction of uranium from contaminated soils varied from 126 to 40 (Table 2). The most significant enrichment by ^{235}U isotope (up to 2.4%) was reached in the soil sampled directly near the IV unit. Differences between expected isotopes ratios and those obtained experimentally exceeded substantially the error of mass-spectrometric analysis. Finding of high-enriched uranium presents the presumption that isotopic heterogeneity of nuclear fuel in the IV unit existed before the accident.

Isotope fractionation in leaching of uranium observed in the work [1], confirmed by the work [15]and probably by the other one [6], showed that correspondence of uranium isotopic composition in the solution to that of the soil could be reached provided that the analyzed element was completely dissolved. But hot particles are rather resistant to action of acids. Complete dissolution of hot particles was observed only after roasting of the samples at 650 ^{0}Ñ with

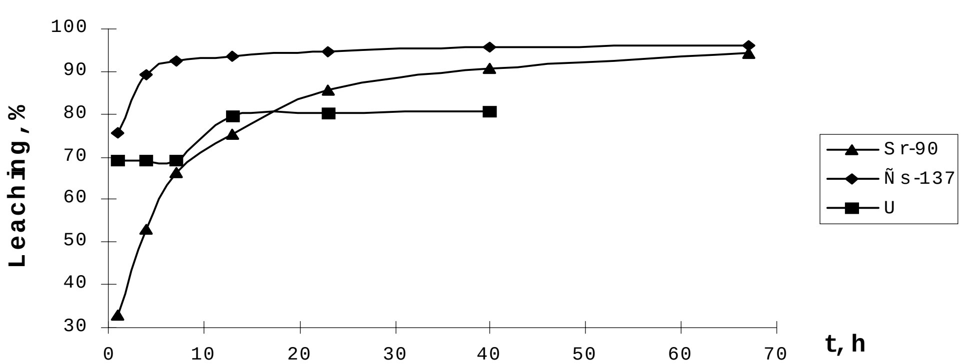


Fig. 3. Kinetics of leaching of ^{137}Cs and ^{90}Sr radionuclides, and fuel uranium from the graphite hot particles [3].

subsequent treatment with nitric acid at heating or with mixture of chlorate and hydrofluoric acids [2]. In the cited work [1] completion of uranium extraction into liquid phase was not qualified, so statement of uranium isotopic composition in the solid phase (in soil) presented in Table 2 was not quite correct. However, this circumstance does not influence upon basic results of experiments on leaching of uranium from contaminated soils that testify the possibility of fractionation of uranium isotopes ^{235}U and ^{238}U between solid and liquid phases.

Factors of separation may be used for numerical representation of fractionation effects. If ^{235}U and ^{238}U contents in the mixture of uranium isotopes are expressed in mole parts, the relative isotope contents in the solid and liquid phases would be presented as follows [16]:

$$R = x/(1 - x),$$

where: x is the mole part of ^{235}U isotope, and $(1 - x)$ is the mole part of ^{238}U isotope.

Coefficient of the single separation is given by the equation:

$$\alpha = R^*/ R,$$

where the index * is attributed to the liquid phase.

Factors of separation calculated on the data of Table 3 are presented in the Table 8. Presence of any other uranium isotopes which contents did not exceed 0.3% by mass, was not taken into account in calculation of the mole parts of ^{235}U and ^{238}U isotopes.

Factors of separation of uranium isotopes in leaching of uranium from different soils by the acids are in the range 1.3 - 1.6; in leaching by the same but oxidated solutions the factors vary in the range 2.5 - 5. Result of uranium leaching from the soil sampled on the bank of Paryshev channel (Table 8, No. 6) was the exception. Fractionation of isotopes in oxidation with 7M HCl in this case exceeded by an order of magnitude the effects of the rest experiments. Authenticity of the more high separation of isotopes in leaching by oxidated solutions was confirmed by the results of independent experiments on determination of isotopic compositions of the valent forms of uranium [2], which showed enrichment of U(VI) form by ^{235}U isotope.

Different mobility of ^{235}U and ^{238}U isotopes caused by their unequivalent energetic position in the solid phase should be assumed to explain satisfactorily the fractionation of uranium isotopes: nuclides with the lower energy of bond in the solid phase pass predominantly into liquid phase.

It is still unclear which of the uranium-containing fractions in soil has unequivalent energetic bonds of ^{235}U and ^{238}U isotopes, and how that difference could be generated.

Since fractionation of uranium isotopes in leaching from natural minerals usually does not take place, so observed isotope separation in the experiments is due to presence of technogeneous uranium of dispersed fuel (solid-phase fuel-containing fallouts, formed in result of the IV unit accident). Comparison of the results of leaching of uranium from graphite particles (Table 7) and that from the soils (Tables 3 and 5) shows the difference in the isotope enrichment of uranium. Fuel-containing fragments of graphite particles formed through condensation of evaporated fuel did not exhibited practically the isotope fractionation in leaching. Rebuilding of the structure took place in recrystallization of uranium. Defects of the lattice that was characterized by the difference in the mobilities of uranium isotopes were eliminated, even if they existed in the initial substrate. Thus, only the particles formed by mechanical fragmentation of the fuel can contain uranium with different mobility of isotopes.

Two kinds of the particles, therefore, can be distinguished by the uranium isotopes mobilities in the dispersed fuel formed as the result of the Chernobyl accident. They are the particles formed by mechanical fragmentation of tablets and the particles formed in recrystallization of the fuel.

It enables to assume the presence of at least two beings of uranium in irradiated dispersed fuel:

1) Uranium of irradiated fuel in products of fragmentation of the fuel - particle of indefinite

Table 8. Factors of separation of uranium isotopes between solid phase and solution in its leaching from the soil.

No	Sampling site	Leaching agent	R ^{235}U in soil	Solution			
				without oxidation		after oxidation	
				R^*_1	α_1	R^*_2	α_2
1	Cooling pond	8 Ì HNO_3	0.0223	0.035	1.58	0.085	3.82
2	st. Yanov	2 Ì HNO_3	0.019	0.0246	1.29	0.082	4.32
3	v. Yanov	6 Ì HNO_3	0.016	0.0206	1.29	0.049	3.09
4	v. Leliv	7 Ì HCl	0.013	0.021	1.61	0.042	3.27
5	v. Leliv	2 Ì HNO_3	0.013	0.019	1.51	0.032	2.48
6	Paryshev channel	7 Ì HCl	0.0106	0.064	6.0	0.36	34.2
7	Paryshev channel	8 Ì HNO_3	0.0105	0.016	1.55	0.053	5.04

habitus. It may be partially oxidated. Uranium isotopic composition is close to 1-2% enrichment.

2) Uranium of irradiated fuel in form of spherical or fiber-shaped particles that undergone the recrystallization in result of evaporation and condensation. Recrystallization fuel uranium as a part of graphite particle may be in oxide form or probably metallic uranium. Isotopic composition should be close to 1% enrichment, and insignificant part of this uranium has isotopic composition close to 2% enrichment.

Fractionation of uranium isotopes between liquid and solid phases is not observed in exposure of the second type fuel particles to water solutions. When the fuel particles of the first type are exposed to water solutions, uranium in liquid phase may be enriched by ^{235}U isotope relative to the uranium of the solid phase exposed to leaching.

What is the reason of different mobility of ^{235}U and ^{238}U isotopes in dispersed fuel? Two hypotheses are worth an attention.

The first one supposes heterogeneous composition of nuclear fuel of RBMK reactor consisting of fractions with different enrichment by ^{235}U, uranium isotopes of the more enriched fraction having higher mobility due to features of preparation technology.

Another hypothesis is based on the assumption that selective loosening of bonds of separate ^{235}U atoms takes place in the solid body under action of slow neutrons, to which ^{235}U nuclei have relatively large values of capture cross sections. Energy of the nuclei in excited state is probably sufficient to loosening of the chemical bonds of ^{235}U in the solid phase for a long time. In this case the probability of the process of excitation of ^{235}U nuclei due to reversible absorption of neutrons without fission is yet uncertain. It is also not clear whether the excitation of ^{235}U nuclei takes place in a standard mode of operation of RBMK reactor, or it is somehow connected with the emergency state of the IV unit of the Chernobyl NPP.

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Impact of Radiation on the Population during the First Weeks and Months after the Chernobyl Accident and Health State of the Population 10 Years Later

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After the nuclear catastrophe at the Chernobyl NPP on the 26th of April 1986, the USSR government immediately took all measures to classify the fact of the accident itself and its consequences for the population and the environment. The USSR government released instructions marked with "*top secret*" to classify all data on the accident at the Chernobyl NPP, especially on those related to the health of the population that suffered from the accident. Then followed instructions by the USSR Ministry of Health and the USSR Ministry of Defence to classify irradiation doses accumulated by the population, liquidators (people that had been involved in liquidation of the accident consequences) and the military personnel. These regulations demanded that medical staffs should not make the diagnosis of "acute radiation syndrome" in the files of the military-liquidators and replace it by something else.

The classified documents have not been accessible for many years. Only in 1991, when the Soviet Union was collapsing, the author of this material had managed to obtain secret protocols [1] of the Operative Group of the Politic Bureau of the Central Committee of the CPSU (the Communist Party of the Soviet Union). These protocols stated a number of persons were subject to irradiation and hospitalised during the first days after the Chernobyl accident.

Secret protocols of the Operative Group

In the protocol of the 4th of May 1986, the first description about the health state of population appears: "The report of Mr. Stchepin (First Deputy Minister of Health Care of the USSR - A.Ya.) on hospitalisation and medical treatment of the population subject to radiation effect: It is noted that by the 4th of May a total of 1,882 persons have been hospitalised. The total number of persons examined reached 38,000 persons. 204 persons have been found suffering radiation syndrome of different seriousness. Among them 64 are children. 18 persons are in critical state. 1,900 beds in medical institutions of the Ukrainian SSR have been allocated to hospitalise the persons suffering from the consequences. The Ministry of Health Care of the USSR along with the VCSPS (The USSR Central Soviet of Trade Unions - A.Ya.) allocated a special health centre in Michailovskoye near Moscow for the persons suffering mild forms, and health centres in cities Odessa and Evpatoriy with total 1,200 places. A total of 6,000 beds in health centres institutions and 1,300 beds in pioneer camps were allocated near Kiev."

Protocol on the 5th of May 1986: "It is reported.. by Mr. Stchepin that the total number of hospitalised persons amounted to 2,757 among which 569 were children. 914 have symptom of radiation syndrome and 18 out of them are in critical state."

Protocol on the 6th of May 1986: "It is reported.. by Mr. Schtepin that by 9-00 on the 6th of May the total number of hospitalised persons is 3,454. 2,609 of them are on stationary treatment, including 471 children. According to the updated information, the number of persons suffering acute radiation syndrome reached 367, including 19 children. 34 of them are in critical state. In the 6th Moscow Hospital there are 179 persons on stationary treatment, including 2 children."

The cynicism of the authorities shown in the document is striking: "The proposal of the Ministry of Health Care of the USSR on the expedience of publishing data on the number and state of persons hospitalised in the 6th Moscow Hospital should be accepted, taking into account that there are working American specialists in this hospital." If the Americans were not working in this hospital, the world would have never learned about the number of people suffering from the Chernobyl accident and undergoing treatment in the 6th Moscow hospital.

Protocol on the 8th of May 1986: "It is reported.. by Mr. Schtepin that in the course of the last day the number of hospitalised increased by 2,245 persons including 730 children. .... By 10.00 on the 8th of May the number of persons on stationary treatment amounted to 5,414 including 1,928 children. The diagnosis of radiation syndrome has been concluded in 315 cases."

Protocol on the 10th of May 1986: "It is reported.. by Mr. Schtepin that in the course of the last 2 days 4,019 persons have been hospitalised including 2,630 children. The total number of persons in hospitals is 8,695, including 238 persons with diagnosis of radiation syndrome, 26 of which are children. In the

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course of the last day 2 persons died, and 33 are in critical state."

Protocol on the 11th of May 1986: "It is reported.. by Mr. Schtepin that in the course of the last day 495 persons have been hospitalised. .... The total number of persons undergoing treatment and medical examination in hospitals constituted 8,137 including 264 persons with diagnosis of acute radiation syndrome. 37 persons are in critical state. 2 persons have died during the last day."

Protocol on the 12th of May 1986: "It is reported.. by Mr. Schtepin that in the course of the last day 2,703 more persons have been hospitalised, generally in Byelorussia. 678 persons have been discharged from hospitals. 10,198 persons are undergoing treatment and medical examination in hospitals."

Beginning from the 13th of May 1986, the number of hospitalised persons in the reports of the Deputy Minister of Health Care of the USSR sharply decreased, while the number of discharged persons started to increase.

Protocol on the 13th of May 1986: "Make note that in the course of the last day 443 persons have been hospitalised, 908 persons have been discharged from hospitals. 9,733 persons including 4,200 children are undergoing treatment and medical examination in hospitals. Diagnosis of radiation syndrome has been concluded in 299 cases including 37 children."

Protocol on the 14th of May 1986: "It is reported.. by Mr. Schtepin that in the course of the last day 1,059 more persons have been hospitalised. 1,200 persons have been discharged from hospitals."

Protocol on the 16th of May 1986: "It is reported.. by Mr. Schtepin that by 16th of May 1986 the number of hospitalised amounted to 7,858 persons including 3,410 children. Diagnosis of radiation syndrome has been confirmed in 201 cases. The total number of perished and deceased persons is 15, including 2 persons that have died on the 15th of May."

However, as the documents show, these data were not thorough and exact. At the meeting of the Operative Group on the 16th of May, the following decision was taken: "The task should be given to Mr. Schtepin to obtain more exact information on the number of persons hospitalised and suffering radiation syndrome, that are in hospitals in Moscow and other cities of the RSFSR (Russian Soviet Federative Socialist Republic), the Ukraine, and Byelorussia, including military personnel and Ministry of Inner Affairs staff."

Protocol on the 20th of May 1986: "It is reported.. by Mr. Schtepin that over the last 4 days the number of hospitalised increased by 716 persons. Diagnosis of radiation syndrome has been confirmed in 211 cases, including 7 children. The total number of deceased persons is 17. 28 persons are in critical state."

Beginning from the 26th of May 1986 the description on the number of hospitalised persons in the secret protocols of the Operative Group of the CPSU Central Committee Politbureau became irregularly, not at every meeting.

Protocol on the 28th of May 1986: "It is reported.. by Mr. Schtepin that 5,172 persons are undergoing treatment in hospitals, including 182 persons with the confirmed diagnosis of radiation syndrome. The total number of deceased persons by the 28th of May constituted 22 persons (plus 2 persons had perished in the accident)."

Protocol on the 2nd of June 1986: "It is reported.. by Mr. Schtepin that 3,669 persons are undergoing treatment in hospitals, including 171 persons with the confirmed diagnosis of radiation syndrome. The total number of deceased persons by the 28th of May constituted 24 persons (besides, 2 persons had perished in the accident). 23 persons are in critical state."

This is the last mentioning about the number of hospitalised persons in the secret protocols of the Operative Group, although the Group itself continued to exist until the early 1988. Its last meeting was held on the 6th of January 1988.

A question arises: why did the process of discharging people from hospitals become so rapid after the number of persons hospitalised for treatment had exceeded 10,000? The answer to this question can be found in the same secret documents.

Protocol No.9 on the 8th of May 1986: ".... The Ministry of Health Care has confirmed the new norms of acceptable levels of the population irradiation 10 times higher than old norms. Increase of these norms to levels 50 times higher than the previous is possible in specific cases." And further: "By these means the health safety of the population of all ages is guaranteed, even in case the current radiation situation remains for 2.5 years." These norms have been confirmed even for pregnant women and children.

Such action means that, by applying the new norms exceeding the old ones by 10 to 50 times to more than 10,000 people hospitalised for treatment due to irradiation by the accident, these people had become healthy automatically and were discharged from hospitals and clinics. It as well explains the sharp decrease in the number of people suffering the acute radiation syndrome. It explains the fact that at all further meetings of the Operative Group on Chernobyl no information appeared on the hospitalised persons. It goes without saying that the Soviet party leadership increased the acceptable irradiation doses by 10 to 50 times in order to conceal the true number of the affected people. To a significant extent they succeeded.

As the process of democratic transformation began in the USSR, however, the truth about the real scale of population irradiation due to the Chernobyl catastrophe gradually started to emerge. In the parliamentary hearings in the USSR Supreme Council in 1990, Academician Ilyin, the director of the Institute of Biophysics, one of those who were concealing the truth about the health of people in the affected territories, had to admit under the pressure of deputies' inquiries and the facts in the affected territories (including mine — A.Ya) that "1.6 million children received irradiation doses that are worrying us; the decision should be taken on how to act further [2]." He also admitted that "if the dose limits were lowered to 7 rem per 35 years (of life — A. Ya.), we would have to increase the number of 166 thousand people that are now planned to be relocated approximately by 10 times. Relocation of a total of 1.6 million people would have to be considered. The society must balance all the risks and profits of such an action." As one can see, neither the health of people nor the real state of things was considered, but only the economic side of the problem was. The USSR was not able to relocate such number of irradiated people. Thus, the officials were trying to conceal the truth about the health of the population from the people itself.

Health state of the people ten years later

The results of studies conducted by conscientious scientists ten years after the Chernobyl accident are striking. According to the estimate of the World Health Organisation, the number of liquidators - people who took place in liquidation of the accident consequences - amounts to 800,000. Russian scientists estimate this number as approximately 600,000. Nobody knows the exact figure because, according to the documents the present author obtained already in 1989, "Persons who had taken part in the extermination of the accident consequences after the 1st of January 1988 should not be included in the registry from 1989 by the order of the Ministry of Health Care of the Ukrainian SSR." However, all-union organisations about health care report that morbidity and mortality increase among the liquidators. They mainly suffer from vegetovascular dystonia, heart diseases, lung cancer, gastrointerstinal diseases and leukaemia. According to the data of the Ukrainian officials, approximately 8,000 liquidators have died over the ten years after the Chernobyl catastrophe. The official data states that a total of 2,000 liquidators in Russia have died within the same period. In newspapers this number reaches 50 thousand people.

According to the reports of the Ministry of Health Care of Belarus, the total morbidity in the most contaminated areas of this country has increased by 51 percent in comparison to the period before the Chernobyl accident, including lung and stomach cancer, as well as the genitourinary system problems.

The data of the Ukrainian officials state that 148 thousand people have died due to the consequences of the Chernobyl catastrophe over the ten years after the catastrophe.

Special attention is needed in the situation of children in the Ukraine. According to the report of the Ukrainian Research Institute of Paediatrics, Obstetrics and Gynaecology of the Ministry of Health Care of the Ukraine, the statistical data bear evidence of a continual increase in infant mortality as compared to the period before the Chernobyl accident, while in the rest of the Ukraine it has even decreased by 6 percent. In some regions the primary morbidity has increased by 1.5-2 times over the last ten years. In particularly affected territories the morbidity of endocrine system, blood and blood-forming organs, as well as the number of hereditary malformations, neoplasms have increased by 2-3 times. There are areas where the primary morbidity is 14-20 times higher than the average rate in the Ukraine. The incidence of child thyroid cancer has significantly increased. While only 2-3 cases of thyroid cancer were registered annually before 1986, 200 cases were registered in 1989 in the Ukraine.

The most widely spread children diseases in the affected territories are: thyroid hyperplasia of 1st and 2nd degrees, diseases of digestive organs, caries, diseases of throat and nose, diseases of the nervous system, anemias, vegetovascular dystonia, diseases of respiratory organs, heart diseases, allergic diseases, and rachitis [3].

The birth rate in the Ukraine has decreased from 15 per 1,000 persons in 1986 to 11.4 at present (the death rate 13.4). The situation has worsened especially in 75 districts of strict radiation control in the Kiev, Zhitomir, Chernigov and other (total 11) regions of the country. The indices of children mortality in these districts are 1.6-2 times higher than the Ukrainian level [4, 5].

According to the data of the same institute, medical examinations of women show increases of different complications during pregnancy as well as increases in the number of pathological birth and birth with complications. The number of anemias and pregnancy interruption threats has increased 1.5-2 times. Already during the first year after the Chernobyl catastrophe, a two-fold increase in the number of bloodying at birth was registered (from 3.5 to 7.5 percent). Over the following years this rate has increased to 9.2 percent.

The morbidity has increased for cardiovascular diseases, diseases of the liver, and neurocirculatory dystonia by pregnant women in the strict radiation control districts [6].

Delay of foetus growth is registered in its main indices. This means the possibility of hypotropia development.

Health state indices of children in the Zhitomir region (Ukraine) have significantly worsened over the last three years. According to the report of the Zhitomir official medical authorities, the number of premature-born children has grown. Every second child in the first year of its life belongs to the risk group. Only 38 percent of children, born before the Chernobyl catastrophe, were found to be healthy. The morbidity among these children has increased by 27 percent.

The group of children with infant-cerebral paralysis and oncological diseases has grown significantly. In 1992-1994 2 children with brain-cancer have been registered every year in Zhitomir, while in 1994 it was already 8. Thyroid hyperplasia, autoimmune thyroiditis among the Zhitomir children are registered by 4 times as often as compared to the republican average [7].

In the capital of the Ukraine - Kiev, children irradiated at the moment of the accident constitute a special group of population. The morbidity among children up to 14 years was 1,554.5 per 1,000 children (the average rate in the Ukraine is 1,308). One needs to note the higher morbidity of Kiev children in mental disorders - 40.2 per 1,000 children (the Ukraine - 30.0); diseases of respiratory organs - 995.4 (the Ukraine - 743.1); chronic bronchitis - 8.4 (the Ukraine - 4.7); bronchial asthma - 4.6 (the Ukraine -2.8); as well as in diseases of digestive organs in comparison to the average Ukrainian rates.

However, a dramatic tendency common in the Ukraine, Russia and Belarus should be noted, particularly in the increase in the number of thyroid cancer among children. Most of these cases are found in Belarus. According to the data of the World Health Organisation, 21 cases were registered in the period from 1966 to 1985. After 1986 the number of cases amounted to 379. Within the period from 1986 to 1989, 18 cases have been registered, in 1990 - 29, in 1991 - 59, in 1992 - 66, and 46 cases only in the first half of 1995.

According to the data of the World Health Organisation, 680 cases of thyroid cancer among children have been registered in Russia, the Ukraine and Belarus by December 1995. The data of the European Association for Studies of the Thyroid Gland shows that this number is only the beginning of the outbreak, and in the next 30 years thousands of children will suffer from thyroid cancer.

The above mentioned data on morbidity and mortality development, especially among the children residing in the affected territories, testify to the fact that, in the first days after Chernobyl catastrophe, millions of people have been subject to irradiation. It is far beyond thousands of people reported in the secret documents of the Operative Group of the Politbureau of the CPSU Central Committee. As time passes more since the catastrophe at Chernobyl, people will learn more and more about the results of this catastrophe and its impact on genes of future generations of Russia, the Ukraine and Belarus, as well as on the ecology of the whole planet.

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Chernobyl 1996: New Materials concerning Acute Radiation Syndrome around Chernobyl

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We have already reported that in March and June of 1992 we managed to discover 82 medical histories in the Central district hospital (CRH) of the Khoiniki district of the Gomel region (town Khoiniki) with the description of radiation injury, which emerged in the first days and weeks after the accident at the 4th power unit of the Chernobyl NPP [1]. We have found the symptoms of acute radiation disease in eight cases. A brief account of this fact in the press has caused interest in the Republic of Belarus, the USA and Japan [2, 3].

However, a more elaborate analysis of the data found in the medical documents, compiled by the staff of the CRH in May-June 1986 was hampered by the absence of reliable (not misrepresented) information on the radiation situation in the Khoiniki district in the first days after the accident when, as one might expect, radiation dose could be so strong enough to induce radiation syndrome.

In 1996 we have succeeded in getting reliable data on the radiation situation in the Khoiniki district. These were data of the Civil Defence Headquarters of the Khoiniki district, remaining in private notes of the Chief of the Civil Defence Headquarters (all data have been submitted to the republican archives in Minsk immediately after the accident).

According to the existing practice, all data on the radiation situation in the first days after the accident have been concealed by the USSR Hydro-meteorological Committee, although these data were of the greatest interest in order to assess the scale of the accident. The same happened to the data of the Civil Defence Headquarters of the Khoiniki district: they were concealed by the Belorussian Hydro-meteorological Committee.

However, as we have compared the data on radioactive contamination presented by the Civil Defence Headquarters with the data of the Medical and Epidemiological Station of the Khoiniki district, we found that they coincided to a great extent.

The usual argument to reject the data acquired on local areas has been that measurements were conducted by semiskilled staffs using improperly calibrated devices. However, in our case this argument has no power.

The Chief of the Civil Defence Headquarters of the Khoiniki district - Kayuda Alexander Ivanovitch had previously worked as a nuclear submarine mechanical engineer. He had been serving in the submarine fleet until 1983. Besides technical maintenance of the nuclear reactor, he was responsible for measurements in the reactor compartment. He has been holding the post of the Civil Defence Headquarters Chief since 1983. Even before the accident, he had been conducting measurements of the radiation background in the 10-20 km distance from the Chernobyl NPP by means of the DP-5V dosimeter. According to his data in June 1985, exposure dose rate on the ground near the village Radin was 240-250 μR/h (the same dosimeter showed only 40 μR/h in the reactor compartment of a nuclear submarine). The enhanced radiation background in the vicinity of the village Radin could not be explained by reasons other than (radioactive) discharge from the Chernobyl NPP.

According to the data of the Civil Defence Headquarters, systematic dosimetric studies were not conducted on the 26th and 27th of April in the territory of the Khoiniki district by any civil or military organisation. The Civil Defence Headquarters started to conduct the first dosimetric studies on the 28th of April at 8 a.m. Below are given some of the results of the ground radiation measurements conducted by the Civil Defence Headquarters:

Town of Khoiniki — 8 mR/h;
Villages: Strelitschevo — 14 mR/h,
Dron'ki — 30 mR/h,
Orevitschi — 89 mR/h,
Borschevka — 120 mR/h,
Radin — 160 mR/h,
Ulasy — 300 mR/h,
Tschemkov — 330 mR/h,
Masany — 500 mR/h.

According to the instruction on population radiation protection existing at that moment, the major part of the Khoiniki district population had to be evacuated because many residents of the district were likely to suffer the whole-body doses of hundreds of rem — such was the conclusion of the Civil Defence Headquarters, announced at the district meeting in the evening of the 28th of April.

The conclusion about the necessity of immediate evacuation of the district residents was supported by the Gomel region Civil Defence Headquarters Chief, D.F. Zhukovskiy (mechanical engineer of special power plants) and nuclear physicists from the Obninsk NPP who were also present at this meeting. The district administration rejected the demand of the

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district and region Civil Defence Headquarters.

However, the evacuation of children and pregnant women from the 30km zone began on the 1st of May, and on the 5th of May the evacuation of the rest of the population. The number of evacuated residents totalled to 5,200 persons. All of them underwent medical examination at the CRH which has been reorganised into a Military Field Hospital (MFH) on the 5th of May. From this day military radiologists from Severomorsk, Severodvinsk and the Far East started to work at the CRH. The official symptoms for stationary examination at the MFH were as follows:

- The exposure dose rate of the thyroid gland is more than 1,000 μR/h.
- Contamination of clothing, footwear, skin, underwear is more than 0.1 mR/h.
- Accumulation of radionuclides in internal organs (thyroid gland, liver, kidneys, genitals) from 800 to 1,000 μCi.

Approximately 12 thousand residents of the Khoiniki district came within these factors: all of them have undergone medical examination in the Military Field Hospital (there have been 32 thousand residents in the Khoiniki district before the accident).

Medical histories (approximately 12 thousand) have been stolen from the hospital archive in November 1990. After the loot, the records of the archives have not been kept in order. At the time we started to search for the remaining medical histories, medical files were found to be huddled in a stack in the attic of an ancillary building. As it is already mentioned, we have found 82 medical histories of patients from contaminated territories, who entered the hospital within the period from the 1st of May and till the middle of June 1986. These 82 histories are considered to be only a small part of the total, most of which were stolen from the archive in 1990.

22 medical histories of patients from the Bragin district have been excluded from the present report.

The Military Field Hospital (MFH)

60 medical histories from the hospital archives have been used for a retrospective analysis. All entries in these histories are very brief, reflecting a fact accounted for by both the considerable amount of work and the inspective reasons. The diagnosis at the discharge from the MFH had been subject to especially strict inspection: we have not found a single mentioning of radiation injury.

However, the reasons coming to the hospital for medical examination due to stay in the zone of radioactive contamination were not subject to inspection. The contents of these reasons remaining in their medical histories are of our interest.

Reasons coming to the MFH are as follows:

1. Radiation sickness Grade II.
2. The dose rate of thyroid grand — 10-16 mR/h.
3. Complaints of general weakness, headache, stomach aches, nausea, vomiting, dropsy of lower extremities.
4. Child from radioactive zone.
5. Hospitalisation for medical examination due to stay in the zone of increased radiation and changes in blood tests (leukocytes 2,500 mln/l).
6. Complaints of nausea, vomiting, salivation. Exposure dose rate of thyroid gland is higher than 3,000 μR/h.
7. Radioactive contamination. Exposition dose rate of the thyroid gland is higher than 3,000 μR/h.
8. Leukocytopenia: leukocytes — 2,300 mln/l. Headache.
9. Directed by the primary medical service with radioactive contamination diagnosis. Dosimetric data of the thyroid gland: more than 3 mR/h. Leukocytes — 2,900 mln/l.
10. At the time of the accident the patient stayed within 300 meters from the Chernobyl NPP. Leukocytopenia: leukocytes — 3,200 mln/l.
11. Radioactive contamination: liver 5-10 mR/h. Thyroid gland — 1.5 mR/h.
12. Radiation burn of face and hands.
13. Radiation injury, nasal bleeding.

Apart from the reasons coming to the MFH, complaints of the patients about their health state are also of interest. The following complex of symptoms was found most frequently: headache, strong weakness, nausea — more than 30% of the total number of patients. These symptoms are typical of so-called vegeto-vascular dystonia (VVD).

Second was the complex of symptoms characterised by vomiting, stomach ache, dizziness, poor appetite, pains in the heart area, dry and bitter mouth — up to 10%. Neurocirculatory dystonia (VVD + pains in the heart area) — 13%.

Below is given the list of patients' complaints found in the medical histories:

Headache — 33 cases,
strong weakness — 29,
nausea — 20,
dizziness — 10,
pains in the heart area — 8,
vomiting — 7,
poor appetite — 7,
dry and bitter mouth — 7,
salivation — 3,
arthralgia pain — 3,
scratchy feeling in the throat — 3,
drowsiness — 2,
diarrhoea — 2,
disturbed sleep — 2,
pains in the right subcostal area (liver) — 2.

The following complaints have been registered only once: increased temperature, defecation and urination retention, retardation, nasal bleeding, vascular bleeding, ear noise, skin itch, sweating, dry cough.

The patients were coming from the following residential areas: Towns: Khoiniki, Pripyat. Villages: Borschevka, Orevitschi, Ulasy, Pogonnaya, Molotschki, Kazhushki, Dron'ki, Chvoschevka, Tschemkov, Veliki Bor, Vysokaya, Budovnik, Novoselki, Lomatchi, Maleshev, Novopokrovka, Klivy, Amel'kovstchina, Erapov, Pudakov, Tul'govjtchi, Veletin, Tchechi, Dvorishtche, Rudnoe.

As a result of a retrospective analysis of 60 medical histories, the cases have been divided into three groups:

1. Acute radiation syndrome (ARS).
2. Radiation reactions.
3. High exposure dose rate of the thyroid gland without clear clinical symptoms.

Radiation Syndrome

1. Krychenko Nikolay Alekseyvitch (fictitious), man, age: 20, worker, from the village Borschevka.

Time of admission to the CRH: the 1st of May, 2:00. Complaints by admission: recurrent vomiting, general weakness, abdominal pains (in epigastrium area, mainly left), headache, bitter mouth.

History: the patient came to the village Borschevka to his relatives, intending to get sun-tanned and fishing in the river Pripyat. He spent two days — 26th and 27th of April on the bank of the river Pripyat. On the 28th of April vomiting came (up to six times a day), nausea, abdominal pains, the temperature rose (to 39). Stool retention was observed. The patient took antidote according to the direction of a physician.

Results of medical examination: retardation, flaccid. The tongue was coated with white fur. Stool retention for three days. Temperature — 36.6.

Radiation gamma background (!): clothes were strongly contaminated. Gamma dose rate from the side of the liver — 1.5 mR/h.

Medical examination on the 1st of May at 5:30 a.m. The patient complained of general weakness, nausea, vomiting (once since admission to hospital), retention of urination and constipation. Health state of the patient in the afternoon of the 1st of May: confused speech, complaints of headache, dizziness, recurrent vomiting. Blood analysis: leukocytes — 3,600 mln/l, trombocytes — 260,000/ml. Analysis of urine: protein — 4.65 g/l.

The patient was transferred to the Gomel regional hospital on the 3rd of May.

Additional data. On the 29th of April he was examined by the Medical Service Chief of the Civil Defence Headquarters, V.I.Kobylko: confused speech, complains of headache, weakness, recurrent vomiting. The patient conveyed that he had come to get sun-tanned and fishing in the river Pripyat on the 26th and 27th of April. He was subject to a second medical examination at the CRH on the 1st of May: the patient was still in an emergency state: retardation, confused speech. Diagnosis: Grade II-III ARS.

The village Borschevka, where the patient had come, is situated at 17.5 km to the north of the Chernobyl NPP on the right bank of the river Pripyat. Number of inhabitants on the 1st of January 1986 — 311 persons.

Radiation measurements in the village Borschevka. The data of the Khoiniki district Civil Defence Headquarters: the exposure dose rate on the ground in the village Borschevka on the 28th of April was 120 mR/h. Air measurements on the 20th of May; 300 meters above the village Borschevka — 28 mR/h; on the ground — 50 mR/h.

The data of the Khoiniki district Medical and Epidemiological Station: on the 29th of April 1986 the exposure dose rate on the ground in the village Borschevka was 60-100 mR/h, Sr-90 — 13.4 Ci/km^2.

The clinical characteristics of the disease corresponds to Grade III ARS: the irradiation dose, apparently exceeds 300 rem. The patient had received the main dose of ionising irradiation within two days — 26th and 27th of April, which testifies to the fact that during these two days there was a very high radiation level in the area of the village Borschevka. As the radiation level on the ground on the 28th of April has been 120 mR/h, one can draw a conclusion that the high level of ionising irradiation was contributed by short-lived radionuclides.

The severity of radiation injury was determined not only by high irradiation level, but also by the fact that the patient was getting sun-tanned (there weather was hot). One can presume that there were many people taking vacation on the bank of the river Pripyat during the weekend (26th and 27th of April). We can state that during these two days high irradiation doses could be received by the people far outside the Khoiniki district, especially by those who were getting sun-tanned, took outer clothes off due to hot weather, spent much time in the open air.

2. Medical history N2505/467. Man, resident of the village Borschevka, milker, age: 47, works in the collective farm "Pervoe Maya" (The First of May). Admitted to the CRH on the 2nd of May, 2:45. Directed by the head physician of the Pogonyansk rural hospital. Diagnosis: Grade II ARS.

By admission the patient complained of nausea, vomiting, weakness, abdominal pains. He said that he had fallen ill on the 1st of May, when pains in epigastrium area, nausea and vomiting came.

Medical examination on the 2nd of May, 16:30. Vomiting did not recurred. Health state improved. Abdomen painful.

Blood analysis: leukocytes — 4,700 mln/l. The patient left the hospital on the 4th of May without official permission.

3. Medical history N7539/464. Man, age: 82, resident of the village Borschevka. Admitted to the CRH on the 3rd of May 1986. Complaints of general weakness, headache, abdominal pains, nausea, vomiting. Dropsy of lower extremities was found by evening. The patient left the hospital on the 4th of May.

4. Medical history N2520/476. Woman, age: 48. Admitted to hospital on the 3rd of May from the village Molotchki.

First symptoms of an ailment became apparent on the 28th of April 1986: nausea, vomiting, strong general weakness, diarrhoea (up to 4 times a day). The patient consulted a doctor on the 30th of April.

Medical examination on the 3rd of May: the patient complained of pains in epigastrium area, nausea, vomiting, salivation. 7th of May: the exposure dose rate of thyroid — 3,000 μR/h. Blood analysis from the 9th of May: leukocytes — 3,500 mln/l. Discharged from hospital on the 13th of May 1986.

Retrospective analysis:

Grade I-II ARS — might be substantiated by typical clinical symptoms and stay in radiation contaminated area, the exposure dose rate of thyroid and leukocytopenia. The intestinal upsets draw the attention in the health state of the patient.

Clinical symptoms of ARS of the patient became apparent on the 28th of April, which testifies to the fact that on the 26th and 27th of April she received a dose higher than 100 rem.

The patient resided in the village Molotchki (20 km from the Chernobyl NPP, number of inhabitants — 124). According to the data of the Civil Defence Headquarters, the exposure dose rate on the ground in the village Molotchki on the 28th of April was 280 mR/h (two times higher than in the village Borschevka). According to the data of the Medical and Epidemiological Station, the exposure dose rate on the 29th of April was 130-190 mR/h, on the 30th of April — 60-70 mR/h, Sr-90 — 25 Ci/km^2.

5. Man, age: 35, resident of the village Dron'ki, works in the state farm "Orevitschi".

Admitted to the CRH on the 3rd of May 1986, 20.30. Complaints: weakness, dizziness, nausea, vomiting. The patient had fallen ill on the 28th of April, when the symptoms (weakness, nausea, vomiting) appeared for the first time. These symptoms remained for a week (from the 28th of April to 2nd of May). The health state worsened on the 3rd of May.

Data of medical examination on the 3rd of May: the patient shows slight retardation, he said that he had received a dose of 60 rad.

Discharged from hospital on the 6th of May. The village Dron'ki (35 km from the Chernobyl NPP, 232 residents). According to the data of the Civil Defence Headquarters, the exposure dose rate on the 28th of April was 30 mR/h, and according to the data of the Medical and Epidemiological Station on the same day — 26-28 mR/h. Sr-90 — 2.7 Ci/km^2.

6. Medical history N8977/438. Man, age: 55, resident of the village Amel'kovstchina. Admitted to hospital on the 10th of May. The patient had fallen ill on the 4th of May, when general weakness, abdominal pains, diarrhoea, nausea, vomiting appeared.

Patient complaints: diarrhoea, abdominal pains, weakness. Blood analysis: leukocytes — 3,200 mln/l.

7. Medical history N8302/602. Woman, age: 57, village Klivy (70 km from the Chernobyl NPP). Admitted to hospital on the 11th of June due to stay in radiation contaminated zone. She had been ill for 1 month. Complaints: pains in the right subcostal area, nausea, vomiting, dizziness, general weakness, abdominal pains, pains in the back, neck, feet.

20th of May: vomiting once. Blood analysis from the 10th of June: leukocytes — 2500 mln/l, trombocytes — 260,000/ml, erythrocytes — 3.63 mln/ml. Arterial pressure 210/115.

8. Medical history 7588. Infant, age: 2 years and 7 months, village Pogonnoye. Admitted to the hospital on the 4th of May. Diagnosis: aphthous stomatitis, a child from the zone of increased radiation. Complaints: refuses to take food, salivation. Objective signs: dropsy lips, profuse aphthous ulcers on the mucosa of mouth, lips and cheeks. Marked salivation, temperature 37.8.

6th of May: stomatitis remained. The patient was transferred to the regional children hospital.

The village Pogonnoye (1,503 inhabitants) lies at 27 km from the Chernobyl NPP (the exposure dose rate on the 28th of April, according to the data of the Medical and Epidemiological Station was 30-35 mR/h, Sr-90 contamination density — 10 Ci/km^2).

We have attributed this case to radiation syndrome, although vomiting is not apparent with the patient. The aphthous stomatitis can be explained as beta-injury. The refusal to take food, increased temperature and profuse salivation indicate the severity of the health state.

Let us draw some conclusions. The patients stayed in the radiation contaminated areas and received a relatively high dose of ionising radiation. Similar clinical symptoms appeared in all the patients, which are characteristic of ARS. The patient Krivenok takes a central place in our list: his case may be called a standard ARS case for the 30 km zone.

Radiation Reactions

The following syndromes have been established:

1. Hemopathology — cytopenia, leukocytopenia.
2. Astheno-vegetative syndrome.
3. Neurocirculatory dystonia.
4. Syndrome of laryngitis.
5. Beta-injury of the mucosa and skin.
6. High gamma radiation of the thyroid gland

Leukocytopenia

9. Medical history N7784. Woman, age: 65, resident of the village Amel'kovstchina, admitted to hospital on the 12th of May. Diagnosis: radioactive contamination. Measurement on the 15th of May: clothes — 500 μR/h. Thyroid gland — 1,200 μR/h. Blood analysis: leukocytes — 2,200 mln/l. Discharged from hospital on the 20th of May 1986.

10. Medical history N8011/554. Man, age: 21, town of Khoiniki. Admitted to hospital on the 23rd of May with the diagnosis: "Hospitalised for medical examination due to stay in increased radiation zone, with changes in blood analyses."

Blood analysis: leukocytes — 2,500 mln/l. Radiation of the thyroid gland — 130 μR/h. Treatment according to the scheme used by Grade I ARS: gluconat calcium, citric acid, multivitamins, hypotisiad, mineral water, isophenin, cholagogue medicines.

Discharged from hospital on the 2nd of June.

11. Medical history N8318/604. Man, age: 41, town of Khoiniki, driver. Admitted to hospital on the 13th of May. Radiation from the side of the liver — 80 μR/h, of the thyroid gland — 35 μR/h. Blood analysis: leukocytes — 2300 mln/l, trombocytes — 144,000/ml. Complaints: headache.

12. Medical history N7641/318. Woman, age:33, resident of the village Pogonnoye, from the zone of contamination. Complaints: moderate headache, dry and bitter in mouth on May 6. Blood analysis: leukocytes **-** 2,200 mln/l on May 7. The exposure dose rate of thyroid **-**1,400 μR/h.

Vegetative-vascular dystonia

13. Medical history N7868/533. Man, age: 64, resident of the village Ulasy, worker on the collective farm "Novaya Zhizn'" ("New Life"), resettled on the 5th of May to the village Strelitschevo.

Admitted to the CRH on the 20th of May 1986. Complaints by admission: general weakness, sleepiness, discomfort, pains in the loin.

Directed by the medical service station with the diagnosis: radioactive contamination. Hospitalised from increased radiation area. Dosimetric examination of the thyroid gland: 1.9-2.0 mR/h. Gamma-radiation intensity on the thyroid gland by admission to the CRH higher than 2 mR/h. Blood analysis: leukocytes — 2,900 mln/l. Discharged from hospital on the 5th of June 1986. From the 26th of April till the 5th of May, the patient stayed in the village Ulasy, where the exposure dose rate on the 28th of April has been 300 mR/h. From the 5th of May to the 15th of May the patient stayed in the village Strelitschevo.

14. Medical history N7805/496/539. Woman, age: 63, resident of the village Novoselki. Admitted to the CRH on the 13th of May. Diagnosis: radioactive contamination. Exposition dose rate: liver — 1,000 μR/h, thyroid gland — 3,000 μR/h. During three days (10-12th of May) the patient stayed in the open air in a 65 km distance from the Chernobyl NPP.

Complaints: headache, nausea, poor appetite, general weakness, discomfort, sleepiness. Blood analysis from the 19th of May: leukocytes — 3,200 mln/l. Discharged from hospital on the 27th of May.

15. Medical history N7795/491. Woman, age: 59, village Novoselki. Admitted to the CRH on the 13th of May. Diagnosis: VVD. The exposure dose rate on clothes on the 14th of May — 700 μR/h. Thyroid gland — 2,000 μR/h. Complaints: headache, nausea, scratchy feeling in the throat. The patient stayed within 60 kilometres from the Chernobyl NPP and spent plenty of time in the open air. Discharged from hospital on the 21st of May.

16. Medical history 7818/495. Woman, age: 49, village Novoselki. Admitted to hospital on the 13th of May. Directed to hospital with diagnosis: radioactive contamination. 14th of May: the exposure dose rate on clothes — 900 μR/h. Thyroid gland — 3,000 μR/h. Symptoms of an ailment have become apparent on the 10th of May.

Before this, the patient stayed within 65 kilometres from the Chernobyl NPP. Complaints: weakness, nausea, poor appetite, headache. Discharged from hospital on the 21st of May.

17. Medical history N7815/502. Woman, age: 57, village Novoselki. Admitted on the 15th of May. The exposure dose rate on clothes — 700 μR/h. Thyroid gland — 2,600 μR/h. Blood analysis on the 19th of May: leukocytes — 2,900 mln/l.

The patient stayed within 65 kilometres from the Chernobyl NPP in the open air. The patient drank milk from her own cow. Complaints: headache, weakness, discomfort, pains in the heart area.

Beta-dermatitis, radioactive burns

18. Medical history N7587/1060. Man, age: 35, resident of the village Veliki Bor. Admitted to the CRH on the 4th of May 1986. The patient was brought from a radiation contamination area with the diagnosis: radioactive burn of the face, hands. Exposure dose rate of the body surface — 300 μR/h. Thyroid gland — 700 μR/h. Complains of discomfort, headache.

19. Medical history N7655/461. Woman, age: 43, milker, resident of the village Vysokaya. Admitted to the CRH on the 6th of May, 23:00. Directed with the diagnosis: radiation injury, nasal bleeding. On the 1st-5th of May the patient had worked on cow-milking in the Tchemkov-Ulasy area. Headache became apparent on the 5th of May. Objective signs: skin integument of face, neck, hands have the colour of dark sun-tan, reddened cheeks. Blood analysis: leukocytes — 3,000 mln/l. The patient left the hospital on the 8th of May without official permission.

20. Medical history N7794/489/540. Woman, age: 64, resident of the village Novoselki. Admitted on the 13th of May. Directed with the diagnosis: radioactive contamination. The exposure dose rate on clothes — 1,700 μR/h. Thyroid gland — higher than 3,000 μR/h. Complaints: headache, nausea, pains in epigastrium area. The patient said that she lived within 60 kilometres from the Chernobyl NPP. The patient worked in the garden. Exposed body parts — sun-tanned. Blood analysis from the 26th of May: leukocytes — 2,800 mln/l. Discharged on the 29th of May.

Neurocirculatory dystonia

21. Medical history N8013. Woman, age: 21, town of Khoiniki. She was working at the Bragin Medical and Epidemiological Station. Admitted to the CRH on the 23rd of May. The symptoms of an ailment had started to become apparent a week before admission to the CRH. The patient repeatedly worked in the areas of increased radiation.

Complaints: sharp pain in the parietal area, nausea, weakness, arthralgia, pains in the heart area, headache, disturbed sleep, anorexia. Discharged on the 2nd of July.

22. Medical history N8060/550. Woman, age: 49, town of Khoiniki. Admitted to the CRH on the 23rd of May. The symptoms of ailment first became apparent on the 3rd of May: weakness, nausea, subfebrile temperature at night. The health state had worsened on the 20th of May, when the temperature rose to 39.

Complaints: headache, strong weakness, discomfort, poor appetite, nausea, pains in the lumbar area, arthralgia, dry mouth.

23. Medical history N 7806/498. Man, age: 67, village Maleshev (lies on the outskirts of Khoiniki). Admitted on the 14th of May.

Diagnosis: radioactive contamination. The exposure dose rate of the thyroid gland — 1,700 µR/h. Blood analysis: leukocytes — 2,400 mln/l, trombocytes — 100,000/ml. Complaints: weakness, headache, dull pains in the heart area. Discharged on the 21st of May.

Syndrome of laryngitis

24. Medical history N 7783/512. Man, age: 50, village Borschevka. Admitted on the 12th of May with the diagnosis: radioactive contamination. The exposure dose rate of the thyroid gland — higher than 3,000 µR/h. Complaints: headache, dry cough, scratchy feeling in the throat. By ENT examination: marked hyperaemia of mucosa. Discharged on the 23rd of May.

25. Medical history N 7785/490. Woman, age: 47, village Nebytov. Admitted on the 13th of May with the diagnosis: radiation contamination. The patient had stayed within 65 kilometres from the Chernobyl NPP. The patient worked in the state farm. Exposed body parts — sun-tanned. Complaints: headache, weakness, itch of the skin, burning in the mouth, dry cough. The exposure dose rate of the thyroid gland — 300 µR/h. Blood analysis: leukocytes — 2,800 mln/l, trombocytes — 140,000/ml.

26. Medical history N 3637/363. Woman, age: 36, village Pogonnoye. Admitted on the 5th of May. Blood analysis: leukocytes — 3,400 mln/l. The exposure dose rate of the thyroid gland — 1,400 µR/h. Complaints: aches, scratchy feeling in the throat. Discharged on the 12th of May.

High gamma radiation of the thyroid gland

27. Medical history N 8239/588. Man, age: 57, village Lomatchi, forest worker. Admitted on the 14th of May. Data of the thyroid gland exposure dose rate measurement — 16 mR/h. Complaints: general weakness, bitter mouth, headache. Discharged on the 14th of May.

28. Medical history N 8011/554. Man, age: 21, town of Khoiniki. Admitted on the 23rd of May for examination from the medical-sanitary field unit with the diagnosis: "radiation level could not be measured (?)". The exposure dose rate of thyroid gland — 13 mR/h. Blood analysis: leukocytes — 2,500 mln/l.

Conclusion

Just a single case (the patient Krychenko) is enough to reject the point of view which the IAEA, the Red Cross, the WHO and other organisations confine to, namely that acute radiation syndrome cases could not have occurred and did not occurred outside of the Chernobyl NPP site. However, the case of the patient Krychenko could not have been single. When in the village Borschevka ARS was observed with at least 1% of inhabitants, the same index must be even higher for the villages Masany, Ulasy and others. It is known that 5,200 persons were evacuated from the 30 kilometre zone of the Khoiniki district, while the total number of inhabitants in this was more than 100 thousand persons. As a result we need to expect more than 1,000 cases of ARS.

The obtained data testify to the fact that the highest ionising irradiation levels was observed on the 26th and 27th of April. Over these two days a dose from 100 to 300 rem could have been received in certain conditions (work in the open air, getting sun-tanned).

It has been also found that the number of irradiated persons in the 30 kilometre zone exceeds the number of inhabitants of this district. This is accounted by a significant number of people who came to spend the weekend (26th and 27th of April) in this area.

The fact that irradiation was at its highest on the 26th and 27th of April points to the possible irradiation of a significant number of Belorussian inhabitants, including those, who lived far outside the 30 kilometre zone (in the first place, those who were getting sun-tanned worked in the gardens and spent a long time in the open air). This factor should be taken into account in the analysis of all ailments registered among the Belorussian citizens in April-June 1986 with a number of peculiarities which were not clearly explained so far.

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Overview of Different Information about Acute Radiation Syndrome among Inhabitants around Chernobyl

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The Chernobyl nuclear catastrophe has divided scientists of the world, studying the consequences of its impact on the health of people, into two opposed, at times irreconcilable blocks. The first block generally comprises representatives of medical officials in the soviet and post-soviet society. They have been concealing the truth from the soviet and the world public for years. This group advocates the point of view that, except for firemen and several staff members who died at the time of the catastrophe, the Chernobyl accident has produced no practical impact on human health and will not do any such effect also in future. The second block consists basically of independent scientists. They are anxious about the facts of concealment of the truth on actual radiation doses, received by inhabitants of the areas around the Chernobyl NPP (ChNPP), as well as about impacts of low radiation dose on human health. Scientists of the second block are convinced that doses received by the population in the first days and months after the catastrophe at the ChNPP have played and will play significantly negative roles in worsening of human health years after the accident. The data on these doses have been deliberately concealed by the authorities from both the sufferers and the public. This fact has been already proven (by the Procurator General of the Ukraine as well).

I have official and unofficial documents in my Chernobyl archive, which are demonstrating two approaching ways to the problems of radiological consequences due to the Chernobyl catastrophe. I would like to emphasise that these documents have never been published anywhere.

In searching the answer to the question about the acute radiation syndrome among inhabitants in the areas around the Chernobyl NPP in the first weeks and months after the catastrophe, we will compare positions, arguments and conclusions of two blocks based on the facts presented in these documents.

What has been publicly said about risks of irradiation by soviet medical officials?

Official position of the party leaders of the Soviet Union on the problem about the scale of the catastrophe at the ChNPP and its impact on human health has been known from the party press. Its main conclusion was the following: the population has experienced no health changes and will not experience any. This political diagnosis was made considering the ideological conflict between totalitarianism and democracy. It did not contain a shred of truth. The overall concealment of truth on radioactively contaminated areas had lasted for three years — till the first Congress of People's Deputies of the USSR. The lies of both the authorities and the medical officials were at first disclosed by speeches of the deputies, acting on behalf of the affected territories' electorate, of the Gorbachev period, and by thefirst open hearings at the parliament session on the catastrophe at the ChNPP and its consequences for human health and the environment.

The official medical documents from my archive allow to trace easily the dynamics of changes in the position of "fathers" of the notorious soviet 35-rem concept for safe living of the population in the affected territories. Briefly, the essence of this concept lies in a belief that a person may receive 35 rem over 70 years without health disorders. A month after the accident this "ceiling" was increased to 70 rem over 70 years, and several months later was decreased to 50 rem over 70 years, then to 35 rem. The same official scientists — L.A.Ilyin, E.I.Chazov and A.KGuskova had stated in their book, written before the Chernobyl accident in 1982, that the threshold is 25 rem over lifetime. Hence, we can conclude the "scientific" nature of the mentioned official concept.

The first open report under the title "Radio-contamination Patterns and Possible Health Consequences of the Accident at the Chernobyl Nuclear Power Station" (70 pages typescript) was presented by Academician L.A.Ilyin at the General Session of the Academy of Medical Sciences of the USSR in Moscow, which took place on the 21st-23rd of March 1989 [1]. An important remarkable thing: this open report had taken place just on the eve of the first Congress of the People's Deputies of the USSR (the Congress opened on the 25th of May 1989). The Moscow authorities had no doubts that this question was going to be raised by deputies at the Congress, thus they decided to avoid the blow in advance.

Although the report was made by L.A.Ilyin, it was signed by 23 official medical celebrities from Russia, the Ukraine, Byelorussia. In the Soviet Union, responsibility has always been collective and never been personal. This was more convenient and safe. Many of the above-mentioned scientists still hold influential posts in science and, even 11 years after the catastrophe, they continue to deny the obvious and proven facts about the impact of the Chernobyl catastrophe on the health of the population.

In the paragraph "The Characteristics of Radiation Exposure of the Population, and Theoretical Premises for Prediction of Late Radiological Consequences" of the report, it was noted that "thyroid irradiation doses as a result of radioiodine incorporation were delivered over a comparatively short period — two to three months after the accident. .... Immediately after the accident, the Ministry of Health of the USSR implemented a previously composed emergency regulation on the maximum acceptable concentration of ^{131}I in milk (3,700 Bql^{-1}), corresponding to a radiation dose to thyroid of children of 0.3 Sv (30 rem). Preliminary assessments suggest that, due to a series of measures recommended by the Ministry of Health of the USSR to protect the population from radiation in the early phase, and especially to prevent or reduce radioiodine intake by the human body, ... probable radiation doses were on average by 50% and in some places by 80% lower than they would have been had the protective measures not been taken." The authors of the report state that "absorbed doses were calculated by computer for inhabitants of each settlement in the strict control zones for different times after the accident, including prediction of radiation burden in humans up to the year 2060." The authors specify that, although the widely accepted hypothesis of non-threshold impact of radiation on human health "exaggerates the actual risk of late effects", they have used this approach, "realising its limitation for extrapolation and a need for prudent interpretation of the results obtained." So, what are the limitations that the authors bear in mind? In their report, they state that "one of the main objections (to the non-threshold hypothesis — A.Ya.) is that the values of risk factors e.g. probabilities of effect per unit of dose, have in fact been deduced from observations at high doses and high dose rates." And further on: "No stochastic effects of somatic or genetic nature have been observed in the low dose range." These statements are at least strange even for a non-specialist in radiobiology, because at that time the results of studies on impact of low radiation doses on human health have been already published by such world-known scientists as John Gofman, Rosalie Bertell, Ralph Greyb, Petko, etc. Furthermore, one should consider that the United Nations Scientific Committee on the Effects of Atomic Radiation, which "legitimatised" on international scale the non-threshold (not the threshold) concept of low radiation doses impact on human health, had followed scientific, not emotional estimates.

In the paragraph "The Prediction of Possible Stochastic Effects in Different Groups of the Population of the USSR after Exposure of the Thyroid as a Result of the Accident at the ChNPP", the authors give, by means of the specified approaches, their "predictions for three levels of exposure of the whole population and separately for children aged 0-7 years at the time of the accident: 1) for 39 districts of 9 regions where the levels of exposure were relatively high (total population about 1.5 million, including 158,000 children); 2) for the entire population of these regions (15.6 million, including 1.666 million children aged 0-7 years); and 3) for the population of the central regions of the European part of the USSR (75 million, including 8 million children aged 0-7 years)". For the first time after the catastrophe at the ChNPP these data have been opened to the public. Bear in mind that the report was made in 1989, three years after the catastrophe had happened.

What are the official prognoses? "... according to the linear (non-threshold) hypothesis, the projected number of malignant thyroid tumour among children aged 0-7 years is around 90 in the whole period of 30 years following the accident. This includes about 10 projected fatal cases." For the whole population of these districts (1.5 million) a possible 200 excess cases of malignant tumour over the 30 years period were predicted without correction of the specified hypothesis.

Investigation of the possible consequences of irradiation of thyroid for the whole population in the relevant regions (9 regions — A.Ya.) and, in the first place Kiev, Gomel, Bryansk and Zhitomir regions shows that malignant tumour may amount to $3.3*10^2$, including $3*10^1$ incurable cases." The prediction for the population of the Central regions of the European part of the USSR, including the whole territory of the Ukraine, Byelorussia, Moldavia and several central regions of the RSFSR (now Russian Federation) — 75 million people, including 8 million children aged 0-7 years — are following. "The projected numbers of thyroid malignant tumour caused by radiation in the 30 years following the accident are as follows: incurable tumours in children — up to 20 and in the whole population — up to 50; curable malignant tumours are up to 170 and up to 400 cases, respectively."

In the paragraph "Prediction of Possible Late Effects of Whole Body Exposure in Various Groups of the Population of the USSR as a Result of the Accident at the ChNPP" of the report, the estimates of the population irradiation are given. Here appears the 35-rem concept of the Ministry of Health of the USSR. It is especially noted that for the population of the strict control zones (SCZ) "the estimations of late effects was based on the actual doses in the four years following the accident and on the projected doses until 2060, the latter having been calculated on the assumption that restrictions on the use of home-grown products would be lifted in the SCZs." Hence, two simple questions arise. Firstly, the time of this report was three years, not four, since the accident. If this is an error on the part of the authors, it is very symptomatic. Secondly, WHO and WHEN had ACTUALLY evaluated the doses received by the population in the first 2-3 months? I know very well about the efforts made by officials in the Narodichi district of the Zhitomir region in order to eliminate primary medical documents representing the ACTUAL doses. Instead, medical staffs were ordered to register understated dose values. Are these "ACTUAL" dose estimates worth of belief? Of the same nature are the official secret documents of the Academy of Medical Sciences of the USSR from my archive. According to these documents, even autopsies of those who died after the accident, including children, have not been carried out in the strict control zone in Zhitomir region. However, if the authors of the report are confident in what they say, why were these "actual doses" not accessible, and are still not accessible for analysis not only to common people interested in these problems, but also to doctors of medicine, radiobiology?

The conclusion, drawn by the authors in the prediction of the future of the population of the strict control zones, is astonishing: "Despite a trend for increase in spontaneous morbidity and mortality of malignant neoplasm, which is registered in data from all over the USSR, values of these parameters are assumed to remain stable throughout the investigated 70 years period. Hence, ratios of increase in the number of excess fatal tumours over their spontaneous level can only be corrected to their decrease." This idea is repeated in the general conclusion: "The data presented in this report provide evidence that the predicted levels of the discussed radiogenic effects as a result of the accident at the Chernobyl NPP, in the majority of cases including the population in the strict control zones, will likely be in the range of values which are less than standard deviations of spontaneous levels of the corresponding pathology." In other words, among the population and, in the first place, among the population residing in the strict control zones and being exposed to irradiation every day since the catastrophe at the ChNPP, the authors say, there will be less fatal cases of induced cancers than among the population of all other territories. Speaking of thyroid tumour, the authors conclude that "excess incidence of radiogenic tumour of this organ may be noticeable." In short, it may or may not be noticeable. Today, only 11 years, instead of 30 years, since the catastrophe at the ChNPP, it is obvious what these collective soviet prediction are worth.

A year later, at the parliament sessions in the Supreme Soviet of the USSR, the same academician L.A.Ilyin told deputies that "1 million 600 thousand children have received doses that are causing our worries; we need to decide what is to be done further." In 1990 in the meeting of the Supreme Soviet of the USSR, the Chairman of the Government Commission on Liquidation of the Consequences of the Accident at the Chernobyl NPP, V.Ch.Doguzhiev said [2]: "... the irradiation dose of 62 percent of the population who were subject to medical examination was found to be 1 to 5 rem. Out of 1.5 million people residing in areas most contaminated with radioiodine, including 160 thousand children, thyroid irradiation dose of 87 percent of adults and 48 percent of children was at most 30 rem. Of 17 percent of children the dose amounted to 100 rem."

What have soviet medical officials been saying about radiation dose to the public?

As I was sorting my Chernobyl archive, which accumulated a great deal of various materials, I came across a very interesting document that may become a sensation. Over 11 years after the catastrophe at Chernobyl, many different secret official documents have been published (by me, as well). However, I have seen nothing of the kind so far. FOR THE FIRST TIME concrete and ACTUAL doses, received by people in the first months after the catastrophe at the CNNP, are concerned.

On the 26th of May 1987 the Minister of Health of the Ukrainian SSR, A.E.Romanenko reported a letter N428c "On course of implementation of the decree N527-dsp of the Ministry of Health of the USSR from the 13.04.1987" to the Minister of Health of the USSR, E.I.Chazov [3]. With stamps of "Secret" and "No right for publication" of the CPSU (Communist Party of the Soviet Union) Central Committee, there was noted: "215 thousand inhabitants, including 74.6 thousand children, reside in the districts with increased radiation levels of the Kiev, Zhitomir and Chernigov regions. .... 39.6 thousand persons, that have not been registered previously, were found ill. In cases of different somatic disorders, patients are subject to continuous observation, hospital and out-patient treatment. The total number of hospitalised persons over the year is 20.2 thousand persons, including 6 thousand children." And now — attention: "IN THE FIRST MONTHS AFTER THE ACCIDENT AT THE ChNPP DOSIMETRIC MEASUREMENTS OF THYROID GLAND OF ALL CHILDREN HAVE BEEN CONDUCTED. THE CONTENT OF IODINE RADIONUCLIDES, EXCEEDING 500 REM WAS FOUND AMONG 2.6 THOUSAND CHILDREN (3.4%)." Could it be that the group of soviet scientists, who signed the above-mentioned report, as well as Academician L.A.Ilyin, did not know about these literally deadly facts? In that case, how is it possible to consider the estimates of radiation doses and predictions of their effects, presented in the 70 pages of the report on the session of the Academy of Medical Sciences of the USSR, to be scientific?

It is still unknown to the public how many other children have received thyroid irradiation less than 500 rem. The Minister of Health, E.I.Chazov in his memorandum [4] to the CPSU Central Committee on the 16th of November 1987 N3634s, with stamps of

"Secret" and "No right for publication" of the CPSU Central Committee, reports: "By 30.09.1987, 620,016 people are subject to hospital observation. 5,213 people have been hospitalised for thorough medical examination and specifying of diagnoses established, but not related to radiation effects, during hospital examination." It is not known whether the Minister had taken into account 2.6 thousand children in the Ukrainian radiation zone with more than 500 rem of thyroid irradiation. If he had, how could he explain that these truly crazy doses, unbelievable not only for children but also for adults, was not related to the impacts of irradiation? The most reliable explanation, from my point of view, is that the CPSU Central Committee wanted to hear their own "truth". And the Minister had not failed to present it.

In the draft of the decree of CPSU Central Committee "On implementation of the resolution of the XXVIII Congress of the CPSU "On political estimation of the catastrophe at the Chernobyl NPP and the course of elimination of its consequences", dated the 28th of December 1990, reported by the Secretariat of the CPSU Central Committee to the General Secretary of the CPSU Central Committee, V.A.Ivashko, it was noted [5]: "The consequences of the accident continue to produce effect on birth-rate and life-span. Thus, over the past 4 years, birth-rate in the Belorussian SSR has decreased by 10 percent; malignant tumour mortality has increased. It has increased by more than 19 percent in Mogilev and Gomel regions." These conclusions of the CPSU Central Committee have nothing in common with the optimistic conclusions on estimations of doses, presented in the before-mentioned report, signed by 23 scientists of the Academy of Medical Sciences of the USSR a year earlier.

This means that the following is quite real: the actual estimates of the doses received in the first 2-3 months after the catastrophe at the Chernobyl nuclear plant are unknown to the public even after 11 years.

Some light was cast upon the classifying and distortion of actual doses by an Academician of the Academy of Medical Sciences of the USSR, the director of the All-Union Scientific Haematological Centre, Professor A.I.Vorob'ev. He wrote an article "Why Soviet Radiation is the Safest" in Moscow News dated 18th of August of 1991 [6]. The author reported that "in the first days 15,000 people have been mistakenly hospitalised in the Ukraine because there were no specialists in the accident area. However, on the 2nd of May 1986, an instruction on diagnosing acute radiation syndrome (ARS) was published, and then all the people hospitalised by mistake have been discharged from the hospitals." This discharge suggests some affairs to be considered and concluded. In my book "Chernobyl: Top Secret [7]" I have published 40 secret protocols of the Operative Group of the CPSU Central Committee Politburo on liquidation of consequences of the accident at the ChNPP. These protocols indicate that the Politburo had urgently revised the maximum acceptable doses and increased them by several times. Just then all the hospitalised —according to the protocols their number was really 15,000 people — have been found healthy and discharged. Is this what Professor Vorob'ev means? In this case, contrariwise, his confession is just another indirect acknowledgement of the fact that approximately 15 thousand people have received ARS during the first weeks and months, and only the special regulation issued by the Politburo in concordance with the court medics had helped the soviet government not only for concealing this fact, but also not to hospitalise new victims of the catastrophe by the new dose limits.

Further in his article the professor seems to contradict himself. He reports that "In 40% of examined inhabitants of the Chernobyl region no irradiation doses have been found, 50% have received 50 rad, and more than 5% have received a dose of 50-80 rad. In the last group a marked increase in tumour incidence may be expected. 2% of inhabitants in the contaminated districts... have been irradiated with a dose of more than 100 rad. Among liquidators, this dose group is even larger." Vorob'ev also notes in his article: "In some persons in Gomel and Bryansk regions, such changes in some cells have been found that indicate the effects of highly intensive radiation! A discrepancy is obvious: the whole body dose was 30-50 rad, while the exposure of some cells was about 1000 rad and more." The professor had reported this facts to the Ministry of Health Care and the Academy of Medical Sciences of the USSR, but had received no answer to his scientific assumptions.

In 1989 the newspaper, Moscow News invited several people's deputies (the author of this report as well) to a round table on consequences of the catastrophe at the Chernobyl nuclear plant [8]. A deputy from Byelorussia Ales' Adamovich (deceased) reported: "... autopsies of people, who had died of other diseases, for example from ischemia, revealed that their lungs — this was registered by Professor E.Petryaev — contained enormous amounts of so-called "hot particles". Up to 15 thousand! 2 thousand of such particles are enough for cancer!" As is noted in the manuscript [9], which was sent from Israel to me by a former soviet nuclear physicist, Sergey Titkin, such effects of incorporation of solid particles has been known long ago — tobacco smoke, coal dust, silica (at great amounts causing silicosis). In the cases of Chernobyl, particles of reactor fuel that have been in the reactor, incorporated into lungs and have rigidly stuck to the lung tissue are under consideration.

In the information of the USSR State Committee on the Utilisation of Atomic Energy, compiled for the IAEA Experts Meeting in Vienna on the 25-29 August 1986 "The Accident at the Chernobyl Nuclear Power Plant and its Consequences [10]", the following is reported about the results of gamma-spectrometric analysis of radiation, emitted from the body of those who suffered from the accident: "practically, in all patients, without evident relation to the presence or the severity of ARS, uptake of a complex mixture of nuclides, principally, isotopes of iodine, caesium, zirconium, niobium, ruthenium into the body was observed." There is another mentioning about incorporation of radionuclides. Further: "Excess fatality, related to the ChNPP accident discharge will increase spontaneous mortality from cancer of the irradiated population by less than 2 percent. .... in the present stage, incorporation of radionuclides through inhalation by inhabitants within the formed radioactive tracks can be neglected in estimation of dose burdens." It is also noted in this report that different radionuclides were found in lungs of some of the deceased from acute radiation syndrome after the catastrophe.

Obviously, a special study should be conducted in order to evaluate the actual scale of the danger of incorporated nuclear fuel dusts. From my own studies and interviews with hundreds of people who were in the affected zones immediately and several months after the catastrophe, it becomes evident that the scale of the accident was so enormous that ALL persons talked about radioactive dust, scratchy feeling in the throat, tractors lacking airtight, etc. People were associating radionuclides deposited on the ground with dusts that could be incorporated into their organism. They called it radioactive dust. Apparently, no one considered the particularity of so-called hot particles, penetrating into the human organism and sometimes irradiating it fatally. This is also one aspect of the problem of the radioactive contamination for inhabitants in the areas around Chernobyl.

Missed lessons of Chernobyl

Igor Geraschenko, a specialist of nuclear physics, which formerly lived in Kiev and lives in the West at present, has handed over to me a manuscript of his article "Missed lessons of Chernobyl [11]". (It is unknown if this article had been eventually published.) From the point of view of unbelievable coincidences, the article contains quite interesting facts. To make my point clear, I will go forth with rather a long quotation:

"So what were the doses received by the people in the area of the catastrophe? Nobody knows this for sure. There have been almost no devices to measure radioactivity level in the area of the catastrophe. One of my acquaintances, a captain of the MIA (Ministry of Internal Affairs — A.Ya.) had spent a week in the encircle of the catastrophe area. He had no device for measurement of radioactivity, and he does not know what dose he had received. Transport drivers who worked for evacuation of the people had no measurement devices either. Did this happen accidentally? By no means! It was easier way to lie to one's own people and the trustful world public.

According to unverified data, in the town Pripyat (the nearest settlement to the nuclear station) the radioactivity level has been 1 to 10 R/h. (Data that I have verified show that the radiation level in Narodichi of the Zhitomir region in the first days was 3 R/h, although Narodichi is located at 80 km from the ChNPP — A.Ya.). The relationship between the radiation level and the distance from the point of the explosion is very complex (wind direction, rain from the radioactive cloud and many other factors play important roles). However, the average radiation level is assumed to be inversely proportional to square of the distance, i.e., the radiation is four times less as the distance becomes two times larger (from the point of the explosion).

The maximum radiation level that I have personally measured in Kiev in late May (1986 — A.Ya.) was 0.0018 R/h. I measured it with a standard army device, taken from a class of Civil Defence. According to the measurements of my acquaintances in early May in Kiev, the radiation level amounted to 0.003 R/h. The distance from the exploded reactor to Kiev is about 130 km, and to Pripyat is about 5 km.

Thus, the average radiation level in the town Pripyat must have been $(130:5)^2$=676 times higher, i.e. about 2 R/h. Well, the values of 1 to 10 R/h are quite plausible for Pripyat.

The evacuation had begun only 36 hours after the explosion. Hence, the inhabitants of Pripyat have received a dose of 36 to 360 R. On the 26th of April they were 45 thousand people. How many of them are still alive? I do not know. (The manuscript of the article is dated May 1987 — A.Ya.) I know that approximately 15 thousand have died out of those who were being brought to the Kiev hospitals at nights .... I can say only the following: I was not collecting panic rumours. All information presented in this article has been obtained directly from those who worked on liquidation of the consequences of the catastrophe: transport drivers, hospital staffs, military personnel from the surrounding and many others.

No attempt had been made to treat the people that were brought to Kiev. There was no such possibility. It was impossible to obtain blood for transfusion and marrow for transplantation to several thousands of people. These patients were lying not only in radiological departments, but also in the wards, in the corridor, and in the basement of the hospital. In one of the hospitals, even a part of morgue was allocated for this purpose.

These 15 thousand people died from acute radiation syndrome."

A surprising coincidence of different sources: according to the secret protocols of the Operative Group of the Politburo, approximately 15 thousand people have been hospitalised during the first weeks. Academician A.I.Vorob'ev wrote in his article that 15 thousand people have been hospitalised by mistake and, after the medical staffs received the instruction for ARS (acute radiation syndrome), the patients were discharged. The witness by physicist, I.Geraschenko mentions this number as well. With only one terrible rectification: these people have died.

The further discussion of Geraschenko is also interesting:

"Such number will not surprise an attentive reader. About 70 thousand people died in Hiroshima (only an insignificant number of them died as a direct result of the explosion — the majority died due to the consequences of radioactive contamination), and in our case only 15 thousand by a discharge thousands of times larger. Definitely, there have been much more victims. Firstly, I mean only those who were mentioned in the data I have obtained. Secondly, the consequences of irradiation are long-term. Dozens and hundreds of thousands more will die from cancer induced by radiation, but this is going to happen later: the latent period can last for years."

I.Geraschenko made the statement about the 15 thousands of deceased in an interview to the newspaper "New-York City Tribune", and in the hearings on the consequences of the Chernobyl catastrophe in the US Congress. He told that, instead of the "acute radiation syndrome" diagnosis, "vegeto-vascular dystonia", "vascular dystonia", etc., were diagnosed in the case of people affected by the accident. This is already a proven fact. In the medical records of the deceased, such words were written as "has undergone a course of treatment", "needs no further treatment".

Recent status of the public health in the territories affected by the catastrophe

A new concept of living in the affected territory has been elaborated in the government of the Russian Federation, related with the radioactive contamination as a result of the catastrophe at the Chernobyl NPP. In this regard, the Ministry of the Environment of Russia and the Ministry of Labour of Russia are studying more deeply the health problems in 16 regions of the Russian Federation affected by the catastrophe. The fact is taken into consideration that the majority of people residing in this territories have learned that they live in a zone of radiation danger only 7 years after the catastrophe in Chernobyl. It is noted in the report of specialists of the Ministry of Labour of Russia and the Ministry of the Environment of the Russian Federation, M.S.Malikov and O.Yu.Zitzer [12] that the Chernobyl catastrophe has affected 138 administrative districts, 15 cities of region subordination, and more than 7,700 settlements with a population of 2.7 million people. According to the data of April 1995, the number of Russian citizens, the death of which is attributed to involvement in liquidation of the consequences of the Chernobyl catastrophe, amounts to approximately 7 thousand. The number of people, whose living standards have worsened due to the catastrophe, or who have become invalid due to this reason, amounts to approximately 20 thousand people.

In the report of the specialists of the Ministry of Labour of Russia and the Ministry of the Environment of the Russian Federation, an unexpected confirmation was found of the facts in the before-mentioned secret letter of the Minister of Health of the Ukraine, A.E.Romanenko to the Minister of Health of the USSR, E.I.Chazov on high accumulation of radionuclides in thyroid of the Ukrainian children. According to the authors, at present 2.4 million people, including more than 500 thousand children under 14 years, are living in the Ukrainian territory affected by the catastrophe at the Chernobyl NPP. The most alarming, as is noted in the report, is the fact that 150 thousand inhabitants have received thyroid irradiation doses by dozens or hundreds of times higher than the acceptable level. In particular, thyroid doses of 5.7 thousand children were 200 rad, and those of 7.8 thousand adults — higher than 500 rad [13]. At the same time, the established acceptable dose is 5 rad. In this group of the affected population, 12 cases of malignant thyroid tumours in children have been registered only in 1991.

The experts note that diseases of respiratory and digestive organs, endocrine and blood circulation systems take a significant place in the structure of illnesses of children in the radiocontaminated zone of the Ukraine. As well, an increase in the number of neoplasm has been noted.

Medical examination of 583 children of the first class of school in Kiev, has shown a retardation in body development in a significant part of children in 1992 in comparison with 1982. Retardation is expressed more markedly among girls.

As the authors of the report state, the analysis of rates of mortality from malignant neoplasm in the population of the Ukraine residing in the territories adjacent to the zone of the Chernobyl NPP for the periods of 1980-1985 and 1986-1991 bears reliable evidence of an increase in the mortality from cancer of mammary gland, urinary organs and prostate.

Assessment of strontium-90 accumulation in the organism of Belarussian citizens after the accident at the ChNPP has shown that the evaluated absorbed doses in red bone marrow turned out to be 2.5-3 times higher than in the period before the accident. In 3 percent of the cases the doses have exceeded the average values by 4-8 times.

The Russian specialists note that iodine deficiency in some regions of Belarus known for endemic goitre (there is a lot of areas characterised by anomalous concentration of certain microelements, including radionuclides present due to the accident discharge of the ChNPP) had caused the maximum impact of a complex of radiotoxic factors on developing thyroid disorders. This may be a reason for more severe injury of thyroid than expected on the basis of the known dose-effect relationship.

The values of the plutonium concentration in hair of inhabitants of the Gomel region has been an order of magnitude higher than in hair of residents of Minsk.

Medical examination of 902 children in Bragin, Choiniki and Narovlya districts of the Gomel region had shown that 218 of them suffer anemic syndrome. Among them, goitre of the first degree was manifested in 68.3 percent of girls and 52.6 percent of boys, goitre of the second degree in 24 and 18.2 percent, respectively, and goitre of the third degree in 1.4 percent of children. A higher level of illnesses of blood and hemopoietic organs, endocrine system, respiratory organs, digestive organs and an increase in the number of neoplasm have been found in children from the controlled areas.

The similar situation is also observed in the children living in the controlled areas of the Kiev, Zhitomir, Cherkasy and Rovno regions in the Ukraine.

The Russian specialists are also concerned about neonatal mortality during pregnancy and child-birth by women living in the areas of increased radiation risk after the catastrophe at the ChNPP. As it is noted, this mortality tends to increase. The rate of normal child-birth has decreased to a significant extent. The number of congenital anomalies of newborn is growing. (There is a restricted laboratory in Zhitomir in the Ukraine with anomalous newborn humans and animals stored in alcohol that have been born after the catastrophe at the ChNPP in the territory of Zhitomir). In the period before the accident the rate of abnormal child-birth (for 100 pregnancies) had been 9.6. After the catastrophe this rate increased to 13.4. A significant relation was found between this rate and dose burdens of women. It is noted that adaptability of newborn to the environmental conditions, i.e. increased radioactivity as well, has decreased substantially in the first 6 years after the accident.

Here it will be pertinent to return to the manuscript of the Russian immigrant, physicist from Kiev, Igor Geraschenko "Missed Lessons of Chernobyl" that was handed to me in England in 1991. He also mentions this topic. He wrote: "There are other victims of Chernobyl — those who had never seen nothing. These are children killed before birth. After the explosion physicians recommended pregnant women in Kiev and other places to do abortion. I know of several cases in which these forced abortions were made in the 6^{th} month of pregnancy officially by doctors in hospitals. .... over the last year (the year under consideration is the first year after the catastrophe at the ChNPP — A.Ya.) no less than 20 thousand pregnancies have been aborted due to the Chernobyl catastrophe only in Kiev. And how about the women evacuated from Pripyat?"

While I was travelling through the contaminated villages of the Zhitomir region several months after the catastrophe, I heard the same: pregnant women were advised to make abortions, but were recommended not to tell anyone about such advice. One should note that such pieces of advice were given immediately after the catastrophe at Chernobyl. Today, even 11 years since the catastrophe, specialists refer to its severe consequences for pregnant women. This is also an indirect confirmation of the fact that no one knows the actual doses received by the population, including women of reproductive age in the first weeks and months after the explosion at Chernobyl. We can only guess that these doses were significant, judging from their effects years later.

Eleven years passed since the nuclear explosion in Chernobyl. However, the public still do not have reliable information on the ACTUAL doses received by the people affected by the Chernobyl radioactive tracks in the first weeks and months after the gravest anthropogenic catastrophe which had ever happened on Earth. In the first place, the world scientific and the semi-scientific nuclear community, which serve the world's political establishment and are not inclined to disclose the truth, should bear the responsibility for this. The disclosure of this truth may lead to a radical change of nuclear contribution in the world power system. The interests of "moneybag" — the world nuclear lobby — have been shown to be more important than the interests of the whole world community. However, shall it always be this way?

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Dose Assessment for Inhabitants Evacuated from the 30-km Zone Soon after the Chernobyl Accident

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Introduction

The first detailed report about the consequences of the Chernobyl accident was presented to IAEA from the USSR government in August 1986, about 4 months later since the beginning of the accident [1]. According to this report, more than two hundred cases of acute radiation syndrome (ARS) occurred as a result of the accident, among which 29 persons died (besides, two persons died on the day of the accident by other reasons). All cases of ARS were stated to have happened to firemen and workers involved immediately in the accident, while there was no case of ARS among inhabitants around the Chernobyl site. This opinion of the former USSR authorities was succeeded till now in reports of international organization such as IAEA, WHO, OECD/NEA [2-4].

Along with the process of the collapse of the USSR, there appeared several publications that indicate a number of cases of ARS among inhabitant around the Chernobyl site. Our attention should be paid to the following two reports. The first one is the secret protocols of the Operative Group of the Politic Bureau of the Central Committee of the Communist Party of the Soviet Union, disclosed in 1992 by Alla Yaroshinskaya [5, 6]. Many pieces of information can be found in this document about ARS among inhabitants, including those for children. She contributed herewith an article, ″Impact of Radiation on the Population during First Weeks and Months after the Chernobyl Accident and Health State of the Population 10 Years Later.″ One sentence is cited here from the protocol on May 10, 1986: ″The total number of persons in hospitals is 8,695, including 238 persons with diagnosis of radiation syndrome, 26 of which are children.″ Another important report about ARS was made by Vladimir Lupandin [7]. He investigated in 1992 medical records made in May-June 1986 at the Central District Hospital of the Khoiniki district of the Gomel region of Belarus, located adjacent to the Chernobyl site. Although a theft of the medical archive happened in November 1990, he found 82 medical records of inhabitants who suffered from irradiation. Among them he confirmed 8 cases of ARS. Details of his finding are described in his article ″Chernobyl 1996: New Materials concerning Acute Radiation Syndrome around Chernobyl"

Apparently, findings by Yaroshinskaya and Lupandin are in contradiction to the opinion of the authorities. It seems to be difficult to reconcile the two different opinions about the occurrence of ARS among inhabitants around Chernobyl. So, we can only say, which is true? In order to answer this question, we come up to another question. How much was the level of irradiation for inhabitants? Could it be the level that causes ARS?

In this report we try to evaluate irradiation dose of inhabitants around Chernobyl until their evacuation, based on the data which became available recently.

Materials and methods

Under the tradition of the Soviet system, the information concerning the consequences of the Chernobyl accident had been treated to be secret. As also disclosed by Yaroshinskaya [5], for example, the Soviet government issued on June 27, 1986 an order, ″To consider as secret: data about the accident; data about results of treatment of sufferers; data on irradiation of personnel involved in liquidation of the consequences of the disaster.″ Although some data on the radiation situation were included in the USSR report in 1986, they were not enough to do independent analysis or to check the validity of estimates contained in it. Through the Soviet period, we could only find fragmentary information about the radiation situation soon after the accident around the Chernobyl site.

In 1996, interesting data were presented in reports of the collaboration work between European Commission and three affected CIS countries (Ukraine, Belarus and the Russian Federation) [8].

Dose rate on May 1, 1986

Fig. 1 shows the radiation situation at settlements within the 30-km zone around the Chernobyl site on May 1, 1986, five days after the accident [9]. It is stated that these data were measured by special teams of the Chernobyl NPP staffs and other specialist, using GM counter at 1 m above the ground.

As seen in Fig. 1, a large variation is observed in the spatial distribution of radiation situation. The maximum of 3,306 μGy/h is observed at village Krasnoe about 6 km north from the site. High values of dose rate are generally observed at settlements in the north half of the 30-km zone, which corresponded

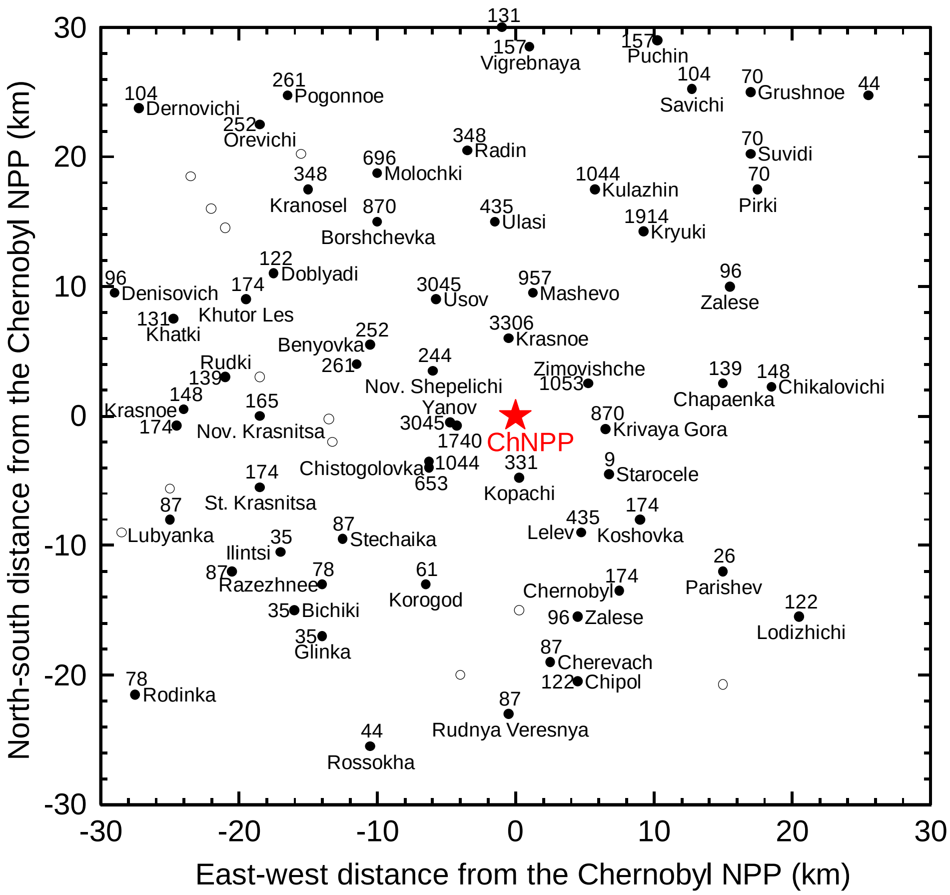

Fig 1. Dose rate in air at settlements within the 30-km zone around the Chernobyl site on May 1, 1986 [9], unit: μGy/h.

to the fact that radioactive clouds from the destroyed reactor moved to north-west and north from the destroyed in the first and second days after the accident [1, 10].

It was reported that the first evacuation of 45,000 inhabitants in Pripyat, a city built next to the Chernobyl site for workers of the station, was carried out on April 27, 1986, the next day of the accident [1]. The second evacuation of inhabitants who were living within the 30-km zone was made during the period from May 3 to May 5 [11]. So, these people stayed in the highly contaminated area for 7-9 days. The number of inhabitants evacuated in the stage was reported to be 90,000 [1]. The evacuation was finally completed on May 14 [11].

Dose rate change during the first days in the Khoiniki district

An interesting data on dynamics of dose rate change measured in the Khoiniki district, which corresponds to the north-west part of Fig. 1, is also presented in the same EC/CIS report [12]. In Fig. 2 is shown the measured change of dose rate normalized per unit deposition of ^{137}Cs in the Khoiniki district together with calculated ones by us. The measurement of dose rate was carried out by Civil Defence of Belarus, maybe, with GM counter.

In the solid line of our calculation (calculation 1), the deposition of other nuclides (18 nuclides) than ^{137}Cs were determined from their deposition ratios to ^{137}Cs reported by Izrael et.al. [13], values of which are shown in Table 1 together with dose rate conversion factors per unit density of each nuclide on the ground. Calculation of exposure rate in air per unit deposition of ^{137}Cs was made by the next equation.

$$r(t) = \sum_i DF_i \cdot DR_i(t) \qquad (1)$$

where *r(t)*: γ-ray exposure rate at time *t* calculated at 1 m above the ground from the mixture of deposited nuclides, densities of which are normalized to unit ^{137}Cs deposition, (μR/h)/(Ci/km^2 of ^{137}Cs)

DF_i: exposure rate conversion factor from unit density of nuclide *i* on the ground, calculated by us based on the infinite plain model, (μR/h)/(Ci/km^2)

$DR_i(t)$: density ratio of nuclide *i* to ^{137}Cs at time *t*.

If we can reconstruct dynamics of exposure rate changes during the first days after the accident, external irradiation at each settlement can be calculated by combining the dose rate data in Fig 1 with their changes.

As seen in Fig. 2, the solid line (calculation 1) gives a little higher exposure rate than the measured one for the first two weeks after the accident. This period is critical in dose formation of inhabitants who were evacuated from May 3 to May 5. So, in order to fit the calculated curve to the measured, we reduced the deposition ratios for ^{95}Zr and ^{140}Ba to halves of them in Table 2. Thus, we calculated the dotted line (calculation 2), showing a good agreement with measurements for the first two weeks.

In the curve of the measured data, an increase of exposure rate is noted from May 16 to May. 20. It can be considered to reflect the late phase release from the destroyed reactor that is recently reported by Dobrynin et.al. [14], which may support our reduction of deposition ratios for ^{95}Zr and ^{140}Ba.

Procedures for dose estimation

Dose values of external irradiation from deposited radionuclides on the ground, external irradiation from radioactive clouds in air, and internal dose through the inhalation path are evaluated for inhabitants who stayed in their settlements until evacuation, based on the following procedures.

Step 1: Calculation of external dose equivalent from deposited nuclides on the ground

The next two assumptions were made in order to calculate external irradiation.

A. All deposition occurred at a time at 12:00 on April 27, about 36 hr after the accident

B. Dose rate change at each settlement can be expressed with the curve of the dotted line in Fig. 2. In other word, the composition of deposited nuclides was same for all settlements.

At first, the deposited density of ^{137}Cs, A_{Cs137} [Ci/km^2] is calculated by the next equation,

$$A_{Cs137} = \frac{R_m(\text{May }1)}{0.0087 \cdot r(\text{May }1)} \qquad (2)$$

where R_m(May 1) : absorbed dose rate in air on May 1, shown in Fig.1, μGy/h,

r(May 1): exposure rate calculated by (1) at 12:00 on May 1 per unit deposition of ^{137}Cs, (μR/h)/(Ci/km^2),

0.0087: conversion factor from μR to μGy.

By the way, density on the ground of i nuclide, $A_i(t)$ other than ^{137}Cs can be easily obtained from values of deposition ratios given in Table 1.

Then accumulated exposure dose in air until the time of evacuation, D_{exp} [R] is calculated by the next equation,

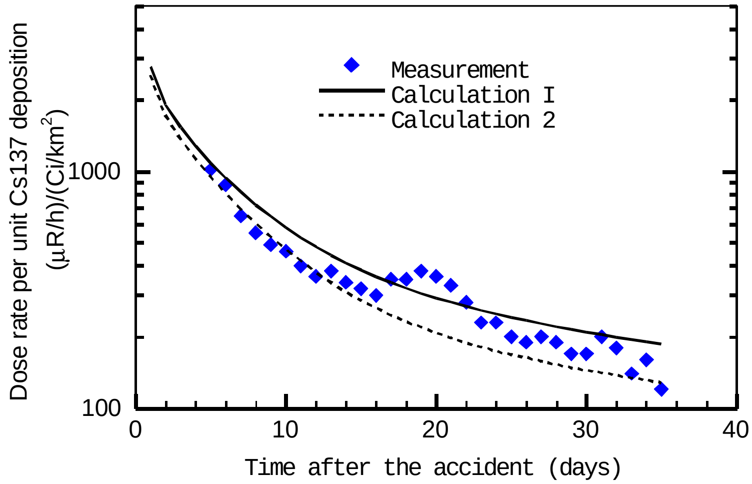

Fig. 2 Dose rate change in the Khoiniki district normalized per unit deposition of ^{137}Cs [12].

Table 1 Composition ratio and dose rate conversion factor of nuclides deposited around the Chernobyl site (Cs137=1) [13].

Nuclide	Half life	Relative composition (at the time of the accident)	Dose rate conversion factor (μR/h)/(Ci/km^2)
Sr91	9.7 h	1.2*	20
Zr95	65.5 d	3.3	29
Zr97	17 h	1.6*	29
Nb95	35 d	3.3*	15
Mo99	2.75 d	7.5	2.8
Ru103	39 d	5.3	9.6
Ru106	367 d	1.3	3.7
I131	8.04 d	20	7.6
I133	21 h	40*	12
I135	6.7 h	35*	34
Te132	3.25 d	33	46
Cs134	2.05 y	0.5*	29
Cs136	13 d	0.3*	39
Cs137	30 y	1	11
Ba140	12.8 d	3.6	43
La140	1.67 d	3.6*	39
Ce141	32.3 d	3.5*	1.8
Ce143	1.38 d	3.1*	4.9
Ce144	284 d	2	0.55

* These values are evaluated by the author, considering inventory ratios.

$$D_{exp} = A_{Cs137} \int_{12:00 \text{ Apr } 27}^{12:00 \text{ day of evac}} r(t)dt \qquad (3)$$

The day of evacuation was obtained or assumed from the information in the paper by Likhtarev et.al. [11].

Finally accumulated exposure dose in air is converted into the value of external dose equivalent, D_{ground} [Sv], using the following relation.

$D_{ground} = 0.61 \cdot 0.82 \cdot 0.0087 \cdot D_{exp}$ (4)

where 0.0087: conversion factor of R to Gy

0.82: conversion factor of Gy to Sv

0.61: apparent shielding factor of

inhabitants.

Values of theses three parameters were chosen also from the data by Likhtarev et.al.[11]. The apparent shielding factor of 0.61 can be applied to rural people who spent outdoors for 0.42 faction of day and stayed in wooden houses (shielding factor = 0.33) for the rest of time.

Step 2: Estimation of external dose equivalent from radioactive clouds

Usually, in assessments of the consequences of hypothetical nuclear accidents, the amount of ground deposition is evaluated from air concentration of radionuclides. Here, inversely, integral concentrations in air of nuclide i, C_i, [Ci/m^3·sec] is evaluated, assuming deposition velocity of deposited nuclides,

$$C_i \quad \frac{A_i}{V_i} \qquad (5)$$

where C_i: integral concentration in air of nuclide i, Ci/m^3·sec,

V_i: deposition velocity of nuclide i, m/s.

0.005 m/sec for iodine

0.002 m/sec for other nuclides

Values of V_i are obtained from the Reactor Safety Study [15, 16].

External dose equivalent from radioactive clouds, D_{cloud} [Sv] is obtained from the next equation

$$D_{cloud} = 0.61 \sum_i FC_i \cdot C_i \qquad (6)$$

where, FC_i: dose conversion factor of nuclide i calculated based on submersion model [16], Sv/(Ci/m^3·sec),

0.61: apparent shielding factor chosen as the same as Step 1.

Step 3: Estimation of internal dose equivalent from inhalation of contaminated air

Based on the integral concentration obtained in Step 2, internal dose equivalent from inhalation, D_{inh} [Sv] can be calculated from the next relation,

$$D_{inh} = 0.61 \cdot 0.00022 \sum_i FI_i \cdot C_i \qquad (7)$$

where, C_i: integral concentration of nuclide i,

FI_i: inhalation dose conversion factor of nuclide i for 1 week after incorporation, Sv/Ci,

0.00022: breathing rate, m^3/sec,

0.61: apparent shielding factor.

Values of *FIi* are specially calculated by us to obtain internal dose for the short period (1 week) after incorporation, using the next equation.

$$FI_i = FIicrp_i \frac{FIrss_i(7\text{day})}{FIrss_i(50\text{year})} \qquad (8)$$

where $FIicrp_i$: dose commitment conversion factor from inhalation of nuclide i evaluated by ICRP [17]

$FIrss_i$(7day) and $FIrss_i$(50 year): internal dose equivalent conversion factor of nuclide i, for 7 days and 50 years, respectively, given by the RSS [16].

The contribution of external irradiation from radioactive rare gases and internal dose from the path of ingestion are neglected in our procedures.

Results and discussion

The main purpose of this report is to investigate the radiation situation around the Chernobyl site from the viewpoint whether or not there was a possibility of irradiation that caused acute radiation syndrome among inhabitants until their evacuation. On the other hand, it is difficult to say univocally the level of irradiation dose that causes acute radiation syndrome because definition of acute radiation syndrome itself is of unclear nature and it depends on many factors such as irradiation conditions and individual factors. According to ICRP [18], acute irradiation of 0.5 Sv is evaluated to be a threshold of slight bone marrow injury. Following the traditional conception about ARS, however, we consider here 1 Sv of dose equivalent as the criterion of ARS.

Average irradiation dose

We have applied the above procedures of dose assessment to five settlements; villages Usov, Krasnoe, Kryuki, Borshchevka and Chernobyl city. Krasnoe is the highest point in Fig. 1. About Usov (10km to NW) and Chernobyl (15km to SE), external irradiation is also evaluated by Likhtarev et.al. [11]. The report of Lupandin includes typical cases of acute radiation syndrome in Borshchevka (18km to NW). Kryuki (17km to NE) is located in the area of most highest level of ^{137}Cs contamination [19].

Table 2 Estimates of average dose for inhabitants at settlements in the 30-km zone until evacuation

Settlement	Dose rate on May 1 (mGy/h)	Day of evacuation	Deposition of ^{137}Cs (Ci/km^2)	Accumulated exposure in air (R)*	External dose (Sv)		Inhalation dose (Sv)	Total dose (Sv)
					Ground	Cloud		
Usov	3.045	May 3	430	64	0.28	0.04	0.13	0.44
Krasnoe	3.306	May 3	470	69	0.30	0.04	0.14	0.48
Kryuki	1.914	May 5	270	40	0.17	0.02	0.08	0.28
Borshchevka	0.870	May 5	120	18	0.08	0.01	0.04	0.13
Chernobyl	0.174	May 5	25	3.6	0.02	0.002	0.01	0.02

* Contribution from cloud is not included.

Results of our calculation are summarized in Table 2. As seen in Table 2, the highest dose of 0.48 Sv was obtained for inhabitants at village Krasnoe. About 60 % of the total dose were external irradiation from deposited nuclides on the ground. About 30 and 10 % were from external irradiation from clouds and inhalation path, respectively. According to the results of Table 2, the average dose of inhabitants in settlements within the 30-km zone around the Chernobyl site did not reach 1 Sv of the criterion for ARS,

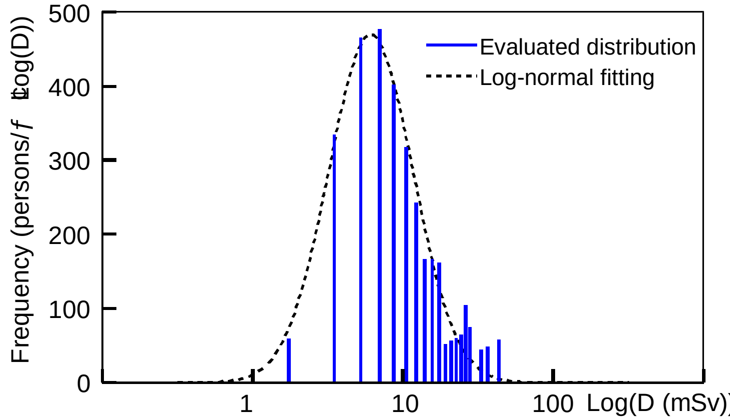

Fig. 3 Distribution of evaluated individual external dose of evacuees from Paryshev [9]

Distribution of irradiation dose for inhabitants

It should be noted that values in Table 2 are given as estimates for average doses of inhabitants in each settlement. Actual doses to individuals were naturally distributed around average doses. In order to investigate the possibility of ARS, therefore, the distribution of individual dose among inhabitants should be taken into consideration. Many factors are considered to be related with possible distribution of irradiation doses; inhomogeneity of contamination, variation of individual behavior, difference of shielding ability of buildings, etc.

In the course of the EC/CIS work, individual external doses were evaluated for 335 inhabitants who evacuated from village Paryshev [20], located about 20 km south-east from the Chernobyl site (26 μGy/h on May 1, 1986, see Fig.1). Questionnaires on daily behavior and living conditions of individuals until their evacuation were used to estimate individual external dose. The result of their dose distribution is redrawn in Fig. 3 together with a fitting curve of log-normal distribution. As seen in Fig. 3, the variation of external dose can be described very well by the log-normal distribution. Based on the log-normal fitting, the 95 percentile point of the dose distribution is calculated to be 2.92*(average dose), where $2.92 = 10^{0.284*1.64}$. Values of 0.284 and 1.64 are the standard deviation and the multiplying factor to get the 95 percentile point, respectively.

Here it is assumed that the distribution of external dose in Paryshev can be applied to other villages. It is also assumed that the distribution of inhalation dose has a wider deviation than that of external irradiation by two times, giving its 95 percentile point as 5.84*(average inhalation dose). Thus, 95 percentile doses and percentages of inhabitants dose of which is expected to exceed 1 Sv are calculated in five settlements in Table 2 and shown in Table 3.

Table 3 shows that substantial parts of inhabitants at Krasnoe (18 %) and Usov (15 %) could receive irradiation exceeding 1 Sv before their evacuation. At Usov 159 persons were reportedly there at the time of the accident [11], which means 25 persons exceeded 1 Sv.

Comparison with other evaluations

Estimates of collective external does for evacuees from the 30-km zone are given in the 1986 USSR report [1]. Those values are divided into groups of settlements dependent on the distance from the Chernobyl site. Average external doses are calculated and shown in Table 4. The average external dose of 24,200 people who were at 3 - 15 km at the time of the accident is calculated to be 0.45 Sv, and that of 65,700 people at 15 - 30 km is 0.05 Sv. These doses are consistent with our estimates shown in Table 3 although the 1986 report denied the occurrence of ARS among inhabitants.

A comprehensive work on external dose reconstruction for evacuees was made by Ukrainian scientists, Likhtarev et.al. [11]. Based on the questionnaires on daily behavior to 36,000 evacuees, they reconstructed individual external dose of about 31,000 evacuees from the 30-km zone, including about 14,000 in Pripyat city. The average and the maximum external doses of the evacuees (excluding the people in Pripyat) were evaluated to be 0.00182 Sv and 0.383 Sv, respectively. Based on these estimates, it is difficult to suppose the occurrence of ARS among inhabitants around the Chernobyl site. Table 5 is a comparison of external dose between by the present author and by Likhtarev et.al. Our estimates are lager than those by Likhtarev et.al. by

Table 3 Dose value of 95 percentile and fraction of inhabitants exceeding 1 Sv

Settlement	Average total dose (Sv)	95 percentile (Sv)	Fraction exceeding 1 Sv (%)
Usov	0.44	1.65	15
Krasnoe	0.48	1.79	18
Kryuki	0.28	1.04	6
Borshchevka	0.13	0.47	<1
Chernobyl	0.02	0.09	~0

about 3 times. The reason of the difference is unknown so far although the same values of shielding factors and dose conversion are used.

Several points should be mentioned about the work by Likhtarev et.al. At first, they excluded about 4,000 persons from their dose reconstruction with the reason that they stayed in highly contaminated areas or visited the Chernobyl station. Secondly, their work is mostly related to the territory of Ukraine. As seen in Fig. 1, highly contaminated areas extended to the north part of the 30-km zone, which belongs to Belarus.

Conclusion

Our findings are summaized as follows:

- ✧ Maximum dose evaluated as the average in settlements do not reach 1 Sv of the criterion for ARS.
- ✧ Taking into consideration the distribution of individual dose, substantial parts (15 to 20 %) of inhabitants in highly contaminated settlements are evaluated to have received doses exceeding 1 Sv.
- ✧ Our results agree with those presented in the 1986 USSR report, while our estimates are by about 3 times larger than those by Likhtarev et.al.
- ✧ Our results are consistent with the information that there were a number of ARS cases among inhabitants around Chernobyl.

It should be noted that our estimation does not include contributions of external dose from rare gases and internal dose from ingestion. Negligence of these paths does not mean they were negligible. It is simply because they are difficult to be evaluated.

It is also noted that a typical case of ARS in the report of Lupandin is observed in village Borshchevka, where ARS is difficult to be expected from our estimation. This case can be considered to be examples beyond the method of our estimation because the patient is reported to have stayed on the dike of Pripyat river from April 26 to 27 for fishing. Lupandin mentioned the possibility of a lot of such cases.

Finally, we have to say that there are still a lot of questions that should be answered about the Chernobyl accident. For example, the authors have one question for more than ten years. How much was the irradiation level that was received by young soldiers of the Chemical Troops of the Soviet Army who arrived at Chernobyl on the next day of the accident and supposedly took part in the first works for liquidation in the atmosphere of several hundreds of roentgen per hour?

Table 4 Average external dose of evacuees reported in 1986 USSR report

Distance from the Chernobyl site	Number of Settlement	Population (persons)	Average external dose (Sv)
3 - 7 km	5	7,000	0.54
7 - 10 km	4	9,000	0.46
10 15 km	10	8,200	0.35
15 - 20 km	16	11,600	0.052
20 - 25 km	20	14,900	0.060
25 - 30 km	16	39,200	0.046
3 - 15 km	19	24,200	0.45
15 - 30 km	52	65,700	0.050
3 - 30 km	71	90,000	0.16

Table 5 Comparison of estimates of external dose by the present study and by Likhtarev et.al.

Settlement	Average external dose (Sv)		A/B
	Present work (A)	Likhtarev (B)	
Usov	0.32	0.118	2.7
Chernobyl	0.018	0.0060	3.0

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Current State of Epidemiological Studies in Belarus about Chernobyl Sufferers

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Introduction

The present paper is an analysis of the results of epidemiological studies in Belarus about the after-effects of the accident at the Chernobyl atomic power station (ChAPS), based on published data at scientific institutes, organs and institutions of Ministry of Health. The special system in the Republic of sanitation for the affected population and its statistical outcome allows to obtain annually the data on morbidity and mortality of different cohorts of this population. The health both of the affected by the catastrophe and of the whole population of the Republic is influenced by economic, environmental (i.e. of natural and social medium) factors connected with individual behaviours, medical and sanitary situation. The higher level of disease incidence among the affected people can be explained, in a certain degree, not only by the ChAPS accident after-effects but also by the established sanitary system and improved diagnostics quality. Meanwhile, the adduced data are of interest as a basis for long-term observation, evaluation of tendencies and choice of directions of priority in further researches.

The adduced material indicates aggravation of health state of the republican population, especially of those who suffered as a result of the ChAPS catastrophe. Undoubtedly, the higher disease incidence of the affected people (which constitute a fifth part of the total population) increases the morbidity in Belarus as a whole.

1. State Register of persons affected by radiation due to the Chernobyl APS accident

The Belarus State Register was created upon the Decree of Council of Ministers of Republic of Belarus No. 283 of 5 May 1993 following the Article No. 63 of the Law of Republic of Belarus “About Social Protection Of Citizens Affected By Chernobyl APS Catastrophe” [29].

The State Register is aimed at supervising health state of the people affected by radiation due to the Chernobyl APS accident, as well as at obtaining verifiable data on the bio-medical consequences of the accident.

The State Register consists of four levels of observation: republican, regional, district and the level of institution performing sanitation.

The responsible for holding the State Register and using its data are the next:

- On the republican level - Center of Medical Technologies, Information, Management and Economics of Health of the Ministry of Health of Republic of Belarus (BCMT);
- On the regional level - offices and departments of health of regional executive committees and Minsk Municipal Executive Committee;
- On the district level and level of medical institution - local medical organizations, central district hospitals of the system of Ministry of Health, special medical institutions of other Ministries and organs.

The Ministry of Defence, Ministry of the Interior, Committee of State Security, Administration of Belarus Railway and Belarus Administration of Civil Aviation provide the information to the State Register about the persons under control at their institutional medical organs.

The following groups of persons are to be included into the primary account of the State Register:

- First group (Group 1):
  - Group 1.1) those who took part in the liquidation of the Chernobyl APS accident consequences within the evacuation zone in 1986-1987 or who were engaged in that period in the exploitation or other works at the Station (including provisional staff), including soldiers and civil citizens mobilized and engaged in works related to the liquidation of the accident consequences;
  - Group 1.2) those who took part in the liquidation of the Chernobyl APS accident consequences within the evacuation (alienation) zone in 1988-1989 or who were engaged in that period in the exploitation or other works at the Station (including provisional staff), including soldiers and civil citizens mobilized and engaged in works related to the liquidation of the accident consequences;
  - Group 1.3) those who took part in the decontamination, construction and provision of life of people in 1986-1987 in the zones of primary and following resettlement including servicemen and civil citizens mobilized and engaged in mentioned works;
- Second group (Group 2): those who were evacuated from the evacuation zone as well as those who independently left this zone after the catastrophe;

- Third group (Group 3):
  - Group 3.1) those who live or work in the zone of primary resettlement as well as those who were resettled or independently left this zone after the catastrophe;
  - Group 3.2) those who live or work in the zone of following resettlement as well as those who were resettled or independently left this zone after the catastrophe;
- Fourth group (Group 4): children born by persons attributed to the Groups 1-3 of the primary account except for children included into the 2nd and 3d groups of primary account;
- Fifth group (Group 5):
  - Group 5.1) those who live or work in the zone with right to resettle;
  - Group 5.2) those who live or work in the zone of living under periodic radiation control;
  - Group 5.3) those who live in the settlements where the average equivalent dose or irradiation is higher than 1 mSv/year;
- Sixth group (Group 6): those who took part in the liquidation or suffered from accidents and their consequences at other civil or military nuclear objects as well as who suffered from mentioned accidents or as a result of tests, exercises and other works connected with any species of nuclear installations including nuclear weapon. This fact is to be acknowledged by the corresponding documents of institutions which supervise mentioned objects.

2. Demographic situation in polluted areas

In 1995, 1,840,951 people lived on radiocontaminated territories, including 483,869 children and adolescents. 41,282 of them lived in the zone of following resettlement, including 9,821 children and adolescents.

In connection with revision of pollution maps of the republican territory with radionuclides (Decree of Council of Ministers No. 116 of 19 February of 1996 “About the Confirmation of List of Territories (Settlements and Other Objects) Related to Zones of Radiation Pollution”), the number of settlements situated on polluted territories decreased from 3,221 in 1995 to 2,930 in 1996. The number of population living there decreased correspondingly to 1,625,981 (11.7%). The number of settlements in the zone of following resettlement decreased especially - 50.6%, and the number of residents there - 40.8%. The percentage of the children of 0-14 among those who live on the polluted territories constitute 22.1% (23.7% among townspeople and 19.1% among rural population). By the regions, this rate is something different: in the Brest region the share of children of 0-14 is 27.9% among townspeople and 21.2% among rural people; in the Gomel region - 23.2% and 19.0%, in the Mogilev region - 27.3% and 17.9%, respectively. The share of children in towns on the polluted territories is registered to be higher as compared with total population. Whereas a lower share of children is registered among the rural population of the affected territories as compared with that of the total rural population.

In a considerable degree this may be attributed to so-called “ageing” of the rural population of the affected territories as a consequence of movement of working-able people. In the majority of rural settlements the population of 60 and elder constitutes more than 40%.

In 1995, the tendency to growth of mortality and decrease of birth rate continued in the Republic (Table 2.1). The natural growth of population decreased more

Table 2.1. Coefficients of birth rate, mortality and natural increase of population in the Republic of Belarus (per 1000 people)

Years	Number of new-born persons	Number of dead persons	Natural increase	Infantile death rate per 1000 of born alive persons
1980	16.0	9.9	6.1	16.3
1981	16.2	9.6	6.6	16.7
1982	16.3	9.6	6.7	15.8
1983	17.6	9.9	7.7	15.0
1984	17.0	10.5	6.5	15.1
1985	16.5	10.6	5.9	14.5
1986	17.1	9.7	7.4	13.4
1987	16.1	9.9	6.2	13.4
1988	16.1	10.1	6.0	13.1
1989	15.0	10.1	4.9	11.8
1990	13.9	10.7	3.2	11.9
1991	12.9	11.2	1.7	12.1
1992	12.4	11.3	1.1	12.3
1993	11.3	12.4	-1.1	12.5
1994	10.7	12.6	-1.9	13.2
1995	9.8	12.9	-3.1	13.2

and constituted (-3.1) per 1000 people. The same tendency was registered in the Brest, Gomel and Mogilev regions. The infantile death rate was still on the level of 1994 and increased somewhat in the Mogilev region [27, 2].

3. Dosage monitoring in Belarus

The highest average irradiation doses were registered in the participants of liquidation of ChAPS accident consequences. The whole-body irradiation doses within 50-100 mSv were obtained by 30% of “liquidators”, 100-250 mSv - 47%, 250-500 mSv - 7.3%. The comparable doses were obtained by the evacuees from 30-km zone.

The residents of areas with pollution density of 555-1480 kBq/m^2 obtained average doses of irradiation of 50-60 mSv from the moment of the accident. Those who live on territories with pollution density less than 555 kBq/m^2 obtained 20-40 mSv.

The external irradiation dosage of population of radiocontaminated areas stabilized notably by 1989-1990. The average annual doses of internal irradiation of the people in the areas under strict control decreased by 10 and more times as compared with 1986, and, as a rule, do not exceed 0.2-0.5 mSv per year. The internal irradiation is, however, still a leading dose-forming factor on the territories with pollution density with Cesium-137 less than 185 kBq/m^2 [8]. The dosage of irradiation with strontium and plutonium radionuclides is not higher than 5% of total effective equivalent dose and constitutes 0.02-0.06 mSv per year.

The Catalogue of Irradiation Doses in Belarus is composed of settlements situated on the territories with soil pollution higher than 37 kBq/m^2. Some settlements with soil pollution lower than 37 kBq/m^2 are also included, where, by the data of sanitary service, the radionuclide contents in food products produced in these settlements are higher than the republican norm.

The analysis of annual effective equivalent dose (EED) confirmed the conclusion that the isoline of irradiation dose of 1 mSv/year passes in the majority of cases through the territory with the density of pollution with Cesium-137 of 148-222 kBq/m^2. Besides, a number of settlements of Belarus "Palesse" situated on the areas with soil pollution of 37-185 kBq/m^2 and lower are characterized by abnormally high coefficients of cesium transfer in “soil-milk” chain, and, as a consequence, the level of annual EED in them is higher than 1 mSv.

The collective dose of Belarus habitants in the post-accident period constituted nearly 22,000 man-Sv (Table 3.1). Whereas 16,625 man-Sv were obtained from external irradiation, and 5,343 - from internal irradiation. Nearly 80% of external irradiation of the collective dose were realized on the territory of two most polluted regions: the Gomel region with Gomel city (60%) and the Mogilev region with Mogilev city (20%). The rural population of the Republic obtained 47% of the collective dose of external irradiation. The corresponding figures in the Gomel region and in the Mogilev region are 50 % and 70%, respectively [12, 23, 34].

The analysis of collective doses of internal irradiation shows that nearly 50% of collective dose in Belarus in the post-accident period were realized in the Gomel region, and 20% - in the Mogilev region. 60% of the internal collective dose fall on the rural population of the Republic though the number of rural people constitutes 35% of the total Belarus population.

Table 3.1. Collective doses of irradiation of Belarus habitants in 1986-1994, man-Sv

Region, city	Age groups of rural population, years				Age groups of townspeople, years				Sum
	0-6	7-14	15-17	>18	0-6	7-14	15-17	>18	
Brest region	23	105	37	967	15	68	23	398	1,636
Vitebsk region	2	11	3	95	3	13	5	79	211
Gomel region	141	693	239	6,276	99	499	172	2,886	11,005
Grodno region	8	36	12	319	7	32	12	189	615
Minsk region	9	45	15	408	9	41	14	234	775
Mogilev region	67	315	109	2,904	23	109	38	636	4,201
Brest city					2	10	3	58	73
Vitebsk city					2	8	3	46	59
Gomel city					71	335	115	1,950	2,471
Grodno city					3	13	5	78	99
Minsk city					11	50	17	289	367
Mogilev city					13	62	21	370	456

Table 3.2. Collective doses of thyroid irradiation, man-Sv

Region	Age groups, years			
	0-6	7-14	15-17	adults
Brest	7,279	3,137	985	17,651
Vitebsk	1,156	491	152	2,566
Gomel	80,797	34,737	10913	189,301
Grodno	3,010	1,297	410	7,114
Minsk	5,983	2,579	806	13,048
Mogilev	18,810	8,088	2,540	43,643

The analysis of values of thyroid irradiation dose shows that the highest collective dose had formed in the Gomel region habitants (Table 3.2). The principal contribution into the collective dose was made by three mostly polluted districts of the Gomel region: Bragin, Narovlya and Khojniki. Their contribution constitutes 30% of the collective thyroid dose in the Gomel region, while the contribution of the rest 19 districts - 70%.

Almost 20 % of the children of 0.5-2 years and 0.64 % of adults obtained thyroid doses over 1,000 cGy among the habitants of villages of the Khojniki district of the Gomel region resettled before 5 May of 1986 [5].

The radioiodine influence over thyroid took place against the background of endemic goiter (characteristic of many areas of Belarus, especially Palesse) conditioned by the insufficiency of stable iodine in basic foods and water as well as by a number of other factors, in particular, manganese and copper deficit. This, probably, furthered the radioiodine oncogenic effect [20].

4. Cancer-register and malignant neoplasm incidence

The registration of malignant neoplasm in Belarus has been carried out since 1953. However, the registration was not complete in years 50's-60's because the number of oncological hospitals was not enough. The perfectioning of account started at the end of 60's - beginning of 70's and for the first time the full statistical data were obtained in that period. In the last years, the oncological institutions have been receiving regularly the current statistical information with a help of automated registration.

The increase of oncological diseases incidence is registered in the Republic during two decades (Table 4.1). For the 1976-1995 period, the standardized indices in the Republic as a whole increased by 54.1% in men and 35.4% in women; in the Gomel region - 66.2% and 56.1%, in the Mogilev region - 40.3% and 26.8%, respectively.

In the post-accident years, a tendency to increase of cancer incidence of separate locations continues in the regions which were mostly affected by radiocontamination. In the Gomel region, this is an increase of frequency of thyroid cancer in children and adults, tumours of lungs, rectum, colon, mammary gland, bladder and kidney. In the Mogilev region - neoplasm of thyroid, bladder, kidney and mammary gland. We must note therewith that acceleration of the disease incidence growth is reported concerning all forms of malignant neoplasm both in men and in women of the Gomel region [25, 26].

By the end of 1995, 130,541 persons were registered in Belarus: 49,298 men and 81,243 women. In the Republic on the whole, the number of oncological patients by the end of 1995 overreached by 16% the level of 1991; in the Gomel and Mogilev regions - by 29.8% and 24.9%, respectively.

The tumours of respiration and digestion organs are the principal oncological pathology of male population of Belarus (60.5% in the structure of oncological disease incidence). For women - this is the neoplasm of digestion organs, mammary gland and genitals, which constitute 56.6% in the structure of disease incidence

Table 4.1. Absolute number of newly revealed cases of malignant neoplasm in Belarus, 1976-1995

Region	Year										
	Before the accident					After the accident					
	1976	1978	1980	1982	1984	1986	1988	1990	1992	1994	1995
Brest	2247	2472	2427	2621	2781	3011	3150	3523	3741	3844	3949
Vitebsk	2852	2712	2918	2941	3303	3556	3728	4179	4241	4376	4558
Gomel	2584	2945	3001	3313	3257	3733	4004	4185	4477	4883	4964
Grodno	1985	1980	1964	2189	2285	2672	2992	2995	3092	3529	3442
Minsk	2581	2900	2926	3063	3304	3555	4002	4288	4811	5112	5061
Mogilev	2491	2527	2823	2836	3128	3310	3519	3685	3790	3788	3830
Minsk city	1897	2277	2249	2691	2902	3189	3702	4075	4529	4818	4634
Belarus	16637	17813	18308	19654	20960	23026	25097	26930	28681	30350	30438

[9].

The indices of malignant tumours incidence increased in men by 40.2 % and in women by 28.6 % during the 10 post-accident years [34]. The townspeople fall ill with malignant tumours significantly more frequently than the rural people do. Nevertheless the pace of morbidity growth is higher in the rural.

Taking into account the irradiation doses of residents of Belarus polluted areas, it is supposed that in 70 years after the accident the additional deaths from malignant neoplasm will constitute 4,250 cases. In this period, 2,345 cases of thyroid cancer will take place; 234 of them - with lethal end [11]. It is necessary to note that the real increase of this pathology presently is higher than the prognoses.

5. Peculiarities of thyroid cancer incidence in the Republic of Belarus

The Republic of Belarus in the middle of 80's occupied a place among the countries with low levels of incidence of thyroid pathologies. The average standardized index (number of cases per 100,000 persons) of morbidity in 1983-1987 constituted 1.9 for women and 0.6 for men. This was approximately the same level of disease incidence in Denmark, England, Slovakia, Poland, Yugoslavia and Latvia.

In the period from 1986 to 1994, there appeared a tendency to increase of thyroid cancer incidence (Table 5.1), especially from 1991 to 1994. By the data of Republican Oncological Thyroid Centre, only 3 cases of thyroid carcinoma in children were found during 7 pre-accident years. The considerable growth of number of cancer cases in children in Belarus began in 1990 (29 newly diagnosed patients). In 1991, 59 children were diagnosed and operated; in 1992 - 65; in 1993 - 79; in 1994 - 82 children [34].

According to pre-accident studies of thyroid carcinoma incidence in Belarus, there are considerable differences in its registered frequency by territories. The leading place on the frequency of this cancer location in Belarus in 1977-1985 was occupied by Minsk city: 0.8 patients per 100,000 men and 2.7 patients per 100,000 women. Meanwhile the average republican indices were 0.5 for men and 1.5 for women. The last place was occupied by the Brest and Grodno regions. The level of morbidity in the Mogilev region was something lower than the republican one for account of female population (1.3 against 1.5). The indices of morbidity in the Minsk, Vitebsk and Gomel regions were near to the republican level; therewith the ratio of incidence between women and men in the Gomel region was minimum (2.3:1). The maximum ratio of incidence between women and men in pre-accident period was registered in Grodno (6:1) and Brest (4:1) regions.

In the post-accident period, the situation changed abruptly. Already in 1987 the standardized index of thyroid cancer incidence in the Gomel region exceeded for the first time the level of 2.0 and constituted 2.9, against 1.7 in the Republic and 2.6 in Minsk city. This was apparently connected with increased alert of physicians and perfectioning of diagnostic means. During 1988-1989 the index of morbidity in the Gomel region lowered to 2.3. Then in 1990 it increased up to 4.0, while it was the same value in Minsk city and 2.7 in the Republic. The abrupt rise of morbidity was registered in 1991. The standardized index constituted 7.5 (4.6 for men and 10.6 for women) and was much higher than those in Minsk city (3.9) and in the Republic (3.6). Significant rise of thyroid carcinoma incidence was registered also in the Brest region: from 1.2 in 1988 to 3.4 in 1992 and to 6.1 in 1993, principally, due to the increase of share of sick children and young persons. In 1986-1994 the territorial difference within the Republic changed both in men and in women. The maximum morbidity level is registered now in the Gomel region.

The velocity of increase of morbidity in the post-accident period grew to be 1.5 times among the male population and 18 times among women as compared with the pre-accident period. In the Gomel region the velocity of increase of morbidity in men grew to be 6 times and 73 times - in women. The morbidity in the post-accident period increases more

Table 5.1. Indices of thyroid cancer incidence in the Republic of Belarus in periods from 1977 to 1985 and from 1986 to 1994 (number of cases per 100,000 persons)

No.	Age	Sex	Morbidity index	
			1977-1985	1986-1994
1	0-14	men	0.03	1.2
		women	0.1	2.0
2	15-34	men	0.3	0.8
		women	1.2	3.5
3	35-49	men	0.5	1.6
		women	2.4	8.3
4	50-64	men	1.3	2.5
		women	3.0	8.0
5	65 and elder	men	2.5	4.1
		women	3.9	7.0

slowly in men in the Vitebsk and Grodno regions, in women - in the Vitebsk and Minsk regions [1].

The post-accident period is characterized by acute increase of morbidity in children and young persons. The highest value of morbidity in women falls on the age group of 35-49 and constitutes 8.3. In men, like in 1977-1985, the peak is registered among the elderly people and constitutes 4.1. In 1986-1994, 333 children in Belarus fell ill with thyroid cancer. 180 of them lived in the Gomel region at the moment of the accident, 74 - in the Brest region, 19 - in the Grodno and Minsk regions, 6 - in the Vitebsk region, 16 - in the Mogilev region, 18 - in Minsk city. Due to migration, the morbidity index in the Gomel and Brest regions decreased somewhat and considerably increased in the Minsk region.

The notable rise of number of new cases of thyroid cancer among children began in the Gomel region in the fifth post-accident year, and in Brest region - in the seventh year [1]. Verifiable increase of thyroid carcinoma incidence is registered thereby in the Republic of Belarus in the post-accident period both in children and in adults. The highest velocity of morbidity increase is observed in children, adolescents and young adults. The mostly expressed increase is registered in the Gomel region which has undergone the pollution as a result of Iodine-131 release in the highest degree [28, 33, 34].

6. Haematological morbidity in the Republic of Belarus

The scientific haematological epidemiology did not exist both in the former Soviet Union and in Belarus, and the existing registers could not serve as a basis for any comparisons and conclusions of full value. Therefore, in 1988, the Republican Haematological Register was created at the Research Institute of Haematology and Transfusion of the Ministry of Health of Belarus, which is based on the requirements of international scientific haematology. The section of Register related to children's leukosology included 1,364 cases of acute leukemia from 1979 to 1992. In 1993-1994, other 156 cases of acute leukemia were registered in the Republic [34].

The frequency of acute leukemia in Belarus children (up to 14 years old) varied in separated regions and constituted in the pre-Chernobyl period 42.0 cases per 1000,000 children. After the Chernobyl accident this index constituted 43.3 cases per 1000,000 children.

Regarding to sex dependency, the frequency of acute leukemia in children before and after the Chernobyl catastrophe is distributed as follows: 46 (1979-1985) and 48 (1986-1992) cases per 1 mln of boys, and 37 and 39 per 1 mln of girls, respectively. Consequently, the boys fall ill with acute leukemia more frequently than the girls.

During 1979-1992, the highest index of chronic leukosis incidence in Belarus children was registered in the Brest region (3-4 cases per 1 mln). It varied in other regions from 0 to 1.5 (up to 3.5 in Minsk city) and had different tendencies in pre- and post-Chernobyl periods. Since 1992 the tendency to increase of leukemia incidence in children became stronger. The highest frequency of leukemia is in the Gomel region (60 cases per 1000,000 children), but it is followed by the Vitebsk region (48 cases) [22, 34]. The absolute number of children's leukemia cases (acute and chronic) is adduced in Table 6.1.

According to theoretical forecasts, the 9th, the 10th and following years after the radiation catastrophe may become critical for leukosis in children [11].

7. Hereditary pathology in Belarus and the Chernobyl catastrophe

The national genetic monitoring of congenital malformations (CM) has been functioning in Belarus since 1979. Only CM of strict criteria were studied up to 1994. Such CM are diagnosed in any institution related to child-bearing without special methods of study. The specialists in Belarus are quite familiar with them and know their heredity type; unencephaly, spinal cord hernias, cleft lip and (or) palate, polydactyly, reduction malformations of extremities, atresia of esophagus, Downs syndrome, multiple congenital malformations (without Downs syndrome). Besides, by the beginning of the Chernobyl accident, the monitoring of morphogenesis disturbances in embryos and early fetuses began to function in the Republic (since 1980) as well as the monitoring of syndromes of multiple congenital malformations (since 1983) and the monitoring of development

Table 6.1. Leukemia incidence in Belarus children (absolute numbers)

Before the accident		After the accident	
Year	Number	Year	Number
1979	119	1986	103
1980	97	1987	112
1981	99	1988	96
1982	86	1989	104
1983	94	1990	111
1984	92	1991	108
1985	91	1992	104
average 97		average 104	

disturbances in spontaneous abortuses (from 1968 to 1987) [18, 19, 34].

In order to study the possible genetic consequences of the Chernobyl catastrophe, a wide range of study was conducted on the people who had obtained additional irradiation due to radioactive fallout of ChAPS. That study included investigations of types and levels of chromosomal mutations in somatic cells, dynamics of development disturbance in embryos and fetuses, and analysis of congenital malformations (Table 7.1).

The frequency of dicentric and ring chromosomes in women examined immediately after the accident and in their new-born children was practically equal, but they were 10 times as high as in the control group. According to a comparative cytogenetic examination of the same persons before and after the Chernobyl accident, a 6-times increase of frequency of radiation-induced dicentric and ring chromosomes was observed too.

The level of dicentrics and rings in women and new-born children from the Mogilev region who stayed about two years on the polluted territories was higher than both the control level and the frequency of aberrations in women and children evacuated from the Gomel region two months after the accident. The investigations have shown thus that the evacuated pregnant women and their intrauterine fetuses obtained the biologically effective radiation doses as well as the women who have lived for a long time on the polluted territories. Those radiation dose manifested themselves in the growth of number of dicentric and ring chromosomes - the most important index of genetic effects of ionizing radiation on the level of chromosomes. The total mutagenic effect in the evacuated women turned out lesser than that in women living in strict control zone during two years [17, 32].

It was established based on the study of legal medical abortuses that the total frequency of development abnormalities in embryos in Minsk and Gomel cities remains on the pre-accident level. On the contrary, the frequency of development abnormalities in the mostly radiocontaminated districts of the Gomel and Mogilev regions in 1986-1992 was significantly higher than the control numbers. The frequency of all malformations increased in the polluted districts; in the highest degree - the frequency of cleft lip and palate**,** duplication of kidneys and ureters**,** polydactyly and nervous tube defects [18, 19, 34].

From the point of view of a number of specialists, the increase of hereditary pathology in Belarus can be explained just partially by the growth of mutations level under the action of additional ionizing irradiation. Apparently, the complex of negative factors in Belarus after the Chernobyl APS accident made a considerable contribution into the increase of CM frequency.

8. Morbidity and mortality of the people who suffered the ChAPS catastrophe (by the data of the State Register)

8.1. Analysis of morbidity of participants in the ChAPS accident consequences liquidation (Group 1)

The analysis of the data of liquidators in 1993-1995 was made in comparison with the morbidity of adults of the Republic in that period. 33,166 liquidators of Group 1.1 (workers in 1986-1987) in the State Register were under observation of medical institutions of Ministry of Health in 1993, as well as 19,052 liquidators of Group 1.2 (1988-1989). In 1994 - 39,682 and 20,556 liquidators, and in 1995 - 44,890 and 20,151 liquidators, respectively [3, 24].

In the assessment of health state of liquidators, it is necessary to take into account that the men of working-able age without chronic diseases were mainly sent to the liquidation of the ChAPS accident consequences. The average age of liquidators constituted 30-35 at the time of the accident.

Table 7.1. Absolute numbers / frequencies (per 1000 births) of congenital malformations of strict control in three zones of Belarus (1982-1992)

Year of observation	Zones of pollution		Control group ("clean" zone)
	1-5 Ci/km^2	>15 Ci/km^2	
1982	170/5.74	30/3.06	196/5.62
1983	123/3.96	37/3.58	167/4.52
1984	131/4.32	38/3.94	150/4.17
1985	135/4.46	46/4.76	165/4.58
1982-1985	559/4.61	151/3.87	678/4.72
1987	160/5.54	62/8.14	223/5.94
1988	134/4.62	73/8.61	190/5.25
1989	173/6.32	51/6.50	196/5.80
1990	199/7.98	40/6.00	221/6.76
1991	135/5.65	29/4.88	181/5.52
1992	141/6.22	47/7.77	175/5.89
1987-1992	942/6.01	302/7.09	1186/5.85
Coefficient of growth	1.3	1.8	1.2

Table 8.1. Comparison of morbidity of Belarus population (elder than 18) and liquidators (1995, number of cases per 100,000 persons)

Disease	Liquidators	Belarus population	Ratio
Thyroid cancer	23.06	7.10	3.24
Cataract	462.78	156.09	2.96
Malignant neoplasms of lymphatic and blood-forming tissue	26.14	18.59	1.40
Respiration organs diseases	24780.91	23830.97	1.04
Digestion organs diseases	7784.20	1650.90	4.72
Endocrine system diseases, nutritional disorders, metabolism and immunity disorders	3427.02	517.53	6.62
Blood and blood-forming tissue diseases	304.42	69.42	4.38
Mental disorders	3251.75	1090.11	2.98

Table 8.2. Comparison of morbidity of Belarus population and evacuees from alienation zone (1995, number of cases per 100,000 persons)

Disease	Evacuees	Belarus population	Ratio
Thyroid cancer	12.66	7.05	1.79
Cataract	443.15	147.34	3.01
Malignant neoplasms	215.24	345.43	0.62
Respiration organs diseases	16599.14	25656.22	0.64
Digestion organs diseases	4216.26	1817.14	2.32
Endocrine system diseases, nutritional disorders, metabolism and immunity disorders	2367.69	583.86	4.05
Blood and blood-forming tissue diseases	278.55	73.88	3.77
Mental disorders	2317.04	1124.55	2.06

Concerning neoplasms, there appears a high level of anxiety among liquidators for thyroid cancer and its increase in three years, especially among the liquidators of Group 1.1 (1986-1987).

The increase of benignant tumours in liquidators, including thyroid, also attracts attention. It is more significant in Group 1.1.

The risk to fall ill with diabetes mellitus in all liquidators in 1993-1995 was 1.9-2.2 times as high as in the adult population on the whole. In liquidators of Group 1.1 it was 2.2-2.4 times. Mental disorders are a considerable problem for liquidators (relative risk 1.5-3.0) as well as the diseases of nervous system and sense organs (relative risk 1.5-2.1) including cataracts (relative risk 2.1-3.0), especially for liquidators of Group 1.1 (relative risk 2.7-3.4). The higher incidence and its growth in liquidators, especially in Group 1.1, of cardiovascular system diseases composed of hypertension, ischemia, stenocardia, cerebrovascular diseases, endarterites and thrombocytes as well.

The most significant among the respiration organ diseases are chronic pharyngites, nasopharyngites, sinusites, diseases of tonsils, pneumonias, bronchitis. The risk of liquidators to fall ill with them is 1.4-5.7 times higher than the adult population on the whole [3, 15, 34, 31, 7].

In 1995, 506 liquidators were recognized as disabled (76.0 per 10,000). The disability of 276 out of them was connected with the Chernobyl accident consequences [6].

Thus the liquidators constitute a group of risk of many diseases (Table 8.1).

The mortality of liquidators in 1993-1995 is registered to be lower than that of men of 25-59. The growth of mortality of liquidators is, however, noted. The risk of death from malignant neoplasm for liquidators Group 1.1 is 1.6-1.9 times higher than that for liquidators Group 1.2.

8.2. Analysis of morbidity of adults and adolescents who were evacuated or independently left the alienation zone (Group 2)

By the end of 1995, medical institutions of Ministry of Health had under their observation 7,795 adolescents and adults who were evacuated or independently left the evacuation (alienation) zone in 1986 (Group 2 in the Register) [3].

Like other contingents of the sufferers, the evacuees have the increased level of incidence of endocrine system diseases, digestion disorders, metabolism and immunity disturbances, mainly for account of thyroid diseases (Table 8.2). The rise of thyroidites including autoimmune ones is observed; the diabetes mellitus incidence is increased. The incidence of blood and blood-forming tissues diseases is higher as well as of mental disorders (there is a tendency to increase), diseases of nervous system and sense organs. The high number of cataract cases attracts attention (in 1995 - 443.15 against 147.34 per

Table 8.3. Health state of evacuees from alienation zone: 1993-1995

Groups of evacuees	1993	1994	1995
Healthy (D1)	16.6	13.5	11.7
Practically healthy (D2)	26.5	26.3	31.1
Those who have chronic diseases (D3)	56.9	60.2	57.2
	100%	100%	100%

100,000 of population on the whole). An anxious fact is the high incidence of cardiovascular system diseases and its growth. The risk of this disease for Group 2 in the Registry during the analysed years was 3.1-3.9 times higher than that for the adolescents and adults of the Republic; 3.3-3.7 times concerning hypertension, 3.9-5.7 times - ischemia and 2.0-2.9 times - cerebrovascular diseases [3, 34, 7].

As an integrate assessment of health state of the evacuees, we can evaluate the ratio of health groups: D1 (healthy), D2 (practically healthy) and D3 (those who have chronic diseases). It is obvious that the share of healthy people among the evacuees is lowering (Table 8.3).

Disability of 26 persons (32.5 per 10,000) was recognized in 1995. The connection with the ChAPS accident consequences was established in 8 cases of them [6].

The mortality of the evacuated adults and adolescents in 1993-1995 was higher than the mortality of the adults and adolescents of the Republic on the whole, principally, for account of cardiovascular system diseases. The major causes of death of evacuees in 1995 were the next: the first cause was cardiovascular system diseases, on the second place - neoplasm, on the third place - symptoms and undetermined states, on the 4th and 5th places - diseases of digestion organs, traumas and poisonings, on the 6th place - respiration organs diseases [4].

8.3. Analysis of morbidity and mortality of adults and adolescents who lived or are living in the territories of primary and following resettlement (Group 3)

Group 3 in the Registry who had undergone radiation exposure as a result of Chernobyl APS accident constituted 66,440 persons by the end of 1995. 60.8% of them lived in the Gomel region, 15.6% - in the Mogilev region, 8.6% - in Minsk city, 4.4% - in the Vitebsk region, 4.1% - in the Minsk region, 3.3% - in the Grodno region and 3.2% - in the Brest region[3].

The comparative analysis of morbidity of Belarus adults and adolescents and Group 3 in the Registry (Table 8.4) shows that morbidity in 1995 of the adults and adolescents who live or lived in the zones of primary and following resettlement was reliably higher than the adults and adolescents of the Republic by a number of diseases [3, 10,34].

The malignant neoplasm of the residents of Group 3 who were living in “dirty” districts of the Gomel and Mogilev regions was registered more frequently than in persons of Group 3 in the Registry on the whole (461.55 against 369.55). The mortality of adults and adolescents of Group 3 was in 1995 reliably higher than that of the adults and adolescents of the Republic on the whole (1,777.63 against 1,638.32 per 100,000 persons). This includes, first of al,l cardiovascular system diseases (1,244.49 against 821.60), ischemia (625.16 and 525.72). This regularity was observed in every of three registration years (1993-1995) [14].

In 1995, disability of 362 persons of Group 3 was recognized. In 1994 and 1993 - 391 and 472. 28 cases of disability were connected with the consequences of ChAPS accident in 1995 (in 1994 - 48 cases, in 1993 - 46) [6].

8.4 Comparative analysis of morbidity and mortality of adults and adolescents of the Republic of Belarus and of the people those who are living in the zones with right to resettlement and with periodical radiation control (Group 5)

By the end of 1995, 1,354,262 adults and adolescents who lived in the zones with right to resettlement and with periodical radiation control were attributed to Group 5 in the Registry. 75% of this contingent lived in the Gomel region, 10.2% and 10.0% - in the Mogilev and Brest regions, and 2.5% and 2.3% - in Grodno and Minsk regions, respectively [3].

The comparative analysis of morbidity of Belarus adults and adolescents and of Group 5 (Table 8.5) has shown that morbidity in 1995 of the latter was reliably higher than the former by all range of diseases as a whole (57,549.27 against 57,091.01 per 100,000 persons).

As compared with 1994, morbidity of Group 5 in 1995 was higher by all range of diseases as a whole (57,549.27 against 56,827.63) [30, 16, 7 ,10]. The tendency to increase of morbidity in three years (1993-1995) was registered by all range of diseases as a whole, by neoplasms, and by urogenital system diseases. The number of common unspecified goiter was increasing constantly.

Table 8.4. The comparison of morbidity of Belarus population and of Group 3 (residents or migrants of primary and following resettlement) (1995, cases per 100,000 persons)

Diseases	Residents or migrants from polluted zones	Belarus population	Ratio
Thyroid cancer	2.92	7.05	0.41
Cataract	321.55	147.34	2.18
Malignant neoplasms	369.55	345.63	1.07
Respiration organs diseases	17479.77	25656.22	0.68
Digestion organs diseases	3298.18	1817.14	1.82
Diseases of endocrine system, nutritional disorders, metabolism and immunity disorders	1272.24	583.86	2.18
Diseases of blood and blood-forming tissue	175.28	73.88	2.37
Cardiovascular system diseases	4859.63	1629.90	2.98
Diseases of bone-muscle system and connective tissue	5166.37	3720.13	1.39
Symptoms and undetermined states	365.17	134.09	2.72
Mental disorders	1326.28	1124.55	1.18

Table 8.5. Comparison of morbidity of Belarus population and Group5, residents of zones with right to resettlement and periodic radiation control (1995, of cases per 100,000 persons)

Diseases	Residents of polluted zones	Belarus population	Ratio
Thyroid cancer	9.72	7.05	1.38
Cataract	194.34	147.34	1.32
Malignant neoplasms	328.25	345.63	0.95
Respiration organs diseases	24292.87	25656.22	0.95
Digestion organs diseases	2283.21	1817.14	1.26
Diseases of endocrine system, nutritional disorders, metabolism and immunity disorders	722.54	583.86	1.24
Diseases of blood and blood-forming tissue	100.84	73.88	1.36
Mental disorders	1014.96	1124.55	0.90
Urogenital system diseases	4176.90	2891.15	1.44

The mortality of adults and adolescents of Group 5 was in 1995 verifiably higher than the republican level by urogenital system diseases (20.50 against 16.67 per 100,000 persons) and blood and blood-forming tissues diseases (2.92 and 1.11). The verifiable growth of death rate in 1995 as compared with 1994 was registered in the adults and adolescents of Group 5 from all causes as a whole (1,605.10 and 1,556.79) and especially from the following four classes of diseases:
- neoplasm (228.16 and 216.80), including malignant (212.30 and 190.26);
- digestion organs diseases (28.13 and 23.77);
- urogenital system diseases (20.50 and 15.77);
- symptoms and undetermined states (194.87 and 153.56).

The principal causes of death of Group 5 in 1995 were the diseases of cardiovascular system (53.9% in the structure of mortality), neoplasm (14.2%), symptoms and undetermined states (12.1%), traumas and poisonings (9.2%), respiration organs diseases (4.8%). The number of patients with chronic diseases in Group 5 grew during last three years.

8,112 persons were recognized as disable in 1995 (in 1994 and 1993 - 7,780 and 8,952, respectively). The connection with radiation effects was found in 129 invalids in 1995, in 81 - in 1994, in 27 - in 1993 [6].

Conclusion

In the last years the affected population showed thereby more significant - as compared with republican indices - growth of incidence in the majority of diseases (first of all: digestion, urogenital, nervous, endocrine systems, diseases of ear, throat, nose both among adults and among children). Aggravation of health state continues in the participants of liquidation of the ChAPS accident consequences and the evacuees from the alienation zone which have obtained considerable radiation load to organism (rise of incidence of diseases of endocrine, cardiovascular, nervous system etc.).

Considerable growth of thyroid cancer incidence is registered in Belarus children and adolescents, especially in the Gomel and Brest regions. This is conditioned by dose commitments on thyroid gland due to iodine radionuclides in first period after the accident, incorrect iodine prophylaxy, and goitre endemic,. The rise of hereditary pathology is registered too. An expressed increase of oncological diseases is observed therewith mainly in the Gomel region, especially in the districts with high level of radiocontamination and, consequently, significant radiation load. First of all, this relates to the growth of incidence of cancer of lungs, mammary gland, bladder.

The analysis of epidemiological studies performed in Belarus after the ChAPS catastrophe and comparison of them with data obtained in the pre-Chernobyl period testify to the aggravation of health state of Belarus population. The specialists unambiguously recognize the direct influence of radioactive pollution in the environment on rise of thyroid pathologies, hereditary and congenital diseases, and cancers of different localizations. There is no unique opinion about the dynamics of haematological diseases and their causes. The increase is observed therewith of those diseases which can not be simply attributed to radiation-induced ones. Probably, the cause of this is concluded in the combined action of the complex of unfavourable factors existing in Belarus such as;

- radiation factor,
- general aggravation of social-economical situation, decrease of level of life, irrational nutrition,
- psycho-emotional stresses,
- unfavourable ecological factors with non-radiation nature etc.

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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 x 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 x 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 x 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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Dynamics of Health Status of Residents in the Lugyny District after the Accident at the ChNPS

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Introduction

The Lugyny district lies in the northern part of the Zhytomyr region of Ukraine within 110-150 km from the Chernobyl nuclear power station (ChNPS). Its territory is crossed by the southern and south-western tracks that were formed by the Chernobyl accident in April 1986. The total territory of the district constitutes approximately 900 km^2, the territory of agricultural land — more than 300 km^2, and about 190 km^2 of them arable land. Practically all agricultural land in the district have the ^{137}Cs contamination density higher than 1 Ci/km^2 (Table 1).

Prior to the Chernobyl accident about 30 thousand residents were living in the Lugyny district. By the present moment the population of the district has dropped to approximately 22 thousand people due to resettlement from the most contaminated territories and the decrease in the birth-rate (Table 2).

1. Radiation situation within the Lugyny district

All settlements of the Lugyny district (50 in total) according to [1] are categorised as zones of radioactive contamination II, III and IV (see Table 3), and practically all population are qualified for different categories of the accident sufferers (Table 4).

Local authorities constantly have been taking measures to resettle the inhabitants in the zone of obligatory resettlement (zone II). However, many of these inhabitants refuse to leave, others return to their homes after resettlements. The number of resettled from the 1st of January 1996 to the 1st of July 1997, as well as the number of inhabitants of 4 settlements in the zone of obligatory resettlement on the 1st of July 1997, are given in Table 5.

In 48 settlements of the Lugyny district, i.e. in all except the completely resettled Granitny Karier, and Moschanitsa where only 5 inhabitants are remaining, a regular dosimetric monitering of lands is performed.

Table 1. Territory of agricultural land of the Lugyny district with different ^{137}Cs contamination density levels, km^2

Contamination density Ci/km^2	Agricultural land	
	Total agricultural land	Arable land
up to 1	5	2
from 1 to 5	283	162
from 5 to 15	42	25
higher than 15	02	1
Total	332	190

Table 2. Population of the Lugyny district in 1984-1996

Years	Total	Children total	Infants under 1 year
1984	30,049	6,536	445
1985	29,575	6,500	401
1986	29,276	6,500	456
1987	29,225	6,296	296
1988	28,467	5,809	359
1989	27,962	5,819	300
1990	27,420	5,595	200
1991	25,046	4,799	317
1992	24,803	4,643	335
1993	24,883	4,700	352
1994	23,903	4,525	304
1995	23,125	4,389	264
1996	22,552	4,327	269

Table 3. Number of settlements and population size in territories categorised as different zones of radioactive contamination

Zones	Number of settlements	Number of inhabitants
Zone ofobligatory resettlement (zone II)	4	314
Zone of guaranteed voluntary resettlement (zone III)	35	18,815
Zone of intensified radio-ecological control (zone IV)	11	3,423
Total	50	22,552

Table 4. Number of inhabitants of the Lugyny district qualifying for different categories of sufferers

Categories	Total number of inhabitants	Children
I	232	49
II	18,949	2,666
III	3,173	608
Total	22,354	4,323

Table 5. Number of inhabitants of settlements in zone II by 01.07.97

Settlement	Number of inhabitants resettled from 01.01.96 to 01.07.97	Number of inhabitants remaining on 01.07.97
village Malahovka	34	64
village Rudnya Povtchanskaya	22	194
village Rudnya Zherevtsy	13	51
village Moschanitsa	2	5
Total	71	314

According to its results, the registered annual dose rate (Fig. 1), in 7 settlements of the district does not exceed 0.5 mSv/year, i.e. the criterial limit of qualifying as zone of intensified radiological control. None of the registered dose rate reach the value to be qualified for of obligatory resettlement (>5mSv/year). 22 and 19 settlements are qualified to be zones of guaranteed voluntary resettlement and intensified radiological control, respectively.

Regular examinations of inhabitants in settlements qualified for zones of radioactive contamination are performed with use of whole-body counters. Within the 8-year period (from 1989 to 1996) a total of 33,085 adults and 11,016 children has been examined. Radionuclide accumulation exceeding the control norm is found by 3,026 adults and 1,029 children (Table 6). The control norms of ^{137}Cs in the organism are 0.5 µCi for adults and 0.2 µCi for children.

Dynamics of the relative number of cases with ^{137}Cs accumulation in organism of adults and children in excess of the control norms is indicated in Fig.2. A significant increase is observed in 1994 in the background of a general trend towards a decrease. Such splash is explained in the first place by changes

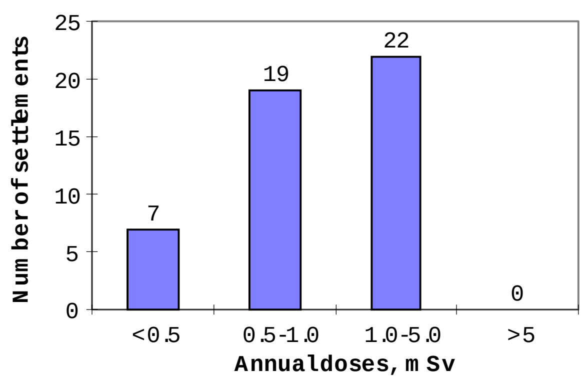


Fig. 1. Number of settlements of the Lugyny district which fit the criteria to be qualified for different zones of radioactive contamination (according to [2])

Table 6. Results of dosimetric control of internal irradiation of the district population living in settlements with soil contamination from 5 to 15 Ci/km^2 and higher

Years	Number of examined persons		Found with dose exceeding norm, persons		Found with dose exceeding norm, %		
	Adults	Children	Adults	Children	Adults	Children	Total
1989	3,198	696	417	103	13	14.7	13.3
1990	8,432	2,296	809	280	9.5	12.1	10.2
1991	5,550	2,685	603	192	10.8	7.1	9.6
1992	3,892	1,636	432	186	11.1	11.3	9.3
1993	3,164	1,037	167	42	5.2	4	4.9
1994	2,156	534	372	164	17.2	30	19.9
1995	1,697	1,415	41	38	2.4	2.6	2.5
1996	4,996	717	185	24	3.7	3.3	3.6

Table 7. Results of dosimetric examination of the internal irradiation of the inhabitants of the district, living in settlements in zones II-IV

Year	Zone II		Zone III		Zone IV	
	Total	With excessive dose	Total	With excessive dose	Total	With excessive dose
1996	155	103 (66%)	4,755	104 (2%)	803	2 (0.2%)
1997	24	3 (13%)	1,749	21 (1%)	283	-

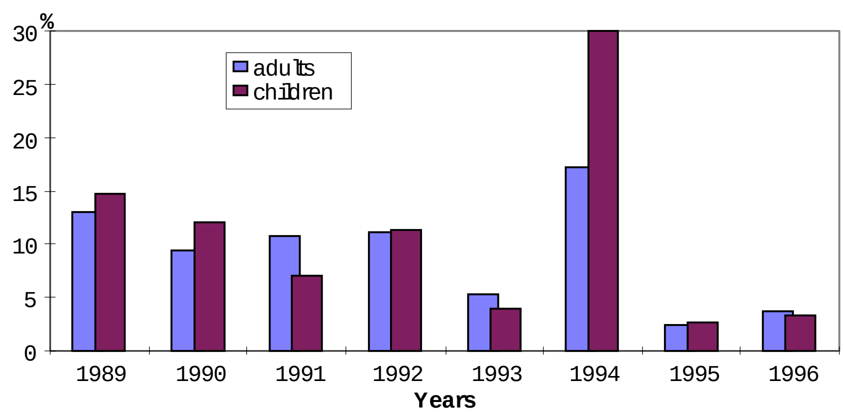


Fig. 2. Dynamics of changes in the relative number of cases with ^{137}Cs accumulation in organism of adults and children in excess of the set control values

in natural conditions, in particular in the rainfall amount and cropping capacity of wild mushrooms and berries. According to the data of radiometric control of foodstuffs in the district, radionuclide accumulation in human organisms is contributed by consumption of milk, mushrooms and berries by the population of the district. Excess of all-union Tentative Acceptable Levels (TAL-91) is 3-5% for milk, 1-5% for meat, 50% for mushrooms and berries for the period of 1993-1995.

Comparison of the internal irradiation dose year by year shows the following: until 1990 maximal registered values of ^{137}Cs in adults exceeded 10 μCi, and beginning from 1991 the maximal values in general constituted 2 μCi in adults and 0.6 μCi in children.

According to the data of the UKP "Truskavets"[1] 2,020 children and parents living in the radiation contaminated territory of the district have been examined. In 80% of children the radio-caesium activity was found to be higher than 1,000 Bq, in 15% — higher than 5,000 Bq.

The relative number of inhabitants with excessive ^{137}Cs accumulation is significantly higher in zones with higher levels of radioactive contamination (Table 7).

According to the data of the thyroid dosimetric conditioning of settlements in the Zhitomir region performed by the UNCRM in 1994 by the request of the Ministry of Chernobyl of the Ukraine, inhabitants of the Lugyny district had received high thyroid

[1] "Truskavets" is a resort in the Carpathians which receives children from zones of radioactive contamination for recreation in summertime.

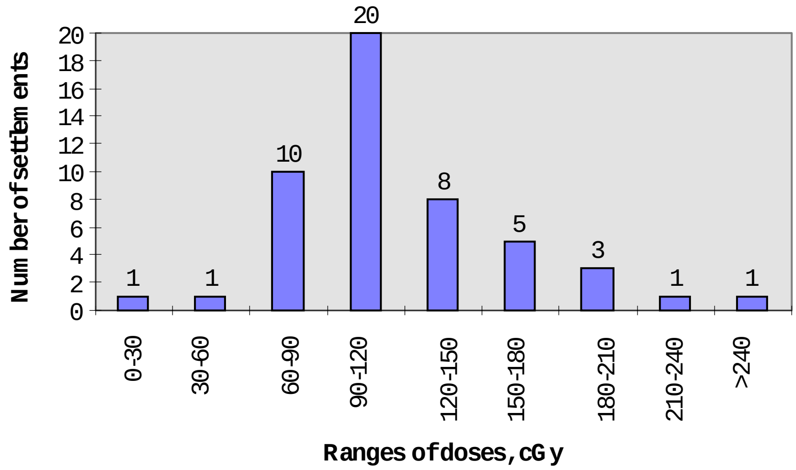


Fig. 3. Distribution of the number of settlements in the Lugyny district according to thyroid irradiation doses for children born in 1986 (according to [3])

irradiation doses during the first stage after the accident, especially children (Fig. 3). In 38 of 50 settlements in the Lugyny district thyroid irradiation doses by children born in 1986 exceed 90 cGy.

The population is divided into seven age-groups in the thyroid dosimetric registration and the relative distribution of thyroid irradiation doses for different age-groups of the population residing in the same settlement is given in Fig. 4.

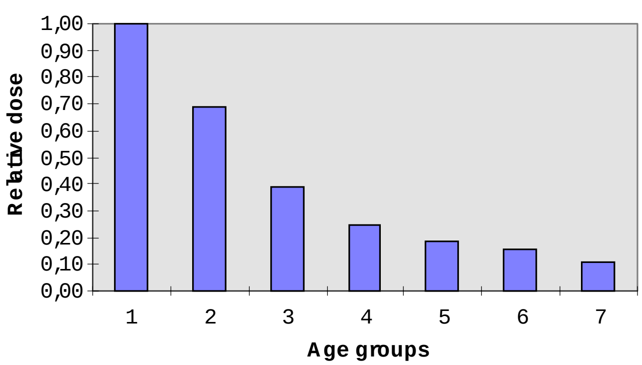
2. Health status indices of the Lugyny district

The medical system of the former Soviet Union was succeeded by the Ukrane, as well as its merits and demerits. It constitutes one kind of hierarchy structure of medical institutions, ranking from national medical centres down to hospitals in regions, districts, and towns (villages). Within the structure of this system, one central hospital is distributed in each district. In the Lugyny district we can, therefore, collect all medical information of the population at the Hospital of the Lugyny Territorial Medical Association (which is the central district hospital) district where one of the present authors is working.

As indices of the health status, we shall analyse state of the immune system, spread of endocrine pathologies, morbidity by newly-born, psycho-neurological status of the population, premature ageing, and structure of mortality.

The immune system

The state of the immune system is one of the most important indices of the health status. According to the data of the Central District Hospital of the Lugyny district, depression of reactivity of the immune system is found practically by all patients. This depression is clinically manifested through the increase in the number and duration of infectious diseases, growth of destructive forms of tuberculosis, relapse of diseases, increase in the number of frequently ill people, reduction of remaining life of oncology patients after



Group	Year of birth
1	1986
2	1983-1985
3	1979-1982
4	1975-1978
5	1971-1974
6	1968-1970
7	before 1968

Fig. 4. Relative thyroid gland irradiation doses for different age-groups of inhabitants residing in the same settlement

Table 8. Remaining life of patients in the Lugyny district with grade III-IV malignant tumours of the stomach and lungs after the moment of diagnosis before and after the Chernobyl accident, (in months)

Years	Remaining life by cancer	
	stomach	lungs
1984	62	38
1985	57	42
-	-	-
1992	15.5	8.0
1993	11.0	5.6
1994	7.5	7.6
1995	7.2	5.2
1996	2.3	2.0

Table 9. Dynamics of the number of the first detected tuberculosis cases in the Lugyny district, per 100 thousand inhabitants

Years	All forms, per 100 thousand inhabitants	Destructive forms among first detected cases, %
1985	75.8	17.2
1986	84.5	28.7
1987	64.0	17.7
1988	54.7	14.5
1989	91.2	37.5
1990	12.2	66.6
1991	28.4	42.3
1992	49.8	33.3
1993	53.9	54.5
1994	59.8	50.0
1995	73.3	50.0
1996	84.0	41.7

their diagnosis, a more severe course of diseases, increase in virulence of infecting agents, as well as growth of the number of allergic diseases.

Investigation of medical records of the patients suffering from malignant tumours has disclosed the following regularity: after the accident at the Chernobyl NPS the remaining life of such patients after the moment of their diagnosis decreases with every year. Before the accident, in 1984-1985 the remaining life of patients with grade III-IV cancer of stomach was about 60 months after the moment of diagnosis, with grade III-IV pulmonary tumours — about 40 months. In 1992 the remaining life made up 15.5 months in the case of grade III-IV cancer of stomach and 8 months in the case of grade III-IV lung cancer, and in 1996 — 2.3 and 2 months (!!!) respectively (Table 8). At the same time the detection techniques, diagnostics and treatment remain at the level of the pre-accident years.

Where does the reason of such difference in the remaining life lie? The importance of the immune system for viability of organism has become especially evident after the accident at ChNPS. The immune system plays an important role in maintenance of stable internal environment of the organism and is involved in anti-tumour protection. Effects of radiation expose the immune system to extreme stress with subsequent development of immune deficiency, which in turn results in progressing of malignant diseases, as well as in contraction of incurable infection and associated diseases, that are generally the cause of death of such patients

Special concern of physicians is also caused by the growth of the number of destructive forms of tuberculosis among the first detected tuberculosis cases (Table 9), which is also an evidence of the depression of the immune system.

By an order of the administration of Health Care authorities, the number of roentgeno-photography examinations in the framework of sanitary observation programmes was sharply decreased in 1990 in order to prevent unjustified additional irradiation of the population. Namely this fact explains the drop in the number of the first detected tuberculosis cases in 1990 as compared to the previous year (Table 9). The drop in 1990 was not the actual decrease in the number of tuberculosis patients. Subsequently, after renovation of the roentgeno-photography rooms and installation of more up-to-date equipment, the roentgenophotography examinations have been resumed to the initial extent.

Endocrine pathology

Endocrine pathology includes diffuse goitre, nodular goitre, diabetes mellitus, liposis and others. Special concern is the growth of endocrine pathology in children. Beginning from 1990-1991 a stable increase in the number of endocrine system diseases in

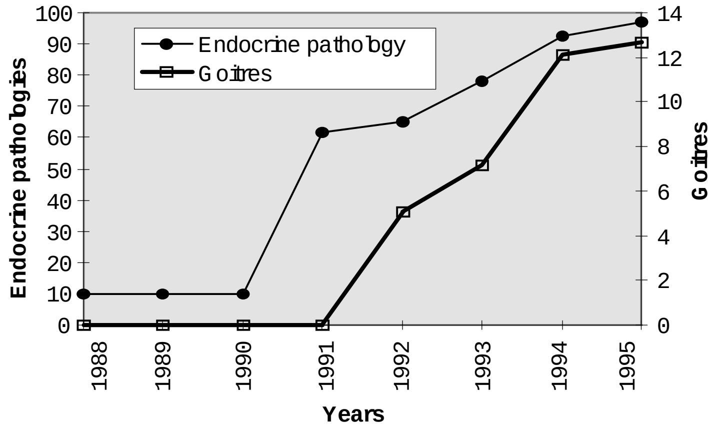


Fig. 5. Dynamics of the growth of endocrine pathology and goitres in children after the Chernobyl accident (per 1,000 children)

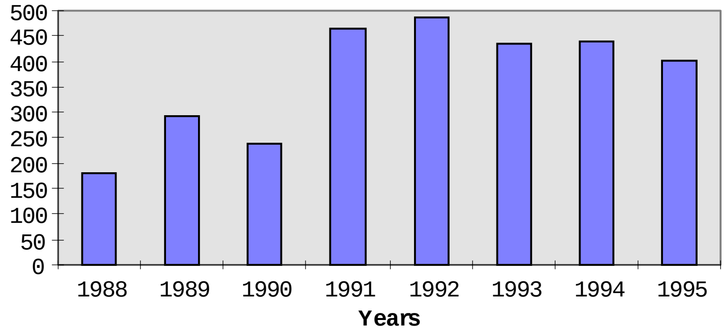


Fig. 6. Dynamics of the number of thyroid gland hyperplasia in children (per 1,000 children)

children is observed (Fig. 5). Prior to 1986 morbidity of endocrine pathology did not exceeded 10/1000. Nodular and diffuse goitres had not been registered in the district at all. By analysis of thyroid morbidity, it is noted that the sufferers are mainly children who were subject to the iodine strike in 1986, when no prophylactics was performed. Iodine potassium prophylactics was started 3 weeks after the accident. Thyroid gland pathology is also observed in adults. Unfortunately, there are practically no medical facilities and financial means to conduct specialised examinations of the population aimed at detection of nodular goitre. Tumours of thyroid gland have not been registered within the period since the accident. However, a significant increase in the number of thyroid gland hyperplasia is established (Fig. 6). Hyperplasia (enlargement) of thyroid gland is not an illness proper, but indicates the reaction of the organism to external injurious effects. Before 1988 hyperplasia of thyroid gland was not registered in the district; at present it is typical of almost half of the children in the district.

Morbidity in newly-born

A growth of the morbidity in newly-born (age of up to 7 days) is marked after the Chernobyl accident, as well as the number of their anomalies (Fig. 7). Dynamics of newly-born anomalies (they are cleft lip, atresia of internal organs), shows a more complex tendency in the post-accident period. However, as Fig. 8 shows, their average level in the period after 1988 is several times as large as the pre-accident level.

Psycho-neurological disorders

Of the most important problems which physicians had to face suddenly and which have been continuously aggravated — is psychological pathology. More and more patients go to physicians with anxiety-depression syndromes and different phobias. Predominant symptoms are neurosis-like conditions, and asthenic and psycho-chondric symptoms that are manifested by way of anxiety, fear and emotional imbalance.

Apparently, as a result of the combined effect of ionising radiation and psycho-emotional stress on the organism, its homeostasis is impaired and an endogenic intoxication emerges, which are leading to psycho-neurological disorders. It is possible as well that low radiation doses determine dysfunction of brain structures, which are being manifested through significant increase of vegeto-vascular dystonia with diencephalic syndromes. Before the accident, practically no cases of vegeto-vascular pathology were registered. At present, this pathology is one of the most widespread causes for people to see physicians.

Physicians faced the problem of psycho-neurological disorders only in the last 4 years.

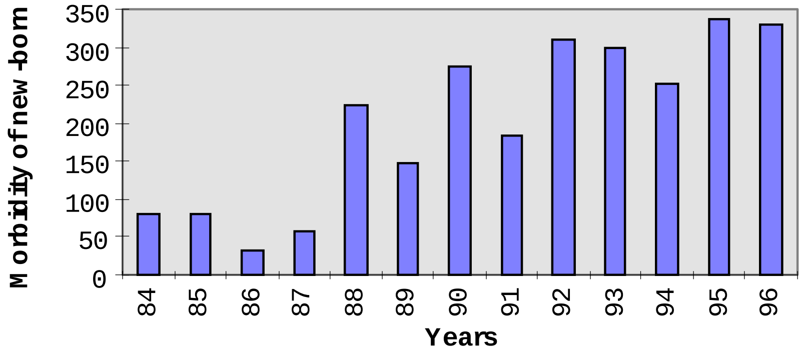


Fig. 7. Morbidity in newly-born (age of up to 7 days), including inherent development anomalies in children (per 1,000 newly-born)

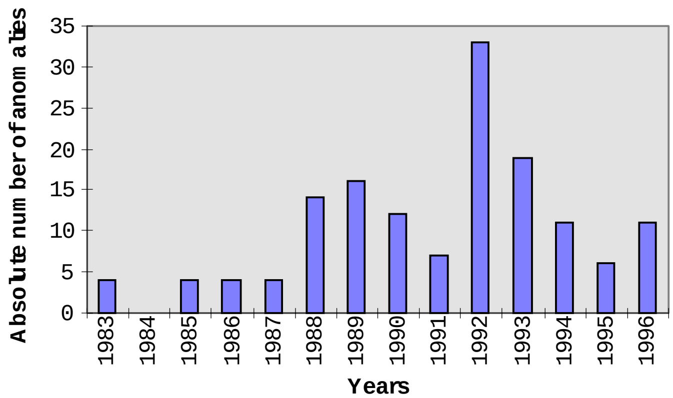


Fig. 8. Dynamics of inherent development anomalies in newly-born (absolute number)

Today, one needs to realise the responsibility to cope with these psychosomatic disorders and diseases because an increase in the number of suicides and severe psychic diseases is to be expected in the future.

Premature ageing

In the course of life process, more and more cells are decaying due to effects of internal and external irradiation factors. This leads to premature ageing and shortening of life span. The fact of early ageing is confirmed by markers of ageing in younger ages. These markers include different tests that determine capabilities of all systems of the organism, e.g. for the cardiovascular system — blood pressure, rapid pulse in young ages, statistically reliable increase in the number of hypertension and ischemic cases in young ages; for nervous system — increase in the number of anxiety-depression syndromes, phobic neurosis-like conditions arising on somatic grounds and others. All of these phenomena can be easily checked in clinical observation.

What has been influencing on the increase of ageing pathologies and associating premature deaths? The major factors are — the increased level of radiation and presence of permanent stress situations. Mechanisms of the effects of these factors are practically the same: their direct or indirect impact on the systems and organs impairs metabolism and circulation of blood, which results in dystrophic processes in organs and systems of the organism determining premature ageing and death. Average life-expectancy of the Lugyny district population before the accident at the Chernobyl NPS (1984, 1985) has been 75 years, after the accident (1990-1996) — 65 years.

Mortality structure

According to the mortality data, after the accident death has become 10 years "younger" than before the accident and the mortality peak falls on the age of 65-69 years (Fig. 9). Women live approximately 8 years longer than men. The total mortality of the population in 1985 in the district was 10.9 per 1,000 inhabitants with maximum mortality in the age of more than 80 years. Oncologic diseases occupied the third place in the mortality structure with an index of 0.7. The first and second places were occupied by cardiovascular diseases (6.5) and diseases of the respiratory organs (1.7), respectively. In the age structure of mortality a smooth rise of the curve was found to the 80-years age in both men and women, with a 10 year longer life expectancy for women.

In 1990 the total mortality was 12.9 per 1,000 inhabitants. As seen in Fig.9, a mortality increase of step character can be noted in the 50-54 years interval (0.8 per 1,000), and a second peak in the 65-69 years interval (1.9). As compared to 1985, the life-expectancy for men in 1990 has dropped by 10

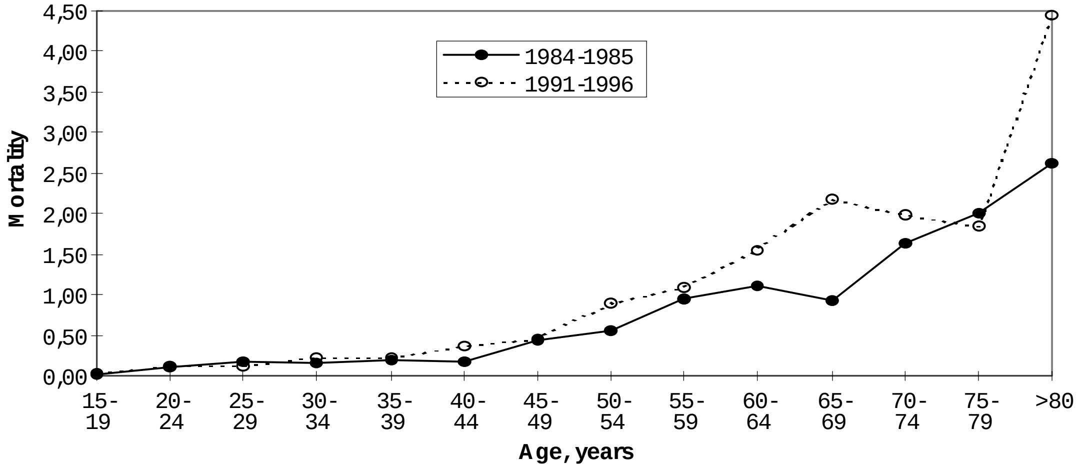


Fig. 9. Age structure of mortality in the Lugyny district in the pre- and post-accident periods

years. In the case of women, the mortality curve is still smoothly rising with a peak on the 65-69 years interval. The life-expectancy for women was 10-15 years longer than for men. Mortality from oncologic diseases was 1.9 per 1,000 inhabitants and moves to the second place after cardiovascular diseases (5.7).

The total mortality in 1991 has increased and was 15.5 per 1,000 inhabitants. The mortality curve of men sharply stepped up with a peak in the 50-54 years interval (0.8) and kept the increased level till 65-69 years. In women the mortality curve is still smoothly rising with a peak on the 60-64 years. On the average, the life expectancy for men was 15 years shorter than for women. Mortality from oncologic diseases occupied the second place (1.6) after cardiovascular diseases (7.3).

The age-profile of mortality of men in 1990-1992 as compared to 1985 clearly indicated that death came 15 years earlier in men than in 1985. Peak of the mortality curve of men has moved to younger ages, indicating that more younger men will die in the future. As far as mortality of women is concerned, the mortality curve has been moving slower and in comparison with 1985 the life expectancy was 5-8 years shorter.

Conclusion

At first it should be noted that the ***immune system*** of inhabitants in the Lugyny district is depressed. This fact is indicated by the followings: drop in remaining life of oncologic patients, reduction of the periods between stages of oncologic diseases, a more severe course of diseases, increase in the destruction of lungs on the background of growth of tuberculosis of lungs, increased morbidity of children, and increase in the number of infectious diseases.

The ***increase in the number of nodular goitres in the background of a significant growth of thyroid gland hyperplasia in children*** occupies the second place.

In the third place is a yet incomprehensible for us physicians ***psycho-neurological aspect with its anxiety-phobic depression syndromes***, which will lead to unpredictable consequences in future.

A ***growth of the morbidity in newly-born*** is established, to be more exact — the prenatal morbidity of the foetus (e.g., inherent pneumonia, etc.).

More and more cases of vegeto-vascular dystonia with diencephalic syndromes are registered.

Premature ageing and a significant reduction of life expectancy is found in inhabitants of the district.

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Radiation Situation and Health Statistics of the People in the Tula Region of Russia after the Chernobyl Catastrophe

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General view of the situation in Russia after the ChAPS accident

The Chernobyl APS accident was the greatest technogenic catastrophe. According to the latest data of the Ministry of Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM of Russia), over 30 million people living in the territory of 19 subjects of the Russian Federation are undergoing radioactive pollution [7].

Large-scale consequences of the accident profoundly affected the policy, economy and social life of the country. Several principal factors are highlighted:

- ✧ Radiation effects on man and the environment;
- ✧ Problems of information about the accident and its consequences - real and imaginary;
- ✧ Psychological impact on population, conditioned by information about the accident, implemented countermeasures, social privileges, compensations and so on;
- ✧ Social-economic impact on the whole country and the affected territories.

Regretfully, the processes which took place in the USSR and, later on, in Russia did not promote the successful liquidation of negative effects of the mentioned factors. Moreover, during 11 years after the accident, an increase of negative consequences has been observed.

As a result of the Chernobyl APS accident, the area of territories in Russia polluted with ^{137}Cs of higher than 37 kBq/m^2 (1 Ci/km^2) amounted to 57,000 km^2. Nearly 3 million people are living there. The territories of the Bryansk, the Kaluga, the Tula and the Orel regions suffered most, where nearly 1.8 million people are living. Almost 300 km^2 of territories with levels over 1,480 kBq/m^2 (40 Ci/km^2) were put out of economic use. All inhabitants there were resettled. Nearly 30,000 km^2 of agricultural land, including 1,710 km^2 with 555 kBq/m^2 (15 Ci/km^2) or higher, and nearly 5,900 km^2 of forest were covered with radioactive pollution [6].

Within the affected territories, a series of protective activities were carried out in different terms after the catastrophe. In the first years after the accident, the radiation-hygienic situation was urgent. High level pollution of local agricultural products was observed: in 1986, 70% of hay and 80% of milk were rejected in the Bryansk region. Part of population received a considerable level of additional irradiation. According to the data of EMERCOM of Russia, as a result of countermeasures and natural processes, the radiation-hygienic situation on the polluted territories became better significantly. **Recently contents of radionuclides in food products are below regulation limits in general.** Nearly 100,000 people are, however, still subject to additional exposure in doses higher than 1 mSv/year, and in 4 settlements (in the mentioned regions) the average additional irradiation dose exceeds 5 mSv/year [7].

Compensations and supports in the affected areas from the government were sufficient until 1992. However, since the end of 1992, the situation got worse abruptly. Negative consequences of the accident in economic development and social sphere are clearly seen in the Bryansk, the Kaluga, the Orel and the Tula regions. In late years there appear in the affected areas greater reduction of industrial and agricultural production, aggravation of demographic situation, lowering of citizens' income, and slow adaptation to the social-economic changes than in the country on the whole.

According to sociological studies of last years, in spite of the complicated ecological situation in these areas, people are concerned more about heavy living conditions, inflation and the critical state of economy rather than about the environmental and medical problems due to the Chernobyl accident. Objective grounds exist for it. **Indices of mean wages and total income are substantially lower there than the Russian average, and the level of salary is lower than the price to buy principal food products.**

The social consequences of the accident are also quite significant. Already in first years there appeared a tendency to migration of a part of population from polluted areas; first of all, intelligentsia (teachers, physicians, rural specialists) and youth. This tendency later on became a mass phenomenon. The government activities related to resettlement promoted this trend. The migration process led to a significant aggravation of the demographic situation in rural areas. The share of pension age people in villages of polluted districts reached 40%, and the number of pre-pension age among the able-to-work population reached 30-40%. It should be noted that a new tendency began to appear in early 90's, and since 1994 it become clear. A stable increase of population in rural districts in the polluted regions is observed. In the Bryansk region the migration-related increase is already over 2 times as high as the natural decrease of population. The cause of this phenomenon is related with social processes which are taking place in Russia and CIS countries. Objective causes exist; people are immigrating from northern and eastern territories of Russia, and from zones of racial and military conflicts both inside Russia and in the republics of the former USSR. **This considerable influx of population into the radiocontaminated territories can cause new problems including increase of social tension.**

It used to be considered that medical consequences of the accident are dominating factors. In fact, more than 100 cases of thyroid cancer were discovered in Russia among those who had been children and adolescents at the time of the Chernobyl accident. This index exceeds by tens of times the average. However, the health state is determined not only by radiation exposure or the ecological situation, but also by the totality of social-economic factors and tendencies of their changes. All these factors determine the observed multiple health disturbances of the population living on the polluted territories. **Perspectives of liquidation of the accident consequences are indissolubly connected with perspectives overcoming the current economic crisis in Russia.** An optimistic forecast says that the medico-demographic after-effects of the accident can be overcome in 10-15 years on all polluted territories. A pessimistic forecast says that the medico-demographic situation in the polluted districts will get worse far more quickly than in Russia on the whole.

It is necessary to mention that a substantial loss of the health of the people was caused not only as a result of irradiation, but also due to the absence (in the first stage after the ChAPS accident) of information about radiation pollution and, later on, its imperfection and distortion. Consequently, psychological disadaptation is observed in the overwhelming majority of adults living on polluted areas. The insufficient and imperfect information to the public and to medical personnel about irradiation effects on organism and prophylactic methods also worsened the harmful consequences of the ChAPS accident .

These can be seen through the analysis of the health state of residents in the Tula region, significant part of which is polluted with radiostrontium and radiocesium from Chernobyl.

TULA REGION

Radioactive pollution in the Tula region

The Inter-institutional Commission on radiation control of the environment at the USSR Goskomgidromet approved the map of radiation situation in the region for the first time on 26.12.1990. 17 districts and Donsk city entered the zone of radiocontamination (>1 Ci/km^2 with ^{137}Cs) as a result of the Chernobyl APS accident. These are districts of Arsenievsk, Belevsk, Bogoroditsk, Venevsk, Volovsk, Efremov, Kamensk, Kimovsk, Kireevsk, Kurkinsk, Novomoskovsk, Odoevsk, Plavsk, Teplo-Ogarevsk, Uzlovsk, Chernsk and Shchekino. In total: 2,048 settlements with 930 thousand population (including 750.6 thousand adults and 165.6 thousand children). At present, the number of population constitutes near 916,000 including 159,689 children. Various districts of the Tula region are situated at 500-600 km from the Chernobyl APS. The total area of radioactive pollution constitutes 14.5 thousand km^2, i. e. 56% of the region area (Table 1).

By 01.01.1997, 16 settlements were excluded from the category of radiocontaminated as compared with 1991; 3 of them - in the zone of 5-15 Ci/km^2, and 11 - in the zone of 1-5 Ci/km^2. The number of residents of the above mentioned districts decreased for the observed period by 23,667: 340 of them - in the zone of 5-15 Ci/km^2, and 23,324 - in the zone of 1-5 Ci/km^2 [1].

It is also noted that, within separate settlements, there are spots which are not representative for all the area of the given settlement and show high levels of pollution areas even from one to several square meters. As a rule, such increased pollution are observed under drains from roofs, in places of storage of manure or ashes, in low parts of earth etc.

The area of agricultural land in the region, polluted with radionuclides is 8,950.77 km^2, details of which are as follows.

1) **1-5 Ci/km^2** - 7,685.55 km^2 of agricultural land (50.1% of total area) including 6,269.23 km^2 of ploughland, 185.87 km^2 of hayfield, 1,230.45 km^2 of fodder land.
2) **5-15 Ci/km^2** - 1,260.82 km^2 of agricultural land (8.2% of total area) including 1,044.92 km2 of ploughland, 32.31 km^2 of hayfield, 183.59 km2 of fodder land.
3) **15-40 Ci/km^2** - 4.40 km^2 of agricultural land (0.003% of total area), all of which belong to ploughland. The districts with the largest polluted areas are the next: Plavsk (2.20 km^2), Uzlovsk (2.20 km^2).

The radioactive pollution of forest (State Forest Fund) in the Tula region amounts to 707.13 km^2, over a quarter of the total forest (2,706.14 km^2) of the region. Out of them, 109.31 km^2 and 597.82 km^2 are situated in the zones of 1-5 Ci/km^2 and 5-15 Ci/km^2, respectively.

According to the data of Committee for Liquidation of Radiation Catastrophes Consequences of the Tula region, the pollution of forests is something higher than that of open places and adjacent settlements. This is attributed to lesser migration of radionuclides due to the existence of leaf litter in the forest.

Table 1 Radioactive contamination in 17 districts and Donsk city of the Tula region by the Chernobyl accident (01.01.1991) [1].

District	Number of settlement				Population (persons)				Area (1000 km^2)			
	District total	Zone of contamination			District total	Zone of contamination			District total	Zone of contamination		
		Total	Cs-137 level			Total	Cs-137 level			Total	Cs-137 level	
			5-15 Ci/km^2	1-5 Ci/km^2			5-15 Ci/km^2	1-5 Ci/km^2			5-15 Ci/km^2	1-5 Ci/km^2
Arsenievsk	106	106	94	12	13015	13015	6799	6216	1.099	1.099	0.993	0.106
Belevsk	177	151	50	101	30200	28999	3730	25269	1.19	1.078	0.295	0.783
Bogoroditsk	80	80	13	67	68558	68558	5089	63469	0.94	0.94	0.095	0.845
Venevsk	201	33	-	33	39100	9789	-	9789	1.88	0.063	-	0.063
Volovsk	125	125	-	125	18550	18550	-	18550	1.07	1.07	-	1.07
Efremov	205	147	-	147	81900	75587	-	75587	1.6	0.785	-	0.785
Kamensk	100	66	-	66	11100	7518	-	7518	0.934	0.327	-	0.327
Kimovsk	152	147	-	147	59100	58754	-	58754	1.45	1.23	-	1.23
Kireevsk	176	176	39	137	93619	93619	12624	80995	0.930	0.930	0.072	0.858
Kurkinsk	119	61	-	61	15600	10975	-	10975	0.95	0.482	-	0.482
Novomoskovsk	99	65	-	65	172300	169355	-	169355	0.69	0.357	-	0.357
Odoevsk	135	88	-	88	15500	5185	-	5185	1.18	0.637	-	0.637
Plavsk	108	108	54	54	29418	29418	23553	5865	1.02	1.021	0.624	0.397
T-Ogarevsk	116	116	-	116	15628	15628	-	15628	1.01	1.01	-	1.01
Uzlovsk	103	103	22	81	102400	102400	84081	18319	0.617	0.617	0.122	0.495
Chernsk	270	270	21	249	22283	22283	3129	19154	1.62	1.62	0.027	1.593
Shchekino	239	198	18	180	129600	122950	1484	121466	1.39	1.181	0.23	0.951
Donsk (city)	8	8	-	8	77200	77200	-	77200	0.03	0.03	-	0.03
Total	2519	2048	311	1737	995071	929783	140489	789294	19.6	14.477	2.458	12.019

In 1996, the pollution of agricultural land decreased something as compared with preceding years, and it decreased by more than 100 times as compared with the situation in 1986 (for ten years). Radiocesium transfer to agricultural crops decreased notably both for account of natural decay of radioactivity and due to agrochemical activities (soil liming, introduction of phosphoric and potash fertilizers). According to the data of radiation surveillance of food products and animal fodder on 01.01.1997, the maximum concentrations of cesium radionuclides in milk, meat, vegetables and fruits were 38.4, 22.6, 17.0 and 6 Bq/l(kg), respectively. All of them did not exceed values of TAL-93 (Temporarily Admissible Level) for milk (370 Bq/l) and for meat, vegetables and fruits (600 Bq/kg). By the spectrometric data, the maximum concentration of strontium radionuclides in food products was 0.4 Bq/l(kg) against admissible levels from 37 to 100 Bq/l(kg).

Last year, however, an increase of cesium radionuclides was registered in 5 out of 26 samples of mushrooms collected in autumn in neighborhoods of the following settlements:

- village Krasnopolskoe of the Kimovsk district,
- village Lugovoe of the Kimovsk district,
- village Bogoroditsk (Dachi station);
- farm Beloozero of the Kimovsk district.

Two-times excess over TAL-93 was observed in samples.

In this connection, **further and permanent laboratory studies are necessary for samples of mushrooms** that are now the principal path of internal exposure of the population in radiocontaminated areas, as well as development of recommendations on their consumption.

Dosimetric surveillance of population

The results of radiation surveillance of the environment on 01.01.1997 show that the level of gamma-background has stabilized in last years and is within the limits of fluctuations of natural characteristic in middle latitudes of the Russian Federation (15-25 μR/h). Exceptions are some settlements of the Arsenievsk, the Uzlovsk, and the Plavsk districts where the average level of gamma-background is up to 30-40 μR/h (the temporarily admissible value: 60 μR/h). There are also separate local spots in these districts where the level of gamma-background exceeds 60 μR/h, reaching up to 260 μR/h.

Regretfully, the specification of radiation situation in 118 settlements planned in 1996 by the Tula Center on Hydrometeorology and Monitoring of Environment was not implemented due to the lack of finance from the Federal budget.

According to the data of the State Sanitarian-Epidemiologic Inspectors, cesium content in organisms of residents in the Arsenievsk, the Novomoskovsk, the Uzlovsk and the Shchekino districts does not exceed the level of preceding years and is lower than the admissible levels (122.1 kBq for adults). The average and the maximum values of cesium content in the organisms of adults were 0.96 k Bq and 9.3 kBq, respectively. For children, they were 0.74 kBq and 4.4 kBq, respectively.

A group of persons (machine-operators, cattle-breeders, plant cultivation workers) has been examined with direct measurements of external irradiation doses with thermoluminescent dosimetry in the Plavsk, the Arsenievsk, the Uzlovsk, the Chernsk districts and Donsk city. The mean external dosage of the examined people, including the contribution from the natural background (2.2 mSv/year), was 2.32 mSv/year. The maximum was 3.66 mSv/year.

According to calculation of the St. Petersburg Research Institute of Radiation Hygiene and the Regional Centre of Gossanepidnadzor, the average annual effective dose of population in 1996 (in 2,041 settlements of the radiocontaminated zone) was not higher than the admissible level of 1 mSv/year. The maximum value of the average annual effective dose (0.71 mSv/year) was registered in Rozhdestveno-1 village of Samozvanovsk rural administration of the Plavsk district.

Health statistics of population

Large-scale industrial centers are situated on the polluted territories of the Tula region, including chemical ones. These are as follows: “Tula-Chermet” company, Kasacharsk Metallurgical Group, “Novomoskovskij Bytkhim” company, Aleksinsk Chemical Group, “Azot” (Novomoskovsk and Shchekino), Efremov Chemical Group, Efremov Synthetic Rubber Plant, and others. **These enterprises pollute the environment with heavy metals, dioxins, oxides of nitrogen, sulfur, carbon, aromatic hydrocarbons, volatile organic compounds, cyanides, pesticides, herbicides etc. [3].**

It was noted in the State Report “*On the State of the Natural Environment of the Russian Federation*” of 1994-1996: “...Moscow and Tula regions are characterized by the largest releases of pollutants into the atmosphere. Their contribution constitutes respectively 24% and 21% of the total release in central regions of the Russian Federation”, “...from the substances polluting the natural water resources in the Tula region the followings can be noted: nitrogen and phosphorus compounds, iron (8.5% of total release in the RF), aromatic hydrocarbon (26% of total release in the RF)...”. “Azot” company (Novomoskovsk) was noted as the biggest enterprise polluting the surface reservoirs; 51.4 mln m^3 of polluted waste waters were released by it [3].”

All the above mentioned factors undoubtedly have been influencing the health state of the population and demographic indices, together with radiation factors due to the Chernobyl accident

Birth rate and death rate in the Tula region

In Fig. 1 are shown the dynamics of birth rate (thick lines) and death rate (thin lines) observed during 1985 - 1995. The data are divided into three groups: the whole region, 18 contaminated areas (17 districts + Donsk city), and 7 clean districts. In this case, ′clean′ merely means that the level of contamination is below 1 Ci/km^2 of ^{137}Cs

As can be seen from Fig. 1, there are observed continuous opposite trends of increase of death rate and decrease of birth rate in all three groups. Natural increase of population in the region turned to minus since 1988 and the minus trend continues to become larger with time. At first, this trend can be explained by the change in the age structure of population. The Tula region is becoming "older": nearly 30% of inhabitants are now over 60. One of the reasons for such change of the age structure is considered emigration of young people from the contaminated areas. This trend is influencing indices of various diseases.

Neoplasm in adults

Morbidity of neoplasm in adult population is shown in Fig. 2. In addition to the data of two groups (18 contaminated areas and 7 clean districts), separate data in 4 districts are plotted. Districts of the Plavsk and the Uzlovsk are chosen from the most contaminated districts, while the Venevsk has the least level of contamination within the 18 contaminated areas (Table 1). The Novomoskovsk is the district where heavy industries are located. All data in Fig. 2 have a slight trend of increase of neoplasm morbidity. The morbidity in the 7 clean districts is somewhat larger than in the 18 contaminated areas. Within the 4 districts, the data of the Novomoskovsk tends to show a higher value.

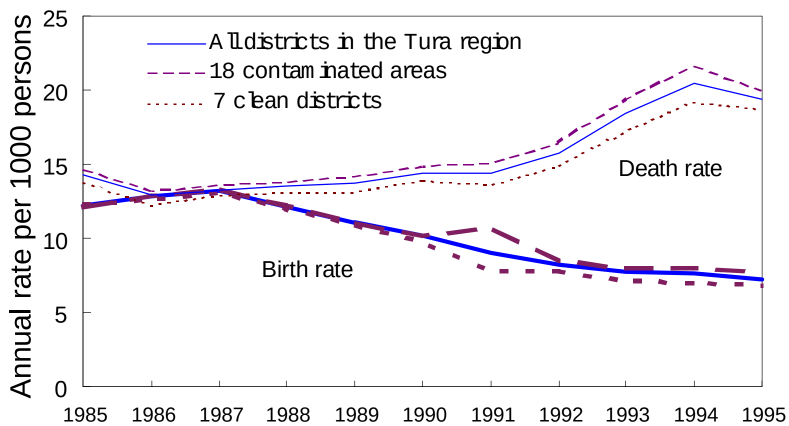

Fig. 1 Birth rate and death rate in the Tula region (1985-1995): all districts, 18 contaminated areas and 7 clean districts [5].

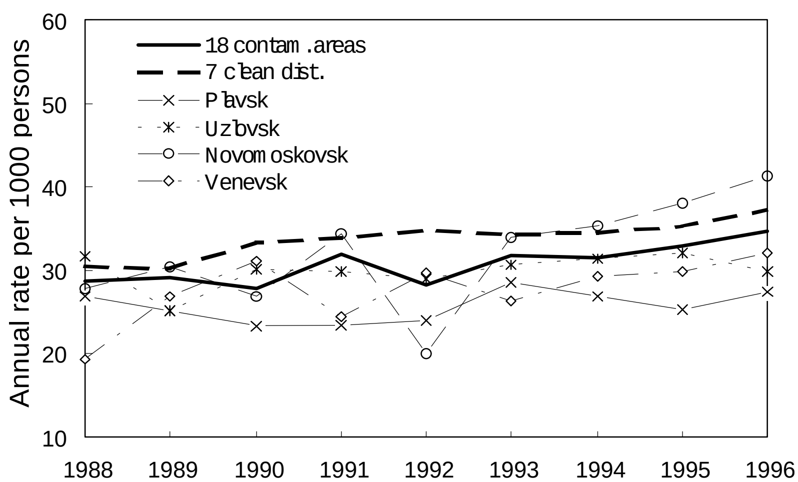

Fig. 2 Morbidity of neoplasm in adults in the Tula region (1988-1996): 18 contaminated areas, 7 clean districts and 4 districts (Plavsk, Uzlovsk, Novomoskovsk, Venevsk) [4].

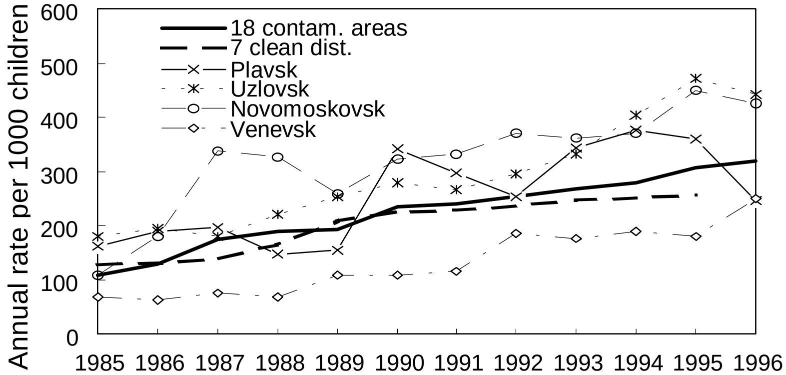

Fig. 3 Total morbidity of children in the Tula region (1985-1996): 18 contaminated areas, 7 clean districts and 4 districts (Plavsk, Uzlovsk, Novomoskovsk, Venevsk) [5].

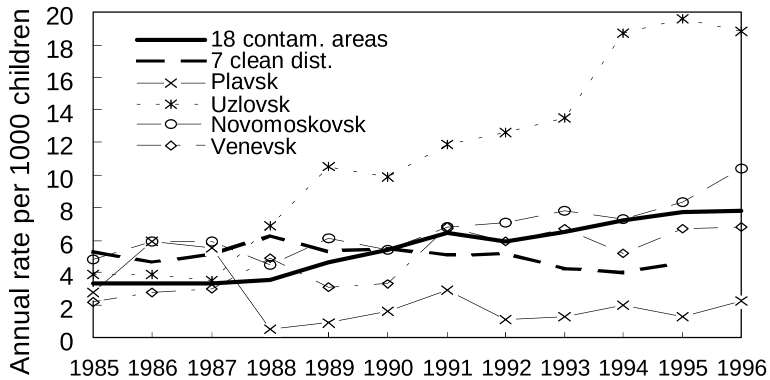

Fig. 4 Morbidity of anemia in children in the Tula region (1985-1996): 18 contaminated areas, 7 clean districts and 4 districts (Plavsk, Uzlovsk, Novomoskovsk, Venevsk) [5].

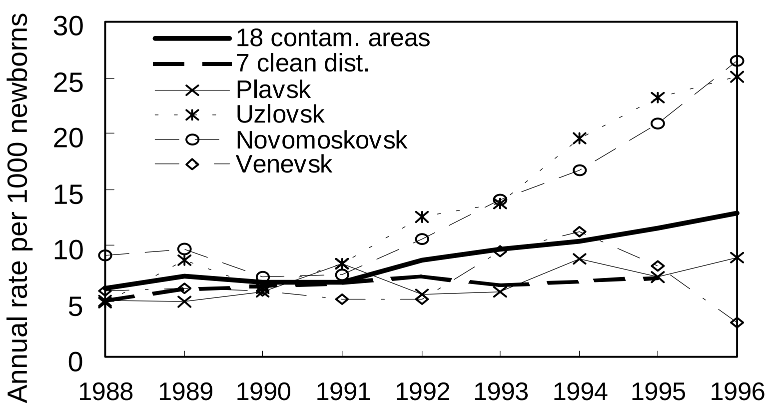

Fig. 5 Incidence rate on congenital anomaly of newborns in the Tula region (1988-1996): 18 contaminated areas, 7 clean districts and 4 districts (Plavsk, Uzlovsk, Novomoskovsk, Venevsk) [5].

Total morbidity in children

Total morbidity in children is shown in Fig. 3. There are also seen apparent trends of increase. The averages both in the 18 areas and the 7 districts show a similar trend of increase, while the values in 4 districts are at different levels. As a whole, the statistical data indicates that the number of ill children has doubled over 11 years. The Venevsk keeps the least level, and the Novomoskovsk and the Uzlovsk are at the highest level.

Anemia in children

Fig. 4 shows morbidity of anemia in children. The increase in the Uzlovsk after the Chernobyl accident is remarkable as compared with increases in other data. On the other hand, the level in the Plavsk decreased after the accident. The difference between the Uzlovsk and the Plavsk is about ten times in 1994-1996 although both districts are heavily contaminated.

Congenital anomaly in newborns

Incidence of congenital anomaly in newborns is shown in Fog. 5. Remarkable and stable increases are observed in the Uzlovsk and the Novomoskovsk after 1991. Until 1991, the average in the 18 contaminated areas was the same level as in the 7 clean districts, then the former showed a departure from the latter. It is also noted that values in the Plavsk and the Venevsk remain at the stable levels.

All data shown above about the health statistics in the Tula region are telling us that the health state of the people are worsening, including the health of children and newborns. It is difficult at present to prove the causes of these deteriorating trends because, as described before, there are a lot of factors that are influencing the health state of the people. Besides, the quality of the data for health statistics should be also reviewed; some statistics among ordinary diseases show unbelievable difference of morbidity between districts, sometimes reaching several tens of times.

Liquidators

A large number of specialists from the Tula region participated in the liquidation of the ChAPS accident, including groups of volunteers - miners who worked in drifting tunnel under the 4th reactor of the ChAPS.

The total of 2,240 persons are registered as liquidators in the Tula region. The data of external exposure dose established with 1,826 liquidators indicates the following distribution of external exposure (cGy): 732 men (0-5), 224 men (5-10), 170 men (15-20), 702 men (over 20) [1].

According to the data of the State Report “About the State of Health of Population of the Russian Federation”, morbidity among the liquidators is 2-3 times as high as that in ordinary population [2]. The most frequent diseases among this category of citizens are the following: diseases of blood circulation organs (38.4%), functional encephalopathy (37.7%), neurocirculatory dystonia with mental disorders (10.2%), neoplasm (2.5%).

Table 2 Death causes of liquidators in the Tula region (1986-1995) [5].

Cause of death	Cases	%
Injury and poisoning	54	43
Disease of respiratory organ	11	8.7
Malignant neoplasm	17	13
Disease of urine system	3	2.4
Disease of blood circulating system	35	28
Disease of nervous system	1	0.8
Disease of ingestion system	2	1.6
Disease of endocrine system	1	0.8
Others	3	2.4
Total	127	100

Long-term psychological stress caused rise both of psychological, somatic diseases and of physical disadaptation. This led to the formation of syndromes such as headache, giddiness, lowering of memory and quickness of wit, depression, obtrusive disorders, phobias, pain in muscles, bones, metallic smack in mouth, and absence of ability to work in the second half of day.

Structural changes in thyroid appeared after 4-6 years. They are manifested by latent hypothyroidism without changes in thyroid hormones. The autoimmune thyroidites are the earliest consequences of Chernobyl accident.

Out of 2,240 liquidators registered in the Tula region, 127 persons had died until the end of 1995, including 19 deaths 1995. Causes of their deaths are shown in Table 2. The percentage of suicides and accidents connected with abuse of alcohol is high and constitutes 50% of these deaths.

By the end of 1995, 1,176 liquidators (53 % of the total) were recognized as disabled persons. In Fig. 6 are

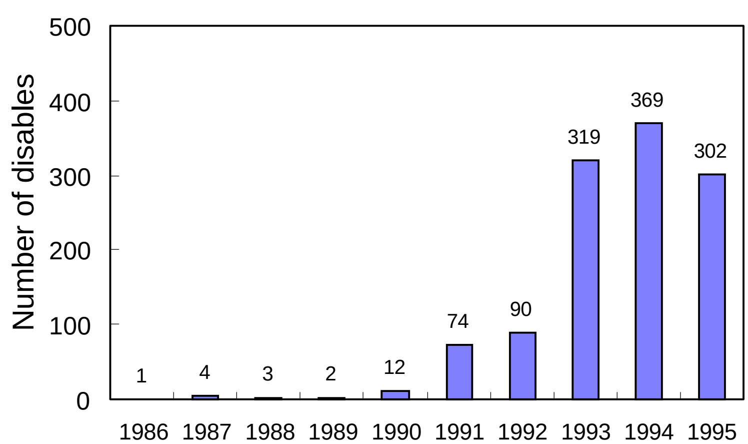

Fig. 6 The number of liquidators recognized as the disabled in the Tula region [5]

seen the dynamics of their registration. Drastic increase of the number of the disabled is observed since 1990. It can be said that all liquidators may soon fall into the category of the disabled.

Conclusion

Long-term programs are necessary in order to minimize the medical consequences and to increase the efficiency of medical assistance to those who have undergone radiation action as a result of the Chernobyl catastrophe. It is also necessary to evaluate objectively the state of health of the sufferers, to obtain scientifically grounded conclusions on effects of "low" radiation doses on human organism, and to estimate the genetic consequences for future generations. These programs must foresee the implementation of various activities, including:

1. Provision of further monitoring of persons attributed to the groups of risk, especially:
   - ✧ those whose thyroid was irradiated when they were children and adolescents;
   - ✧ children born by mothers whose thyroid was irradiated in their children-adolescent age;
   - ✧ children whose thyroid was irradiated in pre-natal period;
   - ✧ pregnant women;
   - ✧ liquidators of 1986-1987 and their children born after 1986.
2. Provision of medical-prophylactic institutions on the polluted territories (of district and regional levels) and clinics of research centers with modern medico-diagnostic equipment, as well as regular supply of necessary reagents and medicines to hospitals and clinics.
3. Development of system of rehabilitation medical activities and sanatorium bases for the Chernobyl sufferers, especially for children.
4. Supply of food products with radioprotective properties; fresh vegetables, fruits etc., especially for children in the polluted territories.
5. Scientific study of radiation action combined with action of other carcinogens including chemical pollutants.
6. Implementation of educational programs on problems of environmental and radioecological safety, and introduction of ecological knowledge and skills which promote self-adaptation of different age groups to stress factors.
7. **All above mentioned recommendations will not have positive results without improvements of social, ecological and economic situations in the country.**

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Present Status of Childhood Thyroid Carcinoma in Belarus following the Chernobyl Accident

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Introduction

In April, 1996, a joint international conference ("One Decade after Chernobyl") was held in Vienna, Austria in cooperation with the International Atomic Energy Agency (IAEA), the World Health Organization (WHO) and the European Commission (EC).

In this meeting, they came to the conclusion that the abnormality of health condition definitely related to the Chernobyl accident was only thyroid cancer in children for the moment. On the other hand, they reported that it would be too early to give comments scientifically on leukemia and other disorders.

It has been already known that the incidence of pediatric thyroid cancer in Belarus, Ukraine and the Russian Federation is rapidly increasing after 1990. About 800 children in these 3 CIS countries have been treated surgically until the end of 1995. More than half of them were found in Belarus. Furthermore, according to the final report of the Vienna international conference, several thousands of patients with thyroid cancer, who were less then 15 years old at the time of the Chernobyl disaster, may appear in the future although scientific proof is difficult. Considering seriousness of the prediction, appropriate measures should be taken as soon as possible in these highly contaminated countries.

In the present report, we provide the resent status of pediatric thyroid cancer in Belarus. In 1990 after the Chernobyl breakdown, the government of Belarus established the National Thyroid Cancer Center following a rapid increase of childhood thyroid carcinoma, as a special institute for not only clinical services but also basic researches. Dr. Demidchik E.P., a professor of the department of Oncology, Minsk Medical Institute was elected the director of the Center. Additionally, it has been also decided that surgery for all cases of the pediatric thyroid cancer in Belarus

Table 1. Number of thyroid cancer in Belarus before and after the Chernobyl Accident

Period	Adults (more than 15)	Children (under 15)
1975-1985	1,342	7
1986-1996	4,006	508

Table 2. Age distribution of children with thyroid cancer in 1986-1995 (age at the time of the accident)

Region	Total population*, thousands	Number of thyroid cancer children	Number of cancer by age		
			0 - 4	5 - 9	10 - 14
Brest region	1,520	97	68	27	2
Vitebsk region	1,300	7	4	3	0
Gomel region	1,670	225	149	72	4
Grodno region	1,160	24	12	11	1
Minsk region	1,410	20	14	5	1
Mogilev region	1,270	21	14	6	1
Minsk city	1,630	26	17	8	1
Belarus	9,960	420	278	132	10
%		100	66.2	31.4	2.4

* ~~Adult people~~ is included (data in 1986).

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should be performed here at the Center. The data described herein were composed of the operative results in those children with histopathological proof of thyroid cancer after surgical treatment at the Center.

Childhood thyroid carcinoma in Belarus after Chernobyl

The number of patients with thyroid cancer in both children and adults in Belarus is shown in Table 1. During the 11 years before the Chernobyl explosion (1975-1985), there were only 7 cases of pediatric thyroid cancer. However, in the same duration after the accident (1986-1996), the number of pediatric patients was 508 with remarkable increase, which was 72 times compared with the pre-accident period. Meanwhile, with respect to adult patients, the number of thyroid cancer in the former period was 1,342 and in the latter - 4,006. It increased in about 3 times compared with the pre-accident duration. In cases of adults, the increase of the incidence of thyroid cancer might be due to not only the recent improvement of diagnostic procedures, but also the frequent medical examinations after the accident. It is, therefore, necessary to continue more precise and detailed investigations in the future.

When all of the 508 children with thyroid cancer are classified with accord to their birth places (Regions in Belarus) as depicted in Fig. 1, there is found an apparent geographical feature proving that the majority of pediatric patients was born in the highly contaminated areas; 268 patients in Gomel Region (52.8%) and 122 in Brest Region (24.0%). Furthermore, dividing their birthday into 3 groups; i.e. pre-accident, at the time of the accident and post-accident, 497 cases belong under the pre-accident group (97.8%), 6 under the time of the accident (1.2%), and 5 under the post-accident group (1.0%). It has been clarified that most of the children are grouped into the pre-accident category.

The age distribution at the time of the Chernobyl breakdown in 420 children operated until 1995, demonstrated as follows: 0-4 years old was 66.4%, 5-9 years old - 31.4%, and 10-14 years old - 2.4%. More then half of the patients were classified into markedly young-aged population (Table 2 and Fig. 2). Four children born after the accident were excluded.

The annual frequency of the pediatric thyroid cancer in Belarus before the accident was 0.1 per 100,000 children, which is almost the same level as all over the world. However, after the accident, those levels were gradually elevating: i.e., 1.2 in 1990, 2.8 in 1992, 3.5 in 1994, 4.0 in 1995, and 3.8 in 1996. In the highly contaminated Gomel Region, the yearly incidence after the breakdown was as follows: 3.6 in 1990, 11.3 in 1991, 13.4 in 1995 and 12.0 in 1996, respectively. All of these values after 1991 were more than 100 times compared with that of the world. In Brest region, the incidence in 1996 was also high, 7.3. On the other hand, in Vitebsk Region, the less contaminated area, no pediatric thyroid cancer has been found since 1993.

These several clinicoscientific data shown here strongly suggest that childhood thyroid carcinoma rapidly increasing in Belarus has been attributed to radioactive contamination by the Chernobyl accident. In particular, radioactive iodine would be a main carcinogenic factor on the thyroid gland. Physiologically, the thyroid gland concentrates iodine for the synthesis of thyroid hormone. It is, therefore, generally accepted that radiation-induced thyroid

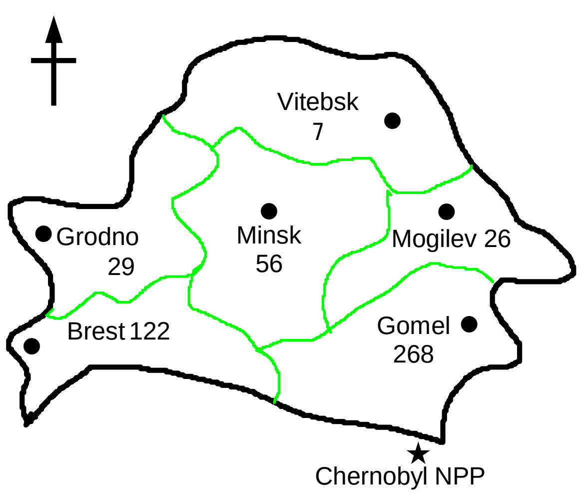

Fig. 1 Geographical distribution of child thyroid cancer in Belarus (1986-1996: 508 cases)

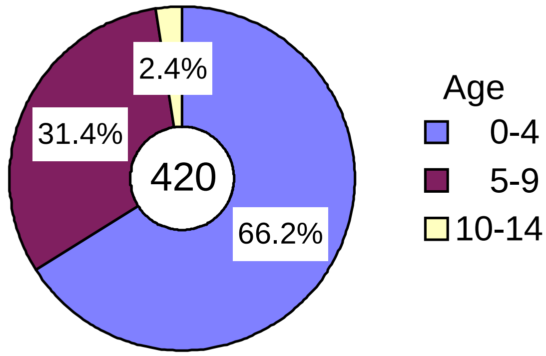

Fig. 2 Age structure of children with thyroid cancer (age at the time of the accident)

cancer after a radionuclide-releasing event would be initiated through this pathway. However, the exact and precise mechanisms of carcinogenesis have not been elucidated yet. Moreover, it is also extremely difficult to prove the initiation process of carcinoma directly. Further basic investigations should be extensively continued.

The recent change in childhood thyroid carcinoma has demonstrated a gradual decrease of the patient number showing 91 cases in 1995, 84 in 1996 and 27 till the end of May 1997. On the contrary, teenager patients with thyroid cancer older then 15 years old are apparently increasing since 1993; i.e., 4 cases in 1990, 1 in 1991 and 1992, 25 in 1993, 21 in 1994, 25 in 1995, and 26 till the end of October 1996, respectively. In this teenager group, the same geographic characteristic is also observed as the children previously described; that is, 70% of the operated patients have been sent to this Center from both Gomel and Brest Regions. These facts suggest that the incidence of thyroid malignancy in teenagers and young adults progressively is increasing instead of children.

Problems for the near future

At present, those patients with thyroid carcinoma who had undergone radical surgery at the time of their childhood are reaching adolescence or youth. They are carefully thinking over their own future life. Particularly, young women are seriously worrying about marriage, pregnancy and delivery. Moreover, they really fear hereditary effects on their new-born babies. Some of them, therefore, are considering to avoid marriage and/or delivery.

Judging from these sad matters, health consequences of the Chernobyl disaster have definitely just emerged. Hence it appears that socio-psychosomatic cares will become exceedingly crucial means in the near future for not only children in the growing-up stage, but also their parents. We should keep in mind that there is a need for educational programs of this aspects as a trial of humanitarian medical supports.

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Lens Opacities in Children of Belarus Affected by the Chernobyl Accident

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Introduction.

Eleven years following the Chernobyl accident, the increase in the incidence of thyroid disease, thyroid carcinoma in particular, has become evident and universally recognized. The mentioned pathology is given much prominence by physicians and scientists involved into the problems of oncology and thyroidology all over the world. Such great attention to thyroid problems has both positive and negative sides. In particular, in the majority of the research projects conducted both in Belarus and outside the Republic, priority is given to thyroid disease, though other medical aspects of the Chernobyl accident are studied insufficiently.

Reports about the increase in cataracts among the Ukrainian population living in the region of the Chernobyl Atomic Power Plant have been met with certain skepticism [14]. At the same time, American specialists do not exclude the possibility of radiation genesis of lensopathias revealed among the citizens of the Ukraine at the result of complex joint clinic-epidemiological study conducted by American and Ukranian specialists in 1991 [16].

It is well known that radiation cataract is one of the direct effects of ionizing radiation. Organ of sight, according to literature reports, is highly radiosensitive. The most radio-vulnerable part of an eye is lens in which cataract is developing in response to both external and internal exposure. In children, focal lens opacities are localized in embryonic nucleus, but in elderly people, alongside with embryonic nucleus, they are also localized in adult nucleus and cortical layers. Lens opacity is the result of biochemical changes occurring in it, and it is caused by lens fibers damage [10].

The data available in radiation medicine show that eye damage occurs, mainly, due to considerable doses of radiant energy. Single effect of 200 rad X-ray, induces the development of radiation cataract with long latent period [8]. Skin, mucous membranes and cornea respond to radiation earlier and at considerably lower doses. During the acute period, conjunctivitis, keratitis and eyelid dermatitis develop. In two years, teleangiectasia is observed.

Retina, as well as nervous elements of an eye, are more radio-resistant. The earliest radiation effect is manifested by changes in the retina electrical potential and in threshold phosphen values, as well as by changes in dark adaptation of visual irritation threshold [5, 11].

The process of the lens growth has a number of peculiarities: new lens fibers are being formed due to cell-division of single layer epithelium located on the interior surface of the lens bag covering the anterior lens surface. Each newly developing lens fiber is located under the lens bag both on the anterior and posterior lens surface. Taking into account that the lens is surrounded by the bag from all the sides, previously formed fibers cannot be torn away from the tissue component and remain in its structure for the whole of life. At the same time, constant formation of new fibers from the peripherally located epithelium layer leads to the following: older fibers are being gradually pushed aside from the lens bag to the central part of the lens. So, in the process of growth, the more consolidated part of the lens is being formed, i.e. the nucleus consisting partially from already atrophied lens fibers, as well as surrounding it younger peripheral cortical layers. Cell-division of lens epithelium and the formation of new lens fibers is occurring during almost the whole of life. Alongside with this, the increase in lens weight, the changes in its dimensions and chemical structure are observed with age. Average water content in the lens makes about 65% and is subject to considerable age fluctuations. Besides the lens, to such tissues also belong cartilage, cornea, teeth, the wall of a large blood vessel, etc. In mineral lens structure, univalent Na and K cations prevail considerably over the two-valent Ca and Mg cations; among anions, sulfates prevail over chlorides and phosphates [1].

N.A.Vishnevsky (ref.[7]) distinguishes five stages in the development of radiation cataract:

1. initial stage - accumulation of focal vacuoles and opacities between the lens capsule and the cortex in the center of the lens;
2. clusters of focal vacuoles and opacities between the lens capsule and the cortex begin to extend and acquire the form of irregular disk which resembles the tufa at biomicroscopy, the observed decrease in visual acuity being negligible in this case;
3. opacity acquires the form of a cup or a ring-shaped roll with darker optical edges. At biomicroscopy, tufa-like opacity has the form of meniscus. Visual acuity decreases;
4. at electroophtalmoscopy, in the center of the lens,

disk-like opacity is seen with a tender rim within the periphery. At biomicroscopy, focal vacuoles and opacities under the anterior capsule in the center of the lens, as well as anterior and posterior surfaces, are getting more consolidated; the slot in the middle is being filled with homogenic contents;

5. extensive, pelliculated opacities.

It has been ascertained that cataractogenic threshold is determined not only by individual radiation sensitivity and localization of radiation effect, but also by the quality of exposure, its dose in the exposed focus and the duration of the exposure [10].

Studies of the health status in individuals affected by the atomic bombing in Hiroshima and Nagasaki conducted by the research board of the Hannan Chuo Hospital, the city of Osaka, Japan, showed that eye disease was observed in 18% of the exposed population which is 5 times more frequent than among the non-exposed [17]. However, in this case, radiation influence differed considerably from that in Chernobyl.

In the late period after the accident, the main dose-forming nuclide is ^{137}Cs which penetrates into the body with food-stuffs (milk, vegetables, meat) and is distributed in the following way: 80% of incorporated radionuclide is being accumulated in the muscular tissue, 10% - in the osseous tissue, and the remaining part of it circulating freely in blood [2,3,4]. Cesium, as well as potassium, belongs to the group of alkaline elements with the diffuse type of distribution in the body and participates in intracellular metabolism [12]. With average beta-exposure energy of 170.8 keV, ^{137}Cs is able to influence electric and metabolic processes occurring in various tissues and organs.

Therefore, the aim of the investigation was to study the frequency and character of lens opacities in children permanently residing in the contaminated territories of the Republic of Belarus with anomalously high coefficients of transition of ^{137}Cs radionuclides through the food chain.

Material and methods.

Selection of regions

During 1992-1995, complex clinic-ophthalmological examination of 134 children aged 6-15 permanently residing in Stolin and Luninets districts of the Brest region, was conducted on the base of the Clinic of the Research Institute of Radiation Medicine and Endocrinology. The control group was represented by 92 children of the same age permanently residing in Braslav district of the Vitebsk region who were examined under the same conditions.

Selection of study regions was determined by the character of radiation situation and peculiarities of the exposure dose formation. Stolin and Luninets districts in the Brest region are located in the south of the Republic of Belarus in the zone of wood-lands and are characterized by insufficient levels of local radioactive contamination and by automorphic type of soils which have high coefficients of ^{137}Cs radionuclide transition into the food chain (Table 1). Actual dosimetric and radiation-hygiene characteristics of the examined children is given in Table 2.

All the examined children were permanently living at the controlled territories. Each child was interviewed about his/her dietary habits. The conducted interview showed that milk, potatoes and leafy vegetables were the most frequently consumpted food-stuffs. Practically all of these food-stuffs were from private households (private cows and personal plots) and were consumpted without any limitations. During the post-accidental period, the consumption of mushrooms and forest berries was observed among the examined individuals. As it is seen from the given data, the exposure dose formation was realized, mainly, through the internal component and was caused by incorporation of ^{137}Cs radionuclides. According to the data of individual monitoring of ^{137}Cs activity in the body (conducted with the help of Whole-Body-Counter), its constant level has been ascertained in the examined children during the post-accidental period.

General clinical examination

Table 1. Radiation characteristics of the examined settlements in 1992

Region	District	Settlement	^{137}Cs content in soil, kBq/m^2	Local exposure dose rate, μR/hour		
				min	average	max
Brest	Stolin	Olmany	363	19.5	27.3	37.8
	Luninets	Barsukovo	377	19.5	39.0	46.8
		Perinovo	137	3.9	15.6	27.3
Vitebsk	Braslav	Akhremovtsy	3.7	-	8	-

Table 2. Dosimetric and radiation-hygiene characteristics of the examined children

Group	^{137}Cs body burden, kBq	Index of ^{137}Cs activity, kBq/kg	^{137}Cs excretion level with urine, Bq/l	Annual effective radiation dose, mSv			Accumulated effective radiation dose, mSv		
				external	internal	total	external	internal	total
Main	24.4 (1.2-173.9)	0.56 (0.03-3.03)	239.9 (24-928)	0.49 (0.32-0.72)	1.65 (0.09-8.8)	2.2 (0.4-9.7)	3.4 (2.3-5.2)	12.0 (0.7-63.0)	15.4 (3.2-71.0)
Control	0.74 (0.004-1.07)	0.02 (0.00007-0.037)	4.4 (3.7-7.8)	0.009	0.05 (0.0002-0.1)	0.06 (0.009-0.11)	0.06	0.35 (0.002-0.8)	0.4 (0.06-0.9)

Note: the figures in brackets give minimal and maximal values

Examination of children was conducted at the Hospital of the Research Clinical Institute of Radiation Medicine and Endocrinology and included clinical examination of a pediatrician, collection and assessment of life anamnesis, anthropometry, hematological, hormonal and biochemical investigations, ultrasound study of the thyroid gland and abdominal organs, urine analysis on ^{137}Cs radionuclide content, measurement of ^{137}Cs radionuclide activity in the body using the Whole-Body-Counter.

Study of life anamnesis showed that in the examined children no factors were observed that could cause the development of lens pathology, i.e. roentgenological investigations of the cranium, exposure for medical aims, chemiotherapy, and diabetes mellitus.

Ophthalmological methods

Ophthalmological examination included the assessment of visual acuity of a patient, as well as biomicroscopy performed with the help of a slit lamp at maximal mydriasis. The revealed lensopathias were determined in accordance with the 3-d International Classification of lens opacities (lensopathias) [15]. The obtained results were introduced into the protocol of ophthalmological examination.

Statistical processing and data analysis

The data of clinical, laboratory, instrumental, ophthalmological and dosimetric studies were introduced into the computerized data base [9]. Statistical programs accompanying the data base allow to perform the retrieval arbitrarily with subsequent statistical processing:

- primary statistical processing of a variation series (N, arithmetical mean, root-mean-square deviation, mean error, confidence interval, mode, median, asymmetry and excess coefficients, character of variants′ distribution);
- determination of the significance of 2 series distinctions with the help of Student′s criterion;
- calculation of 2 series correlation coefficient (with the use of Fisher′s transformation for N<50);
- calculation of correlation matrix (10*10 parameters);
- calculation of coefficients and derivation of the equation of 2 series regression with representation of the correlation field on the chart;
- methods of non-parametric statistics (signs test, Spearman′s rank correlation, Mann-Witney′s test).

Results

At the result of the conducted ophthalmological examination, lens changes have been revealed which can be classified as opacities in the form of vacuoles, flakes, dots and spokes (strokes). Vacuoles, as well as flaky, focal and stroke-like opacities, were observed both in the nucleus and in cortical lens layers and, as a rule, were not accompanied by clinical changes, such as, first of all, the drop in visual acuity. Their number in a lens varied considerably and ranges from 1 to 20. While analyzing the obtained data, the following gradation for the number of total opacities in two lenses was used: 1-5, 6-10 and >10. Opacities also differed by their size which, due to measurement complications, were determined at the level of qualitative evaluation: small, medium and large.

Table 3 shows the distribution of children with lensopathias of the main control group.

From the given Table, it is seen that in the main group, the number of children with lensopathias accounted to 82.1% which is by 12.5% more than in the control. It should be mentioned that in the main group, the number of children with lensopathias of both lenses was by 24.4% more as compared with the control. At the same time, prevalence of one lens opacities didn’t differ significantly in children of the examined groups. The number of children with large opacities in the form of flakes and strokes accounted to 34 (25.4%) in the main group, while in the control, only one child had a

Table 3 Distribution of the examined children with lensopathias

Presence of lens opacities	Examined group			
	Main		Control	
	n	%	n	%
left lens	16	11.9	20	21.7
right lens	22	16.4	17	18.5
both lenses	72	53.7	27	29.3
Total	110	82.1	64	69.6

Table 4. Distribution of the examined children with regard to multiplicity of total opacities in both the lenses

Examined group	Number of total opacities in both the lenses					
	1-5		6-10		>10	
	n	%	n	%	n	%
Main	77	57.5	24	17.9	9	6.7
Control	56	60.9	7	7.6	1	1.1

Table 5. Distribution of the examined children with regard to lensopathias localization

Part (zone) of lens	Examined group			
	Control		Main	
	Right eye	Left eye	Right eye	Left eye
Anterior capsule	2 (2.1%)	1 (1%)	6 (4.5%)	5 (3.7%)
Zone of splitting	-	-	1 (0.7%)	-
Anterior cortical zone	2 (2.1%)	3 (3.3%)	24 (17.9%)	15 (11.2%)
Adult nucleus	3 (3.3%)	6 (6.6%)	12 (8.9%)	4 (3.0%)
Embryonic nucleus	19 (20.6%)	13 (14.1%)	25 (18.7%)	24 (17.9%)
Posterior cortical zone	21 (22.8%)	25 (27.2%)	47 (35.1%)	48 (35.8%)
Posterior capsule	10 (10.9%)	12 (13.0%)	23 (17.2%)	26 (19.4%)

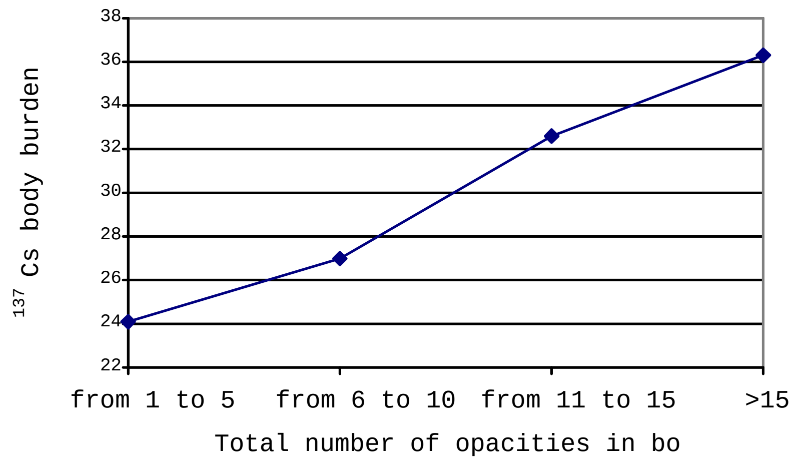

Fig.1. Relationship between the number of lens opacities and the level of ^{137}Cs radionuclide activity in the body of the examined children

large stroke-like opacity (1.1%).

Frequency of occurrence of multiple lensopathias in the examined children differs considerably (Table 4).

It has been ascertained that the number of children with the total number of opacities from 1 to 5 was identical in both the examined groups. With 6-10 opacities, the number of children in the main group was 2.4 times more than that in the control. More than 10 total opacities occurred 6 times more frequently also in children of the main group.

Location of opacities in different zones of lens is being assessed differently with regard to the indication of radiation effect. Posterior cortical zone opacities are considered to be more significant in this respect. In this connection, the data on opacity prevalence in all parts of the lens have been analyzed in the examined children (Table 5).

As it is seen from Table 5, opacities of the posterior cortical zone of lens occurred more frequently and were more pronounced in children of the main group. The second place was occupied by focal embryonic nucleus opacities. No significant distinctions between the opacity prevalence in different zones of localization of the right and left lenses were revealed. In the process of lens growth, fibers which are being formed in the anterior cortical zone, migrate to the posterior cortical zone. Therefore, analogic transfer of the damaged fibers and the increase in the number of actual opacities in the posterior cortical zone at the expense of the anterior one may possibly occur.

To determine the character of lensopathias development with age, individual dynamic ophthalmological examination of 21 children from the main group was conducted. The examination lasted three years, with one year interval. The increase in the number of opacities in 9 children (42.9%) and lack of dynamics in 12 children (57.1%) has been ascertained. So, lensopathia progression is observed, approximately, in half of the cases, which reflects the unfavorable dynamics of the given pathology in children with the enhanced risk of radiation effect.

The data about the relationship between the total number of lensopathias of both the lenses and the level of ^{137}Cs radionuclide activity in the body, are of particular interest (Fig.1).

As it is seen from the given Figure, with the growth of the level of ^{137}Cs radionuclide activity in the body, the total number of opacities in both the lenses increases. This may be the indication of a certain interrelation existing between the radionuclide incorporation and its influence on the organ of sight.

Primary cataract was diagnosed in 3 children

(2.2%) of the main group permanently residing in the village of Olmany, Stolin district, aged 11, 12 and 15 years, accordingly. The accumulated total effective exposure dose at the time of diagnosis made 15.3, 17.1 and 25.9 mSv, accordingly. The disease could be attributed to the 1-st stage of the irradiation cataract development (according to N.A.Vishnevsky) and was characterized by vast accumulation of focal vacuoles and opacities between the lens capsule and the cortex not only in the center of the lens, but also within its periphery. The reduction in visual acuity in the given children was negligible.

Discussion

Questions of the effect of small radiation doses on lens and the mechanism of this effect remain to be open for discussion. It is possible to assume the possibility of relatively high damaging effect of ionizing radiation with internal exposure. V.I.Gerasimov [6] studied quantitative value of possible non-stochastic effect in the form of lens damage in mice at chronic internal exposure from ^{137}Cs and ^{90}Sr. Statistically significant decrease in light-transmitting eye capacity in animals from experimental groups was observed, which may testify to the cataractogenic effect of studied internal exposure doses.

The above mentioned effect of small radiation doses may be connected with the occurrence of non-lethal damages in the genetic apparatus of lens fibers which leads to the accumulation of functionally defective cells with reduced vital capacity. It causes the damage of normal regeneration of tissue and increases the lens opacity.

Peculiarities of lens metabolism are characterized by bradytrophia which means that some tissues have a negligible number of capillaries or do not vascularize at all [13]. Bradytrophic tissues are characterized by the following features:

- progressing dehydration during the lifetime;
- consolidation of structure;
- formation of inclusions of organic and inorganic substances in gradually consolidated parts of tissue;
- concentration of tissue colloids due to progressing consolidation of tissue;
- loss of nitrogen contents as the result of dehydration of substances;
- lack of blood in dehydrating tissues of the body.

Numerous literature reports show the age-specific relationship of lens changes in animals affected by radiation. With the exposure dose of more than 3Gy [6], the latent period of cataract development is almost linearly dependent on age; and in younger experimental animals, this period is shorter. With the dose of X-ray exposure of 2-3 Gy, the lens changes occurred more frequently in old animals. Higher doses (3-9 Gy) caused the lens opacity in younger animals first, but later, the bigger changes were observed in older animals. Doses higher than 9 Gy, lead to lens opacities more frequently in younger animals. Sensitivity of mice lens to chronic radiation effect was more pronounced in the second half of the life as compared with the first half of the life with ^{137}Cs incorporation. Though, it is hardly possible to transfer these data on a human being. At the same time, taking into account that lens radiosensitivity of animals and human beings is similar to a certain extent, the data of these experiments arouse concern.

Local fixation of incorporated radionuclides in lens tissues for the whole of their life may appear to be the possible mechanism explaining their negative effect. This leads to gradual destruction of neighboring lens tissues which tends to increase with age. As the result, less pronounced focal opacities may be formed first, with subsequent development into larger - flaky and stroke-like opacities. Taking into account that the lens tissue lacks intensive metabolism, the possibility of fixed radionuclide elimination is not large.

As a rule, the level of dose loads in the examined children do not correspond to the universally recognized dose level at which irradiation cataract develops. According to the IAEA data, based on the results of the studies conducted in Hiroshima and Nagasaki, the dose of 200 mSv absorbed by lens is considered to be clinically significant exposure dose which induces the development of ophtalmological disorders in children. From the above mentioned data it follows that actual accumulated exposure doses in the examined children were, approximately, 12.5 times lower. Nevertheless, during the examination, considerable structural lens changes have been revealed in these children, such as an increase in the number of opacities and the degree of their diffusion.

In case of radionuclide incorporation, conditions of exposure dose formation are being changed considerably. These include physico-chemical properties of radionuclide, its organotropy, peculiarities of metabolism, character of its distribution in the body, etc. From the point of view of microdosimetry, protracted fixation of radionuclide in the tissue may lead to the formation of high local exposure dose which causes the development of structural and functional changes. It is not excluded that such mechanism of radiation effect is functioning in this case.

Conclusions

1. Frequency of occurrence of lensopathias in children from the main group made 82.1% which is by 12.5% more than in the control, mostly due to opacities in both lenses.
2. The number of children with large opacities markedly prevailed in the main group (25.4%) as compared with the control (1.1%).

3. The number of children with multiple opacities (more than 6) was larger in the main group and made 24.3% (8.7% - in the control).
4. Predominant localizations of lensopathias were: posterior cortical zone, posterior capsule and anterior cortical zone.
5. Positive relationship between the level of ^{137}Cs radionuclide activity in the body and the intensity of lens opacity has been revealed in the examined children.
6. Individual lensopathia dynamics in children of the main group was characterized by aggravation of the disease in 42.9% of cases; no changes were marked in 57.1%.
7. Primary cataract was revealed in 3 children of the main group (2.2%) and was characterized by a large number of opacities between the lens capsule and the cortex, both in the center of the lens and within its periphery, which explains the lack of pronounced sight decrease.

Study perspectives

Taking into account the importance of the obtained data, it is planned to continue the study in the following main directions:

1. conduction of prospective observation over the children with lensopathias and the elaboration of model of the development of lens pathology with age;
2. conduction of biodosimetric studies in the given group of children;
3. to study the role of chemical factors of the environment in the formation of lens pathology in children;
4. elaboration of measures of lensopathia prophylactics and correction in the given category of children.

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Genetic Consequences of the Chernobyl Accident for Belarus Republic

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Introduction Numerous studies have shown that a great number of residents in Belarus, Russia and the Ukraine were exposed to radiation due to radioactive nuclides ejected from the Chernobyl reactor, which increased genetic load, manifested in particular, as chromosome aberrations (Lazjuk G.I. et al., 1990; Pilinskaya M.A. et al., 1994; Sevankaev A.V. et al., 1995). The increase was registered for unstable and stable, chromatid and chromosome types of aberrations (Stepanova E.I., Vanyurikhina E.A. 1993, Vorobtsova I.E., Bogomazova A.N., 1995, Sevankaev A.V. et al., 1995). Proceeding from the findings that the number of dicentric and ring chromosomes (which are the main indicator of radiation mutagenesis at chromosome level) was increasing simultaneously with the increase of other aberrations which are common for chemical mutagenesis (Pilinskaya M.A. et al., 1994; Lazutka J.R., 1996) and from the fact that actual mutation incidences exceeded the calculated figures for the doses obtained (Pilinskaya M.A. et al., 1992, Sevankaev A.V. et al., 1995), one can not exclude the possibility that chromosome aberrations found in the population affected by the Chernobyl disaster are caused not only by ionizing radiation but also by various mutagenes, and the doses based on physical dosimetry could be underestimated.

It is quite obvious that the level of chromosome aberrations can be used as a biological indicator of harmful mutagenic effects on the organism. However, the method is not yet capable of (or only partially suited for) detecting the actual genetic risk even in the cases when aberrations are found in gametes, not in peripheral blood lymphocytes as usually done. The study of the dynamics of genetic losses, as spontaneous abortions and perinatal death due to inherited anomalies, and the study of the dynamics of malformed children births are probably the most reliable methods to determine genetic risk due to any mutagenic factor affecting the population, including ionizing radiation. This is related to the fact that there are a great sequence of events (gamete selection, preimplantation and embryonal death) occurring between gamete mutations (to say nothing about a somatic one) and births of children with congenital diseases. It is nearly impossible to count them and this leads to various uncertainties. Only direct methods, which count the final effect, with all their drawbacks, can provide accurate information on genetic losses. We have estimated possible genetic consequences for the residents of Belarus Republic due to the Chernobyl accident by studying malformations found in legal medical abortuses and by counting congenital anomalies in fetuses and newborns.

Dynamics of anomalies found in legal medial abortuses

The incidence of anomalies has been studied in embryos and fetuses obtained from pregnant women in Minsk-city (control) and in the areas under thorough radiological control (TCA). Contaminated areas in Gomel and Mogilev regions with ^{137}Cs of 15 Ci/km^2 (555 kBq/m^2) and more are placed into the category of thoroughly controlled areas. Five to 12 week abortuses were obtained through curettage and examined by pathoembryologists at Belarus Institute for Hereditary Diseases. The investigation was carried out using dissection under a stereo-microscope. If required, serial histological sections were additionally studied. In all cases the age of embryos or fetuses was determined using the system developed at the Carnegie Institute. Malformation frequency was determined not for the number of examined abortuses, but for the number of examined organs, since after the curettage not all organs were always suitable for the examination. Moreover, since some anomalies are observed by persistence of the structures characteristic of particular stages of embryonic development, when counting particular anomaly, only embryos whose age exceeded the age of corresponding physiological persistence were taken into consideration. All anomalies found at dissection and histological examination have been recorded. In total, 33,376 abortuses, including 2,701 abortuses obtained from TCA, have been studied for the period from 1986 (the second half) to 1996.

The results are partially presented in Table 1. As the table shows, malformation frequency for legal medical abortuses from TCA is considerably higher than that from Minsk-city, which has been observed for both periods of pre-Chernobyl 6 year and post-Chernobyl 11 year. It should be mentioned that the total frequency of 7.21 in TCA during 1986 to 1995 has been found lower than it was in 1992 (9.87) (Lazjuk G.I. et al., 1996).

Significant increase has not been found for

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Table 1 Frequency of Malformations Found in Induced Abortuses in Belarus

Malformations	Regions under study		
	Minsk		TCA
	1980-1985	1986-1996	1986-1995
The number of abortuses examined	10,168	20,507	2,701
Malformation frequency to the number of examined samples (%) *including:*	5.60	4.90	7.21*
CNS anomalies	0.32	0.53	0.54
polydactyly	0.63	0.53	0.79
reduction limb defects	0.07	0.10	0.28

- *significant difference ($P<0.05$)

anomalies most characteristic for radiation exposure; the central nervous system and anomalies with the greatest contribution of *de novo* mutations (polydactyly and reduction limb defects). However, tendency of their number increase is rather obvious, especially for reduction limb defects.

Dynamics of congenital malformations in newborns

The birth frequency of children with congenital malformations (CM) was studied based on the National Monitoring which has been functioning throughout the whole Republic since 1979. Congenital malformations unambiguously diagnosed in neonatal period are registered irrespective of the level of technical facilities of a medical institution. In each case of congenital malformation, the diagnosing physician fills in a special form registration, which is sent to the Minsk Genetic Center. The scientists of Institute for Hereditary Diseases verify the record completeness and diagnosis during regular trips to the areas, or during consultations with families at the Center. Anencephaly, severe spina bifida cystica, cleft lips and/or palate, polydactyly, reduction limb defects leading to disability, esophageal atresia, anorectal atresias, Down's syndrome and multiple malformations are registered both in stillborns and in fetuses obtained through induced abortion after prenatal diagnostics. The results are presented in Table 2 for the ^{137}Cs contaminated areas and for the control. Thirty regions, where ^{137}Cs contamination density was found to be less than 1.0 Ci/km^2, were taken as the control.

It is clearly seen that the total CM frequency increased both in the control and in the areas contaminated with ^{137}Cs. Moreover, as the level of contamination becomes higher, the greater increase of malformed children birth is seen. While the 50% increase is shown in the control, it is 83 % in the areas with contamination over 15 Ci/km^2. It is quite obvious that the increase of CM in the control can not be caused by ionizing radiation due to the Chernobyl accident. However, dependence on contamination with radioactive Cs can not be excluded for the 1% increase over the control (51-50) recorded in 54 regions and for 33% increase (83-50) in 17 regions.

Such increase can be explained by at least 4 factors.

a) Higher birth frequency of malformed children after the Chernobyl accident is considered to be not a true increase of anomalies in embryos, but only an artifact, the result of more complete registration, in other words, it is the result of closer interest in «disaster areas»,

b) teratogenic effects of embryo exposure to radioactivity from the Chernobyl Nuclear Station,

c) the result of gamete mutations in either parent due to additional exposure on gonads, or

d) the result of a complex of negative factors including the Chernobyl disaster (radiation plus chemical pollutants, poor nutrition, alcoholism).

Artifactual origin of increasing number of CM under the long-term National Monitoring, as it is in Belarus, is virtually excluded, firstly, by counting of only unambiguously diagnosed CM, secondly, by constant control of registration completeness by the researchers from Belarus Institute for Hereditary Diseases, thirdly, by practically equal frequencies before the Accident in various regions and, finally, by the correlation between the increase of CM frequency and the level of contamination.

Teratogenic effect is excluded, since the doses received by intrauterine fetus for a teratogenic terminational (or crucial) period were below threshold. No woman who gave birth to a malformed child, has received over 55 mSv for the period starting from the accident till the end of the 1st trimester. The 1st trimester includes the terminal period of neural tube defects, the most characteristic congenital malformation for radiation teratogenesis. No significant increase of nervous system CM has been found in newborns and abortuses recorded in the National Monitoring (Tables 1 and 2).

Table 2 Incidence of Obligatory Registered Malformations in Belarus for 1982 to 1995 (per 1000 neonates)

Malformation	Areas contaminated with Cs-137				Control (30 regions)	
	>15 Ci/km^2 17 regions		>1 Ci/km^2 54 regions			
	1982-1985	1987-1995	1982-1985	1987-1995	1982-1985	1987-1995
Anencephaly	0.28 11	0.44 26	0.24 48	0.64* 226	0.35 23	0.49 63
Spina bifida	0.58 23	0.89 53	0.67 132	0.95* 335	0.64 42	0.94* 120
Cleft lip and/or palate	0.63 25	0.94 56	0.70 137	0.92* 324	0.50 33	0.95* 121
Polydactyly	0.10 4	1.02* 61	0.30 60	0.66* 232	0.26 17	0.52* 66
Limb reduction defects	0.15 6	0.49* 29	0.18 36	0.35* 123	0.20 13	0.20 26
Esophageal atresia	0.08 3	0.08 5	0.12 23	0.15 53	0.11 7	0.14 18
Anorectal atresia	0.05 2	0.08 5	0.08 16	0.10 35	0.03 2	0.06 8
Down's syndrome	0.91 36	0.84 50	0.86 170	1.03 362	0.63 41	0.92* 117
Multiple malformations	1.04 41	2.30* 137	1.41 277	2.09* 733	1.18 77	1.61* 205
Total	3.87 151	7.07* 422	4.57 899	6.90* 2423	3.90 255	5.84* 744
Percent increase before and after Chernobyl	83		51		50	

*Significant difference (p - 0.05) between the values for 1982-1985 and for 1987-1995.

Thus, the most probable cause leading to the increase of birth of malformed children in Belarus is an increased level of mutations due to chronic additional exposure of the population or a complex of negative factors. This can be indirectly evidenced by;

a) an increased level of mutations in peripheral blood lymphocytes in the population of Belarus, the Ukraine and Russia, who has received additional exposure (Lazjuk G.I. et al., 1995; Pilinskaya M.A. et al., 1992; Vorobtsova E.A., Bogomazova A.N., 1995);

b) the most marked increase of CM frequency in general and CMs with great contribution of *de novo* mutations (polydactyly, reduction limb defects and multiple CM) in the area with ^{137}Cs contamination density of 15 Ci/km^2 and above. At the same time, an increase of malformed children due to trisomies (Down's syndrome is an example), which are *de novo* mutations, has not been found.

To determine a possible relation of increased CM frequency with additional radiation, dependency of CM frequency on additional radiation dose in Gomel and Mogilev regions (excepting large industrial cities) was investigated and compared with the control data in Vitebsk region, which is considered the most safe for radioactive contamination. The values of average cumulative dose were calculated at Institute of Radiation Medicine for individuals of 18 years of age and older in those regions. They represent the combined external and internal exposure since the Chernobyl accident.

Table 3 shows the result of the analysis. Average cumulative doses per each 1% increase of CM in the contaminated regions over the CM increase in the control region are calculated to be 0.31 mSv and 0.20 mSv, for Gomel region and Mogilev region, respectively. Based on these values we can estimate a doubling dose of genetic effects due to radiation exposure to be 0.02 - 0.03 Sv. Our estimate of doubling dose is considerably smaller than the value of 1 Sv adopted by ICRP and UNSCEAR. This suggests that genetic effects of radiation exposure is much higher than it has been usually considered, or the physical dosimetry used to obtain dose values of the population significantly underestimated the real doses.

Conclusions

Table 3 Comparison of CM frequencies with additional radiation doses obtained by rural population of Belarus at the age of 18 years and older

Region under observation	Frequency of CM per 1000 births		Average cumulative dose by Chernobyl (mSv)	Cumulative dose per % Increase of CM (mSv/%)
	1982-85	1987-95	1986-94	
Gomel region	4.06±0.39	7.45±0.24	13.40	0.31
	Increase: 83 %			
Mogilev region	3.50± 0.53	6.41±0.30	8.82	0.20
	Increase: 83 %			
Vitebsk region	3.60±0.63	5.04±0.27	0.24	-
	Increase: 40 %			

Long-term studies have shown the evidence of increased frequency of anomalies in embryos of the residents in Belarus. They are manifested as increased malformation frequencies found in medical abortuses and increased frequencies of CM revealed in newborns. The causes for such increases have not been determined clearly. However, the correlation of anomaly increase found in embryos with the level of contamination density of the areas, and the correlation of CM frequency with group average doses, as well as the increase of CMs with great contribution of dominant *de novo* mutations, evidence a radiation factor playing a certain role in the dynamics of CM.

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Monitoring of Cytogenetic Damages in Peripheral Lymphocytes of Children Living in Radiocontaminated Areas of Belarus

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The complicated radiation situation in Belarus conditioned by the large scale and irregularity of radioactive precipitation as a result of the Chernobyl APS catastrophe, resulted in a number of different sources of irradiation to children.

In the first period after the catastrophe, short-lived isotopes, mainly I-131, made the principal contribution to the formation of irradiation to children. Dose values for thyroid in children turned out 3-10 times as high as in adults /1-2/. The situation having arisen after the Chernobyl disaster is characterized by different duration of contact with radiation and by diversity of pollution comprising irradiation from external and incorporated radionuclides. An intensive radionuclide mixture discharge continued till 10th of May. Their large quantity was released into the environment from the destroyed reactor for 2 weeks more.

Regretfully, information on genetic important dose in children population based on the data of physical dosimetry is practically absent. Counts of chromosome aberrations in peripheral blood lymphocytes (PBL) of the people who live in particular radioecological conditions are at present the most objective biological indicator of radiation effects. Chromosome injuries are the earliest and the most significant among intracellular reactions to ionizing radiation; they can be calculated precisely. Therefore, the WHO, IAEA and UNSCEAR documents /3-5/ recommend to use cytogenetic methods in order to estimate the value of dose absorbed by organism.

The necessity of using methods of biological dosimetry and, in particular, traditional cytogenetic analysis of unstable chromosome aberrations - such as dicentrics and ring chromosomes - was confirmed repeatedly in the studies of the consequences of people's overexposure in different nuclear catastrophes /6/. However, it is considered that the use of unstable type aberrations in biological dosimetry is not possible in remote times after overexposure /7/. It is connected with the fact that the frequency of cells having dicentric and ring chromosomes is decreases with the course of time after irradiation.

The cytogenetic monitoring of Belarussian children was started by the Human Radiation Cytogenetics Group of the Institute of Genetics and Cytology of the Academy of Sciences of Belarus in June 1986. Groups of children for cytogenetic examination were formed on the basis of administrative division of the territory (Table 1).

The aims of the present work is to analyse the data of 1986 as a practical case of cytogenetic method in the assessment of absorbed dose in children from Gomel region affected by the Chernobyl APS catastrophe, and to compare the data of cytogenetic examination of 1986 with the results obtained in the following years.

In this connection, we examined children evacuated from 10 villages within the 30-km zone of Bragin district, Gomel region, exposed to short-time (2 weeks) radiation, mainly due to fallout of short-lived radionuclides, and children residing in settlements in Bragin and Khoiniki district, Gomel region. The data of radiation monitoring of the radiocontaminated areas are given as of July 1, 1989 (7).

The results of cytogenetic examination of children in Minsk, and Braslav of Vitebsk region, were used as a control. Selection of the children was random. Significance of the differences was calculated by t-Students test.

Conventional methods (9-10) were used for preparing cytogenetic specimens. Blood samples were taken and transferred to the laboratory for cultivating within the same day. Fetal calf serum (10%, Minsk), phytohemagglutinin Difco P, 100 IU penicillin/ml in 0.5 ml of blood were added to the culture medium, consisting of Eagle's minimal essential medium (Moscow). For each individual 2-3 cultures were set up. 200- 300 cells per child were examined for asymmetrical chromosomal aberrations (dicentrics, centric rings, and excess acentric fragments) and chromatid aberrations (breaks, exchanges).

In Table 2 are presented group-average data on chromosome aberration yield for 60 children from 10 villages in the 30-km zone of Bragin district. The children were evacuated on May 7-8, 1986 to a "clean" zone in Minsk region (two weeks after the

Table 1. Districts from which the study cohorts were sampled and their contamination levels

Village	Radionuclide contamination (Ci/km^2)		
	Cs-137	Sr-90	Pu-239
30-km zone of Bragin district, Gomel region			
v. Nudichi	18.38	3.02	0.0503
v. Ilichi	22.03	3.44	0.0140
v. Glukhovichi	13.26	1.81	0.0201
v. Refalov	20.48	3.35	?
v. Kozeluzhtsy	20.43	3.60	0.0106
v. Jasmentsy	9.00	3.69	?
v. Krug-Rutka		3.80	?
v. Gorodistche	6.00	0.97	0.0030
v. St. Urkovichi		1.40	
v. Krivichi	3.45	0.98	0.0188
Bragin district			
t. Bragin	19.23	1.79	0.0418
v. Burki	11.0	0.7	?
v. Mikulichi	17.0	0.95	?
Khoinik district			
t. Khoinik	6.0	0.93	?
v. Novoselki	19.1	1.97	?
v. Rudnoe	14.0	3.0	?
v. Rudakovo	10.0	1.83	?
Narovlya district			
t.Naovlya	17.0	0.9	?
Control zone			
c. Minsk	0.04	0.02	0.0016
t. Braslav	0.04	0.02	0.0016

Table 2. Cytogenetic damages in peripheral blood lymphocyte of children evacuated from the 30-km zone of Bragin district and residing in Bragin town examined in 1986.

Settlement	No. of children examined	No. of cells scored	No. of Cells with aberr. (mean per 100 cells±SE)	No. of dic/ring per cell
30-km zone (10 villages)	60	18000	6.8±0.2	0.0095
t. Bragin	15	3900	7.7±0.4	0.0053
Control	18	3000	1.4±0.2	0.0006

Chernobyl nuclear accident). Cytogenetic examinations were conducted in August, 1986.

A statistically significant increase of the level of aberrant metaphases, aberrations per 100 cells, including markers of radiation effect, namely, dicentrics and centric rings, was revealed for all the groups examined. Thus, the level of chromosome-type exchanges in the spectrum of chromosome aberrations in children's lymphocytes varied from 0.0065 per cell to 0.0133 in different villages. The population average number of dicentrics/rings per cell in the children from the evacuation zone was 0.0095, being 0.0006 in the control.

Because of poor organization of radiation monitoring in the first months after the Chernobyl accident, the data of biological dosimetry have become more and more important. Biodosimetry

Table 3. Whole-body dose of liquidators and of a group of children evacuated from the 30-km zone of Bragin district

Liquidators (1)		Children from 30-km zone (our own data)	
Whole-body dose (rem)	% of examined	Whole-body dose (rem)	% of examined
5-10	30	1-20	10
10-25	47	20-30	26
		30-40	32
25-50	7.3	40-50	32

Table 4. Distribution of children by Iodine-131 content in thyroid and liver according to the γ-radiation exposure dose rate measured on 7-8 May 1986

γ-radiation exposure rate (μR/h)	% of examined with exposure rate	
	in area of neck	in area of liver
10-49	-	16.1
50-99	27.5	45.2
100-200	45	35.5
200-350	27.5	-
700	-	1.6

Table 5. Radionuclides in organisms of children from Gomel region

Radionuclides	Concentration of minimum/maximum value, Ci/l	
	Blood	Urine
Cesium-134	$0.127x10^{-9}$ - $1.17x10^{-9}$	$0.199x10^{-9}$ - $9.751x10^{-9}$
Cesium-137	0.13 $x10^{-9}$ - $6.86x10^{-9}$	0.57 $x10^{-9}$ - 2.5 $x10^{-9}$
Potassium-40	$2.073x10^{-9}$ - $6.70x10^{-8}$	$1.586x10^{-8}$ - 6.7 $x10^{-8}$
Zirconium-95	0.97 $x10^{-9}$ - $1.46x10^{-9}$	$0.973x10^{-9}$ - 0.34 $x10^{-9}$
Antimony-125	2.45 $x10^{-9}$ - $0.21x10^{-9}$	-
Silver-110	6.7 $x10^{-10}$- $5.6x10^{-11}$	-
Ruthenium-106	-	$0.648x10^{-9}$ - $2.162x10^{-9}$
Cerium-144	-	$0.648x10^{-8}$ - 2.23 $x10^{-9}$
Zinc-65	-	$1.189x10^{-9}$ - 1.1 $x10^{-10}$

carried out on the basis of our findings by using different standard curves (4,12-13) to evaluate absorbed dose has shown that the recorded level of chromosome aberrations in children evacuated from the 30-km zone of Bragin District and residing in Bragin town corresponds to the dose of 200-500 mSv.

According to the data of the Institute of Radiological Medicine (Belarus) based on the methods of physical dosimetry, radiation doses received by residents of those districts for 1986 to 1988 did not exceed 155 mSv. The reasons of the discrepancies in the estimated doses require further thorough investigation .

According to the estimations of EC/IAEA/WHO /1, 11/ the highest doses were obtained by the liquidators of the consequences of the Chernobyl APS catastrophe. The dose of whole-body irradiation spreads as follows (Table 3): 30% of studied people obtained 5-10 rem; the majority of liquidators - namely, 47% - obtained 10-25 rem, and only 7.3% - 25-50 rem /1/. Our data of biological dosimetry of children from the 30-km zone show the shift of dose distribution to the side of higher dose. Consequently, the resettled children and the children living in Bragin district and born before the catastrophe represent the same groups of high genetic risk as the liquidators do.

Based on the data of measurement of radioactive Iodine-131 content (7-8 May 1986) with portable γ-irradiation dosemeters, only 27% of examined people had the indices of exposure dose rate from 50 to 100 μR/h, the rest - from 100 and higher (Table 4).

The comparison of distribution of children by the whole-body irradiation dose (on the basis of cytogenetic examination) with internal dose for thyroid and liver by intake of radioactive iodine isotopes into the organism for the same period, showed the qualitative correspondence of both distributions, i. e. with the shift to the side of higher doses.

In order to confirm the presence of radionuclides in children organisms, the direct analysis was carried out of γ-radiating radionuclides in their biological media. The radionuclides in blood and urine of 37 children from the age of 4 to 15 from controlled areas were studied at the Institute of Nuclear Energy of the Academy of Sciences of Belarus by means of γ-spectrometer “ADKAM-300” of “ORTEC” firm (USA). It was established that the next radionuclides

Table 6. Sample of the cohorts and observed yields of unstable chromosomal aberrations in 1986

Settlement	Average age (y)	No. of children examined	No. of cells scored	No. of Cells with aberr. (mean per 100 cells±SE)	No. of dic/ring per cell
Gomel region					
Bragin district					
v. Burki	7-14	6	1500	5.7±0.6	0.0055
v. Mikulichi	7-14	17	4250	6.8±0.4	0.0063
Narovlya district					
t. Narovlya	12	7	1750	4.9±0.5	0.0041
Minsk					
Control 1985		18	3000	1.4±0.2	0.0006
Control 1986		17	4250	1.5±0.2	0.0006

Table 7. Sample of the cohorts and observed yields of unstable chromosomal aberrations in 1987

Settlement	Average age (y)	No. of children examined	No. of cells scored	No. of Cells with aberr. (mean per 100 cells±SE)	No. of dic/ring per cell
Gomel region					
Khoiniki district					
t. Khoiniki	1-6	5	652	3.7±0.7	0.0092
v. Novoselki	1-6	6	700	7.6±1.0	0.0143
v. Rudnoe	1-6	10	2050	9.8±0.6	0.0098
Narovlya district					
t. Narovlya		5	1250	6.4±0.7	0.0064
Control		17	4250	1.5±0.19	0.0006

were present in blood: Cesium-134, Cesium-137, Potassium-40, Zirconium-95, Antimony-125, Silver-110. In the urine, the next radionuclides were found besides above-mentioned: Carbon-14 (June 1986), Ruthenium-106, Cerium-144, Zinc-65, Zirconium-95 (1986-1987-1988). There were found in the excrement: Cesium-134, Cesium-137, Potassium-40 (Table 5).

Table 6 shows the principal results of cytogenetic examination of children residing in Burki and Mikulichi villages of Bragin district and Narovlya town of Narovlya district of Gomel region. In all groups, the number of cells with unstable aberrations - dicentrics and centric rings - differed significantly from the control one. The dose values calculated on the basis of cytogenetic analysis of unstable aberrations are proximate to the doses obtained by the children of Bragin town shown in Table 2.

Thus acute and prolonged irradiation obtained by the children in Bragin district and Bragin town were considerable in the first period (first weeks and months after the accident) and, obviously, conditioned not only by short-lived isotopes (molybdenum, technetium, lanthanum, barium), inert gases (xenon, krypton) and I-131, but also by long-lived isotopes of cesium, strontium and plutonium /1/. They are comparable (and even higher) with the dose obtained by the liquidators. Regretfully, these dose commitments were not taken into account before, and still are not considered in recent assessment of obtained doses values.

In the second stage (1987-1991), prolonged external and internal irradiation for account of long-lived radionuclides of cesium, strontium, plutonium and others is the particularity of dose formation of the children living permanently on radiocontaminated territories, in addition to the early formed dose during the 1st stage including the thyroid irradiation. It should be noted that in most cases the same children were not examined in the samples.

The cytogenetic effect specific for radiation action was also revealed in children in Bragin town examined in 1988. A similar picture was observed in a group of children in Bragin, examined in 1991 by using the micronuclei method under cytokinetic block (10). The results confirmed the fact that an increased level of chromosome aberrations remained in lymphocytes of the children. The number of detected binuclear cells with micronuclei was 5.3 times higher than the number in the control. Such situation was arisen, obviously, as a result of relatively balanced state between formation of mutation and disappearance both on the level of blood-producing cells and on that of peripheral blood.

However, the more complicated picture of mutation process was discovered in lymphocytes of younger children (age from 1 to 6). In the spring of 1987 clinical and cytogenetic examination was carried out of 21 children, aged 1-6 years, residing permanently in the settlement of Khoiniki and in the villages of Novoselki and Rudnoe, Khoiniki district, Gomel region. The data obtained indicated an increased level of chromosome aberrations in cultures of peripheral blood lymphocytes of these children's groups: 3.7±0.7; 7.6±1.0; 9.8±0.5 % of aberrant metaphases, respectively, as compared to 1.5-0.5% in the control (Table 7). In all examined groups chromosomal aberrations of exchange type were found - dicentrics and centric rings - the frequency of which was over one degree as high as that of control group. The highest frequency of dicentrics and rings as well as of cells containing such type of aberrations was revealed in the children of Novoselki and Rudnoe villages.

In spring of 1987 and 1988 cytogenetic examination of the same children of Bragin and Khoiniki districts was conducted in dynamics. The first examination was carried out 12 months after the Chernobyl nuclear accident. An interval between the first and the second examinations was also 12 months. The increase of chromosome type aberrations from 5.2±0.5% in 1987 to 8.7±0.6% in 1987 ($p<0.001$) was observed. A significant increase in the cell number with 2-4 aberrations (from 16.4±3.3% in 1987 to 27.0±3.4% in 1988, $p<0.01$) was observed in the same children. Cells with 2 and more aberrations were not found in the control.

It was shown experimentally that the external irradiation dose of population in radiocontaminated areas of Belarus had stabilized by 1989-1990; meantime, strontium radionuclides content in organisms of the people had increased 2.5-5 times as compared with pre-accident period /1/. Probably, the increase of the level of chromosomal aberrations with the course of time and appearance of multiple injuries in cells of small children are connected with this situation.

Some "rogue" cells, which were named by Awa and Neel (15) , were found by the present authors in lymphocytes of the children in Khoiniki and Bragin districts almost a year after the Chernobyl accident. Single "rogue" cells were detected by other researchers in various groups of children living in the radiocontaminated areas of Belarus (16). However, those authors do not ascribe emergence of "rogue" cells to radiation exposure, though we consider the question doubtful.

More frequent occurrence of cells with 3 or 4 aberrations with increase of the time of children staying in the radiocontaminated areas of Khoiniki and Bragin districts seems to be associated with the time change of the dose structure due to increase of internal contribution to the total radiation dose.

According to available data, Cs-137 and Cs-134 contents in the examined children's organisms in Khoiniki and Bragin districts, Gomel region, in 1987-1988 varied between 0.18 and 9.14 μCi (the data were obtained by a whole body counter). However, no correlation was revealed between the total γ-activity of the organism and the yield of chromosome aberrations. In this connection, the decrease of dose rate from external (1, 17-18) and incorporated (1,18) γ-sources on one side, and the increase of accumulation of α- (1, 19) and β-sources (1,20), on the other side, deserve attention.

The present results have shown that the level of cytogenetic damages in human cells was higher in all radiocontaminated regions than in the control. Thus, In the 2nd period the high tempo of mutation process is characteristic in peripheral blood lymphocytes of all (100%) examined groups of children in Gomel region, as well as the appearance of multiple aberrations in cells of considerable part of children. The task of following surveys is the detailed characterization of peculiarities in the 2nd and the 3rd periods of mutation process dynamics in populations of somatic cells of children in Belarus.

Conclusion

The presented data of cytogenetic investigation of different groups of children affected by ionizing radiation as a result of the Chernobyl APS catastrophe allow to make the following conclusions:

- The use of cytogenetic method in the investigation of children born before the Chernobyl accident made possible to reveal significant increase of unstable chromosomal aberrations as compared with control groups.
- The absorbed dose of 200-500 mGy was evaluated for the children from the 30-km zone of Bragin district and Bragin town with the use of materials of cytogenetic investigation conducted in 1986.
- It is shown that the level of unstable type aberration in young children is rather increasing with the course of time than decreasing. The appearance of multiaberrant cells in children several years after the Chernobyl APS catastrophe, probably, testifies the effect of dense ionizing radiation of plutonium and its fission products on children.

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Study of Genetic Effects in Somatic Cells of Children Living on the Contaminated Territories in Belarus

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Due to the Chernobyl APS accident in April 1986, a series of serious radiological consequences were brought in Belarus: the pollution of her territory with radionuclides with gamma-, beta- and alpha-radiation, and “hot” particles found in human organisms [1]; the high irradiation doses obtained by children in first period after the catastrophe; the chronic influence of complex of radionuclides with various biological effects on the organisms for many years. Constant external and internal exposure and their combined action on organisms and their cells, including the blood formation system, required the development of new approaches to evaluate mutation process in lymphocytes of peripheral blood of children [2].

The application of the conventional cytogenetic method analysing chromosomal aberrations in metaphase was necessary in the first stage of examination of children population in 1986-1990 because it enabled to apply the biological dosimetry to the estimation of radiation doses of individuals and groups. In the course of time after the catastrophe, the information obtained by this method has decreased. Besides, by this method of metaphase analysis, it is difficult to study simultaneously both the chromosomal aberrations induced in a series of cellular generations of lymphocytes and the hereditary cellular-lethal effect, comparing the level of chromosomal aberrations with that of gene mutations based on comparatively small volumes of children blood. We proposed and proved a new scheme applying micronucleus technique to cytogenetic examination. This method permits to take into account all the above mentioned deficiencies of the conventional method [2].

We organised genetic monitoring of Belarus children in the following two ways:

1. The monitoring (individual and group) was carried out with the children in the same settlement (for example, Bragin), which made possible to observe the dynamics of mutation process in peripheral blood cells.
2. The genetic examination (individual and/or group) was carried out with the children in several settlements with different radioecological situation in the same period of time (as it was in Komarin and Malejki settlements of the Bragin district), which made possible to fulfil comparative analysis of mutation frequency.

1. Dynamics of *in vivo* mutation in lymphocytes of peripheral blood of the children in Bragin town (1988-1994)

At the first stage of cytogenetic examination, blood smears were taken from the children in the radiocontaminated zones in order to study non-proliferating lymphocytes in peripheral blood. Presently, this method of blood analysis is one of the most popular laboratory tests used at the screening stage without the process of cell cultivation. The structural changes of lymphocyte populations obtained by this method is considered a high-sensitive index of irradiation at low doses [3,4].

It is known that cell division is necessary for micronuclei to be formed. Consequently, we can consider that the frequency of micronuclei registered in circulating blood lymphocytes is governed by the damages of blood-forming cells *in vivo*, possibly, as a result of genetic injuries on the level of stem cells and/or preceding cells of hemopoiesis which develop to recognizable cells of peripheral blood.

We have been investigating structural changes in lymphocyte populations such as the level of mono- and polynuclear cells with micronucleus, number of micronuclei in them, as well as of disturbances in blood cell morphology in all three groups of lymphocytes; small, wide-cytoplasmic lymphocytes and lymphocytes with plasmatization of cytoplasm, which represent the polymorphism of these cells in children [6,7].

In this connection, since 1988, the cytogenetic monitoring of children in Bragin town has been organized based on two age groups: the first group (1-7 years old) and the second (7-15 years old). It is necessary to note that there were different characteristics of the same age groups examined in different years. The young group, examined in 1988, consisted of equal number of children born before and after the Chernobyl catastrophe, whereas the old group (7-15) wholly was born before the catastrophe. The children of 1-7, examined in 1990, constituted a mixed group, and the children of 7-15 were born before the catastrophe. The groups, examined in 1994, were uniform: the children in the young group were born after the catastrophe, and those in old group - before the catastrophe.

Thus, comparison of the results of cytogenetic examination of children "by horizontal" within one year and "by vertical" in dynamics (1988-1994) allows to answer the question concerning the differential sensitivity of hereditary material of children lymphocytes in dependence of age, period of birth before or after the accident, period of living on radiocontaminated territory, and others.

1.1. Study of the spontaneous level of *in vivo* mutation in lymphocyte population of peripheral blood of the children in the control group

The quantitative and qualitative assessment of cytogenetic effects of ionizing radiation is impossible without the knowledge of spontaneous level of *in vivo* mutation observed in lymphocyte populations of peripheral blood of the Belarus children. The spontaneous level of mutation not only determines the reliability of increase of induced structural mutations in lymphocytes of the children in Bragin town and other areas, but also create the basis to carry out the population studies with the given method.

The first information about the spontaneous frequency of micronuclei in erythrocytes in peripheral blood of healthy people as compared with their level in ill patients was obtained by hematologists. The principal attention in those studies was paid to the qualitative but not quantitative characteristics [5]. Just in 1976, Countryman and Heddel introduced lymphocytes as the next cellular indicator of micronuclei in man [8].

After the Chernobyl catastrophe, papers appeared which indicated the increased micronuclei level in lymphocytes of peripheral blood of the affected people [9]. However, uncertainty of information about the spontaneous level of *in vivo* mutation in lymphocytes of human peripheral blood restrains the advance of population-genetic investigations.

Therefore, it is quite natural to do special studies and analysis to know the spontaneous level of micronuclei in lymphocytes of children peripheral blood. So, we carried out cytogenetic studies of spontaneous level of structural and quantitative chromosomal injuries in lymphocytes of the children of two principal age groups, living permanently in Minsk. In 1988-1990-1994, we examined 139 children of age from 1 to 15 years. The summary data is shown in Table 1.

The analysis of cytogenetic structure of lymphocytes of the children in Minsk has shown that polynuclear lymphocytes represent only a small fraction of the whole lymphocyte population. In this connection, mononuclear lymphocytes have been chosen as the principal object of study. A complicated

Table 1. Dynamics of *in vivo* mutation mononuclear lymphocytes of peripheral blood of the children in Minsk city.

Year	Age group of children* /number of examined	Number of analysed lymphocytes	Number of cells with micronuclei		Number of micronuclei in cells		Distribution of cells by the number of micronuclei				
			Absolute number (AN)	x ± Sx (%)	AN.	x ± Sx (%)	1	2	3	4	5
1988	1 (n=20)	8705	61	0.7±0.1	61	0.7±0.1	61	-	-	-	
	2 (n=18)	3226	28	0.9±0.2	28	0.9±0.2	28	-	-	-	-
1990	1 (n=15)	3974	21	0.5±0.1	21	0.5±0.1	21	-	-	-	-
	2 (n=20)	1863	25	1.3±0.3	25	1.3±0.3	25	-	-	-	-
1994	1 (n=15)	1339	21	1.6±0.3	21	1.6±0.3	21	-	-	-	-
	2 (n=18)	769	15	1.9±0.5	15	1.9±0.5	15	-	-	-	-

*:1 - the young age group of 1-7 years, 2 - the old age group of 7-15 years.

Table 2. Dynamics of *in vivo* mutation in binuclear lymphocytes of peripheral blood of the children in Minsk city.

Age group*	Number of analysed lymphocytes	Number of binuclear cells		Number of cells with micronuclei		Number of micronuclei in cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	AN	x±Sx	1	2	3	4	5
1988												
1(n=20)	8705	105	1.2±0.1	-	-	-	-	-	-	-	-	-
2(n=18)	3226	64	1.9±0.2	-	-	-	-	-	-	-	-	-
1990												
1(n=15)	3974	24	0.6±0.1	-	-	-	-	-	-	-	-	-
2(n=20)	1863	43	2.3±0.3	-	-	-	-	-	-	-	-	-
1994												
1(n=15)	1339	38	2.8±0.4	-	-	-	-	-	-	-	-	-
2(n=18)	759	38	4.9±0.8	-	-	-	-	-	-	-	-	-

*:1 - the young age group of 1-7 years, 2 - the old age group of 7-15 years.

picture has been revealed for mononuclear lymphocytes with micronuclei. First of all, we are to note that only cells with one micronucleus were found during the years examined. However, the variations in the frequency of micronucleus cells were observed. The significant difference in the level of micronucleus cells between the young and the old groups was found only in 1990, whereas in 1988 and 1994 the levels of such cells were approximately equal among two groups. On the other hand, growth of the frequency of micronucleus cells was revealed with time in both groups.

There were no substantial differences between the children born before and after the Chernobyl accident. We also could not find dependence of micronucleus induction on sex.

Regretfully, among all the analysed of lymphocyte populations *in vivo*, a considerable number of binuclear cells were found, which are extremely rare in healthy children (Table 2). In 1988, a increasing tendency of binuclear lymphocyte frequency was observed in the old children groups compared with the young group. Then this difference turned out statistically significant in the following years. The highest indices were revealed in the children born before the Chernobyl accident. As is seen in Table 2, cells with micronuclei were not found among binuclear lymphocytes. Thus, lymphocytes populations in peripheral blood of the examined children in Minsk is characterized by increasing tendencies of the number of mononuclear cells with micronucleus and the number of binuclear cells *in vivo*.

As we noted earlier, there are a limited number of investigations dedicated to the quantitative and qualitative *in vivo* assessment of micronuclei in lymphocyte populations of human peripheral blood. The data on the spontaneous level of micronuclei in lymphocytes were obtained in other researches in which a sufficient number of adults were examined in China. Thus, when 183 persons of both sexes in the age of 45.6±13.9 were examined, 0.16±0.35 micronuclei were found per 1000 analysed lymphocytes [10]. Consequently, approximately equal frequency of micronuclei was registered both in the children of Minsk and in the adults of China. However, unlike in the Chinese population, our investigations discovered high occurrence of binuclear lymphocytes. Apparently, the peculiarities of mutation process in lymphocyte populations of the children in Minsk are linked to the unfavourable radioecological situation.

In 1996, one more article was published in which *in vivo* micronuclei analysis of peripheral lymphocytes was used in combination with an application of the FISH method to an adult group of various ages [11]. Nevertheless, due to the fact that the number of examined people is insufficient, it is not clear whether the levels of micronuclei and polynuclear cells depend on age, sex and other factors. However, the data obtained in the present study can be used to estimate the levels of spontaneous and induced mutation in lymphocytes of peripheral blood of the Belarus children.

1.2. Dynamics of *in vivo* mutation in lymphocytes of peripheral blood in the children of Bragin town

The cytogenetic monitoring of the children of Bragin town in 1988-1994 discovered certain regularities in the dynamics of mutation process in lymphoid cells *in vivo* (Tables 3-5).

The most substantial results of them are as follows:

1. Significant increase of the level of cytogenetic injuries, as compared with corresponding control groups, in lymphocyte populations of peripheral blood of the children of all age groups regardless of their birth date (before or after the Chernobyl accident); the number of polynuclear lymphocytes, the levels of micronucleus cells, and the number of micronuclei in them.
2. Statistically significant differences from the control, not only in quantitative aspects - the frequency of mutation in lymphocytes, but also in qualitative one - distribution spectrum by the number of registered injuries in one cell. According to the results of micronuclei analysis, the common phenomenon in the children groups in the radiocontaminated areas is the presence of subpopulation of cells with several micronuclei - 2, 3, 4 and more, while they are absent in the control preparations. This can serve as a proof of contact of the given children with dense ionizing radiation.
3. Significant difference in the frequency of *in vivo* mutation in lymphocytes of peripheral blood between in the children born before the Chernobyl catastrophe and in the children born on radiocontaminated areas of Bragin town after the catastrophe. The number of cytogenetic injuries grew with the course of time (i.e. depended on the accumulated dose), and in 1994 it increased by about one order as high as in 1986.
4. The level of mutation frequency registered in the children born after the Chernobyl accident also increased with the course of time, or with the increase of accumulated dose. But it is in a lesser scale than in the children born before the accident.

Table 3. Dynamics of *in vivo* mutation in mononuclear lymphocytes of peripheral blood of the children in Bragin town.

Year	Age group of children* /number of examined	Number of analysed lymphocyte	Number of cells with micronuclei		Number of micronuclei in cells		Distribution of cells by the number of micronuclei				
			AN	x±Sx	AN	x±Sx	1	2	3	4	5
1988	1 (n=23)	4444	113	2.5±0.2	144	3.2±0.2	91	16	4	1	1
	control (n=20)	8705	61	0.7±0.1	61	0.7±0.1	61	-	-	-	-
	2 (n=22)	7802	248	3.1±0.1	345	4.4±0.2	175	55	12	6	-
	control (n=18)	3226	28	0.9±0.2	28	0.9±0.2	28	-	-	-	
1990	1 (n=18)	6371	272	4.2±0.2	397	6.2±0.3	180	64	23	5	-
	control (n=15)	3974	21	0.5±0.1	21	0.5±0.1	21	-	-	-	-
	2 (n=17)	16622	677	4.0±0.1	942	5.6±0.1	484	131	54	6	2
	control (n=20)	1863	25	1.3±0.3	25	1.3±0.3	25	-	-	-	-
1994	1(n=15)	1707	65	3.8±0.4	95	5.5±0.5	41	18	6	-	-
	control (n=15)	1339	21	1.6±0.3	21	1.6±0.3	21	-	-	-	-
	2 (n=25)	1331	323	24.2±1.1	561	42.1±1.3	164	98	48	8	5
	control (n=18)	769	15	1.9±0.5	15	1.9±0.5	15	-	-	-	-

*:1 - the young age group of 1-7 years, 2 - the old age group of 7-15 years.

Table 4. Dynamics of *in vivo* mutation in binuclear lymphocytes of peripheral blood of the children in Bragin town.

Age group*	Number of analysed lymphocyte	Number of binuclear cells		Number of cells with micronuclei		Number of micronuclei in cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	AN	x±Sx	1	2	3	4	5
1988												
1(n=23)	4444	477	10.7±0.6	24	0.5±0.1	33	0.7±0.1	16	7	1	-	-
C(n=20)	8705	108	1.2±0.1	-	-	-	-	-	-	-	-	-
2(n=22)	7802	756	9.6±1.0	78	0.9±0.1	109	1.3±0.1	50	25	3	-	-
C(n=22)	3225	64	1.9±0.1	-	-	-	-	-	-	-	-	-
1990												
1(n=18)	6371	629	9.8±0.1	98	1.5±0.1	122	1.9±0.1	78	17	2	1	-
C(n=15)	3974	24	0.6±0.1	-	-	-	-	-	-	-	-	-
2(n=17)	16622	1515	9.1±0.2	282	1.6±0.0	396	2.3±0.0	199	61	15	5	2
C(n=20)	1863	43	2.3±0.3	-	-	-	-	-	-	-	-	-
1994												
1(n=15)	1707	64	3.7±0.4	5	0.2±0.0	5	0.2±0.0	6	-	-	-	-
C(n=15)	1339	38	2.8±0.0	-	-	-	-	-	-	-	-	-
2(n=25)	1331	247	18.5±0.8	36	2.7±0.4	44	3.3±0.4	29	6	1	-	-
C(n=18)	769	38	4.9±0.7	-	-	-	-	-	-	-	-	-

*:1 - the young age group of 1-7 years, 2 - the old age group of 7-15 years.

Table 5. Dynamics of *in vivo* mutation in trinuclear lymphocytes of peripheral blood of the children in Bragin town.

Age group*	Number of analysed lymphocyte	Number of trinuclear cells		Number of cells with micronuclei		Number of micronuclei in cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	AN	x±Sx	1	2	3	4	5
1988												
1(n=23)	4444	83	1.8±0.1	83	1.8±0.1	83	1.8±0.1	83	-	-	-	-
C(n=20)	8705	-	-	-	-	-	-	-	-		-	-
2(n=22)	8702	130	1.6±0.1	11	0.1±0	16	0.2±0	6	5	-	-	-
C(n=18)	3226	49	1.5±0.4	-	-	-	-	-	-	-	-	-
1990												
1(n=18)	6371	198	3.1±0.2	29	0.4±0	39	0.6±0	21	6	2	-	-
C(n=15)	3974	-	-	-	-	-	-	-	-	-	-	-
2(n=17)	16622	455	2.7±0.1	71	0.4±0	97	0.5±0	51	14	6	-	-
C(n=20)	1863	-	-	-	-	-	-	-	-	-	-	-
1994												
1(n=15)	1707	28	1.6±0.3	-	-	-	-	-	-		-	-
C(n=15)	1339	-	-	-	-	-	-	-	-	-	-	-
2(n=25)	1331	90	6.7±0.6	84	6.3±0.6	87	5.5±0.6	81	3	-	-	-
C(n=18)	769	-	-	-		-		-	-	-	-	-

*:1 - the young age group of 1-7 years, 2 - the old age group of 7-15 years.

5. Significant differences found in the level and the spectrum of cytogenetic injuries of bi- and polynuclear lymphocytes in the children born before and after the Chernobyl catastrophe. It is necessary to stress that the significant increase of polynuclear lymphocytes in peripheral blood of the children in Bragin town is also connected with the factors of the radioecological situation.

From our point of view, *in vivo* cytogenetic analysis of lymphocytes with use of peripheral blood smears becomes an important part in the scheme of screening examination of the children in the polluted areas of Belarus. As it is seen from the results of our study, the most suffering part of the children population is those who were born before the catastrophe. So, they are just to be the principal object of investigation and rehabilitation activities.

2. *Ex vivo* study of mutation in lymphocytes of peripheral blood in the children of the Bragin district (1992)

The application of micronuclei analysis of peripheral blood lymphocytes under the condition of cytokinetic block during cell cultivation allows to distinguish clearly the cells which have not passed the mitosis and the cells after first and consequent mitoses [2, 12]. It is known that PHA reagent used for cell cultivation stimulates mainly small T-lymphocytes to cell division [13]. Therefore, by analysing effects on non-stimulated lymphocytes in cell culture, we can look into a heterogeneity of examined lymphocyte populations as compared with the results obtained by the smear method. Besides, the micronuclei registered in mononuclear T-lymphocytes in cell culture are also the result of their expression in process of lymphoid cell divisions *in vivo* [2].

In this connection, micronuclei frequencies in mononuclear and binuclear T-lymphocytes of peripheral blood were examined in order to reveal the effect of low doses of external and internal irradiation as well as of their combined effects, comparing the results of *in vivo* condition with those of *ex vivo* ones. Besides, such approach allowed us to follow to some degree the transgenerational somatic effect. Both the elimination of cells from circulating blood after the “acute irradiation” in the early post-accident period and the appearance of new ones containing unstable aberrations were registered in our experiments in a series of cell generations of lymphocytes. As a result of such analysis, we tried to get an answer to the question: “what is the trend of selection for micronucleus cells (plus- or minus-trend) during the process of their mitotic division?’.

In the same day of March of 1992, blood was taken from 2 children groups of 12-13 years old in Komarin town and Malejki village in the Bragin district of the Gomel region. The blood was transported to Minsk and analysed immediately [2, 12]. In accordance with the Law of Republic of Belarus of 12 November of 1991, the territories polluted as the result of Chernobyl accident were divided into zones in dependence of the density of soil pollution with radionuclides and the degree of radiation effect on man [1]. Both settlements belong to the zone of consequent resettlement, i.e. the zone on which the density of pollution is from 15 to 40 Ci/km^2 with Cs-137 or 2-3 Ci/km^2 with Sr-90, and the average annual effective equivalent dose can overreach 5 mSv per year (over the natural and technogenic background). The density of pollution of territory of Komarin town is 3.0 (Cs) and 2.8 Ci/km^2 (Sr), and that of Malejki village - 9.0 (Cs) and 2.8 Ci/km^2 (Sr) [14].

2.1. *Ex vivo* study of mutation in stimulated and non-stimulated T-lymphocytes of peripheral blood of the children in Komarin town

The results of micronuclei registered in mononuclear lymphocytes of the children in Komarin town are presented in Table 6. A significant inter-individual variation was observed in the frequency of micronucleus cells and the number of micronuclei in mononuclear cells. The individual cytogenetic examination showed that only in 3 children(No. 2, 4 and 9) significant increase of micronucleus cells and of micronuclei frequency per 100 analysed cells was observed. These indices did not differ from the control values in the rest of children. However, the group average indices of mononuclear cells with micronuclei and the indices of micronuclei per 100 cells in children of Komarin town overreached statistical significant level over the corresponding indices in the control (Minsk city).

It is substantial that cells with multiple micronuclei were found in the children of Komarin town, which appear in *in vitro* conditions under the quite high doses or the action of dense ionizing radiation. It is necessary to note also that the cells with chromatin pulverization were found in the half of examined children. The group average index of pulverization constituted 1.6±0.2%. Such phenomena were never observed in the control. This may be considered as confirmation of their elimination and appearance *de novo*.

Table 6. Individual analysis of *ex vivo* mutation in non-stimulated mononuclear lymphocytes of peripheral blood of the children in Komarin town (1992).

No.	Number of analysed cells	Number of cells with micronuclei		Number of micronuclei in mononuclear cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	1	2	3	4	>4
1	101	1	0.99±0.98	1	0.99± 0.98	7	-	-	-	-
2	291	8	2.75 ±0.96	17	5.84 ±1.37	6	-	-	-	1(10)
3	500	8	1.60 ±0.56	10	2.00 ±0.63	12	2	-	-	-
4	500	13	2.60 ±0.71	16	3.20 ±0.79	6	-	-	1	-
5	500	6	1.20 ±0.49	6	1.20 ±0.49	6	-	-	-	-
6	304	4	1.32 ±0.65	5	1.64 ±0.73	3	1	-	-	-
7	55	-	-	-	-	-	-	-		-
8	292	3	1.03 ±0.59	3	1.03 ±0.59	3	-	-	-	-
9	286	6	2.10 ±0.85	6	2.10 ±0.85	6	-	-	-	-
10	349	3	0.86 ±0.49	4	1.15 ±0.57	2	1	-	-	-
11	153	4	2.61 ±1.29	4	2.61 ±1.29	4	-	-	-	-
12	351	4	1.14 ±0.57	4	1.14 ±0.57	4	-	-	-	-
Group total	3682	60	1.63 ±0.21	76	2.06 ±0.23	54	4		1	1
Control	3405	27	0.79 ±0.15	29	0.85 ±0.16	25	2	-	-	-

Table 7. Individual analysis of *ex vivo* mutation in binuclear lymphocytes of peripheral blood of the children in Komarin town (1992).

No.	Number of analysed cells	Number of cells with micronuclei		Number of micronuclei in binuclear cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	1	2	3	4	>4
1	18	-	-	-	-	-	-	-		-
2	90	6	6.67± 2.63	6	6.67± 2.63	5	-	-	-	-
3	500	18	3.60± 0.83	19	3.80± 0.86	17	1	-	-	-
4	274	17	6.20± 1.46	23	8.39± 1.66	13	3	-	1	-
5	307	7	2.28± 0.85	7	2.28± 0.85	7	-	-	-	-
6	237	8	3.38± 1.17	9	3.80± 1.24	7	1	-	-	-
7	15	1	6.67± 6.44	1	6.67± 6.44	1	2	-	-	-
8	79	4	5.06± 2.47	4	5.06± 2.47	4	-	-	-	-
9	52	5	9.62± 4.09	8	15.38±5.0	4	-	-	1	-
10	288	11	3.82± 1.13	11	3.82± 1.13	11	-	-	-	-
11	52	5	9.62± 4.09	5	9.62± 4.09	5	-	-	-	-
12	328	4	1.22± 0.60	5	1.52± 0.68	3	1	1	-	-
13	117	6	5.13± 2.04	8	6.84 ±2.33	5	-	-	-	-
14	500	11	2.20± 0.66	15	3.00± 0.76	9	1	-	1	-
15	95	7	7.33± 2.68	8	8.42± 2.85	5	1		-	-
Group total	2952	110	3.73 ±0.35	129	4.37± 0.38	98	8	1	3	-
Control	16631	199	1.20± 0.08	217	1.30± 0.09	18	-	-	-	-

Table 8. Comparison of group average indices of *ex vivo* mutation in non-stimulated (mononuclear) and stimulated (binuclear) lymphocytes of peripheral blood of the children in Komarin town (1992).

Nuclearity of lymphocyte	Number of analysed cells	Number of cells with micronuclei		Number of micronuclei in binuclear cells		Distribution of cells by the number of micronuclei					Morphological changes of nucleus	
		AN	x±Sx	AN	x±Sx	1	2	3	4	>4	AN	x±Sx
Komarin												
mononuclear	3682	60	1.63± 0.21	76	2.05± 0.23	54	4	-	1	1(10)	66	1.79 ± 0.22
binuclear	2952	110	3.73±0.35	129	4.37± 0.38	98	8	1	3	-	66	2.24 ±0.27
Control												
mononuclear	3405	27	0.79± 0.15	29	0.85± 0.16	25	2	-	-	-	1	0.03
binuclear	16631	199	1.20 ±0.08	217	1.30± 0.09	181	18	-	-	-	-	-

The results of micronucleus analysis of binuclear lymphocytes of peripheral blood with use of cytocholasin B in cell culture of the same children [12] are adduced in Table 7. As shown in the Table, the group average indices of micronucleus in binuclear cells are approximately three times as high as the corresponding indices in the control (the difference is statistically significant). However, the results of individual cytogenetic examination indicate only a tendency of increase of mutation level in binuclear lymphocytes in the majority of children of this group. Two children of the experimental group (No. 5 and 12) did not differ in the mutation level from the control, and in one child (No. 9) the index of micronuclei rate per 100 analysed cells was significantly higher than the control.

Regretfully, the obtained material does not allow to carry out an exact quantitative assessment of transgenerational somatic effect and individual sensitivity because the proliferative activity of lymphocytes of the children in Komarin town turned out to be extremely low. However, the comparison of group average indices of the level of micronucleus cells indicate their significant increase in binuclear lymphocytes as compared with mononuclear ones, i.e. as a result of one cell division in culture (Table 8).

The fact of unusually large decrease of proliferative response of T-lymphocytes to PHA is worth attention. It was not observed in our experiments with the children in other settlements of the Bragin district with higher indices of territory pollution with cesium and strontium, such as Malejki village of the Bragin district. This lymphocyte reaction is apparently connected with the factors of radioecological situation of this settlement which is situated immediately close to the Chernobyl power station. Besides, the pulverization of genetic material was discovered and morphologically reproductive perishing of lymphocytes (1.5% of cells) was registered as well. Taking into account these high indices of mono- and binuclear cells perishing, we can suppose that a considerable share of micronuclei registered in binuclear cells arose *de novo*.

2.2. *Ex vivo* analysis of micronuclei in stimulated and non-stimulated T-lymphocytes of the children in Malejki village

At the cultivation of lymphocytes of peripheral blood of the children in Malejki village, the contrary picture was revealed referring to the proliferative indices as compared with cell cultures of the children in Komarin town. The proliferative response of lymphocytes to PHA was so high that we could analyse only about 50 mononuclear among bi- and polynuclear lymphocytes per each child. In this connection, we could assess only the group average indices, and the results are adduced in Table 9. However, we can complement the picture of mutation process in mononuclear lymphocytes of peripheral blood of the examined children with the data obtained by analysing this cell populations with *in vivo* smear method. As shown in Table 9, the level of micronucleus lymphocytes *in vivo* in the children in Malejki village is 5 times as high as the corresponding indices in the children in Minsk city, and that of micronuclei in them - more than one order. In both cases the differences are statistically significant.

The comparison of micronucleus frequency in *ex vivo* non-stimulated lymphocytes of the children of the experimental group with the control also showed significant increase. But it is only two times higher than the control in this case.

Taking into consideration the presence, among the examined *in vivo* and *ex vivo* lymphocyte populations, of cells with various morphological changes of their nuclei (apoptosis, necrosis, pulverization and others), in other words, the strong selection in minus-trend of the micronuclei frequency at mitotic divisions, we can suppose that the micronuclei analysed in binuclear cells, like in the respective experiments with lymphocytes of the children in Komarin town, were expressed *de novo*.

Table 10 shows the data of individual cytogenetic examination of 15 children in Malejki village. The results of cytogenetic examination allow to divide this group into 2 subgroups: the 1st subgroup consists of the children in which the frequency of binuclear cells with micronuclei and of micronuclei in binuclear cells are on the level of control, and the 2nd subgroup consists of the children in which the lymphocytes have the frequency of binuclear cells with micronuclei on the level of control whereas the second index - micronuclei number per 100 cells - is statistically higher than the control.

The 1st subgroup is also unequal by the spectrum of registered micronuclei. In children No. 3 and 4, the cells with 3-4 micronuclei were registered among 500 analysed cells, the child No. 10 had one cell with 15 micronuclei among 1000 analysed cells.

It is necessary to note a change observed in the results of cytogenetic examination of lymphocyte populations of peripheral blood in the children of the Bragin district. According to our *ex vivo* individual examination in 1986-1988, 100% of children showed significantly increased levels of mutation. In 1992, however, only *in vivo* analysis at the individual level allowed to register significant disturbances.

In theory of cytogenetic analysis, under the condition of uniform exposure, the distribution of chromosomal injuries in cells is considered to follow the Poisson distribution [15]. The preliminary analysis of our results showed that the hemopoietic tissue in the majority of the children in Komarin and Malejki received not uniform but non-uniform dose of radiation.

Table 9. Comparison of group average indices of *in vivo* and *ex vivo* mutation in lymphocytes of peripheral blood of the children in Malejki village (1992).

Nuclearity of lymphocytes	Number of analysed cells	Number of cells with micronuclei		Number of micronuclei in binuclear cells		Distribution of cells by the number of micronuclei					Morphological changes of nucleus	
		AN	x±Sx	AN	x±Sx	1	2	3	4	>4	AN	x±Sx
in vivo												
Malejki												
	1429	54	3.78± 0.50	156	10.91± 0.82	16	19	7	14		58	4.76± 0.56
Control												
Mononuclear	7945	57	6.72± 0.09	58	0.73± 0.10	56	1	-	-	-	-	-
ex vivo												
Malejki												
Mononuclear	1250	27	2.16± 0.41	34	2.72±0.46	24	2	-	-	1(6)	23	1.84 ±0.38
Binuclear	10000	126	1.26± 0.11	230	2.30± 0.15	103	12	2	2	7	23	0.23± 0.05
Control												
Mononuclear	3405	27	0.79± 0.15	29	0.98± 0.16	25	2	-	-	-	1	0.03
Binuclear	16631	199	1.20± 0.08	217	1.30± 0.09	181	18	-	-	-	-	-

Table 10. Individual analysis of *ex vivo* mutation in binuclear lymphocytes of peripheral blood of the children in Malejki village (1992).

No.	Number of analysed cells	Number of cells with micronuclei		Number of micronuclei in binuclear cells		Distribution of cells by the number of micronuclei				
		AN	x±Sx	AN	x±Sx	1	2	3	4	>4
1	500	10	2.00± 0.63	63	12.60±1.48	5	2	-	-	3(30)-1 c.
2	800	11	1.38± 0.41	13	1.62± 0.45	9	2	-	-	-
3	500	7	1.40± 0.52	10	2.00± 0.63	6	-	-	1	-
4	500	8	1.60± 0.56	12	2.40± 0.68	5	2	1	-	-
5	1000	10	1.00± 0.31	10	1.00± 0.31	10	-	-	-	-
6	700	11	1.57± 0.47	39	5.57± 0.87	9	-	-	-	2(15)
7	1000	6	0.60± 0.24	8	0.80± 0.28	4	2	-	-	-
8	800	9	1.12± 0.37	10	1.25± 0.39	8	1	-	-	-
9	500	6	1.20± 0.49	6	1.20± 0.49	6	-	-	-	-
10	1000	6	0.60± 0.24	20	2.00± 0.44	5	-	-	-	1(15)
11	500	11	2.20± 0.66	20	4.00± 0.88	8	-	1	1	1(5)
12	700	7	1.00± 0.38	7	1.00± 0.38	7	-	-	-	-
13	500	3	0.60± 0.34	3	0.60± 0.34	3	-	-	-	-
14	500	11	2.20± 0.66	13	2.60± 0.45	7	3	-	-	-
15	500	10	2.00± 0.63	13	2.60± 0.45	7	3	-	-	-
Total	10000	126	1.26± 0.11	245	2.45± 0.15	103	12	2	2	7
Control	7580	102	1.35± 0.13	109	1.44± 0.14	95	7	-	-	-

Thus, the results of cytogenetic analysis of the children in the Bragin district testify at present that, apparently, the leading dose-forming factor is internal irradiation with complex of radionuclides including α-, β- emitters.

3. Genetic examination of the children in Komarin and Malejki settlements of the Bragin district of the Gomel region

The ionizing radiation causes a whole range of genetic changes in somatic and sex human cells: gene mutations, chromosomal aberrations, and genome mutations. In this connection, the assessment of genetic risk of the children living on the radiocontaminated territories in Belarus depends on the completeness of study about genetic effects of chronic radiation at low doses. Therefore, beside of the individual and group cytogenetic monitoring, it is important to pay attention to the problems of mutagenesis connected with gene mutations.

The scheme of genetic examination of children, proposed and developed by the Institute of Genetics and Cytology of the Academy of Sciences of Belarus, is based on the Norman's method [16] which detects mutations in locus of hypoxanthine-guanine-phosphoribosil transferase (HPRT).

The short-term Norman's method was chosen for detecting mutant T-lymphocytes due to the next reasons: the potential possibility to apply it to the monitoring of populations because of its relative simplicity and lesser cost (as compared with other methods of gene mutations account), the possibility to

Table 11. Individual data of the frequency of TG-resistant lymphocytes in cells culture of the children in Komarin town of the Bragin district

Group/child No.	Number of TG-resistant cells
Control	6.1 * 10 - 6
Komarin	
1	260.2 * 10 - 6
2	211.2 * 10 - 6
3	485.9 *10 - 6
4	315.8 *10 - 6
5	214.3 *10 - 6
6	374.0 *10 - 6
7	410.7 *10 - 6
8	306.4 *10 - 6
Group average	314.4 *10 - 6

Table 12. Individual data of the frequency of TG-resistant lymphocytes in cells culture of the children in Malejki village of the Bragin district

Group/child No.	Number of TG-resistant cells
Control	6.1 * 10 - 6
Malejki	
1	2.2 *10 -5
2	4.2 *10 - 5
3	3.6 *10 - 4
4	8.0 *10 - 5
5	7.4 *10 - 5
6	1.6 *10 - 4
7	1.6 *10 - 4
8	1.8 *10 - 4
9	6.8 *10 - 5
10	5.8 *10 - 5
11	1.0 *10 - 3
12	3.9 *10 - 4
13	3.8 *10 - 4
14	1.6 *10 - 4
15	7.4 *10 - 5
Group average	2.2 *10 -4

analyse simultaneously the gene mutations and the micronuclei as chromosomal aberrations analog, the possibility to use a series of parallel cultures because of the difficulty to obtain from children big volumes of vein blood as well as the possibility of full automation of research.

Tables 11 and 12 present the results of TG (thioguanine) -resistant induction in lymphocytes in peripheral blood of the children in Komarin and Malejki settlements as compared with these indices in the control group of Minsk city.

As are shown in the results of Tables, the frequency of TG-resistant T-lymphocytes in the control group constituted 6.1 x 10^{-6} cells. In 100% of examined children from the given settlements, the level of mutant lymphocytes was significantly differing from the control. The significant quantitative inter-individual variations were also observed within the groups of examined children. So, the number of TG-resistant lymphocytes in the culture of cells of the children in Malejki village varied from 2.2 x 10^{-5} to 1.0 x 10^{-3}, that of the children in Komarin town - from 2.1 x 10^{-4} to 4.8 x 10^{-4}. The comparison of group average index of TG-resistant lymphocytes frequency in the children in radiocontaminated zones with the index in the control group of donors in Minsk city reveals substantial excess of mutant cells in the experimental group (approximately two degrees).

The obtained results conform the data by other authors of the examination of persons irradiated as a result of the accident in Goiania (Brazil) in September 1987. The conditions of irradiation in Goiania were quite similar to those of some population groups due to the Chernobyl catastrophe. In both cases, the people were subjected to the external and internal irradiation. The papers of Natarajan *et.al.* [17, 18] indicate the increase of TG-resistant lymphocytes in irradiated persons 10 to 100 times higher as compared with the control group.

Thus, the results of genetic examination of the children of 12-13 years old who live permanently on radiocontaminated territories of Komarin and Malejki settlements in the Bragin district of the Gomel region have shown a necessity and a possibility to evaluate radiation dose to individuals and groups after many years since the Chernobyl catastrophe, based on the frequency of gene mutations in HPRT locus.

Conclusion

The general conclusion of our study, which has to be addressed at first, is the seriousness of discovered genetic disturbances in the examined children in Bragin town and other settlements in the Bragin district of the Gomel region.

The results of seven-year monitoring of children with use of *in vivo* micronucleus analysis of lymphocytes have shown that the highest level of mutation was found in the children born before the Chernobyl catastrophe. Consequently, the principle of radiation protection according to the level of average annual radiation dose is not acceptable to protect the children in the Bragin district because it does not take into account the total radiation dose since 1986 which conditions the radiation consequences for children health.

The analysis of the results of 1988-1994 indicates that, under the chronic action of ionizing radiation, complicated interactions between mutation pressure and selective process against cells with genetic injuries have been taking place in lymphocyte populations of the children in the Bragin district. Substantial differences between the examined children and the control were found in the level of mutations registered in peripheral blood lymphocytes both *in vivo* and *ex vivo*. The micronuclei level in lymphocyte populations *in vivo* did not decrease during 1988-1994. On the contrary, it increased approximately one order, whereas one mitotic division *ex vivo* in cell culture indicated substantial changes in different trends.

The cells with gene mutations capable to continue their life activity, apparently, undergo the selection in minus-trend to some extent but, probably, also contribute to the plus-trend selection both *in vivo* and *ex vivo*. As a result, in the last years we observe in *ex vivo* examination the high level of gene mutations against the background of relatively low level of chromosomal injuries.

The results of genetic monitoring of the children subjected to the long-term non-controlled radiation action with different intensity and duration in the Bragin district have shown that the frequency of gene mutations in HPRT locus can be a highly efficient bioindicator to evaluate individual and group irradiation. The obtained results confirm a principal necessity to carry out genetic monitoring of Belarus children with obligatory use of this method to account gene mutation . Simultaneous registration of mutation spectrum and frequency obtained with *in vivo* and *ex vivo* examination of peripheral blood lymphocytes in children will give more reliability to the bioindicator of chronic radiation effects.

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Results of Long-term Genetic Monitoring of Animal Populations Chronically Irradiated in the Radiocontaminated Areas

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Introduction

The artificial geochemical land where all organisms lived and will live under the conditions of increased level of radiation was set up due to the Chernobyl disaster in 1986. An urgent necessity for studying the various biological effects of chronic influence of low intensity radiation on both individual organisms and populations arose.

Combined cytogenetic and radioecological investigations in wild populations of terrestrial small mammals (bank vole = *Clethrionomys glareolus, Schreber* and yellow-necked mouse = *Apodemus flavicollus, Melchior*) and in laboratory mice have been carried out by our laboratory since 1986. Our test organisms have contacted closely with low intensity radiation in the radiocontaminated areas of Belarus and absorbed low whole-body dose.

We study the following problems: dynamics of radionuclide concentration in wild populations of small rodents; dynamics of mutation process in somatic and germ cells over many generations as well as embryonal lethality; dynamics of population density, age and sex structure of mammalian populations. The large part of results obtained are presented here.

Materials and methods

Wild populations of small mammals (rodents)

Bank voles and yellow-necked mouse were collected in summer-autumn period from four forest populations in sites chosen for long-term monitoring with limited people activities and differing ^{137}Cs contamination density of soil:

1. - Priluksky reserve (near Minsk, 330 km north-west from the Chernobyl power station, 8 kBq/m^2);
2. - Berezinsky Biosphere reserve (Vitebsk region, 400 km NNW, 18 kBq/m^2);
3. - the suburbs of Majsk village (Bragin district of Gomel region, 60 km N, 90 kBq/m^2);
4. - the suburbs of Babchin village (Khoiniki district of Gomel region, 40 km NNW, 1526 kBq/m^2).

According to the official data of the Belarus Meteorological Centre, the density of soil radiocontamination for ^{90}Sr ranges up to about 70 kBq/m^2 in sites 3 and 4.

The γ-radiation dosage rates were measured at height of 3-5 cm from the ground surface by the dosimeters SRP-68-01T and DBG-06T (in 1991-1996) manufactured in the former Soviet Union.

The total γ-activity of the whole-body animals in 1986-1987 was analysed using 32 crystal spectrometry of gamma-gamma coincidences (scintillation NaI(Tl) detector, 150 x 100 mm^2) at the Institute of Physics of Belarus Academy of Sciences. The radiometric analyses of laboratory mice and wild animals have been carried out since 1988 using γ-spectrometer ADCAM-300 (ORTEC, detector GEM-30185) at the Belarus Meteorological Centre and the Institute of Radiobiology (Belarus Academy of Sciences). The soil samples selected in 1989 were analysed using the same spectrometer.

The content of ^{90}Sr in bank vole populations in sites 3 and 4 were estimated by radiochemical analysis in the Belarus State University (Minsk).

The radiation load in animals due to the external γ-irradiation was estimated in term of the value of radiation dose rate and due to the internal γ-activity by the radionuclide concentration in the rodents body.

Evaluation of mutation process levels in bone marrow cells of bank vole was carried out by standard metaphase test [1]; structural (chromosome aberrations) and genomic (polyploid cells) mutations were analysed. The levels of germ cells mutability in bank vole were estimated by the frequency of abnormal sperm head (ASH) in males [28]. Embryonal lethality was analysed according to D. Anderson [2].

Bank vole have a short lifespan and every year 2-3 new generations appear in the populations. It is thus believed that there were approximately 20-22 generations of these rodents for 1986-1996.

Laboratory population of mice

The males of hybrid mice (CBAxC57Bl/6$_j$)F$_1$ were kept in the radiocontaminated settlements A and B under the conditions of low intensity of external and internal (radiocontaminated food of local production has been used) irradiation during 4 months in 1989. The radiocontamination densities of soil for ^{137}Cs in settlement A (village Lomachi, Khoiniki district of Gomel region) and B (Bragin city of Gomel region) were 2351 and 825 kBq/m^2, respectively. The average gamma dosage rates in cages with animals were 43.71 x 10^{-12} and 8.24 x 10^{-12} A/kg (or 610 and 115 μR/h) in A and B, respectively. The control group of animals was kept in vivarium of Institute of Genetics and Cytology (γ-radiation dosage rate was about 0.86 x 10^{-12} A/kg or 12 μR/h).

The radiometric analyses of whole-body animals were carried out using γ-spectrometer ADCAM-300 (ORTEC, detector GEM-30185). The absorbed dose due to the external γ-irradiation was estimated using thermoluminecent dosimeters placed in the cages of animals.

The frequency of chromosome aberrations, polyploid cells in bone marrow as well as the frequency of reciprocal translocations and other cytogenetic injuries in spermatopcytes of the first meiotic division and abnormal sperm head (ASH) were studied by the conventional methods [1, 28].

Dynamics of radiation loads on wild populations of mammals in the radiocontaminated areas

Over the period under consideration the radiation dosage rate was greatly reduced in all sites (Table 1). The most fast reduction of dose rate was recorded in site 4 in May - August, 1986.

It was revealed that over the first five months following the catastrophe (i.e. over the average lifespan of animals under investigation) the absorbed whole-body dose from the external gamma-irradiation in the rodents inhabiting sites 1 and 4 (with contrasting levels of radiocontamination) made up 0,1 and 15 cGy, respectively; and the absorbed dose in animals in site 4 over the five months of 1987 ran to 1,23 cGy [9]. So, daily average dose from the external γ-component in the individuals from the highly contaminated site 4 hardly exceeded 1 mGy even in the first time after the accident. As a whole, it may be said that the animal populations under investigation were exposed to low-dose irradiation from the external and internal components. The research of Cristaldi et al. [6] corroborates this conclusion.

The mean radionuclide concentration in animal populations in all areas under investigation (Table 2, 3) were positively correlated with mean ground deposition of the trapping sites (Spearman, r=1.00, P<0.05 for data obtained in 1989). ^{137}Cs and ^{134}Cs made the main contribution to the total γ-activity of soil and animals samples. Besides two caesiums, we recorded other γ-emitters such as ^{106}Ru, ^{144}Ce and ^{241}Am (since 1991 for site 4). ^{90}Sr mean concentration estimated in 1991 in bank vole populations from sites 3 and 4 made up to 114 and 298 Bq/kg, respectively.

In rodents with fast generation succession we annually detected radionuclide concentrations in the completely renewed populations. Dynamics of radionuclide content in consecutive generations of bank vole (and yellow-necked mouse) over the period of 1986-1996 (and 1986-1989) was characterised by three phases: an increase, a maximum (peak) and a decrease [9, 12, 14]. The peaks of radionuclide accumulation in the populations in the areas with different radiocontamination density fell not at the first but in the next years (1987-1989) following the Chernobyl disaster, i.e. the peaks were observed in subsequent animal generations (Table 2, 3). Thus in populations of two mammalian species we observed shifts of the maximum radionuclide content within 1-3 years. The revealed regularity of the time shift in the maximum of population average radionuclide concentrations in animals as against the maximum of their fallout in 1986 seems to be the result of increase in biological accessibility of radioisotopes to plants and thus to the whole biota. The peculiarity of the radionuclide content dynamics in small mammal populations after the Chernobyl accident is in agreement with the known data on the same retardation in the concentration maximum of ^{90}Sr and ^{137}Cs from the global fallout in hoofed animals [27] and are corroborated by similar results obtained for fish from the Baltic Sea [8] and for various groups of people and animals in Norway [26].

Table 1. Gamma radiation dose rate 10^{-12} A/kg (μR/h or R x 10^{-6} / h in brackets) on the ground surface in four sites in 1986-1996

Site	1986	1987	1988	1989	1991	1992	1996
1	1.79 (25)	0.86 (12)	0.86 (12)	0.86 (12)	0.86 (12)	-	0.86 (12)
2	-	-	-	-	0.86 (12)	0.86 (12)	0.72 (10)
3	42.99 (600)	4.66 (65)	4.66 (65)	4.66 (65)	2.29 (32)	-	1.93 (27)
4	1218.05*-177.69 (17000*-2480)	46.57 (650)	46.57 (650)	43.71 (610)	10.75 (150)	-	11.68 (163)

*This level was measured in May 1986, the others were obtained as the average data over the periods of capture. In 1986 the first catchings were initiated in August (about 120 days after the disaster).

Table 2. Dynamics of radionuclide concentrations in wild populations of bank vole in 1986-1996

Site	Year	Number of animals	Total gamma-activity (Bq/kg)			
			Minimum	Maximum	Mean	U-test
1	1986	27	41	525	187	
	1987	46	38	926	274	*
	1988	24	5	750	245	n.s.(1)
	1989	75	5	429	118	*
	1991	15	5	625	140	n.s.
	1996	30	4	20	6	**
	1986-1996	217	4	926	160	
2	1991	20	5	1524	565	
	1996	40	4	108	25	*
	1991-1996	60	4	1524	205	
3	1986	34	38	78070	9293	
	1988	91	111	215196	23623	**
	1989	142	1237	41501	10591	**
	1991	53	757	25293	5587	**
	1996	18	85	344	162	**
	1986-1996	338	38	215196	12629	
4	1986	42	67	78070	17202	
	1987	65	3885	145410	26503	**
	1988	174	58	950100	81966	**
	1989	176	3636	463741	44407	**
	1990	13	4724	22016	13272	**
	1991	129	654	55132	11191	**
	1996	49	148	4528	1204	**
	1986-1996	648	58	950100	40429	

(1) nonsignificant;
* Ð< 0.05; ** Ð< 0.01 in comparison with data obtained in every site in 1986.

Reduction in radionuclide concentration in bank vole populations under investigation was recorded in 1989. However, a significant decrease in radionuclide content as compared with the initial increase in 1986 has been observed only beginning from 1990 (10 generations) in population of bank vole from the highly radiocontaminated site 4. Since both the radiation dose rate and values of the population mean

Table 3. Dynamics of radionuclide concentrations in wild populations of yellow-necked mouse in 1986-1989

Site	Year	Number of animals	Total gamma-activity (Bq/kg)			
			Minimum	Maximum	Mean	U-test
1	1986	27	42	348	237	
	1987	17	63	365	279	n.s.
	1988	21	5	309	59	**
	1989	27	5	265	78	**
	1986-1989	92	5	365	157	
3	1986	5	820	11111	4196	
	1988	7	1146	48799	11174	n.s.
	1989	52	441	7235	2677	n.s.
	1986-1989	64	441	48799	3725	
4	1986	11	1539	46990	11493	
	1987	27	1894	38480	8411	n.s.
	1988	14	1382	36472	9391	n.s.
	1989	24	1371	61204	15559	xx
	1986-1989	76	1371	61204	11295	

n.s. nonsignificant;
** P<0.01 in comparison with data obtained in every site in 1986 and
õõ in comparison with data obtained in site 4 in 1987, 1988.

body burden considerably decreased in all sites by 1991, it can be stated that there was a significant reduction in radiation load starting from the 12th generation of animals.

Genetic injuries in mammals

A. Dynamics of mutation processes in somatic cells of consecutive generations of bank vole

The mean frequency of aberrant cells in bank vole population inhabiting site 1 (with the least soil radiocontamination density, 8 kBq/m^2) in 1986 didn't differ from the historical pre-Chernobyl control that made up 0.41 % in site 2 [29], and had the tendency to increase the next years (Table 4). It became significantly greater in 1991, i.e. in the subsequent generations of animals.

In populations from more contaminated sites 2-4 (18-1526 kBq/m^2) there were observed significant 2.8-6.4 fold increased levels of aberrant cells in bank vole over all period under consideration as against the results for rodents in site 1 and the pre-accident data (Table 4). The tendency towards increase in the chromosome mutation frequency was also noted in these sites. In 1991 the level of aberrant cells in population in site 3 was significant highly (X^2-test, $P<0.05$) than the data on the previous years (1986, 1988).

The analysis of frequencies of chromosome aberrations and aberrant cells in highly radiocontaminated sites 3 and 4 did not reveal significant differences between these two populations in each year studied. However, the average frequency of aberrant cells during whole period 1986-1991 was significantly higher in site 3 than in site 4 (X^2-test, $P<0.05$).

In populations of animals living in the highly contaminated sites 3 and 4, the aberrations of chromosome type (paired fragments, Robertsonian translocations, pericentric inversions) formed the great part in total yield of aberrations in contrast to the populations in sites 1 and 2 with less ground deposition [13; 14]. It should be emphasised that in one of voles captured in site 3 in 1991, more than 50% of analysed metaphases contained pericentric inversion. We believe that this stable aberration had emerged in bone marrow stem cell producing the clone of changed cells.

Additionally, the cells with 2 and 3 aberrations were found in animals from sites 3 and 4 while no cells with above 1 aberration were observed in populations in sites 1 and 2.

Unexpectedly high cytogenetic effects were recorded in bone marrow cells of bank vole by the test of genomic mutations [13] as against the test of chromosome aberrations (Table 4). It turned out that in 1986 the frequencies of polyploid cells were increased in animals at all sites in comparison with the pre-Chernobyl data (0.04 % according to Yeliseeva et al. [29]. The average frequency of polyploid cells during the whole period 1986-1991 significantly correlated with the soil contamination and the γ-radiation dose rate (Spearman, r=1, $P<0.05$). The level of the genomic mutations rose significantly in populations under investigation from year to year (X^2-test, $P<0.01$) with one exception: population from site 2 in 1992. The frequency of polyploid cells reached 9-12 % in animals from sites 3 and 4 in 1991 and was 200-300 times higher than the pre-accident

Table 4. Dynamics of the aberrant and polyploid cell frequencies (%) in bone marrow of bank vole in 1986-1991

Site	Year	Number of animals	Number of cells scored	Aberrant cells	Polyploid cells
1	1986	10	997	0.40	0.50**
	1988	3	310	0.65	0
	1991	6	741	1.12*	3.51** xx
	1986-1991	19	2048	0.69	1.51
2	1991	20	2164	1.11**	4.25**
	1992	17	1995	1.22**	1.65** xx
	1991-1992	37	4159	1.17	3.01
3	1986	18	2011	1.71**	1.19**
	1988	21	2380	1.75**	8.87** xx
	1991	16	1824	2.54**	9.27**
	1986-1991	55	6215	1.96	6.50
4	1986	16	1743	1.27**	0.23**
	1987	36	3973	1.14**	7.50** xx
	1988	27	2883	1.77**	5.86** xx
	1991	30	4166	1.86**	12.31** xx
	1986-1991	109	12765	1.53	7.71

* $P<0.05$; ** $P<0.01$ in comparison with data on site 2 in 1981-1983 [29];
xx $P< 0.01$ in comparison with data obtained in every previous year (X^2-test).

level.

The fact of annual significant rise in the genomic mutation frequency in consecutive generations of animals living in areas with different ground deposition deserves particular attention.

The hypothesis on the adaptive character of cellular polyploidy at high levels of radiation is being extended [4, 16, 23]. According to this hypothesis polyploidy is considered as a mechanism for concealment (hibernation) of genetic damages in cell: polyploid formation process plays a protective role saving cells from unbalanced genome. In bone marrow, at the same time, polypotent stem cells as well as precursor-cells are target-cells in forming abnormal myelopoiesis and acute forms of leukaemia [30], which are characterised by increased frequencies of polyploidy and other forms of aneuploidy in many cases. Since there are more questions than answers in hemopoiesis process, it can be assumed that, at some ranges of the mutation effects, polyploidization of bone marrow cells is of an adaptive character and, at other ranges, it goes to pre- and pathologic state. It should be noted that there are data on a rise in the frequency of infant leukaemia in children exposed to in utero radiation whose parents live in Greece with different radiocontamination density due to the Chernobyl fallout [18].

Thus, it can be only supposed that increased frequencies (by 2-3 orders) of bone marrow polyploid cells recorded by us exceed the limits of normal response of bank vole and are close to the pre-pathological state of hemopoiesis processes.

So, the study on dynamics of the mutation process in bank vole populations inhabiting regions with different soil radiocontamination density in 1986-1991 has shown that increased levels of chromosome aberrations and genomic mutations emerging in somatic cells de novo in every generation were observed in bone marrow cells of animals within many generations (from 1 to 14) after the accident.

Considering that cytogenetic effects in proliferating cells of bone marrow reflect the dose received within one cell division cycle, increased frequencies of chromosome aberrations and genomic mutations recorded by us in 1986-1992 are considered to have occurred at very low levels of absorbed doses. Thus, according to calculations of Cristaldi et al. [6], the absorbed doses from the external γ and internal γ and β irradiation from ^{134}Cs and ^{137}Cs in bank vole populations in three regions of Sweden with different soil contamination levels (22, 90 and 145 kBq/m^2 for ^{137}Cs) made up 8.8 x 10^{-6}; 26.8 x 10^{-6} and 39.4 x 10^{-6} Gy per day in 1989, respectively. The levels of soil contamination in our sites 2 and 3 were almost equal to those of some Swedish sites. This suggests that the radiation load in animals in sites 2 and 3 were the same order of magnitude and it can be assumed that the values of the doses absorbed by the investigated populations of animals within the cell division cycle are of the order of a few tens or hundreds of mGy per day.

We believe that significantly greater mean frequency of aberrant cells as well as existence of the individual with high content of stable aberration can indicate stronger structural injuries of chromosomes in population from site 3 than from site 4. Since animals in site 3 had lower range of dose loads than that in animals from site 4, we believe that data obtained resulted from abnormal dose relationship of structural injuries of chromosomes at low doses.

B. Dynamics of mutation process in germ cells of consecutive generations of bank vole

Table 5. Dynamics of abnormal sperm head (ASH) frequency in males of wild small mammals

Site	Year	Bank vole			Yellow-necked mouse		
		Number of animals	Number of cells	ASH (%)	Number of animals	Number of cells	ASH (%)
1	1989	13	19500	0.149	10	10000	0.140
	1991	7	10500	0.076	-	-	-
	1996	13	65000	0.085*	-	-	-
	1989-1996	33	95000	0.097	-	-	-
2	1991	22	33000	0.106	-	-	-
	1996	43	215000	0.091	-	-	-
	1991-1996	65	248000	0.093	-	-	-
3	1989	8	12000	0.175	23	23000	0.222^{x}
	1991	26	39000	0.126	-	-	-
	1996	6	30000	0.123	-	-	-
	1989-1996	40	81000	0.132	-	-	-
4	1989	34	51000	0.208	12	12000	0.300^{xx}
	1991	39	58500	0.214^{xx}	-	-	-
	1996	7	35000	0.109**	-	-	-
	1989-1996	80	144500	0.186	-	-	-

^{x} P<0.05; ^{xx} P< 0.01 in comparison with data on site 1 and within every year;
* P<0.05; ** P<0.01 in comparison with data obtained in every site in 1989 (X^2-test).

The frequencies of abnormal sperm head (ASH) in both species of small mammals (bank vole and yellow-necked mouse) in 1989 were higher in sites 3 and 4 in comparison with the data on site 1 (Table 5). The increased frequency of abnormal sperm remained in bank vole population in site 4 in 1991. Thus, it can be stated that many consecutive generations of animals in site 4 with high radiocontamination density had the same range of mutability in germ cells. The significant decrease in the frequency of ASH (X^2-test, P<0.05 and P<0.01) was observed in bank vole populations in 1996 (in sites 1 and 4 respectively).

Unfortunately, we have no control data (with absolutely clear region) or pre-accident ones on the levels of ASH in bank vole populations. And thus, we believe that the frequency of abnormal sperm in highly contaminated sites 3 and 4 in 1996 didn't reach the pre-accident level.

Comparative studies of the average frequencies of ASH in bank vole populations during whole period 1989-1996 demonstrated no significant differences between the least contaminated sites 1 and 2 (0.097 and 0.093 % ASH, respectively). Significant increase (X^2-test, P<0.01) in the average frequency of ASH were observed in population from more contaminated site 3 (0.132 %). And in males from the most contaminated site 4, the level of abnormal sperm (0.186 %) were significant higher (P<0.01) than in animals from all other sites under investigation (1-3). Thus, we can observe the following peculiarity: the higher the contamination density of the site, the higher frequency of ASH. But the frequency of ASH didn't statistically correlate with the soil contamination or the content of incorporated radionuclides. At the time, the average frequency of ASH significantly correlated with the average gamma radiation dose rate during 1989-1996 (Spearman, r=1.0, P<0.05). We believe that the lack of correlation between the level of abnormal sperms and some radiation factors can indicate complex repair processes in germ cells of chronically irradiated animals. This our speculation is in agreement with the data obtained in germ cells of laboratory mice that is discussed below.

C. Embryonal lethality in wild populations of bank vole

The study on embryonal lethality was initiated only in 1988. During 1988-1996 we have caught a few pregnant females in site 1. Thus we have no data on embryonal lethality in the site with the least ground deposition. In bank vole populations from sites 2-4 a tendency towards increase in the frequency of embryonal lethality during the whole period under investigations was observed (Table 6). The average frequency of lethality throughout this period was significantly high only in site 4 as compared with the average data on site 2 (Table 6). But the average frequency of lethality didn't correlate with the soil radiocontamination, gamma radiation dose rate or average level of incorporated radionuclides (Spearman, r=0.0, P>0.05). In site 4 the frequency of embryonal lethality positively correlated with population density (Spearman, r=1.00, P<0.05).

D. Cytogenetic injuries in somatic and germ cells of laboratory mice after protracted internal and external irradiation at low doses

It was revealed that animals kept in the radiocontaminated regions during 133 days accumulated high concentrations of γ-emitting radionuclides and took whole-body radiation loads in the range of low doses (Table 6). Mutagenic effects of long-term irradiation by tests of chromosome aberrations and polyploid cells were observed in mice bone marrow (Table 7). Significantly increased levels of these two types of mutations were recorded in animals kept in the highly contaminated region A (Table 7). There were 56% of chromosome type aberrations from all number of aberrations recorded in

Table 6. Dynamics of embryonal lethality in populations of bank vole

Site	Year	Number of females	Pre-implantation loss (%)	Dead implants (%)	Total embryonal lethality (%)
2	1991	12	0	5.36	5.36
	1992	19	2.20	1.12	3.30
	1996	7	12.50	0	12.50
	1991-1996	38	3.74	2.27	5.88
3	1988	4	0	0	0
	1989	30	5.80	0.77	6.52
	1991	14	8.45	1.54	9.86
	1996	3	20.00	8.33	26.67
	1988-1996	51	7.32	1.33	8.54
4	1988	14	3.17	1.64	4.76
	1989	40	4.48	1.56	5.97
	1991	21	9.90	4.40	13.86
	1996	11	13.73	9.09	21.57
	1988-1996	86	6.73	3.19	9.62 *

* P<0.05 in comparison with data on site 2 (X^2-test).

Table 7. Frequency of aberrant and polyploid cells in bone marrow of laboratory mice (males) after long-term internal and external irradiation in radiocontaminated regions of Belarus in 1989

Region	^{137}Cs deposition (kBq/m^2)	γ-activity of animals (Bq/kg)	Whole-body dose from external γ-irradiation (cGy)	Number of animals	Number of cells	Aberrant cells (%)	Polyploid cells (%)
Control	0	6	0.03	3	646	0.31	0
B	825	853	0.43	4	480	0.63	0.83
A	2351	1103	1.71	27	2970	1.16*	1.11*

* P<0.05 in comparison with control data (X^2-test).

Table 8. Abnormal sperm head (ASH) in laboratory mice

Region	Number of animals	Number of cells scored	ASH (%)
Control	24	38208	0.464
B	33	49985	0.456
A	52	79010	0.582**

** P<0.01 in comparison with control data (X^2-test).

Table 9. Frequencies of cytogenetic injuries in spermatocytes of laboratory mice (males)

Region	Number of animals	Number of cells scored	Reciprocal translocations (%)	Fragments (%)	Sex univalents (%)	Autosome univalents (%)	Polyploid cells (%)
Control	21	7114	0.06	0.33	13.27	5.56	5.74
B	21	10615	0.18*	0.56*	11.77	2.92	10.76**
A	21	5257	0	0.23	14.23	3.87	9.53**

* P<0.05; ** P<0.01 in comparison with control data (X^2-test).

bone marrow cells of mice from group A, while the animals from other two groups had no cells with these type aberrations [10].

The level of ASH (Table 8) was revealed to increase in mice from group A when absorbed dose from the external γ-irradiation was 1.71 cGy and the content of incorporated radionuclides was 1103 Bq/kg [10].

Different type of cytogenetic injuries (structural and genomic) were observed in spermatocytes of males studied (Table 9) [11]. The animals of all group were characterised by high individual variability for each parameter tested.

Reciprocal translocations among structural chromosome injuries are of particular interest. It should be noted that radiation-induced reciprocal translocations emerge with low frequency [1, 5, 20, 21, 22, 25].

Translocations, consisting of two bivalents (quadrivalents) mainly in the form of chains and in rare cases in the form of rings, occurred in the animals analysed by us. One male from group B was noteworthy for complicated configuration of 4 bivalents (octovalent) in the form of chain. On the whole, the mice from this group are characterised by the significantly increased level of reciprocal translocations (Table 9). The obtained level of reciprocal translocations in group B under long-term combined irradiation with low doses (0.43 cGy from external γ-irradiation and 853 Bq/kg of incorporated radionuclides) exceed the effects expected during higher dose extrapolation by single or long-term ^{137}Cs input [20, 22], as well as under long-term external γ+β-irradiation [5, 21].

At the same time no reciprocal translocations were revealed in animals from the more contaminated station with higher radiation loads (radionuclide concentration - 1103 Bq/kg and the dose taken from external γ-irradiation -1.71 cGy). Similar data were obtained on analysing another type of structural chromosome damages - fragments (Table 9). Significant increase in chromosome fragment frequency was recorded in animals from group B as against the control and reduction in that parameter in group A.

Thus, the increased frequencies of structural chromosome injuries were observed in immature germ cells (spermatocytes) only at lower radiation load (group B). Absence of increased mutability, evaluated by chromosome aberration test, on increasing the absorbed dose seems to be the consequence of induction of repair system of the “adaptive response” type. There are abundant data on different inducible repair systems (adaptive response, SOS-repair, etc.) in literature at the present. These repair systems can be induced with low doses of acute and chronic irradiation. Discrepancy between dose-effect curves in the chromosome aberration frequency in somatic (bone marrow) and immature germ cells can be accounted for by some reasons including dose differences in inducing repair systems of germ and somatic cells.

It is known that an increase in radiation above the background level induces two contrary processes in living matter - injury and repair. There is a number of models [24, 19] of abnormal dose dependence of cytogenic injury yield at low levels of absorbed doses. According to one of them [19], repair processes can prevail over injury induction at some levels of low doses. As a result, reduction in the number of injuries even below the spontaneous level can be observed at a certain site of dose-effect curve. However, the number of induced injuries, which make a greater contribution in comparison with repair to the dose-effect curve, increases with a rise in the dose. We think that abnormal dose dependence of chromosome aberration yield in germ cells of the laboratory mice is in agreement with the above-mentioned model of low dose radiation effect. The frequency of chromosome aberrations, as well as reciprocal translocations can be expected to start rising in animal germ cells at higher radiation loads than at those we studied.

The analysis of sex and autosomal univalents (nonconjugated homologous chromosomes) did not exhibit radiation-related effects what is in agreement with the literature data [5, 20, 21].

Genomic injuries in the animals tested (Table 9) were represented by tetra-, hexa-, octo- and higher level ploids. The high frequency of polyploid cells is typical for germ cells of mammal males and, in particular, for mice [17]. Besides, the dependence of the yield of the polyploid germ cell level in mice on the value of absorbed doses is known in the literature [15, 17]. On exposing spermatocytes to X-irradiation with 200 R dose, the frequency of polyploid cells increased by a factor of 15 as against the control [17]. We have revealed that, at much lower absorbed doses but at the combined effects of external and internal irradiation, the levels of polyploid cells in animals from the experimental groups are twice as much as in the control. Furthermore, the tendency towards increasing the ploidy degree was observed in males at the radiocontaminated stations. The cells whose ploidy is above 8n were revealed only in these animals.

Thus, the increased levels of various cytogenetic injuries were detected in somatic and germ cells of laboratory mice exposed to long-term combined external and internal irradiation of low absorbed doses.

Conclusions

Increased levels of the mutation process both in somatic and in germ cells of animals are recorded in natural populations of small mammals exposed to chronic low-dose irradiation during succession of many generations (1-22) following the Chernobyl accident. Since the radiation load on bank vole populations was reduced by 1991, it can be stated that hereditary apparatus of somatic and germ cells of succeeding animal generations (12-22) have higher sensitivity to radiation in comparison with previous ones (1-10) that lived before 1991 and took much higher radiation loads. In other words, there was no genetic adaptation to the mutagenic effect of low level irradiation for the whole investigation period in wild populations of bank vole.

Our results obtained on the somatic and germ cells of small mammals also indicate that the genomic test (examination of polyploidy) has greater sensitivity to evaluate genetic effects of the increased radiation background as compared with the test using chromosome aberrations. The dose-response patterns for genomic mutations in rodent somatic cells differ at low doses from those for chromosome aberrations.

Our investigations show higher sensitivity of both somatic and germ cells of animals to chronic combined external and internal effect of radionuclides in comparison with other irradiation conditions. All cytogenetic effects obtained in wild and laboratory animals at chronic low dose radiation exceeded the expected ones based on extrapolation from the results obtained in the range of higher doses by single or long-term irradiation. Abnormal patterns of dose-response are revealed for different type mutations at low doses of long-term radionuclide influence.

There are data on high rates of genic mutations in animal and human populations in the areas radiocontaminated by the Chernobyl fallout. So, the frequency of germline mutations at human minisatellite loci in children born on heavily polluted areas of Belarus was found to be twice as high as in the control group [7]. In two species of voles (Microtus arvalis and M. rossiaemeridionalis), collected near the Chernobyl nuclear power plant, the range of genic mutations was hundreds of times greater than those typically found in vertebrates [3].

Taking into account increased sensitivity of cells of different organs and tissues of animals from chronically irradiated populations to induction of all types of mutations - genic [3, 7], genomic (polyploid cells) and structural (chromosome aberrations), it is necessary to emphasise that the areas with a wide range of radiocontamination density due to the Chernobyl fallout (8-2351 kBq/m^2 in our tests) are zones with high genetic risk for animals and man.

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Cytogenetic Effects of the Action of Ionizing Radiations on Human Populations

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Introduction

The methodology for assessing the genetic risk from the action of ionizing radiations on human populations has been elaborated by the United Nations Scientific Committee on the Effects of Atomic Radiation (1-3). On the basis of over 30-year international experience of investigation of genetic effects of ionizing radiations in experimental objects (microorganisms, plants, animals) as well as relatively rare investigations of genetic effects in man, UNSCEAR made an estimate of expected genetic effects of radiation in future generations per dose unit - 1 Sv.

The main source of information on absorbed doses has been accepted to be physical dosimetry. This method makes it possible to obtain evidence on the type of ionizing radiation, dose rate, duration of exposure and dose distribution in space. However, evidence on genetically important doses based on physical dosimetric measurements in the case of wide-scale accidents, such as in Chernobyl, is most often very limited.

A promising method for estimating absorbed doses is biological dosimetry, namely cytogenetic analysis (4). Radiation can induce two types of chromosome aberrations: unstable - dicentrics, centric rings, acentric fragments; and stable - reciprocal translocations and other types of translocations.

Most often absorbed doses are assessed on the basis of the frequency of unstable aberrations (dicentrics) (5). Centric rings can also be used for this purpose, but the frequency of their occurrence makes up only 5-10% as compared to the rate of dicentric chromosomes (6). By comparing the rate of dicentric chromosomes with a standard dose-effect curve obtained in an experiment in vitro, it is possible to determine a radiation dose. This method has been recommended for practical use by the documents of WHO, IAEA and UNSCEAR (1, 4, 7). Dicentric chromosomes are easily recognized without using special staining techniques. However, the use of dicentrics as well as other aberrations of the unstable type for the purposes of biological dosimetry is not always possible since the frequency of cells containing such chromosomes declines in time post exposure (8, 9). In this connection, the retrospective assessment of absorbed doses (this primarily concerns cases of emergency and accidents) by the frequency of dicentrics without additional investigations is practically unfeasible, if years have passed since the exposure occurred. More promising for the purpose of biological dosimetry is the analysis of stable aberrations (translocations) the frequency of which remains constant for a long time after exposure to radiation (months, years). The probability of occurrence of stable (translocations) and unstable (dicentrics) aberrations after exposure is the same (10, 11). However, translocations are not subjected to selection during cell proliferation, in contrast to dicentrics. In some works, the data for exposed individuals undergoing radiotherapeutic treatment and for Hiroshima survivors confirm this fact (9, 12).

The use of biological dosimetry, and, in particular, cytogenetic analysis, makes it possible to fill in the gap in the knowledge about absorbed doses in people exposed as a result of large nuclear catastrophes, which was repeatedly demonstrated in studies of the impacts of the accidents at the Chernobyl nuclear power plant in 1986 (13-19), in Goiania (Brazil) in 1987 (20) and other radiation situations (21, 22). In their turn, the data on absorbed doses refined with the help of cytogenetic methods permit assessing the genetic risk from radiation for future generations.

The objective of the present work is the analysis of available materials on practical application of the cytogenetic method for dose assessment in people participating in the post-accidental rescue and clean-up operations in Chernobyl (so-called "liquidators"). These materials will be compared with the results of cytogenetic investigations performed in other regions of Russia exposed to radiation (the village Muslyumovo in the Chelyabinsk region, several localities of the Altai Territory in the vicinity of the Semipalatinsk nuclear test site) as well as with the results of cytogenetic monitoring in the population living around the Three Mile Island (TMI) nuclear power plant (Pennsylvania, USA) where a nuclear accident occurred in 1979. The work presents the results of cytogenetic investigations obtained by the traditional method of analysis of the frequency of unstable chromosome aberrations and by the FISH

Table 1 Cytogenetic results obtained in 1986 in the liquidators of the Chernobyl Nuclear Power accident

[(M ± SEM) ×10^{-3}]

Group	Number of persons	Number of cells scored	Number of chromosome aberrations	Dicentrics + centric rings	Absorbed whole body dose ** mGy ± SEM 1	2
Chernobyl Nuclear Power Plant staff	83	6015	23.7 ± 2.0*	5.8 ± 1.0*	474 ± 315	303 ± 199
Physicians	37	2590	13.1 ± 2.3*	2.7 ± 1.0*	198 ± 212	125 ± 123
Dosimetrists	23	1641	31.1 ± 4.3*	4.8 ± 1.7*	381 ± 345	243 ± 214
Drivers	60	5300	14.7 ± 1.7*	3.2 ± 0.8*	264 ± 211	168 ± 124
Builders of the “Sarcophagus”	71	4937	32.4 ± 2.5*	4.4 ± 0.9*	347 ± 260	221 ± 159
Pripyat population	35	2593	14.3 ± 2.4*	1.9 ± 0.8*	131 ± 168	81 ± 92
Control	19	3605	1.9 ± 0.7*	0	-	-

Level of significance * - $p< 0.05$; SEM, standard error of the mean;
** - dose estimations on the basis of: 1 - reference 15, 2 - reference 23, on the basis of the sum of dicentrics and centric rings (0.011 and 0.018 dicentrics per 1 Gy per 1 cell).

method based on the frequency of stable chromosome aberrations.

Cytogenetic examination of the victims of nuclear accidents

A. *Cytogenetic examination of the liquidators working in Chernobyl*

Cytogenetic examination of the liquidators working in Chernobyl was started in 1986 in the laboratory organized by the N. I. Vavilov Institute of General Genetics of the Russian Academy of Sciences directly in Chernobyl in accordance to the resolution of the Governmental Commission on the liquidation of the consequences of the accident (13, 14, 15).

All examined people working in the zone of the accident in 1986 were grouped as follows:

employeers from the Chernobyl nuclear power plant (CNPP) who participated in the liquidation of the consequences of the accident and in decontamination of the territory in 1986-1987; physicians of the medical station in Pripyat who examined the workers of the Chernobyl nuclear power plant before the accident and participated in the evacuation of the population of Pripyat and the personnel of unit ¹4 and later in medical examination of the liquidators working in the 30 km control zone; a group of dosimetrists who participated in the dosimetric control on the CNPP territory during decontamination works; drivers who transported concrete and other materials for constructing the "sarcophagus" around unit 4;

builders of the "sarcophagus" who directly participated in its construction;

part of the population of Pripyat evacuated after the accident but remaining in the 30 km zone and participating in the liquidation works (members of the local administration, militiamen, workers of consumer's co-operatives, etc.).

Blood samples were collected within several days (groups 1, 3, 4, 5) and within 1-3 months (groups 2, 6) after the evacuation of people from the 30 km zone. The results of cytogenetic examination are presented in Table 1. They demonstrate that the frequency of chromosome aberrations in the examined liquidators significantly exceeds (up to 17-fold) the control level. The highest frequency of cytogenetic injuries was recorded in the builders of the sarcophagus, CNPP personnel and in the dosimetrists. The greatest spread in the frequency of chromosome aberrations between individuals was observed among the sarcophagus builders (up to 16%). A more homogeneous distribution was noted in the group of inhabitants from Pripyat (from 1 to 6%) and in the CNPP personnel (from 0 to 10%).

Absorbed doses were assessed by the frequency of dicentrics and centric rings using a calibration dose-effect curve generated in vivo (analysis of dosimetric data for the liquidators whose absorbed dose was precisely measured by the physical method) (15) and linear coefficients of calibration dose-effect curves obtained in vitro for acute exposure in the low dose range (23). Table 1 presents the values of average absorbed doses calculated on the basis of cytogenetic data. These values are from 81 to 474 mGy in the groups of people exposed to radiation in 1986. The highest level of absorbed doses was recorded for the CNPP personnel, dosimetrists and sarcophagus builders.

It should be noted that the results of dose assessment obtained from the dose-effect curve in vivo (15) completely agree with the real dose situation in Chernobyl while the dose estimate by the calibration curve of Lloyd et al. (23) generated under high dose rate conditions needs correction in view of the peculiarities of dose formation in Chernobyl. The correction factor is apparently equal to the ratio of α coefficients in corresponding regression equations: 0.018 (15) and 0.011 (23) dicentrics per 1 Gy per cell. This ratio in the given case is 1.6. It should also be stressed that according to the data presented in the report of UNSCEAR 1982 (1) the accepted coefficients for different genetic effects are 2.0 upon transition from acute exposure conditions to prolonged exposure and 3.0 upon transition from acute exposure to chronic exposure.

Beginning in 1990, the cytogenetic examination of the liquidators was continued in the Moscow Research Institute of Diagnostics and Surgery of the Ministry of Health and Medical Industry of the Russian Federation (16, 24-26). Over 400 individuals involved in reconstruction works in 1986-1987 have been examined. As a rule, the dose officially recorded in the documents did not exceed 250 mSv. For a significant part of the liquidators (about 30%) information on absorbed doses was lacking. Particular attention was given to the formation of a control group. This group consisting of 82 persons included those who had never had contact with ionizing radiation and had never been subjected to therapeutic and serious diagnostic irradiation. The frequency of dicentrics and centric rings in the control group made up 0.2 ± 0.1 per 1,000 cells (26,849 metaphases analyzed). Cytogenetic examination involved analysis of the frequency of unstable aberrations (dicentrics and centric rings) by the conventional method and analysis of the frequency of stable translocations by the FISH method.

Table 2 gives the main results of cytogenetic examination obtained using the conventional method. Throughout the whole follow-up period, beginning from 1990, the level of cells with unstable aberrations - dicentrics and centric rings - significantly differed from the control. Only in 1995 the frequency of cells with dicentrics and centric rings was at the control level (group 6).

Thus, despite a long period of time after the exposure, a high level of cells with unstable aberrations was preserved in peripheral blood of the examined people.

Analysis of the frequency of stable translocations with the FISH method was carried out in 53 liquidators who worked in Chernobyl in 1986 and in 12 persons from the control group. The cytogenetic study was performed in 1994-1995, i.e. 8-9 years after the accident. The data of this study are presented in Table 3. In the group of liquidators, the frequency of cells with translocations exceeds that in the control group nearly 4-fold. On this basis of the data obtained, an absorbed dose was assessed using the calibration dose-effect curve for acute radiation exposure generated after ^{137}Cs gamma-irradiation of whole blood in the range of 0 to 3 Gy (33). This dose made up 200 mGy. 32 out of 53 examined liquidators had official data on absorbed doses, but no dependence of the frequency of cells with translocations on the radiation dose value was revealed (r=0.143, p=0.44).

Table 4 demonstrates the results of cytogenetic examination with the FISH method for a group of liquidators who had dosimetric data and for liquidators for whom such information was not

Table 2 Results of cytogenetic analysis of lymphocytes in the liquidators and the control group

[(Mean ± SEM) $\times 10^{-3}$]

Group (year of sampling)	Number of persons	Number of cells scored	Number of cells with aberrations	Cdr	a c e
I (1990)	23	4268	14.9 ± 1.9*	1.0 ± 0.5*	5.3 ± 1.1
II (1991)	110	20077	19.7 ± 1.0*	0.9 ± 0.2*	6.8 ± 0.6*
III (1992)	136	32000	31.8 ± 1.0*	1.4 ± 0.2*	9.0 ± 0.5*
IV (1993)	75	18581	34.8 ± 1.4*	0.9 ± 0.2*	11.9 ± 0.8*
V (1994)	60	18179	31.8 ± 1.3*	1.8 ± 0.3*	10.3 ± 0.8*
VI (1995)	41	12160	18.8 ± 1.2*	0.4 ± 0.2	7.3 ± 0.8*
Control	82	26849	10.5 ± 0.6	0.2 ± 0.1	3.9 ± 0.4

Level of significance * - $p< 0.05$; SEM, standard error of the mean;
Cdr, cells containing dicentrics and/or centric rings; ace, acentrics.

Table 3 Frequency of symmetrical translocations in a group of liquidators (pooled data) and in the control group

Group	Number of persons	Number of cells scored	Number ofstable translocations	($F_P \pm$ SEM) $\times 10^{-2}$	($F_G \pm$ SEM) $\times 10^{-2}$	Estimated dose(mGy)
Liquidators	53	45007	166	0.37 ± 0.03*	1.17 ± 0.05	200 (100,300)
Control	12	13586	13	0.10 ± 0.03	0.32 ± 0.05	-

Level of significance * - $p< 0.05$; SEM, standard error of the mean;
F_P, translocations/cell; F_G, genomic translocation frequency.

available. A higher level of cells with translocations was established in the second group including liquidators whose absorbed doses were not officially documented.

Table 5 presents the data of individual cytogenetic analysis with the FISH method for 10 liquidators in whom the frequency of cells with translocations significantly differed from the control level. For these patients, the absorbed radiation doses were estimated in the range from 300 to 1,000 mGy.

It is important that all the above estimates of absorbed doses based on the FISH method were made without corrections for prolonged and chronic exposures.

Thus, the liquidators examined immediately after the exposure to radiation displayed a high level of unstable chromosome aberrations which permitted us to estimate average absorbed doses depending on the character of their work in the range of 81-474 mGy. It was revealed that the level of cells with unstable chromosome aberrations - dicentrics and ring chromosomes - decreases in time but over 8 years after the exposure it exceeded the control level. The use of unstable aberrations for the purposes of biological dosimetry in case years have passed since the exposure occurred requires an experimental determination of a temporal parameter characterizing the dynamics of reduction of the level of such aberrations.

Analysis of the frequency of stable translocations with the FISH method is more promising for biological dosimetry since it permits estimating absorbed doses irrespective of the time post exposure. The cytocenetic examination (analysis of stable translocations) of the liquidators working in Chernobyl demonstrates the possibility of assessing absorbed doses within 8-9 years after the action of ionizing radiations. It should be pointed out that the individual doses were not always in agreement with the dosimetric data presented in the official documents of these people. The scatter in the dose values in the group of examined liquidators

Table 4 requency of symmetrical translocations in two groups of liquidators (with and without official doses)

Group	Official dose	Number of persons	Number of cells scored	Number of stable translocations	($F_P \pm$ SEM) $\times 10^{-2}$	($F_G \pm$ SEM) $\times 10^{-2}$	Estimated dose(mGy)
I	YES	32	26947	84	0.31 ± 0.03	0.98 ± 0.06	100 (0,200)
II	NO	21	18060	82	0.45 ± 0.05	1.43 ± 0.09	300 (200,400)

F_P, translocations/cell; F_G, genomic translocation frequency.
SEM, standard error of the mean.

Table 5 Frequency of translocations (detected by FISH), dicentrics and rings (obtained with conventional scoring) and individual dose estimates (95% CL)

Pat-ient No	Docum-ented dose (mGy)	FIS H m e t h o d					Conventional method		
		cells scored	translo cations	F_P±SEM $\times 10^{-2}$	F_G±SEM$\times 10^{-2}$	Estimated dose(mGy)	cells scored	Dic+ Rc	(dic+Rc) /cell±SEM$\times 10^{-2}$
1	-	583	6	1.03 ±0.42	3.27 ±0.75	600 (400,800)	250	0	0
2	-	1016	15	1.48 ±0.38	4.70 ±0.68	700 (600,800)	1000	8	0.80 ±0.28
5	145	1297	8	0.62 ±0.22	1.97 ±0.39	400 (300,500)	300	0	0
6	170	1314	10	0.76 ±0.24	2.42 ±0.43	400 (300,500)	300	0	0
9	-	473	11	2.33 ±0.69	7.40 ±1.25	1000 (800,1200)	300	3	1.00 ±0.58
12	-	1161	9	0.77 ±0.25	2.44 ±0.46	400 (300,500)	300	2	0.67 ±0.47
34	-	1157	6	0.52 ±0.21	1.65 ±0.38	300 (200,400)	300	0	0
35	-	1209	7	0.58 ±0.22	1.84 ±0.39	300 (200,400)	300	0	0
44	800	1688	11*	0.59 ±0.19	1.87 ±0.33	300 (200,400)	300	0	0
45	293	857	6	0.70 ±0.29	2.22 ±0.51	400 (300,500)	300	0	0

*;10 cells.

Table 6 Frequency of unstable chromosome aberrations in blood lymphocytes in the Altai population

[(M ± SEM) ×10^{-3}]

Group	No of per-sons	No of cells	Cells with aberr-ations	Total number of aberrations	dic + R_c	a c e	C_{dr}	Chromatid aberra-tions
Tyumentsevo (control)	30	7831	10.2 ±1.1	10.7 ±1.2	0.3 ±0.2	5.7 ±0.9	0.3 ±0.2	4.7 ±0.8
Ugly	15	1958	7.8 ±2.0	16.8 ±2.9	3.7 ±1.4*	9.2 ±2.2	1.0 ±0.7	3.1 ±13
Ozernoye-Kuznetsovo	12	1523	12.0 ±2.8	12.0 ±2.8	0.7 ±0.7	6.0 ±1.9	0.7 ±0.7	5.4 ±1.9
Zelenaya Dubrava	24	2749	31.6 ±3.4*	32.0 ±3.4*	1.1 ±0.6*	8.1 ±1.7	1.1 ±0.6*	22.1 ±2.8*
Laptev Log	84	22195	14.4 ±0.8*	16.5 ±0.9*	3.1 ±0.4*	5.3 ±0.5	1.9 ±0.3*	7.6 ±0.6*
Naumovka	26	4275	16.8 ±2.0*	17.5 ±1.9*	2.6 ±0.7*	6.2 ±1.3	2.6 ±0.7*	8.8 ±1.4*
Belenkoye	35	9069	13.6 ±1.2*	16.9 ±1.4*	1.3 ±0.4*	7.3 ±0.9	1.2 ±0.4*	7.5 ±0.9*
Topolnoye	30	6530	20.4 ±1.8*	20.5 ±1.8*	1.7 ±0.5*	6.2 ±1.0	1.7 ±0.5*	12.3 ±1.4*

Level of significance * - $p<0.05$; SEM, standard error of the mean;
dic, dicentrics; R_c, ring chromosomes; ace, acentrics; C_{dr}, cells containing dic+R_c.

constituted up to 1 Gy. However these values may appear to be underestimated as the calculations were made without corrections for prolonged and chronic exposures.

B. Cytogenetic examination of the Altai population exposed to ionizing radiations as a result of nuclear explosions on the Semipalatinsk nuclear test site

As a result of nuclear tests in the air on the Semipalatinsk nuclear test site in 1949-1962, a number of regions of the Altai Territory were exposed to the action of high doses of ionizing radiations capable of inducing serious genetic effects. According to the data of the Semipalatinsk nuclear test site (27), radioactive products from more than 50 explosions made in the air and on the earth for a period from 1949 till 1962 spread in the direction of the Altai Territory. A collective effective dose from the first nuclear explosion in 1949 made up 32,000 man-Sv. A total dose for the Altai population from all subsequent explosions is estimated at 10,000 man-Sv. Thus, the contribution from the explosion in 1949 constitutes about 80% of the total collective effective dose received by the Altai population as a result of nuclear tests on the Semipalatinsk test site (27).

The dotted line indicates the rates of cells with chromosome aberrations in a group of Moscow citizens. Absciss - dose, Sv; ordinate - the number of cells with dicentrics and rings per 1,000 cells.The study of genetic impacts from nuclear explosions for the Altai population was started only when several decades had passed since the radiation exposure. This fact creates a unique situation in estimating genetic effects in the exposed part of the population - it is necessary to choose approaches enabling the study of genetic effects within such a long time after the exposure.

In this section, we present the materials of cytogenetic examination of people from 7 settlements of the Altai region (226 individuals) that suffered most greatly from the explosion in 1949 (21, 22, 28).

In 1992, blood samples were collected in the following settlements: Uglovskoye (average dose - about 0.1 Sv), Ozernoye-Kuznetsovo (about 0.1 Sv), Laptev Log (0.97 Sv) and Topolnoye (2.43 Sv). Later on, in 1993 and in 1994, cytogenetic examinations were continued in the villages Zelyonaya Dubrava (0.18 Sv), Belenkoye (1.87 Sv) and Naumovka (1.86 Sv). The village Tyumentsevo was chosen as a control (0.05 Sv). The social-economic and climatic-geographic conditions were analogous for all examined groups.

The results of these cytogenetic studies are presented in Table 6. In addition to chromatid aberrations (mainly single fragments), the spectrum of aberrations included chromosome aberrations: acentric fragments, centric rings, dicentric and even tricentric chromosomes. Atypical monocentric chromosomes resulting from translocations were also detected. In some exposed individuals cells with multiple chromosome aberrations were found.

In the populations of Zelyonaya Dubrava, Laptev Log, Naumovka, Belenkoye and Topolnoye the frequency of aberrant metaphases significantly

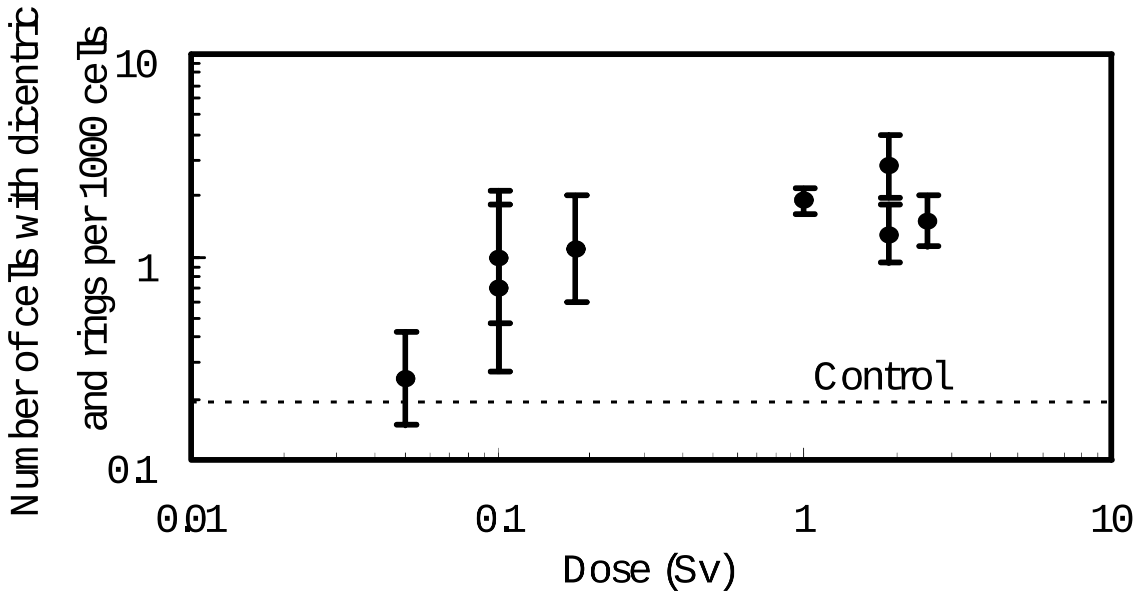

Fig. 1. The frequency of cells with dicentrics and centric ring chromosomes in the examined groups of the Altai population depending on the effective dose of irradiation caused by the nuclear explosion on the Semipalatinsk nuclear test site in 1949.

exceeds the control level. In the same populations, a statistically significant excess over the control level by the frequency of chromatid aberrations was observed. No differences were found by the frequency of acentric fragments (non-associated with dicentrics and centric rings), except an increased frequency of acentric fragments in the inhabitants of the village Belenkoye ($p<0.05$).

Most informative in respect of biological dosimetry are dicentrics and centric ring chromosomes as recognized markers of radiation effects (5). For all examined populations, except the village Ozernoye-Kuznetsovo, the average rate of cells with dicentrics and centric rings (C_{dr}) significantly exceeds the control level. The frequency of these chromosomes in the examined groups of people from the villages Uglovskoye, Naumovka, Laptev Log, Topolnoye, Belenkoye and Zelyonaya Dubrava exceeds the control level 12-fold, 9-fold, 6-fold, 6-fold, 4-fold and 3.5-fold, respectively.

Fig. 1 shows the frequency of cells with dicentrics and centric rings in the inhabitants of several settlements of the Altai region depending on the values of effective doses presumably absorbed by them. These doses were estimated on the basis of experimental measurements and with the help of mathematical simulation performed by the Central Physical-Technical Institute of the Ministry of Defence of the Russian Federation (29).

Statistical analysis of the results presented in Fig. 1 was performed on the basis of linear dose-effect relationship. Approximating equation coefficients were determined by the method of maximum likelihood assuming Poisson distribution. The following linear regression equation was derived:

$$y = (0.8 \pm 0.2)\times 10^{-3} + (0.6 \pm 0.2)\times 10^{-3} \times Sv^{-1} D,$$

where y is the frequency of cells containing dicentrics and centric rings (C_{dr}), D - dose. The level of significance of the linear regression coefficient is $p<0.05$. The results of the study clearly demonstrate that despite a long post-exposure time (several decades) an increased number of cells with unstable chromosome aberrations, the level of which depends on the effective dose value, is observed in peripheral blood of the examined people. It can be inferred that the source of such cells carrying dicentrics and centric ring chromosomes are radiation-injured stem cells of blood-forming tissue.

Among 40,777 cells analyzed in the examined groups of the Altai population 10 cells were found to have multiple chromosome aberrations. The distribution of multiaberrant cells among these groups and their characteristics are shown in Table 7. One multiaberrant cell containing five acentric fragments was found in peripheral blood of the examined persons from Tyumentsevo (control group). Multiaberrant blood cells, including dicentrics, tricentrics and centric rings, were discovered in the examined inhabitants from the settlements exposed to ionizing radiations. The frequency of multiaberrant cells in them is higher than in the control group.

The nature of such multiaberrant cells is not completely understood yet (30, 31). Probably they are induced by chemical or biological mutagenic factors. One of possible explanations of the nature of such cells is the action of densely-ionizing radiations, and first of all, of alpha-particles of various radionuclides, assuming their high concentration in the human body. Since ^{239}Pu, a source of alpha-particles, is a component of the mixture of products of the nuclear explosion that affected the Altai population, it can be inferred that the entry of plutonium into the human organism caused the appearance of multiaberrant cells. This hypothesis is confirmed by the data of A. M. Marenny et al. (32) who detected hot particles (a source of alpha-radiation) in the lungs and in the lymph nodes of ten patients from the radionuclide-contaminated regions of Altai who were operated from lung cancer.

Thus, within 43-45 years after the first nuclear explosion on the Semipalatinsk nuclear test site in 1949, the inhabitants of all examined settlements revealed an increased frequency of unstable

Table 7 Frequency of multiple cells in blood lymphocytes of people from different radionuclide-contaminated areas

Group	Patients *	Age (Year of birth)	Sex	Description of multiple cells
Muslyumovo (116 persons)	1	1949	f	tric-2; dic-3
	2	1975	m	tric-2
	3	1950	f	dic-8; ace-4
	4	1980	m	dic-2
	5	1915	f	tet-1; tric-1; dic-1
	6	1958	f	dic-2
Altai (178 persons)	1	1947	m	dic-2
	2	1945	m	ace-9; SF-1
	3	1930	m	tric-5;dic-5;Rc-1;t-2
	4	1941	m	dic-3; ace-1
	5	1956	m	dic-1; ace-2;
	6	1949	f	dic-2;tric-2; ace-11
	7	1935	m	tric-2;dic-2;t-1;ace-5
	8	1949	f	dic-2; ace-7
	9	1961	m	dic-2
	10	1946	m	dic-1; ace-2
Control (30 persons)	1	1962	f	ace-5

dic, dicentric; tric, tricentric; tet, tetracentric; R_C, centric ring;
ace, acentric (double fragment); SF, single fragment; t-translocation;
* people with multiple aberrations

Table 8 Frequency of symmetrical translocations (FISH method) in blood lymphocytes in the Altai population

Group	No of persons	No of cells scored	No of translo-cations	$(F_P \pm SEM)\times10^{-2}$	$(F_G \pm SEM)\times10^{-2}$
Laptev Log	14	7026	29	0.41 ±0,08*	1.29 ±0,11
Belenkoye	6	3213	18	0.56 ±0,13*	1.76 ±0,19
Topolnoye	4	2762	11	0.40 ±0,12*	1,26 ±0,17
Altai region (Total)	24	13001	58	0.45 ±0.06*	1.42 ±0.10
Control	12	13586	13	0.10 ± 0,03	0.32 ±0,05

Level of significance * - $p<0.05$; SEM, standard error of the mean; F_P, translocation/cell; F_G, genomic translocation frequency; m, standard error of the mean.

Table 9 Frequency of symmetrical translocations (FISH method) in blood lymphocytes in the Laptev Log (Altai region) population

Group	No. of persons	No.of cells scored	No. of translocations	$(F_p \pm SEM)\times10^{-2}$	$(F_G \pm SEM)\times10^{-2}$
I (born before 1949)	8	4271	25	0.58 ± 0.12*	1.82 ±0.17
II (born after 1949ã)	6	2755	4	0.14 ± 0.01	0.44 ± 0.10
Control	12	13586	13	0.10 ±0.03	0.32 ±0.05

Level of significance * - $p<0.05$; SEM, standard error of the mean;

chromosome aberrations, mainly dicentrics and centric rings. The frequency of cells with such chromosome aberrations was linearly related to effective doses presumably accumulated by the populations of the examined settlements. At present, it is hard to say anything about the initial level of dicentrics and centric rings immediately after the explosion since the dynamics of these chromosome aberrations for a period of several decades is unknown. This hinders the use of the presented data for the reconstruction of absorbed doses in the Altai population.

The results of cytogenetic examination of the Altai population with the FISH method are presented in Table 8. The average levels of translocations for the populations of Laptev Log, Belenkoye and Topolnoye are 0.41 per 100 cells, 0.56 per 100 cells and 0.40 per 100 cells, respectively. These values significantly exceed our control level and therefore it is safe to assume the presence of radiation-induced changes in the cell chromosome apparatus in the examined persons. As noted above, about 80% of the external radiation dose falls on the explosion made in 1949; therefore people born before 1949 received the highest doses. In connection with this, the results of examination of this group of the population should be analyzed separately. For example, the group of examined persons from the village Laptev Log included those born before and after 1949. As seen in Table 9, the average level of stable translocations for 8 individuals born before 1949 is 0.58 per 100 cells and for 6 individuals born after 1949 it is 0.14 per 100 cells. In the first group, the frequency of stable translocations is more than 5 times higher than in the control, and in the second group the frequency of stable translocations does not differ from the control level. The data obtained are far from being sufficient to make any final conclusions, however even these results confirm the fact that the most affected part of the population are people born before 1949 and that they must be, in the first turn, in the focus of attention when undertaking medical and preventive measures.

The absorbed dose value estimated by the frequency of stable translocations for three villages, Laptev Log, Belenkoye and Topolnoye, is about 300 mGy. It should be mentioned that this value was obtained using the linear-quadratic dose-effect model for acute exposure (33). The situation observed in the Altai region due to surface nuclear explosions is much more complicated in terms of dosimetry than that could be assessed with the use of this model. It is important to take into account the long-term chronic irradiation from external and internal radiation sources (29). A true estimate of effective doses based on the frequency of stable aberrations can be obtained only given clear-cut data on the dynamics of irradiation of the population both during the nuclear test period and after it. A correction factor 3 is usually used for assessing chronic irradiation doses (1). Hence it follows that in the case of the exposure that took place in the Altai region the linear-quadratic model yields underestimated dose values. In view of the above-stated, the average dose for the examined groups of the population calculated on the basis of cytogenetic analysis makes up about 1 Gy.

It is obvious that the values of absorbed doses for the part of the Altai population exposed to ionizing radiations from nuclear explosions on the Semipalatinsk nuclear test site will be corrected with accumulation of cytogenetic data obtained by the FISH method.

C. Cytogenetic examination of the population of Muslyumovo located on the banks of the radionuclide-contaminated Techa river

In 1949-1951, the plutonium-producing plant (“Mayak”) in the Chelyabinsk region discharged radioactive waste products (a total of 2.76 mln Ci) into the open hydrosystem of the rivers Techa, Iset, Tobol (34). 124,000 people, including 28,100 of those living on the Techa banks, were exposed to radiation. The doses of exposure were rather high - a collective dose made up about 6,000 man-Sv. Nearly 7,500 individuals evacuated from 20 settlements received, according to official data, average effective equivalent doses from 3.5 to 170 cSv (34). The highest radiation doses were recorded for the evacuated population of the village Metlino (170 cSv, 1,200 people). Among non-evacuated settlements, the most serious radiation situation remains in Muslyumovo (30 km from the Mayak plant). In 1949, the population of this settlement was 4,000 people, and at present it is about 2,500 people. The level of exposure here is critical - an average bone marrow dose is 0.25 Gy. In nearly 5% of the population an average bone marrow dose is 1 Gy (35). The first medical examinations were organized within 2 years after the discharge of radioactive waste products into the Techa river only for the population of one settlement in the upper reaches of the river - Metlino. In other settlements the medical examination was started only after 3-6 years. The register of exposed people living along the river was initiated only in 1968. These facts in combination with a high migration of the exposed population has created a situation in which the assessment of remote radiation effects becomes rather difficult.

At the same time, even the first studies showed that the exposure of people in the upper reaches of the Techa river had led to the development of chronic radiation sickness (particularly in Metlino where this disease was diagnosed in 1956 in 64.7% of the adult population and in 63.15% of examined children) (36). Chronic radiation sickness was revealed in a total of 935 people. An increase in the incidence of leukoses in the examined population was established. For a period of 33 years, 52 cases of hemoblastoses were recorded, including 37 leukosis patients among 17,200 people examined since 1950, which is by 15 cases more than expected without irradiation.

Besides chronic radiation sickness, a decrease in immunologic reactivity, depression of hemopoiesis, an increase in cases of vegetovascular dystonia, hypertensive disease, pathologic pregnancy and labor, and increased infantile mortality were recorded in the inhabitants of the riverside settlements. As shown in the work by M. M. Kosenko and M. O. Degteva (36), the mortality from cancer increased in 1950-1982 as compared to a group of people living in non-contaminated areas with similar social-economic conditions.

Cytogenetic examinations of the population of Muslyumovo were performed in 1993-1994. The examination was carried out on a total of 116 persons. The data of the cytogenetic analysis were compared with the results of examination of the control group (30 individuals, 7,831 metaphases analyzed) formed of the inhabitants from a non-contaminated region of the Altai. In view of the tasks of the examination, all people were divided in several groups. The first group included all examined people. The second group united inhabitants of Muslyumovo born before 1949 (beginning of the contamination of the Techa river) and living there permanently. The third group was composed of people born from 1949 till 1956 (this time is characterized by the highest level of contamination of the Techa river). The fourth group consisted of people born after 1957, and the fifth group was formed of migrants, i.e. people who came to Muslyumovo at different times, including those evacuated from villages exposed to radioactive contamination.

Table 10 presents the results of cytogenetic examination by the conventional method (analysis of unstable chromosome aberrations). In all groups, the frequency of chromosome aberrations exceeded the control level. It is worth noticing that the value of this frequency was higher in the second and third groups. In all examined groups exchange aberrations (dicentrics and centric rings) were revealed, and their frequency significantly exceeded (5-10-fold) that in the control group. The highest frequency of dicentrics and centric rings, as well as cells containing such aberrations, was noted in the second and third groups. These results are presented in Fig. 2. The frequency of acentric fragments did not differ significantly in the groups of examined people from Muslyumovo and in the control group. In all examined groups an excess over the control level by the frequency of chromatid aberrations was observed.

Cells with multiple chromosome aberrations were found in the examined persons from Muslyumovo (Table 7). On the whole, 6 multiaberrant cells were discovered among 32,203 analyzed metaphases, including tricentric and tetracentric cells which are not practically found normally.

It can be assumed that the appearance of cells with multiple aberrations is the result of the action of alpha-radiation from plutonium and its fission products (30, 31, 37). According to A. V. Trapeznikov et al. (38), the Techa river contains about 8 Gbq $^{239,240}Pu$. This estimate was made within the river section from 50 km to 240 km from the Mayak plant, i.e. up to the place of confluence with the Iset river.

Thus, the cytogenetic study carried out in Muslyumovo revealed an increased level of

Table 10 Cytogenetic results obtained in a human population continually exposed to low doses of radiation in the South Urals, Chelyabinsk area, Muslyumovo

(M ± SEM) x 10^{-3}]

Group	No of persons	No of cells	Cells with aberrations	Total number of aberrations	dic + R_c	a c e	C_{dr}	Chromatid aberrations
1	116	32203	14.4 ±0.7*	15.3 ±0.7*	2.2 ±0.3*	5.4 ±0.4	1.4 ±0.2*	7.6 ±0.5*
2	23	6730	19.3 ±1.7*	19.4 ±1.7*	2.7 ±0.6*	6.6 ±1.0	1.9 ±0.5*	9.8 ±1.2*
3	46	5730	15.8 ±1.7*	17.2 ±1.7*	3.2 ±0.7*	7.6 ±1.1	2.1 ±0.6*	6.3 ±1.1*
4	49	14052	11.9 ±0.9	12.4 ±0.9	1.5 ±0.3*	3.3 ±0.5	1.1 ±0.3*	7.6 ±0.7*
5	21	5691	13.3 ±1.5	15.4 ±1.6*	2.2 ±0.6*	6.7 ±1.1	0.9 ±0.4	6.4 ±1.1
Cont-rol	30	7831	10.2 ±1.1	10.7 ±1.2	0.3 ±0.2	5.7 ±0.8	0.3 ±0.2	4.7 ±0.8

1, total; 2, born before 1949; 3, born in 1949-1956; 4, born in 1957-1988; 5, migrants.
Level of significance * - $p<0.05$; SEM, standard error of the mean;

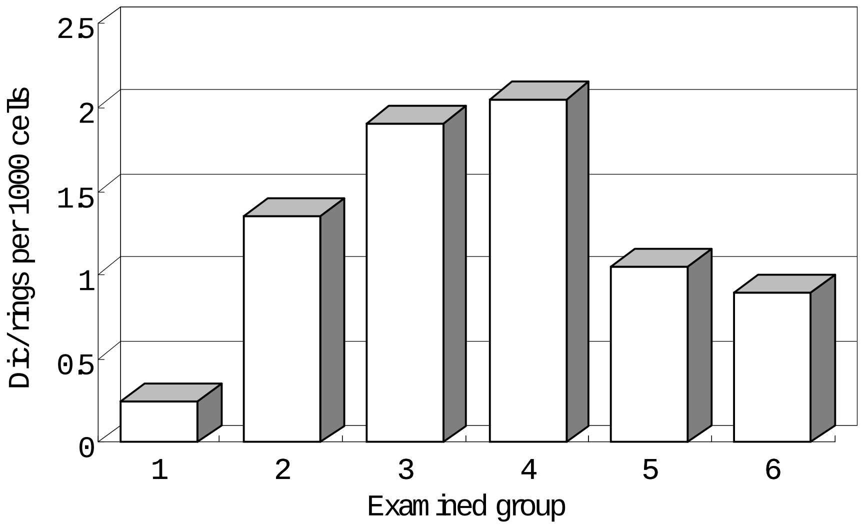

Fig. 2. The frequency of cells with dicentrics and centric ring chromosomes in the examined groups of the population of Muslyumovo (Chelyabinsk region).
1 - control group; 2 - all examined individuals; 3 - born before 1949;4 - born in the period from 1949 to 1956; 5 - born in the period from 1957 to 1988; 6 - evacuated from other settlements.

chromosome aberrations of the exchange type - dicentrics and centric rings - which are characteristic of ionizing radiation exposures. The highest level of such aberrations (9-10 times exceeding the control) was detected in the people born before 1949 or in the period of the most significant contamination of the Techa river with radionuclides. Cells with multiple chromosome aberrations detected in the blood of the examined inhabitants of Muslyumovo seem to be the result of organism exposure to densely-ionizing alpha-radiation from plutonium and its radioactive products.

D. Cytogenetic examination of the population from the neighborhood of the Three Mile Island nuclear power plant in USA

In 1979, an accident occurred at the Three Mile Island (TMI) Nuclear power plant (unit ¹2) located within several miles from the capital of Pennsylvania, Harrisbugr (USA). The extent and consequences of this accident have not been uniquely assessed yet. According to the official data stated in the NUREG report in 1980 (39), no impact from this accident on the population, flora and fauna is expected. At the same time, the discovery of radioactive iodine in the air, calculations of experts concerning the extent of possible discharges of radioactive inert gases, publications of scientists on radiation effects in trees and animals observed after the accident prompt the public and scientists to perform new studies for assessing the impacts from this nuclear incident (40).

In 1994-1995, cytogenetic examinations of the population living in the neighborhood of the TMI nuclear power plant were carried out. The aim of this study was to analyze the level of unstable and stable chromosome aberrations in people assumed to be exposed to ionizing radiations due to the TMI accident. The basis for such assumption were the signs of radiation damages in people (skin reddening, peculiar metallic smack in the mouth, irritation of mucous membranes, vestigo, vomiting, diarrhea, etc.) at the moment of the accident and also a number of diseases that occurred some time later.

The cytogenetic study was carried out in July-August, 1994 and in January-February, 1995. In selecting a group of patients, their possible diagnostic and therapeutic irradiation as well as a number of additional factors that might influence the results of cytogenetic analysis were taken into account. The results of the study are presented in Table 11 and in Fig. 3. Given a relatively normal general level of chromosome aberrations, a significant increase in the frequency of cells containing chromosome aberrations, namely dicentrics, was recorded. In the group of examined people from the TMI region this rate exceeded 10-fold the control level (0.2×10^{-3} dicentrics per 1,000 cells). Dicentrics were found in 20 persons, i.e. in 70% of cases. The rate of cells containing exchange aberrations (dicentrics) varied from 0.2 to 0.8% and exceeded the control level 10-40-fold, respectively. In one patient, a cell with tricentric was discovered.

The obtained results suggest that the group of examined individuals from the TMI neighborhood presumably exposed to the action of ionizing radiations as a result of the accident at the nuclear

Table 11 Frequency of unstable chromosome aberrations in blood lymphocytes from persons living in the neighborhood of TMI

[(M ± SEM) × 10^{-3}]

Groups	Number of persons	Number of cells scored	Total number of aberrations	Cdr	ace	Chromatid aberrations
Population	29	14854	14.0±1.0*	2.0±0.4*	4.0±0.5	7.0±1.0
Control	82	26849	10.9±0.6	0.2±0.1	3.9±0.4	6.6±0.5

Level of significance * - $p<0.05$; SEM, standard error of the mean;
Cdr, cells containing dicentrics and/or centric rings.

Table 12 Frequency of symmetrical translocations detected by FISH and results of conventional cytogenetic examination of persons living in the neighborhood of TMI.

Groups	FISH method				Conventional scoring		
	Cells svored	Translo cations	(Fp±SEM) × 10^{-2}	(F_G±SEM) × 10^{-2}	Cells scored	Cdr	(Cdr ± SEM) ×10^{-2}
Population	3468	17	0.49±0.12*	1.55±0.21	3024	14	0.46±0.12
Control	13586	13	0.10±0.03	0.32±0.05	26849	5	0.02±0.01

F_P, translocations/cells; F_G, genomic translocation; Level of significance * $p<0.05$; SEM, standard error of the mean; C_{dr}, cells containing dicentric and/or centric rings.

power plant is characterized by an increased frequency of chromosome exchange aberrations - dicentrics.

In 6 persons from the examined group the rate of stable translocations was analyzed with the FISH method. Cells with translocations were found in peripheral blood of all examined people, and the level of these cells exceeded the control; in 3 persons these differences were statistically significant. Table 12 demonstrates the data on the frequency of translocations in the group of examined people from the TMI neighborhood. It is seen that its value exceeds 5-fold the control level. Here the frequency of translocations per genome (F_G) and the results of traditional cytogenetic analysis (analysis of unstable aberrations) are also presented.

The ratio of stable and unstable aberrations is assumed to be 1:1 (10, 11). The prevalence of cells with translocations indicates that for a period of 15 years after the accident the level of cells with unstable chromosome aberrations decreased due to their elimination from the blood channel. Despite a rather high level of cells with dicentrics, the retrospective dose assessment in this case is hardly feasible.

The frequency of cells with translocations in peripheral blood of the examined individuals living in the neighborhood of TMI is 0.49±0.06 per 100 cells. This value is close to the level of cells with translocations observed in the Altai population (see Table 8). This fact permits the comparison of these groups with respect to absorbed radiation doses. In view of a limited amount of data (the number of examined persons, the number of metaphases analyzed), an average absorbed dose was determined for the whole examined group of people. On the basis of the obtained cytogenetic data and using calibration dose-effect curves (33) a dose estimate of 0.30±0.10 Gy was obtained. This dose is consistent with the situation of acute radiation exposure. In the case of prolonged and chronic exposure, which is more real for the situation observed after the TMI accident, the dose assessment should involve the use of correction factors 2-3. In this case an estimated dose for the exposed group of people is 0.6-0.9 Gy.

Thus, the cytogenetic examination of people living in the vicinity of the TMI nuclear power plant and presumably exposed to radiation as a result of the accident that took place in 1979 revealed in them an increased level of stable and unstable chromosome aberrations. This finding undoubtedly indicates that the examined group of people was affected by ionizing radiation. The preliminary data on the frequency of translocations obtained with the FISH method made it possible to estimate an average absorbed dose for the given group of examined persons. This value is 0.6-0.9 taking into account the prolonged or chronic character of the exposure.

Conclusion

The presented cytogenetic data obtained from the examination of different groups of people exposed to ionizing radiations permit us to make the following conclusions.

The use of the cytogenetic method for examining people exposed to radiation as a result of the Chernobyl accident, nuclear explosions on the Semipalatinsk nuclear test site, radioactive contamination of the Techa river (Chelyabinsk region) and as a result of the accident at the TMI nuclear power plant (USA) revealed increased levels of unstable and stable chromosome aberrations as compared to the control.

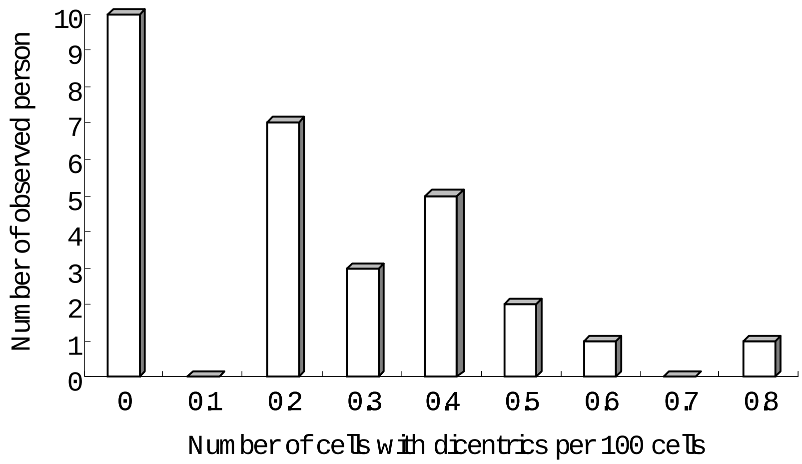

Fig. 3. The distribution of the inhabitants from the TMI region depending on the number of cells with dicentrics.

Dose estimations in the liquidators working in Chernobyl made on the basis of the frequency of unstable chromosome aberrations (dicentrics and centric rings) using the materials of examinations carried out in 1986 yielded values from 81 to 474 mGy.

The level of cells with unstable chromosome aberrations was found to decline in time. At the same time, during 8 years after the accident in Chernobyl this level in the examined people exceeded the control level.

The examination of the populations living in the Techa river region (Muslyumovo), in the Altai region and in the neighborhood of the TMI nuclear power plant (USA) revealed high levels of cells with dicentrics and centric rings significantly exceeding the control values. The detection of such chromosome aberrations within 15-45 years after the action of ionizing radiations suggests the preservation of a certain portion of cells with unstable chromosome aberrations in people with rather high doses. Multiaberrant cells found in the Altai population and in the population of Muslyumovo apparently suggest their exposure to densely-ionizing alpha-radiation from plutonium and its fission products.

As has already been noted, the most widely accepted and sufficiently accessible method of biological dosimetry based on the analysis of the frequency of unstable chromosome aberrations (dicentrics and centric rings) cannot be effectively employed for retrospective assessment of absorbed doses without clear-cut knowledge about the character and rate of temporal elimination of cells containing such chromosome aberrations. Only when there is a possibility of reconstructing the picture of an exposure (dose range, exposure conditions, post-exposure time) using mathematical simulation one can try to make dose estimates by the frequency of cells with dicentrics and centric rings. Otherwise, particularly upon exposure to low doses, when much time has passed since the exposure occurred, the use of this method of biological dosimetry is of low efficiency and practically unfeasible in most cases.

Analysis of stable translocations is presently the most promising method in retrospective assessment of irradiation doses. The efficiency of this method particularly increased after the development of the technology for scoring stable translocations - fluorescence in situ hybridization (FISH) - which permits the cytogenetic analysis to be performed rather easily (41, 42).

The presented results of cytogenetic examination of the liquidators in Chernobyl demonstrate the possibility of dose assessment within 8-9 years after the accident. The range of absorbed doses in the group of examined people appeared to be up to 1 Gy from the background level.

Retrospective assessment of individual doses, particularly in the low dose range, based on the FISH method is impeded by the fact that in order to obtain reliable results it is necessary to analyze a rather large number of cells, which is impossible for several reasons. This task is simplified when we deal with retrospective assessment of a dose for a definite group of people. The obtained cytogenetic data are a good illustration of that. The absorbed dose estimated with the FISH method, taking into account the character of exposure for the populations of three villages of the Altai region, is about 1 Gy and for the population of the TMI region (USA) it varies from 0.6 to 0.9 Gy.

It should be noted in conclusion that the importance of analysis of stable translocations for retrospective dose assessment by no means minimizes the role of cytogenetic examination with the use of the conventional method (analysis of unstable chromosome aberrations) that remains to be decisive in the case of long-term monitoring in human populations from regions with an unfavorable ecological situation.

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Estimation of Absorbed Doses on the Basis of Cytogenetic Methods

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Introduction

Long-term studies in the field of radiation cytogenetics have resulted in the discovery of relationship between induction of chromosome aberrations and the type of ionizing radiation, their intensity and dose. This has served as a basis of biological dosimetry as an area of application of the revealed relationship, and has been used in the practice to estimate absorbed doses in people exposed to emergency irradiation [1,2]. The necessity of using the methods of biological dosimetry became most pressing in connection with the Chernobyl accident in 1986, as well as in connection with other radiation situations that occurred in nuclear industry of the former USSR.

The materials presented in our works [3-8] demonstrate the possibility of applying cytogenetic methods for assessing absorbed doses in populations of different regions exposed to radiation as a result of accidents at nuclear facilities (Chernobyl, the village Muslyumovo on the Techa river, the Three Mile Island nuclear power station in the USA where an accident occurred in 1979). Fundamentally, new possibilities for retrospective dose assessment are provided by the FISH-method that permits the assessment of absorbed doses after several decades since the exposure occurred [7]. In addition, the application of this method makes it possible to restore the dynamics of unstable chromosome aberrations (dicentrics and centric rings), which is important for further improvement of the method of biological dosimetry based on the analysis of unstable chromosome aberrations [9].

The purpose of our presentation is a brief description of the cytogenetic methods used in biological dosimetry, consideration of statistical methods of data analysis and a description of concrete examples of their application.

1. Analysis of chromosome aberrations for the purposes of biological dosimetry

Under the action of radiation the genetic materials of the human organism, as well as any living organisms, experience damages of DNA molecules resulting in chromosome breakage and further in various chromosomal rearrangements. Such rearrangements of chromosomes are observed visually in metaphases of dividing cells, for example, in stimulated human peripheral blood lymphocytes. Single breaks of DNA molecules result in the occurrence in metaphases of chromosome fragments clearly revealed by the cytogenetic analysis. It is important to note that ionizing radiation induces damages affecting both chromosome chromatids, which leads to the appearance of paired fragments (in contrast to single fragments resulting from the damage of one chromatid, which is most often observed under the influence of UV-rays and chemical mutagens). In case there are two and more breaks of DNA molecules in a cell, the broken ends can recombine, creating new rearranged chromosomal structures (dicentric chromosomes, ring chromosomes, translocations, inversions, deletions). With the usual methods of chromosome staining, the most clearly recorded under a microscope are dicentric chromosomes (a chromosome rearrangement with two centromeres taking place due to the association of two broken chromosomes) and centric ring chromosomes (a chromosome closed in a ring as a result of two breaks at the ends of this chromosome). As a rule, such chromosome rearrangements are accompanied by paired fragments (acentric terminal parts of chromosomes). Analysis of the frequency of such easily detectable chromosomal rearrangements in metaphases has formed the basis for the development of methods of biological dosimetry.

Two types of chromosome aberrations can occur under the influence of radiation: unstable (dicentrics, centric rings, acentric fragments) and stable (symmetric translocations, pericentric inversions etc.). The occurrence frequency of unstable aberration, namely dicentrics [10], is most often used to estimate absorbed doses. Sometimes the analysis takes into account centric rings, but their frequency is insignificant in comparison with the frequency of dicentrics (approximately 5-10%) [11].

The advantage of the analysis of the level of dicentrics in biodosimetric studies is that they are easily found with a optical microscope without using special methods of processing and staining. One of the requirements for correct application of this method of dosimetry is to analyse metaphases of the first cell cycle. This is due to the fact that during cell proliferation about 50% of dicentrics are lost during the first postradiation division. The control of the cell cycle with the use of special differential staining of chromosomes (FPG-method) allows us to avoid this mistake [12].

The spontaneous level of dicentrics is characterized by rather low values. Thus, the data on a relative level of dicentrics widely reported in publications show a significant interlaboratory variability of this value. The dicentric frequency in control groups may vary from 0 to $2.35\cdot10^{-3}$ per cell [11]. The average value of the frequency of dicentrics is within the range of $0.3\text{-}0.5\cdot10^{-3}$ per cell. Lloyd et al. [13] analyzed the data on the frequency of dicentrics in control groups of donors that were obtained in 65 different laboratories. An average dicentric level (the extreme values were not taken into account) made up $0.55\cdot10^{-3}$ per cell. In our experiments the spontaneous frequency of dicentrics for 82 donors having no contact with ionizing radiation made up 0.1-0.2 per 1,000 cells (26,849 metaphases analyzed). Thus, it is necessary to obtain reliable results on the spontaneous frequency of dicentrics in laboratories engaged in biological dosimetry in order to do correct assessment of radiation doses.

In experiments with animals [14] and in cytogenetic examinations of patients subjected to radiation therapy [15,16], it was shown that the frequency of dicentrics in lymphocytes of peripheral blood was comparable upon irradiation in vivo and in vitro. This fact is the main prerequisite for the use of calibration «dose - effect» curves obtained in vitro in biological dosimetric studies .

Special cytogenetic methods have been developed to register other exchange chromosome aberrations (inversions, deletions, translocations). The best known methods are G-banding and FISH. The latter was applied in our studies and therefore we shall discuss here the potentialities of this method.

In our experiments lymphocyte cultures and chromosomes preparation were prepared according to standard procedures [1]. Slides prepared for FISH analyses were stored at -20° C under nitrogen atmosphere until use. Slides for conventional analyses were stored for 5 days at room temperature and were then subjected to standard fluorescence plus Giemsa (FPG) staining.

Plasmid DNA of chromosome specific *Hind III* pBS libraries of human chromosomes 1, 4 and 12 [17] was biotinylated [18]. A degenerate a-satellite DNA pancentromeric probe was produced by in vitro amplification using a polymerase chain reaction (PCR) and labeled with digoxigenin [19]. Hybridization, detection of bound biotin-labeled painting probes for the target chromosomes with streptavidin-fluorescein isothyocyanate (FITC) conjugate and the bound digoxigenin-labeled pancentromeric probe with AMCA-labeled (7-amino-4-methylcoumarin-3-acetic acid) antibodies were carried out [19]. Counterstaning was performed with propidium iodide (PI) in antifade solution.

Conventional chromosome analysis was carried out exclusively in complete first division metaphases (M1) identified by uniformly stained sister chromatids. Recorded were all types of chromosomal damage but data are presented only for dicentrics and ring chromosome. About 300 cells were scored from each examined clean-up worker, each irradiated individual from contaminated regions and each control subject. For scoring FISH-painted exchanges, each metaphase spread was analyzed with a filter set allowing a simultaneous observation of FITC and PI fluorescence. The blue AMCA fluorescence of the bound digoxigenin-labeled pancentromeric probe was visualized by using an ultraviolet excitation filter. Chromosome morphology was additionally checked with a filter set providing only PI fluorescence. Depending on the quality of FISH-painting between 300 and 2,000 complete metaphases were scored from each donor. Rearrangements involving painted target chromosomes (yellow) and any other PI stained (red) chromosomes can be easily detected as two-colored structures (yellow/red). Two-colored chromosomes with one blue AMCA centromeric signal were classified either as complete or incomplete symmetrical translocations or insertions. Two-colored chromosomes with two centromeric signals were classified as dicentrics, dic(AB).

Genomic frequencies, F_G, for symmetrical translocations or dicentrics were calculated from the frequencies, F_p, of painted translocations or dicentrics for the target chromosomes by inversion of the equation $F_p=2.05f_p(1-f_p)\,F_G$ earlier applied by Lucas et al. [20] where $f_p=0.192$ is the fraction of DNA contained in the painted chromosomes.

2. Statistical methods of biodosimetry

When processing the results of cytogenetic studies of exclusive importance is the choice of adequate methods of mathematical statistics. This is associated with specific difficulties faced when comparing the frequencies of rare events. Numerous discussions about the methods of biodosimetry and radiobiology of small doses concerned, in the majority of cases, the problems of reliability of statistical interpretations [21].

Statistical processing of the results of cytogenetic analysis includes two necessary stages:

1) Calculation of the level of significance of differences between irradiated and control groups of persons.

2) Evaluation of irradiation doses at the individual and group levels using calibration.

2a. Statistical significance of observed differences in aberration frequencies

Statistical analysis of cytogenetic data should begin with considering the question about the reliable interval of the aberration frequency in the irradiated group. In the case of processing cytogenetic data, this standard procedure has a number of specific features.

We shall enter necessary designations. Let N_0 cells be examined for the control group, and n_0 cells with chromosome aberrations be found among them. We shall designate the corresponding numbers for the irradiated persons as N_1 and n_1. Then the frequencies of

$$u = \left|\varphi_0 - \varphi_1\right| \sqrt{\frac{N_0 N_1}{N_0 + N_1}}$$

cells with chromosome aberrations are $p_0 = n_0/N_0$ and $p_1 = n_1/N_1$. For their comparison various modifications of the Student's criterion are frequently used. For example, u-statistics is calculated by the formula where

$$\varphi_i = 2\arcsin\sqrt{p_i}, \quad i = 0, 1.$$

The differences can be considered as significant, if the obtained value u is higher than 2.

However, the real aberration frequencies are so small that the standard parametric criteria become too conservative. For example, with the same number of estimated metaphases ($N_0 = N_1$) the value u is approximately

$$u \approx \sqrt{2}(\sqrt{n_1} - \sqrt{n_0}).$$

It means, that 9 cells with aberrations in the experiment do not statistically differ from 4 in control cells with any volume of examined material. At the same time the use of finer statistical tests can lead to opposite results. It seems that in processing of cytogenetic data one should completely abandon the Student's criterion and use nonparametric methods.

In some cases, it is enough to use the χ^2 - test which reduce to the calculation of the value

$$\chi^2 = \frac{(N_0 + N_1)(N_0 n_1 - N_1 n_0)^2}{N_0 N_1 (N_0 + N_1 - n_0 - n_1)(n_0 + n_1)}.$$

The differences between the control and the experiment are significant if the calculated value of χ^2 is higher than 4. Otherwise, the observed differences can be attributed to casual reasons.

In the analysis of cytogenetic data the number of examined metaphases significantly exceeds the cells with chromosome aberrations. In this case the expression for χ^2 is simplified:

$$\chi^2 \approx \frac{(N_0 n_1 - N_1 n_0)^2}{N_0 N_1 (n_0 + n_1)}$$

In practice, with same volume of examined material in the control and in the experiment, the primary estimation of χ^2 can be reduced to a very simple formula:

$$\chi^2 \approx \frac{(n_1 - n_0)^2}{n_0 + n_1}$$

There is a very essential restriction for the application of the χ^2 criterion in processing the results of cytogenetic analysis. The number of cells with aberrations both in the experiment and in the control (n_0 and n_1) should be more than 5. If this condition is not met, the χ^2 values may be overestimated and, thus, the significance of differences. On the other hand, with sufficiently large values of n_0 and n_1, the χ^2 criterion is as conservative as the Student's test. Therefore, when processing the results of cytogenetic analysis, it is preferable to use the exact Fisher criterion, which although complicated permits any doubts to be removed in all situations.

The essence of this universal method consists in exact calculation of the probability of occurrence of observed differences under the assumption that the irradiated and control groups are indiscernible by the aberration frequency. According to the combinatorial theory of probabilities with the given assumption, the probability of detecting in the control no more than n_0 of cells with aberrations is equal to

$$P = \sum_{k=0}^{n_0} \frac{C_k^{N_0} C_{n-k}^{N_1}}{C_n^N}$$

where $\tilde{N}_n^N$ - is the number of combinations from N of elements on n, $N = N_0 + N_1$ and $n = n_0 + n_1$. This probability defines the level of significance of difference by exact Fisher criterion [22]. With $P < 0.05$, the aberration frequency in the control is significant lower than in irradiated group (differences are essentially nonrandom).

The formula for P includes the probabilities of hypergeometric distribution, which describes the probability of sample size n without returning to the set of size N. Upon sampling from a large set ($N >> n$), samples with returning can be replaced by samples without returning. Thus, hypergeometric probabilities are replaced by binomial ones, which considerably reduces calculations. In the given approximation the level of significance is equal:

$$P \approx \sum_{k=0}^{n_0} C_k^n q^k (1-q)^{n-k}$$

where $q = N_0/N$. In this sum, the value of the term with the number $k = n_0$ exceeds the rest approximately by one

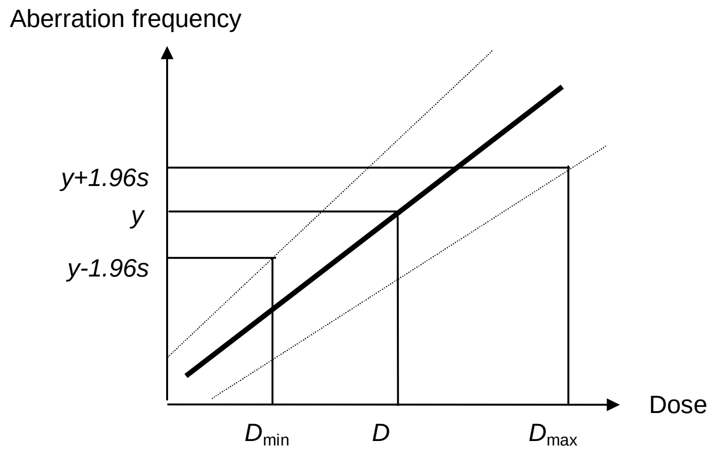

Fig 1. Calibration dose - effect curve with confidential intervals. A scheme of determination of 95%-confidential interval of dose estimation, corresponding to aberration frequency equal to $y \pm s$ is given.

order of magnitude. It can be used for primary estimations of the significance of differences:

$$P \approx \frac{n!}{n_0!n_1!}\left(\frac{N_0}{N}\right)^{n_0}\left(\frac{N_1}{N}\right)^{n_1}$$

If this probability is higher than 0.05, the differences between the experiment and the control cannot be considered significant.

If the sample sizes in the experimental and control groups are identical, the exact Fisher criterion allows the following interpretation: P is the probability of occurrence of no more than n_0 'heads' upon n throwings of a symmetric coin. Let, for example, two aberrations be found in the control and 8 chromosome aberrations in experimental group with identical numbers examined metaphases. Can such differences arise for purely casual reasons? What is the probability to make an error when asserting that the control group differs from the experimental one? According to the last formula, this probability is exactly equal to the probability of occurrence of no more than two "heads" in 10 throwings of a symmetric coin.

2b. Estimation of irradiation doses on the basis of calibration data

Estimation of individual doses of irradiation by the aberration frequency can be conducted on the basis of comparison with previously obtained calibrated data. As a rule, these data are presented by equations of linear or linear-square regression. In this case, the dose estimate is obtained as a result of simple substitution of the observed aberration frequency in a corresponding equation of regression. The procedure of determination of confidence intervals for dose estimates is shown in Fig. 1 taken from [1].

Let the observed aberration frequency is equal to $y \pm s$, where

$$s = \sqrt{\frac{y(1-y)}{N}}$$

is an average error in the aberration frequency y when a sample size is N. Then the upper (lower) estimate is at a point of crossing of the level y+1.96 s (y-1.96 s) with the lower (upper) confidential curve of regression.

An alternative approach consists in complete abandoning the application of regression equations and a direct use of calibration data presented in tabulated form. The appropriate mathematical theory is rather complex and uses Bayes's approach [2]. The theory permits a complete construction of the density distribution of probability of dose estimation corresponding to the observable frequency of aberrations. Numerical examples show that this method, though preferable in mathematical rigidness, does not essentially change evaluations obtained by the regression method [11].

3. Estimation of absorbed doses on the basis of analysis of unstable and stable chromosome aberrations

The basis for application of cytogenetic methods in biological dosimetry is a clear-cut dependence of the frequency of chromosome rearrangements on the doses of ionizing radiation, which has been repeatedly demonstrated in experiments. Having at disposal such dose dependencies obtained in vitro under the action of different kinds of ionizing radiation on cells (calibration curves), it is possible to attack the problem to estimate absorbed doses in irradiated people by analyzing the frequency of chromosome aberrations [1].

The pattern of a «dose - effect» curve for dicentrics and other chromosomal aberrations depends on the

Table 1. Coefficients of the equation $y = \alpha D + \beta D^2$ for dicentrics obtained after irradiation of human peripheral blood lymphocytes by various types of radiation.

Kinds of radiation	$\alpha \pm$ S.E. $[10^{-1}Gy^{-1}]$	$\beta \pm$ S.E. $[10^{-2}Gy^{-2}]$
^{60}Co γ, (0.017 Gy/m)	0.090 ± 0.400	4.17 ± 0.28
^{60}Co γ, (0.5 Gy/m)	0.107 ± 0.041	5.55 ± 0.28
220 kV X-ray (0.5 Gy/m)	0.404 ± 0.030	5.98 ± 0.17
14.5 MeV neutrons	1.790 ± 0.150	7.40 ± 1.39
Fission spectrum neutrons, E=1.6 MeV	3.690 ±0.210	13.34 ± 1.73
Fission spectrum neutrons, E=0.7 MeV	8.350 ± 0.100	-

types of ionizing radiation and its energy characteristics. The analysis of the generalized data of different authors on the dependence of the frequency of dicentrics in peripheral blood lymphocytes on the dose and type of radiation is presented in the work by D.C. Lloyd et al. [13].

For low-energetic radiation this dependence is usually described by the linear-quadratic equation $y = c + \alpha D + \beta D^2$, where c is the spontaneous level of dicentrics. For radiation with high LET the dose-effect dependence is linear $y = c + \alpha D$. As an example, the mean coefficients of the equations of calibration curves [11] are given in Table 1. The biological efficiency of different kinds of ionizing radiation can be judged by the ratio of coefficients.

The biological dose calculated on the basis of the frequency of dicentrics with the use of a calibration curve suitable for a given radiation situation is equivalent to the dose of acute uniform irradiation. The lower limit allowing a reliable (95 % probability) estimation of a dose (as a value equivalent to the dose of acute irradiation) depends on the number of analyzed cells, which is clearly demonstrated by Prof. Bauchinger in Table 2. In reality, with the analysis of about 5,000 cells the lower limit of reliable dose estimation is about 100 mGy for gamma - radiation and 50 mGy for fission spectrum neutrons.

Successful application of the analysis of the frequency of unstable aberrations (dicentrics and centric rings) for estimation of an irradiation dose is possible mainly after a single rather uniform radiation exposure in early (3-4 months) periods. So, in the work of Brewen et al. [23] the case of an emergency irradiation from a ^{60}Co source is described. Using the phantom and film-dosimetry the dose received by the injured person was reconstructed. It made up 127 R. On the basis of cytogenetic analysis the dose made up 144 R. The biological dose corresponded well to the data physical dosimetry.

Retrospective estimation of doses by the frequencies of unstable chromosome aberrations seems to be problematic today. The basic reason is the elimination of cells with unstable aberrations from circulating blood. However there are works where possible approaches for solving this problem are discussed. These approaches are based on the analysis of the processes of elimination of cells with aberrations, or on the analysis of the distribution of aberrations among cells [24,25,9].

The data collected from cytogenetic examinations of patients subjected to radiation therapy [26,27] and people injured as a result of accidents at nuclear enterprises [28-31] have allowed the quantitative description of the processes of elimination of cells with unstable chromosome aberrations and to estimate the duration of the lymphocyte life. Unfortunately, these data are not unambiguous. The parameters characterizing the elimination of lymphocytes

Table 2. Cell number and significantly elevated dicentric frequencies as compared to a background level (14 per 35,500 cells) required for the detection of a dose of ^{60}Co γ-rays (0.5 Gy•min^{-1}) with *p* = 0.05.

Cell number	Dicentrics significant	Dose (Gy)
100	1	0.63
200	2	0.56
500	2	0.31
1000	3	0.24
2000	4	0.17
5000	6	0.10
10000	10	0.074
20000	17	0.056
50000	37	0.041
100000	70	0.033

considerably vary depending on individual radiosensitivity of the donors, conditions of irradiation and the action of various additional environmental factors. There is no universal curve, especially for cases of partial irradiation. Also there is a lot of uncertainty in the estimation of the half-life period of cells with unstable chromosome aberrations which varies from 110 days to 4 years according to different authors. In our studies on the estimation of the half-life period of cells with unstable chromosome aberrations by calculating the ratio of the frequency of stable aberrations (estimated by the FISH method) to the frequency of unstable aberrations, this period is 4 years [9]. Apparently, retrospective dose estimation on the bazis of the frequency of unstable aberrations can be used taking into account the elimination process of cells with aberrations, when it is necessary to estimate an average dose for a group of irradiated individuals. In case of individual dosimetry, the dose can be determined only with a rather wide confidence interval.

For the purposes of retrospective dose estimation the FISH method is most often recommended at present. Stable chromosome aberrations revealed with this method are not eliminated in time, therefore, the dose estimation based on the analysis of the frequency of such stable chromosome aberrations (translocations) is possible within many years after exposure to ionizing radiation.

Biological dose estimates were derived from an acute in vitro ^{137}Cs gamma-ray calibration curve (dose rate 0.5 Gy/min) for FISH-painted translocations (chromosomes 1, 4 and 12) obtained in the laboratory of M. Bauchinger [19] modyfied taking into the data for the control material obtained in our laboratory:

$$y= (0.96\pm0.27)\cdot10^{-3} + (0.95\pm0.21)\cdot10^{-2}\cdot D + (1.45\pm0.14)\cdot10^{-2}\cdot D^2,$$

where y is the frequency of observed FISH-painted translocations (chromosomes 1,4 and 12), D - the absorbed dose, Gy. On the basis of this calibration curve with the application of the FISH method, the estimation of absorbed doses in the Chernobyl liquidators within 8-10 years from the irradiation was carried out [7]. To this and, an experimentally obtained value of the frequency of FISH-painted translocations is substituted in the presented linear-quadratic equation and a corresponding D value is derived by solving the equation.

For instance, in case 1.6 translocations per 100 cells (the frequency 0.016) were observed in an irradiated patient on the basis of a calibration curve, it corresponded to the absorbed dose of 0.77 Gy (95% confidence interval from 0.3 up to 1.10 Gy). If 5 translocations per 100 cells (the frequency 0.05) were observed, the absorbed dose made up to 1.54 Gy.

It should be noted that this calibration curve concerns only a part of cell translocations including FISH-painted chromosomes (chromosomes 1, 4 and 12 in the given case). In principle, the study may involve other painted chromosomes as well. Depending on the size of painted chromosomes and their number, the analysis may include different portions of the entire genome. The calculation of the translocation frequency per whole genome is made using (as indicated in section 1 of this work) the formula of Lucas et al. [20] which takes into account the size and number of painted chromosomes.

Using this methodology the absorbed doses have been evaluated for a group of 52 liquidators, inhabitants of the Altai territory irradiated about 45 years ago from nuclear explosions on the Semipalatinsk nuclear test site, and people living in the region of the Three Mile Island power station at which there was a nuclear accident in 1979 accompanied by an emission of radionuclides to the environment. The results of these studies are presented in a special work.

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Peculiarities of Biological Action of Low Irradiation Doses and Their Probable Relation to the Health State of Participants of Chernobyl Accident Liquidation

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Chernobyl catastrophe is unique not only because of its scale - the amount of released radionuclides, the area of polluted territories, the collective dose obtained by the population and those who took part in the liquidation of accident consequences - but also in connection with extraordinary strong "iodine blow" and existence of millions of people who obtained "low" irradiation doses which had been considered before as absolutely safe. Therefore, to reveal the mechanisms of the action of low dose irradiation and their biomedical consequences is one of fundamental problems solution of which is necessary to develop scientifically grounded criteria of radiation safety.

The latest researches had proved definitively that the low doses cause multiple changes in cells, which remain for a long time after irradiation and provoke changes in their functional activity, and that the processes in cells initiated by low doses differ from ones caused by high doses. At low doses, "dose-effect" dependencies are not linear considerably, indicating incompetence of risk assessment by extrapolation of results from high to low doses.

Therefore, the pre-Chernobyl radiobiological science could not forecast the scales of health disturbance, and could not propose prophylactic measures forestalling the accelerated increase of disease incidence in both adult and children population.

The results of medical observations and fundamental investigations in recent years had changed our attitude considering low doses of irradiation to be absolutely safe and, correspondingly, our attitude towards the problems connected with atomic industry development, radioactive wastes burial and others.

During the activity of the Commission of USSR Supreme Soviet on establishing causes and consequences of the Chernobyl accident, we received reports of different medical institutions on the state of health of participants of the accident liquidation (liquidators) as well as of adult and children population living on radioactively polluted territories. The detailed account of observation materials was presented in the 2nd volume of book "Chernobyl Catastrophe. Causes and Consequences" [1].

In the present paper, we'll briefly show the principal results. In all reports of 1986-1990, it was told about the changes in health state of liquidators after their work in the radiocontaminated areas. Sseveral hundreds of liquidators were examined in the military surgery clinics of Military Medicine Academy in St. Petersburg. after working at Chernobyl. More frequently found for the first time were hypertonic disease (20.8%), chronic gastritis (14%), neurocirculatory disorders (12.2%), ischemic heart disease (3.7%), chronic hepatitis (1.8%), chronic bronchitis (1.8%), disorder of biliary duct (1.2%) and others. These data are especially verifiable because the Military Medicine Academy had the information on health state of all liquidators (militaly men) for a number of years before the accident. Moscow institutes (MORCI, Institute of Diagnostics and Surgery of Russian Federation Ministry of Health, Institute of Urology of Russian Federation Ministry of Health) also studied the disease incidence of liquidators mobilized by military commissariats. The most frequent were the diseases of endocrine and nervous system, cardiovascular system, digestive organs, musculoskeletal system, and disturbances in male reproduction system. Long-term observation of thyroid state showed changes in its function in 10% of examined people.

Nearly 1,100 liquidators were registered at the Research Institute of Medical Radiology of Armenian Ministry of Health and subjected to dynamic observation. The observation of their health state in the period from 1987 to 1990 showed a tendency of increase of level of nervous system diseases (from 31% in 1987 to 51% in 1990). The increase took place principally for account of organic diseases of nervous system with certain decrease of primarily grown functional disturbances. There were also increases of gastrointestinal and respiratory system diseases. Some regularities of changes were observed in the immune status of liquidators. The examination of patients revealed the immuno-deficit of cellular type, which was characterized principally by decrease of T-dependent link of immunity.

The Ukraine State Register contained 180 thousand of those who participated in liquidation of the accident consequences. The incidence of endocrine and immune systems diseases was characterized by significant annually increase, especially in men. Thus in 1990, as compared with 1988, disease incidence in men grew by 3.7-7.1 times. The dynamics of blood and blood formation organs diseases demonstrated growth of incidence both in men and women: in 1990 it was 5 times as high as it was in 1988. The incidence of diseases of nervous and blood circulation systems increased by 2-3 times as compared with 1988.

We must notice that in that period physicians could not practically reveal the dose dependence for liquidators irradiated in doses 10-20 cGy. In some cases, a group of liquidators who obtained irradiation dose 25 cGy and higher, demonstrated higher incidence of mentioned diseases. However, there were no clear dose dependence on the whole. The largest information in that period was in the All-Union Distributed Register which contained 226.9 thousand of liquidators of Russia, Ukraine and Belarus [2]. According to the Register, the statistically significant growth (1.5-2 times) of general disease incidence of liquidators was observed both in separate countries and in CIS as a whole. For five classes of diseases - 1) nervous system diseases, 2) psychical disorders, 3) blood and blood formation organs diseases, 4) digestive organs diseases, 5) vegetovascular distonia - dose dependence was found: the indices of morbidity of liquidators who obtained dose higher than 30 cGy were significantly higher than those of group with irradiation dose 0-5 cGy. The conclusions about negative effect of irradiation on health state of liquidators were not accepted seriously by medical officials in that period. Many tried to explain things by the increase of diseases «revealing» rather than by the increase of morbidity. Others tried to relate all changes in health state to the results of «radiophobia», emotional stress without any connection with irradiation action. However, in recent years the next conclusions are followed. By the data of National (Russian) Radiation-Epidemiological Register, presently, a growth of morbidity indices has been registered [3] for many classes of diseases both among liquidators and among all irradiated population as a whole. First of all, we must notice continuous growths of indices of malignant neoplasm incidence: in 1990 - 151 per 100,000, in 1991 - 175, in 1992 - 212 (128 - morbidity of liquidators normalized to the age distribution of male population of Russia in given year) and in 1993 - 233 (140). The morbidity indices for malignant neoplasm among liquidators were 50% higher than the corresponding indices of the general statistical data on Russia population in 1992, and 65% - in 1993.

The indices of morbidity of liquidators for endocrine system diseases exceed by 18.4 times the control ones, for psychical disorders - 9.6 times, for blood circulation diseases - 4.3 times, and all classes of diseases - 1.5 times. The morbidity indices dynamics for all these classes of diseases for liquidators has a tendency to increase (Table 1) [4].

The majority of people affected by the Chernobyl accident consequences are suffering changes in the immune system [5]. These changes concern mainly thymus - central organ of immune system - and T-lymphocytes which develop in it. The after-effects of these cells disfunction can be very diverse because they fulfill key functions in protection from viruses and microbes, in anti-tumor resistance, and in immune reactions regulation. Thymus hormones content in blood serum of irradiated people is reduced by 3-5 times in average, which causes suppression of T-lymphocytes protective functions by 3-4 times. The risk of immuno-deficits development increases in the affected people, accompanied by the decrease of immune protection and the increase of frequency of development of malignant tumors and infectious diseases. The immunological changes in the Chernobyl accident sufferers are similar to the manifestation of immune system ageing [5].

Thus, the fact of serious change of health state of liquidators is undoubted. However, disagreement exist

Table 1 Incidence of 12 classes of disease among liquidators per 100 thousand people [4]

Classes of disease	1986	1987	1988	1989	1990	1991	1992	1993
Infectious and parasitical	36	96	197	276	325	360	388	414
Neoplasm	20	76	180	297	393	499	564	621
Malignant neoplasm	13	24	40	62	85	119	159	184
Endocrine system diseases	96	335	764	1340	2020	2850	3740	4300
Diseases of blood and blood-forming organs	15	44	96	140	191	220	226	218
Psychical disorders	621	9487	1580	2550	3380	3930	4540	4930
Diseases of nervous system and sense organs	232	790	1810	2880	4100	5850	8110	9890
Diseases of blood circulation organs	183	537	1150	1910	2450	3090	3770	4250
Respiratory system diseases	645	1770	3730	5630	6390	6950	7010	7110
Diseases of digestion organs	82	487	1270	2350	3210	4200	5290	6100
Urogenital system diseases	34	112	253	424	646	903	1180	1410
Diseases of skin and hypodermic tissue	46	160	365	556	686	747	756	726

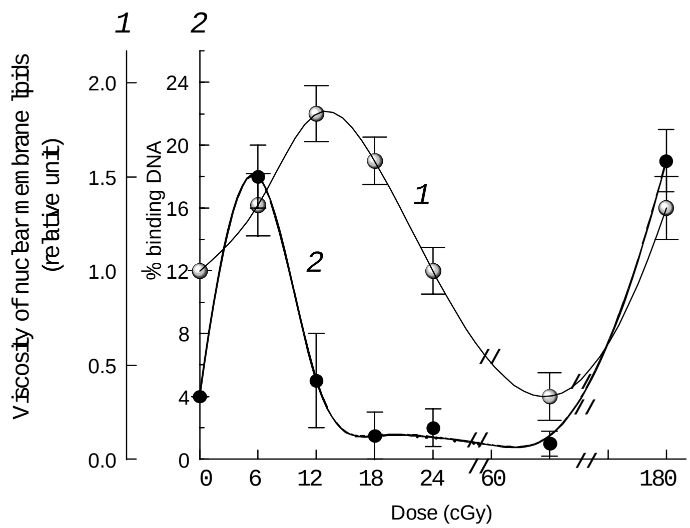

Fig. 1 Percentage of spleen DNA binding with cellulose nitrate (CN) filters (1) and microviscosity of lipids of nuclear membranes of liver (2) of irradiated mice (irradiation rate: 6cGy/day).

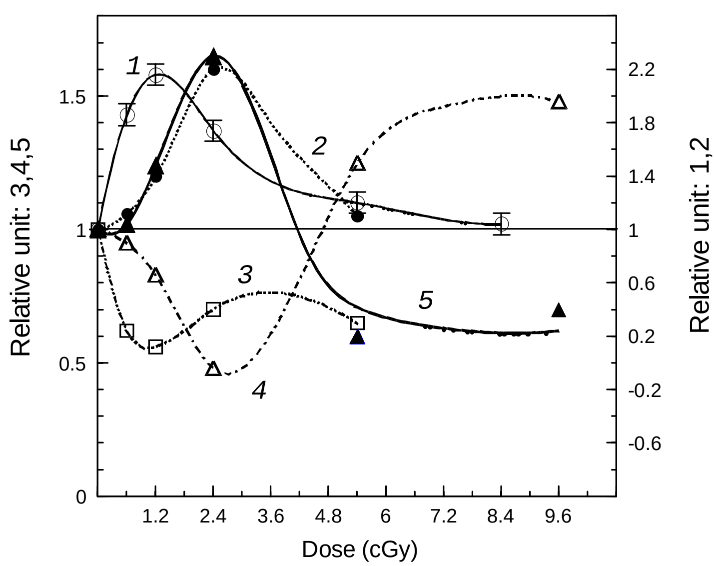

Fig. 2 Dose dependencies of alteration of different structural parameters of genome and nuclear membranes of organs of irradiated mice (irradiation rate: 0.6 cGy/day).

1. DNA retention with CN filters
2. Content of MIF-1 fragment in spleen DNA
3. Alkali elution constant of lymphocytes DNA
4, 5. Rotational correlation time of spin probes

about immediate cause of diseases; the effect of radiation or of psycho-emotional reactions after working in the accident zone. Presently the international organizations (WHO, IAEA) recognize as the main cause of increase of thyroid cancer in liquidators and children population after the accident their irradiation with radioactive iodine, I-131. The rest of diseases, they suppose, are provoked by psycho-emotional reactions.

It is widely known that irradiation not only causes specific reactions but also has «stress» component. Probably, like as specific reactions, «stress» reactions are connected with dosage and dose rate of irradiation. However, while «dose-effect» dependencies are well enough studied for death of irradiated cells, for cell transformation, and for such injuries in DNA molecule as one- and two-thread breaks of DNA-protein joints etc., they are studied quite less for «radiation stress». For a long period, we were occupied in the study of oxidation stress which represents a complex of organism reactions in response to the action of diverse stress factors. Therefore, we undertook investigations of those characteristics as well as of a number of other biochemical and biophysical indices, with regards to their dependencies on irradiation dosage and dose rate. We considered these studies are necessary because changes in active forms of oxygen, lipids peroxidation, antioxidant status of cells, organism organs are important characteristics of pathogenesis, gravity and possibility of treatment, and prognosis of such diseases as malignancy, radiation sickness, neuro-physical disorders, diabetes, cardiovascular diseases, respiratory diseases, digestion and many others [6, 7].

Velocity of alkaline elution of DNA of lymphocytes and liver was studied as well as that of neutral elution and adsorption on cellulose nitrate (CN) filters of spleen DNA, structural (using EPR-method of spin sounds) characteristics of nuclear, mitochondrial, synaptic, erythrocytal and leukocytal membranes. Besides, for the characterization of cell functional activity, the activity and isoforms of aldolase and lactate dehydrogenase enzymes were studied together with the activity of acetylcholinesterase, superoxide dismutase, glutathione peroxidase, velocity of superoxide anion-radicals formation, the composition and antioxidant activity of lipids of above mentioned membranes, and the sensitivity of cells, membranes, DNA, organism to the action of additive injuring factors [8-14].

The bimodal dependence of effects on dose was revealed for all studied parameters. Namely, effects increased at low doses, reached maximum (for low doses), then decreased (in some cases the effect sign reversed) and thereafter increased with the increase of dosage. For example, Figure 1 presents the data on changes of adsorption of spleen DNA and microviscosity of nuclear membranes lipids,

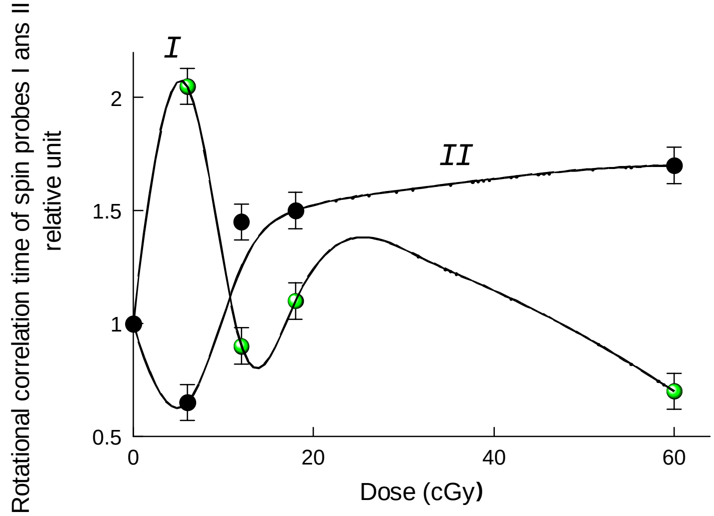

Fig.3 Dose dependencies of alteration of microviscosity of different membrane areas of erythrocytes of mice (irradiation rate: 6 cGy/day).

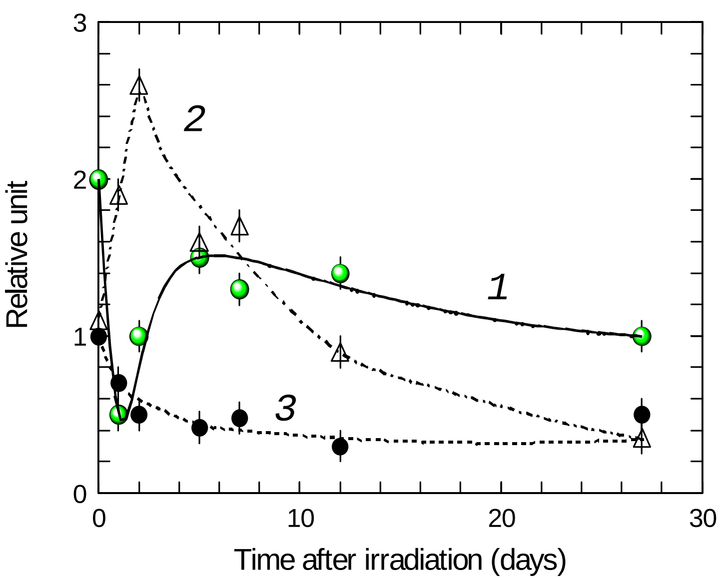

Fig.4 Post-radiation changes of structural characteristics of DNA and nuclear membranes of mice irradiated with 1.2 cGy dose (0.6 cGy/day).

1. DNA retention with CN filters

2,3. Rotational correlation time of spin probes

characterized by the time of rolling correlation of spin sound (I) (ι_1) in dependence of irradiation dose at the intensity 6 cGy/day. Like DNA structural characteristics, microviscosity of membranes lipids changes drastically with irradiation dose, and reached the extreme values were at 6-12 cGy. Note that the level of changes obtained at 6 cGy dose are comparable with changes of structural characteristics of macromolecules at 20-30 times higher doses.

At low-dosage the values of maximum and the dose under which it was reached depended on the nature of studied object and dose rate. In Figure 2 the data are adduced about the changes of genome structural characteristics and nuclear membranes at the irradiation with gamma-rays with lower intensity (0.6 cGy/day). The displacement of maximum to the direction of lower doses with decrease of irradiation intensity is the general regularity of dose dependencies for studied parameters.

The study of genome of irradiated animals by adsorption methods on CN filters in neutral medium permits to observe changes of DNA conformation and to assess the character of recognition of DNA specific sequences by restrictases [15]. As it is seen in Figure 2, at the irradiation intensity of 0.6 cGy/day, the change of adsorption on CN filters of DNA of spleen (curve 1) has the maximum at 1.2 cGy, and at the dose of 5.4 cGy the adsorption value doesn't differ practically from the control one. The results of restriction analysis of DNA of mice spleen using endonuclease EcoRI, expressed in the change of contribution of interspersed repetitions MIF-I in DNA and reflecting the genome structure reconstruction, are represented on curve 2. The dose dependencies of change of mentioned parameters show the extreme character similar to the shift of DNA adsorption maximum to the side of lower doses (1.2 cGy). Analogous but inverse extreme dependence with the minimum at 1.2 cGy was obtained also for the constant of velocity of DNA alkaline elution of mice blood lymphocytes (curve 3).

The changes of nuclear membranes structural characteristics (Figure 2, curves 4, 5) pass over their extremes at the dose 2.4 cGy, while the changes of microviscosity of various areas of membranes are inverse to each other[1]. Unlike the DNA structural characteristics (adsorption), the value of microviscosity of both membrane phases differs considerably from the control in the dose interval of 6-9.6 cGy. The comparable scale of synchronous structural shifts in DNA and membranes under the influence of such low irradiation doses with low intensity deserves attention.

In Figure 3 the data are presented on the change of microviscosity of erythrocytal membranes lipids. Like in all preceding cases, the maximum is observed at low doses. We used the data on changes of kinetic parameters of membrane and cytosol enzymes in cells of irradiated animals for assessing the cells functional activity. The changes of kinetic characteristics of enzymes take place at irradiation doses of 1.2-2.4 cGy.

[1] We used 2 spin sounds; one of them (I) was placed in more hydrophobic area, another - in more hydrophilic one.

Table 2 Changes of ratio of velocity of superoxide radicals generation (VO_2^-) to SOD-activity in liver microsomes and submitochondrial particles(SMP) of irradiated mice (irradiation intensity: 0.6 cGy/day).

Dose, cGy	VO_2^-/Asod $_{microsome}$	VO_2^-/Asod (SMP)
0	1	1
0.6	1.8	1.6
1.2	3.4	0.8
2.4	1.7	1.8
5.4	2.0	1.2

Long-term preservation of altered kinetic properties of enzymes was registered after the irradiation at 1.2 cGy. The disturbance of regulation functions of enzymes was also observed due to changes in correlation between enzyme forms of lactate dehydrogenase and aldolase isoenzyme, and in correlation between enzyme activity and its substrate (superoxide dismutase) (Table 2). Thus, the cells functional activity changes non-linearly with the dose after the low-intensive irradiation. An important factor is the change of sensitivity of separate macromolecules, cells and organism to additive influences of injuring factors both of the same and of other natures. We discovered in our experiments that low-dosage irradiation causes an increase of hemolysis of erythrocytes in mice, and changes the central nervous system sensitivity to the neuromediators, agonists and antagonists. It also changes response of cells to regular influences and repeated irradiation, introducing radiosensitizers and protectors.

The sensitivity of cells of spleen and bone marrow of irradiated animals to the secondary exposure at 6, 7 and 8 Gy doses was studied in the same conditions. It was found that the cells irradiated at low doses have other sensitivity to the secondary exposure [16].

In order to create the scientific bases for forecasting the remote effects of low-intensive irradiation, regularities of early after-effects on macromolecular level were studied. The after-effect of low-dose irradiation to mice, observed in the present study, manifested as alteration of structural characteristics of DNA and membranes (Figure 4) and kinetic parameters of enzymes during all the time of study (27 days) after the irradiation. The post-radiation changes of all macromolecular structures showed non-linear character with gradual return to the control level. Thus, after the irradiation of mice at 1.2 cGy (0.6 cGy/day) which causes the maximum effect, the post-radiation shifts of this parameter were observed.

The data on the change of DNA adsorption and membranes microviscosity after the irradiation at 1.2 cGy dose are compared in Figure 4. The post-radiation changes for lipid sound 1 (curve 2) are expressed stronger than those for sound 2 (curve 3) and inverse to those for DNA as in Figure 2.

The results obtained indicates that there is a close correlation between the processes in mice membranes and genome under the action of low-dosage ionizing radiation both during the irradiation process and afterwards.

We explain the non-linear bimodal dependence of effect on dose on the basis of the idea of the existence of a gap between effects which cause injuries in bioobjects and initialize their recovery systems (Figure 5). In this connection, while the recovery (or adaptation) systems don't function with full efficiency, the effect increases with dose increase, then decreases (or remains on the same level) as the recovery processes become strengthening. Then the effect may be eliminated or may reverse its sign, and increases again with the dose increase when injuries predominate over the recovery. However, in spite of a number of experimental factors confirming such view point, we can't make yet the final conclusion about the mechanism of such dose-effect dependence in the area of low doses of low-intensive irradiation. Alternative explanations of this dependence are presented, e. g. the idea of existence of especial pool of cells sensitive to the action of low-intensive irradiation [17], and a number of others [18, 19].

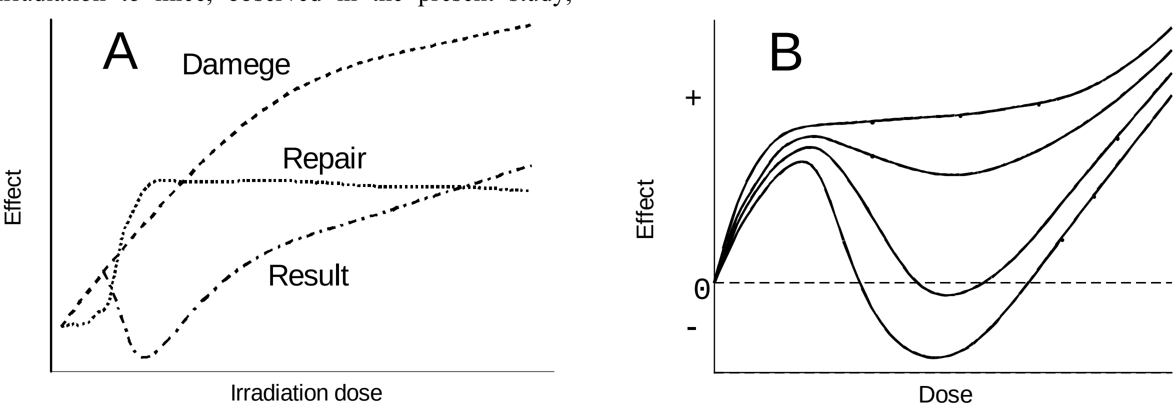

Fig. 5 Scheme of dose dependencies of injury, repaiar and the net effect of irradiation (A) and types of dose-response curves (B).

Table 3 Dependence of different biochemical parameters on irradiation rate.

Criterion	Biochemical parameter	Irradiation dose power, cSv/day	
		0.6	6
Radiation-chemical release for 1 cSv	PB DNA	1	0.3
	ι_{cI} of lipids	$20*10^{-2}$	$7.5*10^{-2}$
	MDA	$9*10^{-2}$	$3*10^{-2}$
Equal-effect doses, cSv	PB DNA	0.6	2.0
		2.4	12
		5.4	30
	ι_{cI} of lipids	0.6	12.0
		5.4	20.0
		9.6	26.0
	MDA	0.6	7.2
		5.4	18.0
		9.6	18.0
Low-intensive maximum (minimum) values	PB DNA	2.2	3.0
	ι_{cI} of lipids	1.2	1.8
	MDA	1.2	2.1
Doses under which the maximum is reached, cSv, and time needed to reach it (days)	PB DNA	1.2 (2)	6 (1)
	ι_{cI} of lipids	2.4 (4)	12 (2)
	MDA	2.4 (4)	24 (4)

Besides, we ought to take into account that, as radiation intensity decreases, the contribution of membranes injuries into the total cells injury increases and there appear new ways of changes in genital apparatus, which are connected with membranes injuries under radiation action.

It is very important to establish the relation between effects at low-intensive dosage and dose rate. But the non-linear and polymodal character of dose dependence makes it difficult to investigate the role of dose rate.

In this connection, we chose several parameters which reflect radiation influences, and studied their changes at dose rate values differing by10 times. Table 3 presents:

1). values of effects per unit dose on initial stages of dose dependencies.
2). doses at which equal effects are observed.
3). values of low-dosage maximum (minimum).
4). doses and time when maximum (minimum) is reached.

Binding percentage of DNA (DNA BP) on cellulose nitrate (CN) filters, properties of viscosity of lipids of erythrocytal membranes (ι_1) and MDA in lipids of erythrocyte membranes were compared. As seen in Table 3, a decrease of irradiation dose rate results in a increase of «radiation-chemical» yield, and in a decrease of the doses under which the equal effects and maximum values of studied characteristics are observed.

The fact of inverse dependence on dose rate in the changes of indices related directly (MDA) or indirectly (ι_1) to lipids peroxidation of membranes is not surprising because theoretical calculation for radiation-chemical yield of peroxides resulted from irradiation gives an inverse dependence of effect on dose rate [20].

All these data show that the organism reaction to low-dosage irradiation is a function of irradiation dose, irradiation dose rate, and time since the beginning of irradiation.

Thus, the investigation showed that:

1). dose-effect dependence shows complicated non-linear character for all studied characteristics at low irradiation doses,
2). low irradiation doses change the sensitivity of biomacromolecules, cells, organs, organisms to the action of other damaging factors,
3). long-term after-effects are observed,
4). inverse dependence is observed in a number of changes,
5). membrane is an important critical target at the action of low-intensive irradiation.

The experimental data indicate that all indices of oxidation stress are changing considerably under the action of low-intensive irradiation. The stress reactions at low irradiation doses manifest the same activity as they do at 20-30 times higher doses. The dose-effect dependence for them is also of non-monotonous, non-linear character. We suppose that these changes can be sufficient to cause various diseases in the organism of liquidators and the people irradiated as a result of the Chernobyl accident.

It is not the psycho-emotional stress, but it is the stress component of low-intensive radiation that can be responsible for the change of health state of liquidators irradiated by low doses.

Biochemical, biophysical, cytological and immunological changes in blood of participants of liquidation of the consequences of the Chernobyl APS accident in 1986-1987.

It is of great interest to clear the question of existence of similar regularities in the population of irradiated people. Regretfully, epidemiological examinations are not always implemented on the level permitting to make certain quantitative conclusions. In this connection, we studied the antioxidant characteristics of plasma and cells of blood of liquidators who had worked at Chernobyl after the accident.

In order to study the effect of ionizing radiation on the system of regulation of peroxidation of lipids (LP) of man, the examination of 104 persons who had worked in 1986-1987 in the zone of the Chernobyl accident (liquidators) and 34 persons who had not registered contact with radioactivity («control» group) was held.

The examination of liquidators was carried out in 1992-1993 during the course of routine observation without connection with concrete diseases. All observed liquidators were considered as absolutely healthy people though many of them talked about various complaints during the examination, of general character as a rule (fatigue, irritation, headache, susceptibility to colds and so on).

Liquidators and the control group did not differ in age. The average age of the examined liquidators was 43, and that of the control group was 45. Well tested and standard biochemical and biophysical methods were used for measuring the indices [21-26].

The object of investigation was cubital vein blood obtained in the morning with empty stomach.

The parameters which characterize the state of LP regulation system (antioxidant status of organism) were determined in this study. The results are adduced on Table 4.

The statistical analysis of results was carried out using a number of statistical methods. Values of Student, Wilcoxon, Mann-Whitney, Kolmogoroff's criteria, criterion of signs; and the multi-factor Mahalanobis's distance between the groups (Hotelling's T-statistics) were evaluated.

The liquidators group significantly differs from the control group in the majority of studied parameters. The content of the most active natural antioxidant - vitamin E (tocopherol) in blood plasma and the quantity of recovered glutathione in liquidators differ from those in «control». Significant differences were found also in the content of antioxidant proteins: glutathione peroxidase and ceruloplasmin, as well as in the non-saturation degree of plasma lipids.

The membranes of erythrocytes of liquidators' blood differed also from the «control» in the quantity of LP secondary products (malonic dialdehyde content), membrane lipids fluidity and degree of lipids non-saturation (Table 4).

Thereby, the people subjected to the ionizing radiation action in various degrees have alterations in the LP regulation system after a long time period (5-6 years after the exposure).

It is well known that the physico-chemical system of regulation of cell metabolism by membranes exists in the organism. Principal components of this system are generation of peroxidation radicals of lipids and antioxidants, the lipids composition, fluidity (microviscosity) of membrane lipid content,

Table 4 Parameters of organism antioxidant status in liquidators and «control».

Index	Control (average)	Liquidators (average)	Significance by Wilcoxon
DLpl (double links in plasma lipids), number of DL/mg of lipids. 10^{18}	0.32	0.33	0.017 *
Dlel (double links in erythrocyte lipids), number of DL/mg of lipids. 10^{18}	0.303	0.30	0.000 *
Vitamin E (conventional units)	20.90	19.05	0.034 *
Vitamin A (conventional units)	2.99	2.85	0.056
Recovered glutathione	19.53	22.19	0.001 *
SOD (superoxide dismutase)	125.41	115.11	0.682
GP (glutathione peroxidase)	7.20	8.87	0.001 *
GR (glutathione reductase)	5.12	4.86	0.760
Hem1 (hemolysis of erythrocytes)	7.23	7.19	0.784
Hem2 (hemolysis of erythrocytes after LP initiation)	7.62	7.81	0.830
MDA1 (malonic dialdehyde in erythrocytes)	1.93	2.22	0.008 *
MDA2 (malonic dialdehyde in erythrocytes after LP initiation)	1.95	2.24	0.003 *
τ_{cI} (time of rotation correlation of spin sound I in erythrocyte membranes)	1.08	1.29	0.000 *
τ_{cII} (time of rotation correlation of spin sound II in erythrocyte membranes)	1.94	1.77	0.022 *
CP (ceruloplasmin)	1.23	1.10	0.046 *
TF (transferrin)	0.78	0.80	0.084
Free radicals with g-factor 2.0	0.69	1.08	0.362
Chromosomal aberrations in lymphocytes	0.81	1.15	0.605

* - indices which differ from control by Wilcoxon's criterion with significance level $p<0.05$

membrane-bound proteins-receptors, enzymes, and channel-forming proteins. All these parameters are linked in normal conditions structurally and functionally. A change of one of them provokes changes of the others (Figure 6). The existence of link with negative inverse relation (the growth of speed of lipids peroxidation causes the enrichment of lipids fractions resistant to the oxidation, and vice versa) allows the system to fulfill the function of adaptation of cell, organ, and organism to the change of environment and to injuring factors, ensuring transition of cell metabolism to another regulation level. The time of relaxation of this regulation system depends on the nature of object (organism, organ, membrane) and changes within the range from 10^2 to 10^4 seconds. In cases either of break of the functional link between the indices, of changes of this link nature, or of long-term action of injuring factor, the system does not return to the normal state. The system of regulation of membranes LP is correlated with other cell regulation systems. It is responsible for cell resistance to damaging factors action and is linked with immune system, ageing processes, cancerogenesis, tumors growth, cardiovascular diseases progress, neuro-psychical disorders, etc. [6].

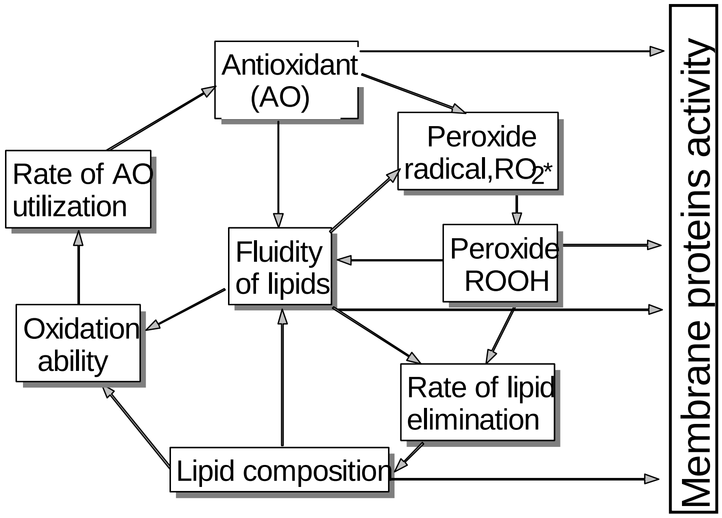

Fig. 6 Scheme of free-radical mechanism in regulation of cell metabolism by membranes.

As it was shown in earlier experimental investigations, during the process of irradiation the concentration of free radicals increases, the number of antioxidants decreases, the lipids enrich with phosphatidylcholine, sphingomyelin, the lipid phase becomes harder (ι_1 increases), and microviscosity of more hydrophilic areas of membrane (ι_2), on the contrary, decreases. The activity of superoxide dismutase, glutathione peroxidase, glutathione reductase changes by stages. Break of connections in the system takes place in a later stage of radiation injury and affects links: AOA-oxidation (changes in contrary directions), ι_1-ι_2 (changes in parallel). Normally, AOA-oxidation changes in parallel, and ι_1-ι_2 do in contrary directions [24].

It was important to determine the changes in the LP regulation system of erythrocyte lipids of liquidators who had obtained doses tens of times lower than those which cause radiation injury. From the experimental data about the existence of close correlation in the change of the regulation system parameters, it was possible to expect an increase of free radical concentration, strengthening of hemolysis, lowering of antioxidants concentration, and increase of hardness (microviscosity) of membranes lipids.

In Table 4, as it was expected, for studied samples of liquidators blood, the concentrations of natural antioxidant - vitamin E and blood antioxidant - ceruloplasmin decreased. The concentrations of free radicals, malonic dialdehyde increased. With the same regularity, the fluidity of different membrane areas changed: ι_1 and ι_2 increased. All this indicates alteration of the antioxidant status of irradiated organism of liquidators.

As far as we are talking about alterations caused by ionizing radiation action, it is important to clear the relation of these alterations with irradiation dosage, Regretfully, we could not get verifiable information on real dose of irradiation of all observed liquidators during their stay in the Chernobyl APS accident zone and, therefore, we could not carry out such analysis on the results of direct dosimetry.

Simultaneously with the study of antioxidant status, the level of chromosomal aberrations in blood lymphocytes was determined in all examined people (by the standard method of study of metaphases of cultivated in vitro lymphocytes). 300 metaphases were studied in the majority of the examined people. The number of chromosomal aberrations, and the number of dicentrics and centric rings were determined among them.

It is known that in a certain range of exposure doses there is a monotonous, practically linearly increasing dependence between exposure dose and the total number of chromosomal aberrations as well as the sum of dicentrics and centric rings number in lymphocytes [24-28], which permits to use the cytogenetic analysis for biodosimetry. We divided thereunder the examined liquidators into several groups in dependence of chromosomal aberration levels and the number of dicentrics and centric rings in their lymphocytes, supposing that thereby we divided them in accordance with their real exposure dose.

As a result, 5 groups of liquidators were formed. The «control» group and the first liquidators group (A group) were composed so that the percentage of chromosomal aberrations in them was not higher than 0.5. The intervals of chromosomal aberrations for another 4 groups constituted respectively 0.5-1 (B group), 1-1.5 (C group), 1.5-2 (D group) and >2 (E group).

Taking into consideration the average level of chromosomal aberrations in lymphocytes of examined liquidators, we may suppose that their average exposure dose constituted 15 cGy (by the number of dicentrics and centric rings - 15 cGy). These calculations confirm the data of Russian Register indicating 15.9 cGy as the average value of liquidators exposure dose in 1986 [3].

These data allow us to consider that the increase of chromosomal aberrations number in groups A-E reflects the increase of dosage obtained by people of these groups.

The data are adduced in Table 5, which characterize the dynamics of alteration of certain indices of antioxidant status in dependence of chromosomal aberrations level in lymphocytes. The change of characteristics in all cases is not of monotonous character. This may be interpreted as an index of complicated dependence of the change of antioxidant status parameters on irradiation dose analogous to one found in experiments.

Table 5 shows that there are differences between these groups in many indices. However, the most interesting is the integral comparison of groups in all set of indices. Such assessment was made using the statistical parameter - Mahalanobis's distance (Hotelling's T-statistics). This method was used many times in the statistical analysis of both experimental and populational multi-factor arrays, and was proved to be successful in the cases when the alteration of a great number of indices in samplings sequence should be reduced to an integral index reflecting all system behavior. In the given case, the control group was compared in succession with all liquidators groups for 15 indices. The most interesting was to compare the liquidators of low (up to 0.5%) level of chromosomal aberrations in lymphocytes with the control group consisting of the people with similarly low level of chromosomal aberrations (up to 0.5%).

It turned out that namely the first group of irradiated people, i.e. those who had the minimal of chromosomal aberrations (<0.5%), by set of indices, differs from the control group significantly (P<0.05) and stronger than other groups do.

If we take into account the mentioned above dependence of number of chromosomal aberrations in lymphocytes on irradiation dosage, we may suppose that the group of liquidators who have insignificant chromosomal aberrations level had obtained low irradiation dose. However, the changes in parameters of their antioxidant status turned out substantial, and obviously indicate the probability of grave and stable disturbance development in the LP regulation system even at low irradiation dose.

The analogous results are obtained in the

Table 5 Mean values of AO indices in the control group and in liquidator groups selected by chromosomal aberrations number.

Indices	Control	Liquidators				
		A	B	C	D	E
DLpl (double links in plasma lipids), number of DL/mg of lipids. 10^{18}	0.34	0.29	0.31	0.31	0.27	0.34
Dlel (double links in erythrocyte lipids), number of DL/mg of lipids. 10^{18}	0.33	0.25	0.26	0.31	0.29	0.30
Vitamin E	23.07	19.80	17.95	20.54	16.13	21.24
Vitamin A	2.99	2.65	2.50	3.20	3.05	3.22
RG (recovered glutathion)	16.70	23.82*	17.57	24.50*	21.98*	25.66*
SOD (superoxide dismutase)	113.12	115.23	120.09	101.08*	136.5	106.76
GP (glutathione peroxidase)	6.91	10.02	9.82	9.26	12.2	7.648
GR (glutathione reductase)	5.61	4.57	5.87	4.66	4.93	4.5
GP-GR (glutahione peroxidase - glutathione reductase)	1.34	2.28	1.91	1.88	2.05	1.97
Hem1 (hemolysis of erythrocytes)	6.78	7.86	11.14*	5.59	7.74	6.70
Hem2 (hemolysis of erythrocytes after LP initiation)	7.27	9.22	10.99*	5.88	6.86	8.17
MDA1 (malonic dialdehyde in erythrocytes)	2.08	2.41	2.74*	1.88	2.67*	1.83
MDA2 (malonic dialdehyde in erythrocytes after LP initiation)	2.07	2.58*	2.58*	2.10	2.88*	1.85
ι_{cI} (time of rotation correlation of spin sound I in erythrocyte membranes)	1.01	1.37*	1.24	1.39*	1.15	1.50*
ι_{cII} (time of rotation correlation of spin sound II in erythrocyte membranes)	2.20	1.51	1.66	1.99	1.48	2.08
CP (ceruloplasmin)	1.16	1.01*	0.92*	1.15	1.18	1.20
TF (transferrin)	0.77	0.82	0.82	0.85	0.72	0.65
Free radicals with g-factor 2.0	0.69	1.20*	1.05	1.02	0.92	1.04
Chromosomal aberrations	0.11	0.18	0.68	1.15	1.66	2.64

*- indices which differ from control by Student's criterion with significance level p<0.05.

correlation analysis of indices of organism antioxidant status in every examined group.

We must note that the observed alterations are not to be considered as some determined pathology. Probably, such alterations in the LP regulation and, consequently, in homeostasis regulation represent so-called pre-nosologic pathology which can remain compensated without manifesting itself clinically, but can realize itself in various diseases in certain conditions. The risk of progress of diverse diseases is to be much higher in the people irradiated even at low doses.

The analogous regularities were found also in the study of immunological characteristics of the same participants of the accident liquidation.

It is interesting to note that we obtained closed dependencies on dose both for immunological index and for antioxidant status. It is very important that the highest deviations are observed in the dose range up to 15 cGy, while these indices are closer to the control ones at the irradiation of 20-25 cGy.

These data confirm once again our idea that the dose dependencies for low-intensive irradiation are of complicated character.

It should be emphasized that the antioxidant and immunological organism statuses are responsible for its resistance to the action of diverse factors affecting health state. The experiments have shown a possibility to control immunological characteristics by changing the antioxidant status in certain direction and vice versa. Therefore, the deficit of antioxidant in the immune systems is a serious index to forecast diseases among persons irradiated at low doses.

Thus, we may suppose that the overall evaluation of such alterations by set of parameters characterizing organism antioxidant status can help to reveal groups of the people with increased risk of different pathologies.

The data obtained in the present study may be

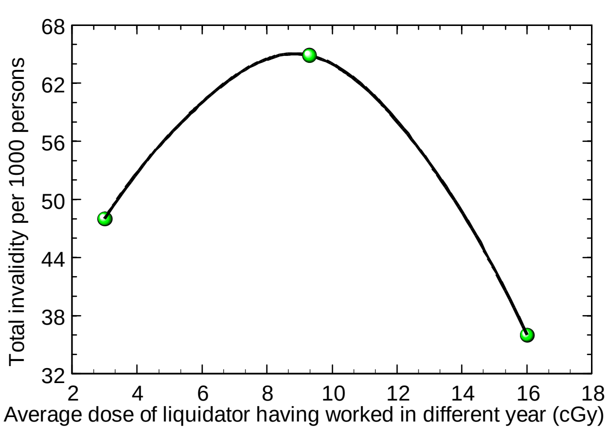

Fig. 7 Dependence of general disability (per 1,000 people) of liquidators on irradiation dose (5 years after their work on liquidation of the ChAPS accident consequences).

considered as one more confirmation of a necessity to apply natural or synthetic antioxidants to the people subjected to the action of ionizing radiation including low doses.

Dose dependencies of health state indices of the cohorts exposed to low-intensive irradiation

We tried to compare the alterations of biochemical and biophysical indices of liquidators blood with the regularities of their health state change.

We registered earlier that the increase of incidence of diseases characteristic for the participants of liquidation of accident consequences (liquidators) - vegetovascular distonia, nervous system diseases, psychical disorders, gastrointestinal diseases and others - shows the same tendency (non-monotonous, non-linear dependence on dosage) as obtained in experiments [1]. A number of biochemical and hematological characteristics in the people irradiated at accidents of atomic stations also manifest complicated dependence on dosage [29, 30].

If we consider that the degree of disablement of irradiated contingent is an integral index of health loss, it is important to estimate the rate of disabled people (per 1,000 liquidators) in dependence of obtained dose or the period of work at ChAPS. It is known that liquidators who worked in 1986 obtained the highest irradiation doses (15.9 cGy) in average, in 1987 - 7.9 cGy, and in 1988 and later - 3-4 cGy [3].

Figure 7 shows the data of disabled people among liquidators groups (per 1000) after 5 years since their work at ChAPS. As it is seen in Figure, the dependence is of extreme character with maximum corresponding to 7.9 cGy dose.

However, it would be the most interesting to study such dependencies for remote irradiation after-effects, namely, for malignant neoplasm increase. The question about the effect of low-dosage irradiation on the appearance of malignant tumors and leukoses is widely discussed in the literature. It is known that ionizing radiation can perform both as promoter and as inductor of malignant neoplasm. Increase of dose rate and dosage of irradiation (up to certain limits) causes decrease of promoting and increase of inducing function of irradiation.

Let us consider from these positions the situation with malignant neoplasm by Chernobyl.

Oncological diseases and death rate among the participants of liquidation of the Chernobyl accident consequences are studied in the wide and deep work implemented under the supervision of Academician A. F. Tsyb and published in the Bulletin of National Radiation-Epidemiological Register [31].

Table 6 Morbidity and mortality (per 100,000 man-years) from malignant neoplasms among liquidators [31].

Index	0 - 5 cGy	5 - 10 cGy	10 - 15 cGy	15 - 20 cGy	20 - 25 cGy	25 cGy and higher
Morbidity						
Leukemia	7.68	6.18	8.03	8.48	6.23	3.04
All malignant neoplasm	117.5	122.30	157.51	142.94	134.54	180.56
Malignant neoplasms of digestion organs and peritoneum	21.94	32.26	49.79	38.16	35.60	37.43
Mortality						
All malignant neoplasm	36.20	39.12	44.96	57.95	56.07	40.82
Malignant neoplasms of digestion organs and peritoneum	9.32	15.10	20.87	21.20	24.92	17.0

Table 6 contains the data on the indices of morbidity and mortality from malignant neoplasm among the participants of liquidation of the Chernobyl accident consequences [31]. It is clear that the dose dependence is not monotonous, and for all adduced examples the minimal values of indices of morbidity and mortality correspond to the dose near 25 cGy, while the maximal values are at the dose of 10-15 cGy.

Similar dependencies are not the unique type of dose-effect relation, though they are observed quite frequently. In a number of cases it is regular linear or linear-quadratic dependence. The range of doses under which the decrease of malignant neoplasm or of death rate from them is registered is different for different diseases and depends, beside of the disease nature, on dose rate. For example, the linear dose dependence of mortality from lungs cancer is observed in mortality for lungs cancer of the people irradiated with radon in houses, and of the miners irradiated with radon doses with much more intensity [32, 33].

Many authors consider that the relation between malignant neoplasm and irradiation is worthwhile only in the case when the cancer incidence increases with the irradiation dose. As described above, taking into account all experiments and studies of irradiated populations as well as the data from literature, the PRESENCE of linear or linear-quadratic dependency IS NOT obligatory for the cases of diseases and deaths from malignant neoplasm at low doses and low-intensive irradiation. The absence of monotonous dependence on irradiation dose and the appearance of maxima at lower dose are confirming radiation effects of cancers induction at low doses, rather than refuting it.

As the conclusion of all mentioned, it should be stressed that the regularities of low-intensive irradiation, the low doses effects are the principally new ways of radiation effect on living objects, the new mechanisms of cell metabolism change. The majority of effects are not induced directly by irradiation but indirectly through the regulation system, through alteration of the immune and antioxidant organism status and sensitivity to the action of environmental factors.

It is noteworthy that the similar regularities of the change of studied parameters were observed both in blood of liquidators and in experimental animals. Not only the similar character of dose-dependency but also the identical systemic multifactor response was discovered about the action of low-intensive irradiation.

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Chernobyl Sufferers in Ukraine and Their Social Problems: Short Outline

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1. INTRODUCTION.

1.1. Change of nationhood and political system in Ukraine after the accident.

At the moment of the Chernobyl NPP catastrophe Ukraine was one of 15 republics of the Union of Soviet Socialist Republics (USSR, or Soviet Union). Ukraine was the second biggest republic (population 51 million) after Russia (population 144 million in 1986). Soviet Union was a strongly centralised state with one and very powerful ruling Communist Party (CPSU), which dominated in all structures - governments, local authorities, army, businesses, culture, society as a whole.

Formally republics were self-governed, but in reality all important decisions were taken in Moscow by the Central Committee of CPSU and the so called Union Government. All management system was known as "command and control". The backbone of vertical authority was the Communist Party committees of all levels - Central, Republic, Oblast, district. There were also party committees at enterprises, organisations, villages and city quarters, which controlled implementation of decisions of higher levels. All resources, including financial - for industries, housing, food etc. - were distributed by central government in Moscow. Local governments and industries were lobbying interests of their regions and enterprises in Moscow.

Actually the only one way of influencing the state (and at that time everything was state!) policy was raising an issue at the meeting of a low-level party committee. Of course, only ideas supported by high level party authorities had some chances to be implemented.

In 1985 a new and dynamic leader of CPSU, Mikhail Gorbachev launched "perestroyka" - reconstruction of the whole system. This had lead to a substantial weakening of the authority of Communist Party. One important feature of perestroyka was "glasnost" - opportunity to publicly express one's opinion, reveal information etc. This opportunity was used to disclose facts and consequences of Chernobyl disaster, and eventually to make this problem an issue of a public policy. Glasnost was used by active political forces in republics, first of all Baltic republics, to begin a struggle for independence. Similar movements began also in Ukraine, Bielarus and other republics. Very often "green" slogans (protests against nuclear power plants, polluting industries) were first in programs of these movements. Such slogans were patriotic, but politically neutral and thus safer then direct appeals to independence. Major political forces were using issues like consequences of Chernobyl disaster, secrecy around this problem, absence of real consultations with sufferers to prove the necessity of real changes of the state system.

Soviet Union was facing extremely severe economic problems in 80-s, caused by the lasting Afghanistan war, huge expenses for armament race and dramatic 1985 drop in world crude oil prices - one of the main export commodities and the source of hard currency income.

Chernobyl disaster, mitigation of impacts of which required huge material and labour investments played an important role in developing economic crisis. Victims of radiation increased the number of suffering people which needed urgent help - like invalids of Afghanistan war, like victims of military conflicts in Azerbaijan, refugees from Georgia, sufferers of Spitak earthquake in Armenia, population in the area of Aral sea.

In August 1991, after the unsuccessful attempt of a coup-d'etat in Moscow, Ukrainian Verkhovna Rada (Parliament) proclaimed the Act of Sovereignty of Ukraine. The communist party lost its role and in less than a year the USSR has disintegrated. Ukraine had become an independent state with full responsibility for all positive and negative issues, including the legacy of Chernobyl catastrophe.

First and subsequent governments of independent Ukraine faced enormous problems with liquidation of Chernobyl consequences. These problems were exacerbated by enormous inflation during 1992-1995 and general breakdown of national economy due to various reasons. Rapidly decreasing quality of life of all population did not allow for proper measures to protect those for suffered from Chernobyl. It is hard to judge whether there existed adequate political will and capacities to sort out the problems and properly solve them.

1.2. Sufferers from Chernobyl catastrophe

a) liquidation of the consequences of disaster: "liquidators"

The first statement about Chernobyl catastrophe from the USSR Council of Ministers said "An accident has taken place at the Chernobyl power station, and one of the reactors was damaged. Measures are being taken to eliminate the consequences of the accident".

Those who “were taking measures” are the first big category of sufferers - “liquidators”.

The first who immediately was affected by reactor # 4 explosion was personnel of Chernobyl NPP and fire brigades - many of theses people died, and hundreds lost their health. Urgent measures to prevent further aggravation of disaster involved thousands of other specialists and workers. For example, to cool and strengthen the basement of reactor building a tunnel under the damaged reactor was dug by miners from Donetsk oblast - hundreds of them are suffering now from different diseases. To dampen the fire and contain the radioactivity, 5 thousand tons of lead, boron and sand had been dropped from helicopters in the heart of the burning reactor this meant irradiation among pilots and others who participated in this operation.

During May-November 1986 a giant construction of sarcophagus was erected. To build it out of more than 400,000 cubic meters of concrete, 7,000 tons of steel tens of thousands of construction workers, engineers, drivers were drafted to work just near the debris of unit 4, where radiation levels were very high.

The deadly decision to start again reactor # 3, situated on the same basement with # 4 and sharing a lot of vital communications, had led to over-irradiation of thousands of workers who constructed necessary walls and rearranged thousands of pipelines and electric circuits.

Of course, all these men working at the reactor 4 and around needed food, housing, transportation etc. Army and militia (police) regiments were guarding the fenced out 30-km exclusion zone. Most of them had only basic understanding of what’s happening and often their doses were very high.

During the years after the accident buildings, roads, machines and equipment needed permanent desactivation - and again this involved hundreds of drivers, dosimetrists, washers. In the course of desactivation houses in tens of villages were demolished and buried, and all the so called “red forest” (hundreds of hectares) adjacent to the power plant, was cut and buried in specially dug huge ditches.

People needed food and basic services, so logistical problems were solved on the highest level - in Moscow, with involved tens of thousands people lived at a time in the city of Chernobyl 30 km from nuclear power plant. The biggest canteen in Chernobyl, organised in a huge ward constructed for cars technical service could house more than 1000 men at a time.

First years after the accident “command and control system” was still strong, and the country (USSR) worked more or less as an army. Workers for the giant construction were recruited in all 15 republics, many of them were volunteers (levels of financial compensation for possible health problems were quite high). Those who did not want to come on their own were recruited to the Soviet Army and in the 30-km zone they were doing what was needed - but being dressed in military uniform.

As it is clear from above mentioned, people were draft from all parts of Soviet empire - and eventually dispersed on its wide spreads. No one knows exact figures - how many “liquidators” worked in Chernobyl. Some estimates give numbers around 600,000. According to the recent data, in Ukraine live about 180,000 liquidators. And, of course, much less is known about liquidators’ radiation doses.

b) population

The second huge category of the sufferers is population - we will speak of Ukraine. First of all, these were people of nearby cities and villages. Immediate victims became those who had rest or work out of houses. Some of them contracted even acute radiation diseases, radiation burns - and all received enormous doses of iodine on thyroid glands. But this was only the beginning - they lost their houses, property, jobs, their native land, after all.

The 50,000 population of the city of Pripyat was evacuated two days after the accident, and in later months and years still more people were forced to leave their homes. People were resettled to newly constructed villages, many found shelter with their relatives and friend all over Ukraine. They lived as refugees, very often in unfriendly surrounding - some illiterate men looked at evacuated as lepers.

Evacuation from contaminated areas continued for many years. Plan of Ukrainian Council of Ministers for 1990-1991 previewed evacuation of 45,000 people from contaminated zones. On contaminated territories of Ukraine in 1990 lived about 1,5 million people. All of them were suffering from Chernobyl.

People in contaminated areas were not allowed to eat wild berries and mushrooms (and this is the territory where traditionally “gifts of woods” are very important part of diet), they were not allowed to use milk of their cows and goats, and the traditional economy of collective-farms producing milk, meat, potato, linen collapsed.

It is hard to say whether evacuated people were in a better situation than those living in contaminated areas (except some limited number of NPP personnel and other privileged categories, who received comfortable apartments in Kyiv and other big cities). The quality of new settlements, built for the evacuated under a big time pressure was often very low, and many people were moving back to their houses in evacuation zone, including the 30-km zone around Chernobyl NPP.

There were direct and obvious sufferings like loss of houses, forced abortions or diseases caused by thyroid irradiation. But there were also hidden losses, like stress, change of life style, uncertainty etc. And, of course, families of Chernobyl “liquidators” suffered a lot.

1.3. Role of media and public politics in disclosing the real situation of people living in contaminated areas and liquidators

The information approach of the Soviet Government towards Chernobyl accident was formulated in a simple order of 27 June 1986: “To consider as secrets: data about the accident; data about results of treatment of sufferers; data on irradiation of personnel involved in liquidation of the consequences of disaster”. Numerous cases of diseases among liquidators and population of contaminated areas were called “radiophobia”.

It was perestroyka and glasnost which eventually led to the disclosure of the truth about the accident. As was already mentioned, democratic movements emerged in many republics of the USSR, and many of them were coloured in green. In Ukraine, the first unofficially (not by the order from the party committee) big rally in Kyiv was organised by Ukrainian Environmental Association “Green world” in November, 1988. At this gathering participants accused official medicine in hiding up the number of Chernobyl victims, the dangers of living in contaminated areas, in lack of care for liquidators and evacuated people.

One of the biggest information successes was documentary filmed by Georgi Shklyarevsky (“Mi-cro-phone!”), which revealed the truth about radiation levels in Narodichi district of Zhytomyr oblast. This documentary was followed by films and articles of other journalists. Some films had been shelved by authorities, like “Threshold”.

Very important role in disclosing the truth about liquidators’ sufferings played documentaries by Rollan Sergiyenko (“Threshold”, “Bells of Chernobyl” and others). In the West, several documentaries about Chernobyl disaster in general, about ill children, abandoned villages and people living in “forbidden 30-km zone” had been shot by different companies and TV programs. They had raise awareness of Western people and initiated the movement to help Chernobyl victims.

In fall 1988 - winter 1989 an election campaign of the first almost free elections of people deputies of the USSR began (role of People Deputies was to some extent similar to the role of Members of Parliament in Western democracies). Many candidates included requests connected with Chernobyl disaster in their programs. For example, Alla Yaroshynska from Zhytomyr oblast wrote in her program: “It is necessary to publish data on the consequences of radioactive contamination in Narodichi district, which are thoroughly hidden from the people. There are many villages with extremely high levels of radiation. On radioactively contaminated areas new construction has been organised, and more than 50 million roubles had been already invested. It is necessary to investigate the usefulness of this construction”.

Real fight against secrecy and for the benefit of sufferers of Chernobyl disaster was launched at the first Congress of People Deputies of the USSR, which took place from 25 May till 10 June in Moscow. People deputies from Ukraine - Volodymyr Yavorivsky, Yuri Shcherbak, Borys Oliynyk, Alla Yaroshynska - raised their voice to help victims of Chernobyl. Right before the Congress, on 24 May 1989, the USSR Government took decision to unclassify information about Chernobyl disaster. Unfortunately, it was easier to reveal the truth than to really help victims.

Another information blockade fell in 1989, when the documentary “Mi-cro-phone!” had been shown in the West. Later that year Volodymyr Yavorivsky openly spoke about the consequences of Chernobyl in the USA, Yuri Shcherbak was invited to the hearing in the Swiss Parliament (Switzerland was preparing vote on the future of Swiss nuclear industry), Alla Yaroshynska participated in a big antinuclear conference in France.

It was now clear that a lot should be done to solve the problems of Chernobyl. But it was also 100 % clear that the public purse of the Soviet Union Central Government is empty, and Ukraine was to elaborate its own Chernobyl policy. This was the task for the new Verkhovna Rada (Parliament) of Ukraine, which was elected in 1990.

Hundreds of candidates to Ukrainian Parliament included Chernobyl problems in their programs. The issue of Chernobyl sufferers became the question of a real politics. Basic laws on Chernobyl were adopted and money were needed to implement them.

Scarce budget resources were needed here and there, economic crisis in Ukraine became graver, but the decision was taken to impose a sort of a special Chernobyl tax and to spend it on the needs of liquidation of the consequences and mitigation negative impacts. Here we set aside the question of how effectively were this money spent.

2. STATE ACTIVITIES TO RESOLVE THE PROBLEMS OF SUFFERERS OF CHERNOBYL CATASTROPHE

As it was described in part 1.1, by the “State” we mean the Soviet Union and its part Ukrainian Soviet Socialist Republic in 1986 -1991, and an independent state Ukraine after December 1991. We will discuss efforts and successes of both legislative and executive branches of power, often calling both “Government”, although interrelations among them were not clear and obvious.

Of course the state (government) - taxpayers, as we would say now - carried the main burden of helping sufferers from Chernobyl. Public activity was essential to disclose the consequences and to attract attention of the state to this or that important issues. Public also played the main role in “independent”, non-governmental assistance, and this is the topic of chapter 3 of this report.

2.1. Soviet "command and control" period. Immediate measures and attempts to formulate a balanced policy

The state was bad prepared to a disaster of such scale as Chernobyl and most of necessary decisions were drafted and taken immediately when they were needed. Fortunately in the initial period there were material and financial resources available and a mechanism of direction was in place - an "undivided union" of the party, the state, the army. This mechanism was not perfect, and its quality was quickly deteriorating, undermined as well by Chernobyl itself.

Obviously Chernobyl disaster was not a case for a public policy, and it would not be such case in any other political system, at least during the initial period. The Soviet people were silent, they did not have vote. They received such vote only at the First Congress of the People Deputies of the USSR in 1989.

Executive power of the USSR - Council of Ministers and numerous ministries - behaved practically independently from the Supreme Soviet (Parliament) until 1989. First period was marked by attempts to hide and to diminish the consequences, and many efforts were needed to alter this approach (see pp.1.3 and 3.1 of this paper).

First decisions on compensations for those working at Chernobyl NPP and around, as well as for those evacuated, had been taken by the Central Committee of the Communist Party and the Council of Ministers of the USSR 7 May 1996. Workers received higher rates, those relocated from the zone of disaster - insurance compensations for their houses and one-time gratuities up to 4,000 rubbles per person. It should be noted that insurance premiums were several times lower than the real cost of abandoned households.

Of course, no compensation was received by women who underwent abortions during evacuation and first weeks after the accident. We could not find the number of such women or reliable information on whether and according to which criteria abortions were recommended (or not recommended) to pregnant women. This information is missing, although in the first period after the accident 2,000 medical teams examined 135,000 evacuated from the 30-km zone, "paying special attention to children and pregnant women" /1, p.540/. Could they turn the time back and annihilate huge doses accumulated by future mothers and foetus? Could they eliminate, reduce or compensate future impacts of these doses?

The question of desirability or necessity of abortions was also widely discussed in all area around Chernobyl, including Kyiv.

By mid-August 1986 some 90,784 persons were evacuated from Ukrainian area around Chernobyl. According to the ordinances of the Council of Ministers of Ukraine more than 11,000 one-family houses had been built for people evacuated from rural areas. People from cities Pripyat (50,000) and Chernobyl (12,000) received apartments in Kyiv, Chernigiv and other cities of Ukraine and other Soviet republics. Many of them moved in October 1988 to the city of Slavutich, built for the personnel of re-started Chernobyl NPP.

As always, a lot of abuses were happening with distribution of apartments, benefits, compensations. To solve their problems, people wrote letters to prosecutors offices, local and central party committees, Councils of Ministers. Pushing these letters through "corridors of power" were people deputies of all levels, journalists, some public organisations.

Evacuated people faced many problems. Often the quality of new-built houses was bad, they were cold and wet. Nature conditions in areas of resettlement were different from those of Chernobyl area - steppes instead of woods. People were complaining, some had moved back to their abandoned villages. In autumn 1988 more than 1000 people lived in the 30-km zone - as a rule, older people, pensioners. Some assistance for them was provided by the administration of the 30-km zone and, from time to time, they received shipments of humanitarian aid.

Even in the privileged city Slavutich, built by joint efforts of 8 Soviet republics, people were suffering from lack of medical care, poor food supply, uncertainty. The council of Slavutich public organisation "Pripyat society" which consolidated more than 2,000 former inhabitants of the city of Pripyat, had written numerous appeals, asking vital questions: "Who will calculate our real doses? Who will organise medical treatment and rest for our children - many of them are ill? When will we receive compensations for the damage to our health? The city of Slavutich is located in radioactively contaminated area, will we have respective privileges?"/2, p.105/

Similar issues were raised by the people in many other areas, like Narodichi, Ovruch, Polisske and others. They pointed out that levels of contamination were too high for safe living - why than to invest? "In our district - 25,000 people. In the district 67 million rubbles has been spent for new construction. 37 millions planned for this year. Easy calculations show that these sums would allow construction of 90 five-storey apartment houses, and all rayon would have homes. Where than this money is invested, when the decision is to be made on evacuating people from this land? Who benefits from this wasted millions?.. Why should someone supply us "clean" food when we could harvest them ourselves on "clean" lands?" /2, p.147/

Still there are no answers to these questions. Polisske, many villages in Narodichi and other districts are abandoned now, in 1997 - after all desactivations and construction...

Many people in contaminated areas (especially those with children) requested evacuation. Many others preferred to live where they lived but insisted on improving infrastructure (gas and water pipelines, paved roads, medical services) and financial compensations. Government was manoeuvring between these two options - both needed huge money, and after 2 years of central (USSR) funding the burden was shifting to Ukrainian budget.

The choice between evacuation and compensations was extremely controversial. Moreover, scientific and legal backgrounds for decisions were missing. As it was put in March, 1989 by TASS news agency: "The Ukraine Health Ministry has recommended the evacuation of five villages in the affected area, even though the ministry insisted that there hasn't been an increase in radiation-related "congenital anomalies" or tumour or blood diseases"/3/.

By the end of 1989 a low effectiveness of desactivation efforts became obvious and the Council of Ministers of Ukraine issued an ordinance allowing people with children under 14 to leave contaminated villages. Actually this decision was providing for some compensation for households which was left by people in contaminated areas. Calculations performed in the end of 80-th had proven that per capita costs of compensations and rehabilitation measures for people who live in contaminated areas are more than 2 times higher than the costs for evacuation.

In 1990 - 1992 several ordinances were endorsed by the Council of Ministers of Ukraine regarding obligatory evacuation, voluntary evacuation and compensations for those who live on contaminated areas. In 1990-1991 there were 13 658 obligatory evacuated persons and 58,700 "voluntary" resettles /1, p.88/.

By 1995 in 57 Ukrainian villages and settlements around Chernobyl lived less than one half of pre-disaster population (we do not mean those settlements which were evacuated).

Liquidators were also badly suffering from poor medical treatment, low pensions and low compensations for their lost health. Many of them were invalids but could not receive official proof that their diseases had been caused by irradiation during their work in the 30-km zone. In specialised wards and clinics for liquidators hunger strikes took place.

In March 1990, the Council of Ministers of the USSR and the All Union Central Council of Trade Unions adopted a special provision which defined the status of "liquidator", demanded regular medical examination of such people and determined some privileges to liquidators. This provision had been put into effect from 1 June, 1990 when the first certificates to liquidators had been issued.

Nevertheless, it was obvious that "soviet justice" did not work any more and real laws and mechanisms for their implementation are needed.

During September-October 1989 Councils of Ministers of Ukrainian SSR, Bielorussian SSR and Russian Federation developed the complex perspective plans of liquidation of consequences of Chernobyl disaster, and the Supreme Soviet (Parliament) of the USSR approved respective State Union-Republican Program. In line with this work, on the 28 of February 1991 Verkhovna Rada (Parliament) of Ukraine passed a law "On the status and social protection of citizens who had suffered due to Chernobyl catastrophe". The Parliament also approved the "Concept of safe living on the territories of Ukrainian SSR with high levels of radioactive contamination due to Chernobyl catastrophe".

In the same time the Parliament adopted decision on the source of funding for implementation of these laws. Enterprises were obliged to pay to a special Fund of Liquidation of the consequences of catastrophe 19 % (later 12 %) of sums of their wages-funds.

2.2. The Law of Ukrainian Soviet Socialist Republic (the law of Ukraine) of 28.02.91 and its implementation

The Law had been passed by the Parliament of Ukrainian SSR 28 February 1991. It was drafted under a serious pressure from "Chernobyl" lobby - people deputies and organisations who represented liquidators and those living in contaminated areas. Later the Law underwent some serious amendments in 1992, 1993 and 1996, mainly because an application of the law revealed some economic miscounts.

"The Law is directed at protection of citizens who have suffered in consequence of Chernobyl catastrophe, and at solving connected with it problems of medical and social character which have appeared because of radioactive contamination of the territory.

The state policy in the area of social protection of sufferers from Chornobyl catastrophe... is based on the principles:

- priority of life and health of people, who have suffered from Chornobyl catastrophe, full responsibility of the state for creating safe and non-harmful conditions of work;

...

- social protection of people, full compensation of detriment to people who have suffered in the consequence of Chernobyl catastrophe;
- use of economic methods of improving quality of life by employing policy of preferential taxation of citizens who have suffered from Chernobyl catastrophe and their unions..." (Article 1. *Here and onwards the law is quoted in unofficial translation of the author of this paper*).

According to the Article 70, added in 1996, citizens received the right to protect in the court their interests and rights guaranteed by this Law.

a) The Law explicitly distinguishes two groups - those who worked on liquidation (liquidators), and citizens (including children) who lived or lives in affected areas (suffers). Children also constitute a separate group with a separate system of privileges and compensations (Chapter V of the Law).

There are four categories of persons who have suffered from Chernobyl. These categories are defined according to the level of damage for their health (manifested and potential) during their work or because they have lived in contaminated areas. Liquidators have categories from 1 to 3, sufferers have categories from 1 to 4. Depending on their category people receive "general compensations and privileges" (Chapter IV. Social protection of the citizens... General compensations and privileges).

Disabled (both liquidators and sufferers) who had lost their health as a result of Chernobyl catastrophe constitute the category # 1. To receive this category a person must have a decision (based on medical examinations, records etc.) of a special certified medical commission which "ascertains a causal nexus of disease or disability and Chernobyl catastrophe". These commissions work in oblast centres.

Whether liquidator (not disabled) receives a category # 2 or # 3 depends on the period and duration of his/her work on liquidation. The fact of his work has to be proven by respective records at the enterprise which issued his/her assignment. For example, to receive category # 2 one should have worked "any number of days in a period from 26 April until 1 July 1996, or more than 5 days in a period from 1 July until 31 December 1996, or more than 14 days in 1997" (Article 14). Another time scale is used for category #3.

Of course, not all records at the enterprises were kept in proper order, and this had led to a numerous cases when people could not receive respective category. Even more frequent were abuses and false documents. Lyubov Kovalevskaya reported /4, p.307/ that of 14 scrutinised 2-nd category "liquidators" from high-level trade-union office only one half proof their category. In 1996 the state launched campaign of verification of liquidators' and sufferers' documents.

b) Definition of categories of "sufferers" is based on the level of radioactive contamination of soil in accordance with the Article 2 of the Law: "Categories of zones of radioactively contaminated territories". There are four zones.

The worst zone # 1 is an "alienation zone" - territory from which people were evacuated in 1986. "Zone of unconditional (obligatory) resettlement" (#2), "zone of guaranteed voluntary resettlement" (# 3), "zone of intensified radiological control" (# 4) are defined according to the levels of contamination. For example, territory is defined as a zone # 4 if it is contaminated by caesium isotopes with density 1.0 to 5.0 Ci/sq.km, or strontium 0.02 to 0.15 Ci/sq.km or plutonium 0.005 to 0.01 Ci/sq.km. There are some additional criteria stipulated by the National commission of radiation protection.

Actual category assigned to each sufferer depends on the zone where he/she lived, and the period and duration of living in this zone. e.g., if "a person permanently lived at the territory of unconditional (obligatory) resettlement on the date of disaster, or by the 1 January 1993 lived not less than two years in the zone of unconditional (obligatory) resettlement..." this person belongs to category # 3.

Actually for categories # 2 , # 3 and # 4 the Law does not distinguish the harm which has been already manifested (in the form of some diseases, or more frequent illnesses, or psychic misfunctions) and potential harm which has not yet developed in some visible form.

Dynamic of numbers of sufferers is impressing, partly because of changes in legislation directed at better social protection of sufferers and partly because of natality. During 1886-1995 the number of people which have the status of sufferer according to Ukrainian laws increased from 540,000 to 940,000 in 1990 and 3,200,000 in 1995 (of them 997,000 children) /1, p.129/.

There are seven grounds why a child can be the sufferer from Chernobyl catastrophe: evacuated from alienation zone, those who lived certain number of years in other contaminated zones, were born from parents who were sufferers of 1st, 2nd or 3rd category, those who have thyroid cancer or radiation sickness, those with thyroid doses higher than the level established by the Ministry of Health (Article 27). Medical treatment of children sufferer is defined as priority for all medical programs and is performed by the best medical and recreational facilities.

Children sufferers from Chernobyl catastrophe have privileges and compensations similar to those of adult sufferers. It is hard to say how efficient are all these measures, and how effective is government in providing equal access of all sufferers to the existing opportunities.

c) There are three other special chapters in the Law. Chapter VI defines mainly compensations and assistance for evacuated people for lost of their property. It also prescribes regulations on providing them with new housing.

Chapter VII regulates the work rules and remuneration for those working in contaminated areas.

Chapter VIII is specifically devoted to pensions, pensions due to disability caused by Chernobyl, and compensations to families that had lost providers.

According to the system of social protection, "general compensations and privileges" higher categories of sufferers have more privileges. The main components of this system are: health (medical care); recreation (vacations, sanatorium); material aids like apartments, houses, reduced rates for water and heat and electricity; social benefits - schools, universities;

economic - taxes and custom privileges; lower pension ages and higher pensions; transportation privileges and others.

These are long and complicated lists: 32 points for category #1, and somewhat shorter lists for other categories.

Never the system was accomplishing in full all that has been prescribed by the law. Always there were people waiting apartments or houses, or waiting free bed in a hospital, or disabled people waiting promised cars. According to the published data (we do not speak of real situation) allocated state funds allowed for covering recreation expenses for each second sufferer in 1991, each third in 1992, each eighth in 1995 /1, p.128/.

For example, all categories can get medicines free of charge, but this good provision very often does not work because pharmacies do not have needed medicines in stock.

Some privileges were directly leading to abuses, like tax exempt status for liquidators or permission to import everything free of charge. There were many articles in newspapers telling of liquidators or sufferers who managed to import new cars every second week. There were also enterprises importing lot of goods duty free and then selling them. Of course these enterprises claimed that this money is being used for the "protection of the sufferers of Chernobyl disaster", but it was hard to control their compliance. As a result, taxation and import privileges were soon revoked.

Some privileges were substantial at the time of endorsement of the law, like compensation for recreation or additional annual payments or special payments for "clean" food. Now many of them are negligible and result mainly in extra paper work for accountants, like 2.10 hryvna ($1.1) monthly extra payment for "clean" food in zone # 3.

The Law bears all signs of the so called "socialist distribution system". At that time (and sometimes now too) the state was the biggest owner and investor in housing, communication systems (telephones), educational and transportation system etc. Easier (in the first place or jumping the queue) access to these services and facilities was a benefit in itself, and this is often mentioned in the law. Indeed this system worked (and was also a huge temptation for abuses). Liquidators could even buy motor boats and vacuum cleaners "out of queue".

Almost at the same time when the Law had been passed the State Committee on Chernobyl was created to manage all related problems (later - the Ministry of Chernobyl). Local authorities with all their infrastructure (social care, medical care etc.) were also extremely tightly involved in these activities. Special "Chernobyl" departments were organised in rayon state administrations and now they carry main responsibility for accounting of sufferers, their needs etc.

d) There are two sorts of compensations: for the damage to health and for lost property. Calculations of compensations for health are based on the minimal monthly salary, which is specified by the Parliament (17 hryvna, or $9.20 in 1997).

For example, one-time compensation for people who were commissioned as disabled of the 1st group (as a rule, these people cannot work and need assistance in everyday life) is 60 minimal salaries (1,020 hryvna, or $550). There are also compensations for families, children of disabled parents etc.

Sufferers of all categories have some extra payments to their pensions and lower pension age. The pension age for category # 2 is lowered by 8 years, so men can become pensioners in 52 instead of 60. Pensioners of this category receive monthly an extra payment 30 % of minimal pension.

Compensations for lost property are defined in a special chapter of the law. This was one of the most controversial issue during all period after the catastrophe, because of extremely diverse conditions of living before and after the resettlement, and because of quickly changing and aggravating economic situation in Ukraine.

Another serious issue was construction of housing and respective infrastructure for evacuated people and resettles. With the so high state expenses on this construction (up to 15 % of all state capital investments) abuses with construction materials and funds were very frequent. And, of course, programs of construction were not achieved: in 1992 the program of resettlement was fulfilled on 19 %, and the program of housing construction on 28 % /5, p.668/.

Compensations, privileges and direct expenses on liquidation of the consequences of the catastrophe (e.g. maintenance of the infrastructure of the 30-km zone) have been an incredible burden on Ukrainian economy. The share of these expenses in the budget of Ukraine was 15.7 % in 1992, 10.9 % in 1993, 5.4 % in 1994 and 3.4 % in 1995 /1, p.79/. The biggest part of this money has been spent on compensation. The structure of Chernobyl budget (estimate) looks like the following: compensations 50 %, resettlement 20 %, health care 9 %, "Shelter (Sarcophagus)" and 30-km zone 5 %, Agriculture/Forestry 6 %, other 10 %. As it was mentioned before, these money are collected as obligatory payments to the special "Chernobyl" fund: enterprises pay 12 % of their wage-fund.

Ukrainian Parliament and Cabinet of Ministers have been facing intense pressure from all sectors of society which badly needed financial and other resources: social protection, medical care, education, local authorities of non-Chernobyl areas and so on. Of course the relatively high privileges to Chernobyl sufferers look unfair. Why only those who had suffered from Chernobyl and radiation are receiving so much? Why not the other areas of environmental crisis, like heavily polluted cities of Dniprodzerzhynsk or Mariupol? Why only Chernobyl children and not those children who are from time to time loosing hair to full boldness in many areas of Ukraine, probably because of high non-specific chemical contamination of air, water and food? This acute problem is still far from solution.

As it was already mentioned, some controversial provisions of the law, like tax exempt status of organisations working in contaminated areas, or import laws for "Chernobyl" organisations have been already revoked.

3. PUBLIC MOVEMENT IN UKRAINE AND INTERNATIONAL ACTIVITIES TO HELP PEOPLE AFFECTED BY CHERNOBYL ACCIDENT

3.1. International medical and humanitarian aid

In this chapter we will pay special attention to "informal", non-governmental help from international community to sufferers of Chernobyl. Few projects of international organisations (IAEA, WHO), very often quite negatively perceived by Ukrainian people, require separate analysis. As a rule the goal of these projects was to offer research assistance to respective Ukrainian institutions and thus these projects were to some extent not directly aimed at sufferers, but at some medical problems.

When Chornobyl nuclear reactor exploded, the Soviet rulers did not yet comprehend the poverty of the state. Ukrainian government, headed at that time by the First Secretary of the Communist Party of Ukrainian Republic Volodymyr Shcherbytsky, refused to accept assistance from foreign countries.

Nonetheless, the policy of openness initiated by Mikhail Gorbachev was gradually dismantling the "iron curtain". Soviet-American Peace Marches, ecological conferences touched the problems of Chernobyl victims.

Assistance came first from non-governmental organisations and charitable foundations. First it was dosimetric and medical equipment, then medicines, vitamins, food. Concentrated efforts were made to protect children.

The process of development of foreign assistance to Chernobyl victims went hand in hand with the process of democratisation in the USSR. Of course, foreign donors needed domestic Ukrainian organisations to advise what is the best way of assistance and to practically deliver this assistance. From the very beginning the leading role in these contacts belonged to newly emerged NGOs - like "Zeleny svit (Green world)", "Chernobyl Union", "Children of Chernobyl", "Rukh (Movement)". Founded in 1989, later Rukh had become a political party. Very often the role of mediators was played by well established Soviet "quasi-NGOs" like trade-unions, young communist and pioneer organisations, Ukrainian Peace Committee and some others.

At the same time, specialised "Chernobyl" funds had been set up in foreign countries. During his visit in the US in October 1989 Volodymyr Yavorivsky implored America's help in forestalling the tragedy of Chernobyl victims. And Americans shipped humanitarian load of medicines, vitamins, powdered milk to Ukraine. All organisation was done by Chernobyl Fund organised by the family of Ukrainian Americans Matkivsky and their colleagues. This shipment was distributed among the people in contaminated areas by Ukrainian movement for independence and perestroyka - Rukh.

In spring of 1989 liquidators and former workers of Chernobyl NPP founded their own NGO - "Soyuz Chernobyl" (Chernobyl Union). Later this union became an international organisation.

Many other international activities were taking place during 1989-1990. We will briefly describe some as examples - not because they are better or different from others, but because an author was somehow involved in them.

a) A very attractive program of support had been suggested by Prof. Edmund Lengfelder from Munich University. Numerous German organisations and authorities (including universities, cities, lands) supplied dosimetric and diagnostic equipment, medical instruments etc. to Ukrainian and Bielorussian hospitals. This action was planned as trilateral co-operation (Germany, Ukraine, Bielorussia), but later Germans concentrated their efforts on Bielorussia. Results of the action were somewhat disappointing for Germans, as during follow-up visits they often found expensive diagnostic equipment to be not in use.

b) French organisation "Medicins du mond" set up a diagnostic laboratory in Kyiv to investigate Chernobyl children. Organisation worked in close relations with local medical authorities. Unfortunately, organisation provided only limited treatment for ill children who were investigated, this was considered unfair ("you use us as guinea pigs"), and after a year the mission was wrapped up.

c) One of the first international organisations which came to Ukraine was Greenpeace. In 1989 Greenpeace set up Ukrainian office with a clear name - "Greenpeace Children of Chernobyl". The aim of this office was to set up a hospital for Chernobyl children, equipped by the most sophisticated equipment. Negotiations with Ukrainian medical and Government authorities were very hard, but eventually all necessary approvals were obtained. Unfortunately, when the design of reconstruction of one of children hospitals was ready, agreement was cancelled by Ukrainian side. Greenpeace was forced to end up with equipping of biochemical laboratory in one of Kyiv children hospitals. Canadian technicians and doctors worked more then one year in the lab performing analyses needed by Ukrainian doctors. Finally the lab was donated to the city of Kyiv. The University of Alberta continued the program of training for Ukrainian doctors using grants from Canadian Government.

Later on Greenpeace had set up (jointly with International Renaissance (Soros) Foundation and Ukrainian Environmental Association "Zeleny Svit (Green World)" an independent environmental laboratory which investigated radioactive contamination of soil, food, water in the area around Chernobyl.

d) Very attractive was the project developed by Dr Martin Walter from the Swiss branch of IPPNW (International Physicians for the Prevention of Nuclear War) and later implemented by SKH (Swiss Commission for Help in Catastrophes). Swiss organisations equipped rayon hospital in Polisske, Kyiv oblast, with modern diagnostic equipment and several years Swiss doctors lived and worked in Polisske side by side with their Ukrainian colleagues. It is hard to believe that Polisske was evacuated in mid 90th (after construction of natural gas supply network, building new apartment houses, reconstruction of roads and millions of roubles invested in desactivation...)

Generally speaking, Ukrainian medical authorities were friendly, but not very constructive. It looked as if they suspected foreign organisations in attempts of learning something secret and extremely valuable about radiation diseases and suffering children. It was also very hard to get letters of acknowledgement from Ukrainian medical organisations and doctors.

Many foreign organisations got involved in assistance to children, including complicated and expensive medical treatment. "Help Chernobyl children" projects were taking all possible forms: organised groups of children, stay in families, organised vacations in Ukraine etc. Tens of countries in Western and Eastern Europe, former Soviet Union, Americas and on other continents - hosted Chernobyl children from Ukraine (and continue to do this now, in 1997!) All sorts of organisations were counterparts of foreign donors in Ukraine. Some figures related to Chernobyl Union activities you can find below, but that is only a small example.

First groups of children often were undergoing careful and specialised medical examinations, but later it appeared not necessary. Some projects were quite controversial, like an annual treatment of Chernobyl children in Cuba hospitals - many experts said that the climate was too hot and transportation costs were too high, but the project goes on.

A lot of humanitarian aid shipments were received in Ukraine. This was medicines, syringes, vitamins, powdered milk etc - tens of 20-ton trucks and airshipments a year. As a rule, such goods were distributed to hospitals and clinics, but also directly to big families, disabled.

The fact of supplying food needs some explanation. The region of Ukrainian-Bielorussian Polissie is a rural, quite poor area with forests, small villages and very bad road system. Traditionally people depended mainly on home supply of food - milk and milk products, potatoes. Wild berries and mushrooms was substantial part of a diet. After the accident, when milk was very radioactive and definitely not recommended for children and babies, this problem became extremely acute: supply of safe fresh milk from elsewhere was practically impossible, and Soviet industry producing children and baby food was agonising (as many other industries at that time). Purchases of imported baby food were limited because of lack of hard currency resources. Thus, any shipment of baby and children food was indeed vital.

Disappointments also happened during this humanitarian aid activities - both from foreign and Ukrainian sides. Foreigners complained for unfair distribution of donations, Ukrainians accused foreigners of supply of outdated medicines or broken equipment. Officials dreamed of co-ordination. An attempt to set up a Co-ordination Committee was made at a Congress of World Federation of Ukrainian Medical Societies in 1991. Fortunately or not, both co-chairmen of Committee did not start a real work, and the idea died without consequences. It seems, however, that the need in co-ordination was quite real - in 1992 the same appeal was expressed by Volodymyr Yavorivsky.

Eventually Committee on Humanitarian Aid had been created at the Cabinet of Ministers of Ukraine. It was headed by Vice Prime-Minister and was solving all questions related to receiving and distribution of humanitarian help. By 28 December 1992 11,439 tons of humanitarian shipments were received in Ukraine /1 p.176/. Of course it is impossible to believe that all loads had been registered at this Committee, so actual number is higher. The biggest donor was Germany (about 50 % of all aid), then Italy, France, USA and other countries. Of received humanitarian aid 67 % was food, 18 % medicines and medical equipment, and 15 % of clothing's and other goods.

Some less successful fund-raising activities were organised by Chernobyl NGOs in the end of 80th - beginning of 90th. These were bus tours to European countries, tele-maraphones, exhibitions. Expenses for such events were sometimes comparable to the sums collected. Some Western Europeans had already sad experience with individual "Chernobyl fund raisers", which collected money or medicines and later were reported to sell these medicines to clinics.

Gradually children summer recreation has become the main "Chernobyl aid" activity, while medical problems are being solved mainly under bilateral or multilateral intergovernmental projects. As an example, the Sasakava Fund helped in equipping and financing examinations of children in several clinics, including one in Ovruch (Zhytomyr oblast).

Intergovernmental assistance to sufferers was quite limited. For example, in September 1991 the special Conference was held in New York to create a special Chernobyl Fund for three regions of the former USSR. Total collected sum amounted to $1,500,000 /1, p.161/. This poor result was partly a consequence of the report prepared and published by the IAEA. This report was prepared during an international investigation headed by Itsuzo Shigematsu (by the way, investigation did not include liquidators). At the very first stages of the investigation "green movement" strongly protested against biased approach of IAEA. When the report has been published the Government of Ukraine also objected against its conclusions.

3.2.Non-governmental "Chernobyl" organisations

Ukrainian writers were the first who began campaign to disclose the truth of Chernobyl in Ukraine. In 1988 the first "green" NGO in Ukraine was created - "Zeleny Svit (Green World)". It was an association with numerous member organisations in many oblasts and districts of Ukraine. Of course, Chernobyl problems were of the highest priority for the "Green world". In 1989 another network of small NGOs appeared as part of "Green world" - Union "Salvation from Chernobyls". Organisations of this Union were founded mainly in contaminated areas.

These NGOs played an important role of pressure groups. This was "vox populi", and it was used by people deputies and local authorities of contaminated regions to redistribute resources in favour of contaminated areas. Often local politicians were using support from these groups in their election campaigns and legislative work.

An important example of such activity was the first public meeting of the State Commission for Liquidation of the Consequences of Chernobyl Accident in Narodichi, Zhytomyr oblast in August, 1989.

Later that year an antinuclear, anti-Chernobyl march had been jointly organised by "Green world" and Ukrainian movement for perestroyka "Rukh". March started at Khmelnytska NPP in Western Ukraine and was to finish in Kyiv. On the route rallies were taking place in numerous villages and towns: people protested against the secrecy in Chernobyl affairs, demanded fair compensation for the victims, demanded clean food, medicines for sufferers, evacuation of children. More than 300,000 people from 5 oblasts signed an appeal to the Supreme Soviet (Parliament) of the USSR. This appeal with signatures had been taken to Moscow and handed over to Ukrainian members of the Parliament (Shcherbak, Yavorivsky and others). They use this appeal to push the badly needed Chernobyl legislation through the Parliament.

Another important project of "Green world" was an Independent Chernobyl Investigation (1990-1992), with participation of lawyers, witnesses etc. This was an attempt to give a legal appraisal of actions of government officers and all others responsible for Chernobyl disaster and clean up (liquidation of consequences). Ideally that would have allowed the victims of Chernobyl disaster to sue the state, officers or managers and to receive through court procedure a just compensation for loss of health or property. Unfortunately, very few lawyers agreed to participate in this project (organisers were thinking of a trial similar to Nuremberg Tribunal). As a result, collected evidences and their legal appraisal did not have convincing value. What is even more important, government officers who were responsible for Chernobyl decisions are still active politicians and they would never allow such process to go too far.

While "Green world" worked primarily with the population of contaminated areas, similar role for liquidators and evacuated people played another NGO "Chernobyl Union International" (CUI), founded in Ukraine in 1989 and registered as an international organisation in 1991. The primary aim of CUI was "to address and mitigate the consequences of the accident... by assisting the 1.5 million direct victims of the Chernobyl catastrophe including children and those disabled due to the effect of the explosion, to deal with the extraordinary social, economic and medical needs they are facing" (Statute of International Organization "Chernobyl Union", registered in the Ukraine Ministry of Justice 24th February, 1992).

Funds for its activity CUI received from other charitable organisations abroad - Bavarian Red Cross, German land and city governments, clinics etc. CUI has not been the recipient of aid, but has served as the facilitator and co-ordinator of relief to institutions, hospitals, clinics etc. The cost of goods and medicines distributed by CUI in Ukraine amounted to tens of millions dollars (compare $1,500,000 collected at the UN Conference in 1991, p.3.1 above).

CUI played an important role in initiating and drafting laws concerning the status and social needs of Chernobyl victims. At that time the CUI President Volodymyr Shovkoshytny was a People Deputy of Ukraine.

Important and still going on program of CUI was organisation of children rest abroad: 231 children in 1990, 1520 in 1991, 1800 in 1992 and so on.

There are also several NGOs named "Children of Chernobyl" in Ukraine and other countries. They organise treatment of children and their rest abroad and in Ukraine.

Separate investigation is needed to assess the role and results of activities of different charitable foundations and enterprises, which were organised by people who had status of sufferers from Chernobyl disaster. Such organisations enjoyed substantial tax privileges and other benefits according to Chernobyl legislation. It is essential that these privileges were stipulated not by the law itself, but by decrees and ordinances of the Cabinet of Ministers, which were often applied selectively, according to the statutes of organisations and some other features.

CONCLUSION

This report is based both on materials published in the Soviet Union and Ukraine and on author's personal experience. Report does not pretend to be a complete investigation of social activities in Ukraine related to Chernobyl disaster.

In 1987-1989 the author worked as physicist in the 30-km zone and in other contaminated areas. This enabled him to meet many people of different levels (administrators, collective-farmers, "self-settlers" etc.). In 1988-1991 author was an active Board member and researcher of Ukrainian Environmental Association "Zeleny Svit (Green World)" - the biggest and most influential Ukrainian NGO at that time, headed by People Deputy of the Soviet Union Yuri Shcherbak.

In 1991-1993 the author worked as a Project Manager and Director of Greenpeace Ukraine office. That was the time when Greenpeace ran a medical assistance project and independent investigation of radioactive contamination in Zhytomyr oblast. These activities required frequent contacts with the Ministry of Health Protection and members of Ukrainian Parliament, with people in contaminated areas.

The author also participated in some humanitarian projects, mainly with Swiss and German partners.

Being a "participant of the liquidation of the consequences of Chernobyl catastrophe, category 2A" author has also personal experience with the system of social assistance.

The author is well aware that this short report is only one drop in the process of disclosing of the role which public and different social forces played during after-Chernobyl period. While - at last! - many documents have been published and analysed /1,5/, a really deep and unbiased analysis of the roles of many important players like IAEA, UN and its organisations, international "green" and anti-nuclear organisations, internal Soviet nuclear lobby, Soviet "green" and public movements is needed. Maybe it is still too early and in-depth analyses is not possible simply because the drama is not finished yet and many players are still on the stage.

Of course it is necessary - as gratuity and acknowledgement - to collect and publish information about all people of good will from all over the world, who have helped the sufferers of Chernobyl catastrophe. This should include both official structures and purely unofficial and private actions.

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Social Aspects of the Chernobyl Activity in Belarus

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Introduction

The Chernobyl accident has caused heavy impact on the environment in Belarus, Russia and the Ukraine. It has also resulted in a significant worsening of the economic situation in the affected republics of the former USSR, as well as in disruption of social life in large territories, growing anxiety and fears among the people living in contaminated areas and significant medical effects on all categories of the people affected by the accident. The USSR authorities knew about the seriousness of the radiological situation caused by the Chernobyl accident from the very beginning. However, at the time of the accident, the Soviet Union was in a state of deep economic crisis and was unable to implement necessary measures to mitigate the radiological consequences of the accident. That was one of the reasons for the USSR to conceal the true information about the accident and its consequences from the Soviet people. The traditional Soviet policy of concealing all data on any unpleasant event happening in the Soviet Union had played a very important role too.

The collapse of the USSR created the formal possibility to develop appropriate policy aimed at mitigation of the Chernobyl consequences in Belarus, Russia and the Ukraine. However, implementation of this policy has been limited due to lack of necessary material and financial means. These and other problems are the subject of the present report.

Official Soviet Policy of Chernobyl Consequences Mitigation

Today it is well known that the Chernobyl accident had been the severest accident in the history of the peaceful use of nuclear energy in the world. However, understanding of this fact had become a very difficult problem for the international community.

On the other hand, the Soviet leaders recognised the disastrous character of the Chernobyl accident already several hours after the explosions at the Chernobyl reactor had happened. Chief of the General Staff of the Soviet Army, Marshall of the USSR S.Achromeev recalled 5 years later that the first information about the accident came to him 1 hour after the explosions at the Chernobyl reactor [1]. Immediately after receiving this information, the General Staff had begun its efforts on assessment of the scale of the accident. Approximately at 10 a.m. (8-9 hours after the explosions) this assessment was finished and it became clear for the General Staff that the accident at the Chernobyl NPP had catastrophic dimensions, and that resources of the whole of the USSR were needed to overcome its consequences. This information was reported to the General Secretary of the Central Committee of the CPSU (Communist Party of the Soviet Union), M.Gorbachev in the morning of the 26th of April 1986.

Early in the morning of this day, the Government of the USSR had formed a Special Commission headed by the Deputy Prime Minister, E.Scherbina. This commission had to organise the necessary measures for liquidation of the Chernobyl accident.

Also, in the early morning of the 26th of April 1986 the USSR Ministry of Power had formed its own commission in order to study the reasons of the accident and for development of necessary measures. The member of this commission, the former Deputy Minister of the USSR, G.Shasharin wrote in his article published in 1991 in the Russian magazine "Novyiy Mir" that he was informed about the accident at the Chernobyl NPP approximately at 4 a.m. on the 26th of April 1986 [2]. At that time he was on his vacation in Yalta in the Crimea.

Two days later the Politburo of the Central Committee of the CPSU had formed the Operative Group of the Politburo headed by the Prime Minister of the USSR N.Ryzhkov. The Operative Group had to co-ordinate the activities of all Ministries and organisations engaged in liquidation of the Chernobyl accident.

The above-mentioned facts clearly demonstrate that the Soviet leaders had all necessary information at their disposal from the very beginning, and recognised the seriousness of the situation caused by the accident. However, this information was not accessible for local authorities that had to organise countermeasures for radiological protection of the population. Sometimes, such information can be received only unofficially.

The former chief of police of Gomel region, General S.Sazonkin recalled later [3] that he had received the first information about the accident at the Chernobyl NPP in a telephone conversation with the chief of the KGB department of the Gomel region. This conversation had taken place in the morning on the 26th of April 1986. The KGB chief told General S.Sazonkin that something had happened at the Chernobyl NPP, and that this information originated from the KGB colleagues from Kiev.

After this conversation General S.Sazonkin had ordered the police of the Gomel region to collect information about the radiation situation in the region. Thus, already on the 26th of April 1986, he had received data that the exposition dose rate in some villages of the Choiniki rayon reached 500 mR/h or 500,000 micro-roentgen per hour. This was about 50,000 times higher than before the accident.

According to General S.Sazonkin [3], the radiological situation in the Gomel region had become more clear to him only on the 1st of May 1986 when he was told by Gomel region authorities about the decision to evacuate all pregnant women and children under the age of 15 years from 25 settlements of Bragin, Choiniki and Narovlya district.

It seems that at first the Soviet leaders had decided to conceal even the fact of the Chernobyl accident. Such conclusion can be drawn from the fact that the first official statements about the accident was made only on the 29th of April 1986, when the Soviet television had given a short statement about the accident at the Chernobyl NPP in its evening programme [4]. However, this statement did not allow to make adequate conclusions about the scale and radiological consequences of the accident.

The Soviet Union was forced to deliver information about the accident due to the position of Sweden, which had established a very high increase in the background radiation on its territory soon after the explosions at the Chernobyl NPP took place.

As a result of the information blockade in the USSR, the general public was assured for a long time that the Chernobyl accident had affected only a limited number of Ukrainian settlements bordering the Chernobyl NPP. Sometimes, this caused surprising results.

It is well known that the territory of the Mogilev region is one of the most affected areas of Belarus. There are many settlements contaminated by caesium-137 to levels higher than 1,480 kBq/m^2 (40 Ci/km^2) [5]. During the first three months after the accident at the Chernobyl NPP even regional authorities of Mogilev did not possess objective information about the radiation situation in the region. Consequently, instead of countermeasures to protect the population from the harmful impact of radiation in the Mogilev region, the region had to carry out various activities outside its territory in the course of liquidation of the consequences of the Chernobyl accident.

These and other interesting facts are given in the secret report submitted by the Special Commission of the Central Committee of the CPSU to the Central Committee of the CPSU. This commission had visited the heavily affected areas of the Mogilev region in January 1987 [6]. For example, the Commission reported that inhabitants of 8 settlements of the Mogilev region have been contaminated by caesium-137 with levels of 1,480 kBq/m^2 (40 Ci/km^2) and higher, and have not received financial support established by a special decision of the Central Committee of the CPSU on the 22nd of August 1986 [7].

According to this document, each member of a family residing in the area with caesium-137 contamination level of 550 kBq/m^2 (15 Ci/km^2) and higher, had to be paid 30 roubles monthly. Such payment was meant for compensation of the financial damages inflicted to the families due to the restriction on consumption of the food-stuffs produced in their private households. Everywhere in the contaminated areas people called this money "coffin money".

The above-mentioned decision of the Central Committee of the CPSU from the 22nd of August 1986 also supposed a 25 percent increase in the salary of each working member of a family living in the area with caesium-137 contamination level of 550 kBq/m^2 (15 Ci/km^2) and higher.

The Commission of the Central Committee of the CPSU had found other violations in the Mogilev region. It reported to the Central Committee of the CPSU that the authorities of this region did not even know about the necessity to use special agrochemical measures developed by Soviet specialists to decrease the transfer of radionuclides into vegetable and animal production [6]. The same situation subsisted in the private sector.

In reality, only some restrictive measures have been introduced in the Mogilev region before January 1987. Most of these measures were related to school children. They had to stay in school 12 hours each day without permission to leave the school building [6].

The facts about the Mogilev region given above were not unique only for Belarus. Alla Yaroshinskaya reported in her brilliant book "Chernobyl: Top Secret" that residents of the Ukrainian village Voroneve (Korosten rayon of Zhitomir region of the Ukraine) had begun to receive their "coffin money" in June 1989, i.e. three years after the accident at the Chernobyl NPP [8].

The situation with the payment of "coffin money" and other financial support was even worse in Russia than in Belarus and the Ukraine. Many regions had been affected by the Chernobyl accident in Russia. However, until April 1990, the authorities had been reporting only about the Bryansk region.

In September 1989 a group of Ukrainian liquidators had sent a letter to the General Secretary of the Central Committee of the CPSU of the USSR, M.S.Gorbachev, the Prime Minister of the USSR Council of Ministers, N.Ryzhkov and the Chairman of the Soviet Trade Union, S.Shalaev [9]. The Ukrainian liquidators complained about the worsening of their health state and about denials of doctors to attribute their illnesses to radiation. They also complained about the absence of social assistance. The liquidators have written in the letter: "We know that the party and the government had agreed and issued a number of documents, but they were not brought to us."

The liquidators from the Ukraine not only asked for social assistance, but also insisted on publication of all documents regulating privileges and compensations for the people affected by the Chernobyl accident. The authors of this letter could not understand that lack of information on medical and social aid was reflecting the official Soviet policy toward the accident at the Chernobyl NPP and its consequences.

Practically, from the beginning, the authorities of the USSR considered this accident an ordinary accident with consequences that could have been liquidated within a couple of years. One should also remember that the human health and the life of the Soviet people had not been the highest priority in the former USSR. Moreover, the Soviet state had no means required for adequate social protection of the population affected by the Chernobyl accident. The inefficient economic system, arms race, the war in Afghanistan, large expenditures for the support of "democratic" movements in their struggle against the "world imperialism" had led the USSR to a state of deep economic crisis in the middle of 80's.

Due to these reasons, the Soviet state attempted to limit the programme of social assistance to the people affected by the accident at the Chernobyl NPP, and even to cease the implementation of this programme at all. Because of that, the inhabitants of the affected areas and liquidators could not get access to the documents establishing their privileges and compensations.

Such policy of the Soviet state in regard to social assistance had caused significant tensions in many cases. Sometimes residents of a village received their "coffin money" and a 25 percent increase in their salary, while the residents of a neighbouring village, that lived in similar conditions and worked together with the residents of the first village, did not receive any such assistance.

Medical Consequences and Problem of Relocation

The other problem of high importance which contributed to the social and psychological tension was the permanent worsening of the health state of the affected population.

In the case of children, a significant increase in different dysfunctions of thyroid, in the morbidity of iron deficiency anaemia, chronic diseases of the throat and nose, chronic bronchitis, bronchial asthma and pneumonia was found in comparison with the preceding years [10].

An increase in the morbidity of cerebrovascular system, hypertonia, chronic bronchitis, ulcers, rheumatism and other diseases was registered by adults living in the contaminated areas[10].

The Belorussian specialists have also established a reliable increase in the rate of congenital anomalies. Thus, the rate of inborn anomalies in the 17 most affected districts of the Gomel and Mogilev regions had increased from 4.27 cases out of 1,000 births in 1984-1985 to 6.89 cases out of 1,000 births in 1987-1988 [10].

However, all these medical effects were not recognised neither by Soviet specialists in radiobiology and radiation medicine nor by foreign specialists [11]. This resulted in the fact that Belarus had to face medical problems by the affected population without any medical assistance from the Centre and other countries of the world. Because of many shortages in the supply of medicines, as well as due to insufficient number of specialists in radiobiology and radiation medicine, the Republic was not able to implement adequate medical assistance to people affected by the accident. The medical situation in the contaminated areas of Belarus was also aggravated because the state did not pay the necessary attention to the problem of summer health improvement by children living in the affected areas.

This situation in this regard had begun to improve only in 1991 when the Belorussian authorities undertook a number of independent actions for liquidation of the Chernobyl consequences in Belarus. In early spring 1989 they declassified secret data on radiological situation in Belarus without asking permission to do so from Kremlin. This allowed the republican newspaper to publish geographic maps with data on levels of radioactive contamination of the territory of Belarus. The published data demonstrated that 23 percent of the Belorussian territory has been contaminated with caesium-137 to levels higher than 37 kBq/m^2 (1 Ci/km^2). It was also told that more than 2 million people were living in the affected territory.

After the secret data on contamination levels as a result of the Chernobyl accident have been published, a number of improvements were made in different areas connected to mitigation of the consequences of the Chernobyl accident in Belarus. For example, 59 thousand children living in the affected areas of Belarus could improve their health in summer in rest establishments, pioneer camps and different sanatoriums located in clean areas in 1989. However, this was only a small fraction of the children from the contaminated areas. The total number of such children constituted approximately 500 thousand.

All problems and shortages in social and medical fields in relation to overcoming of the Chernobyl consequences led the inhabitants of the affected areas to a conclusion that the only way to escape potentially dangerous radiation effects was to move from the contaminated areas to clean ones. Many inhabitants of the contaminated areas had come to this conclusion already some months after the accident at the Chernobyl NPP and left their homes.

As can be seen from the secret report of the Special Commission of the Central Committee of the CPSU cited above, approximately 20 percent of people living in areas of the Mogilev region with the caesium-137 contamination level of 1,480 kBq/m^2 (40 Ci/km^2) and higher had moved to clean areas of Belarus in 1986.

The desire of the inhabitants of the contaminated villages and settlements to be resettled to clean territories had become a dominant factor for the people affected by the accident at the Chernobyl NPP after the publication of secret data in March 1989 by the Belorussian newspaper. This urge was so strong that even the party leaders of Belarus had begun to support the resettlement of people on a scale much greater than the one foreseen in Moscow.

For example, the leader of the Communist Party of Belarus E.Sokolov said at the First Congress of the People's Deputies of the USSR in May 1989 that the inhabitants of the affected areas had to be resettled in case the state was not able to provide normal living conditions without imposing any restriction and excluding the risk of damage to their health as a result of irradiation [12].

Resettlement was implemented in Belarus, Russia and the Ukraine in 1990-1995. About 130 thousand people were relocated in each of these countries from the affected to clean areas. This action required very large financial and material expenditures which had worsened the economic situation in the new states formed after the collapse of the USSR.

Many specialists outside the former USSR believe that extensive relocation of residents from the contaminated areas has been a great mistake on the part of Belorussian, Russian and the Ukrainian authorities.

The reason for such belief lies within the fact that the resettlement had given no improvement of the physical and psychological health state of the population from the affected territories [13]. The critics of relocation cannot understand that responsibility for such measures is born by the authorities of the USSR that were unable to understand the importance of psychological factors.

The lack of objective information about the Chernobyl accident and inappropriate protection measures have contributed to the development of extensive psychosomatic syndrome not only among the affected people but also among the inhabitants of clean areas.

The main legacy of the Chernobyl accident has been the anxiety about the state of health and a social disruption manifested in widespread health disorders not induced by radiation [13]. The authorities of Belarus, Russia and the Ukraine were practically pressed by the affected population to undertake extensive measures on resettlement.

One also needs to recognise that practically all protection measures undertaken in the USSR after the accident at the Chernobyl NPP have failed, such as iodine prophylactics, ban on consumption of contaminated foodstuffs, decontamination of affected settlements, attempts to improve the life standards in the affected areas, etc. The same happened to the state financial support of the people from the affected territories because the inevitably arbitrary allocations have produced an opposite effect, i.e. feeling of inequality and jealousy.

The "350 mSv Concept"

This feeling and the absence of adequate medical aid as well as the informational policy of the state over the years after the accident have caused deep distrust in the authorities and their promises to provide safe living conditions in the affected areas on the basis of the "350 mSv concept". This was the reason for many residents of the contaminated areas to believe that only resettlement could solve their Chernobyl problems. Local authorities of the affected territories shared the same point of view. It was clearly demonstrated at the XI Session of the Supreme Soviet of the BSSR, which had begun its work on the 28th of July 1989.

The main topic of this session was the discussion of the State Programme on Mitigation of the Chernobyl Consequences in Belarus, proposed by the government of Belarus. This Programme was developed on the basis of the so-called "350 mSv concept" approved of by the Head Physician of the Soviet Union on the 22nd of November 1988 [14].

The 350-mSv concept was a typical "threshold" concept based on the assumption that there exists such a dose of radiation, below which exposure causes no harm to the organism. The authors established 35 rem (0.35 Sv) as such a dose. According to this concept, all protective measures and restriction had to be lifted from the 1st of January 1990 in areas where irradiation dose over the period of 70 years was assessed to be 35 rem or less.

The "scientific" basis for the "350 mSv concept" was provided by specialists of the Ministries of Health Care of the USSR, BSSR, Russian Federation and the Ukrainian SSR, under the head of Academician L.Ilyin [15]. In 1988 they had carried out an assessment of the radiological consequences of the accident for the population of the USSR. As follows from their assessment, the biomedical consequences of the Chernobyl accident had to be so negligible that even extensive and careful studies could not have demonstrated harmful effects of the Chernobyl accident.

According to the authors of the assessment, in case all restrictions and protective measures were lifted, 80 percent of the inhabitants of the strict control zones (caesium-137 contamination level 555 kBq/m^2 (15 Ci/km^2) and higher) would have received the lifetime dose of irradiation lower than 0.35 Sv (35 rem) over the period of 1986-2060. 14 percent would have received a lifetime irradiation dose of 0.35 Sv to 0.5 Sv, and only 6 percent would have received doses higher than 0.5 Sv. They also predicted that in case protective measures (decontamination of settlements, construction of roads with asphalt covering, use of special agricultural methods, etc.) are taken, people who would have received doses of 0.35 Sv to 0.5 Sv, would receive lifetime doses lower than 0.35 Sv and 6 percent of the inhabitants of the strict control zones would receive lifetime doses higher than 0.35 Sv. The total number of such persons was determined to be

17,900. 7,340 people in the Bryansk region, 7,360 in Belarus, and 3,200 in the Ukraine. These people needed to be resettled to clean areas.

This assessment was approved in March 1989 at the General Session of the Academy of Medical Sciences of the USSR and submitted to the World Health Organisation (WHO), the International Atomic Energy Agency (IAEA) and other international organisations. Later it was published by a world famous magazine on radiation protection [16]. Thus, the assessment of the radiological consequences of the Chernobyl accident made by the official specialists of the Ministries of Health Care of the USSR, Belarus, Russia and the Ukraine became known to specialists in radiation protection around the world and was accepted by the international radiation community as absolutely correct.

However, the data of the Soviet specialists [15,16] have not been correct. They have been too optimistic. For example, only 91 cases of thyroid cancer by children and adults of Belarus were predicted to happen as a result of the Chernobyl accident. The authors of the assessment predicted that these additional thyroid cancers would appear within 30 years (1990-2020), with the latent period of 5 years.

On the contrary, only 10 years passed since the accident (1986-1995), and 424 cases of thyroid cancer have been registered in Belarus by children under 15 years [17]. The morbidity rate of the thyroid cancer by children had been 1 case per year before the Chernobyl accident [18]. This taken into account, the number of radiation induced cancers over the period from 1986 to 1995 turns out to be 414. This is much more than the 91 cases of thyroid cancer predicted by the Soviet specialists in 1988 [15,16].

The given example illustrates the incorrectness of the official assessment of the radiological consequences of the Chernobyl accident. Hence, a conclusion can be made about the incorrectness of the "350 mSv concept".

The Belorussian Activity in Mitigation of the Chernobyl Consequences

The "350 mSv concept" was categorically rejected by the scientists of the Academy of Sciences of Belarus, as they believed that it had no real scientific basis. The same position in regard to the "350 mSv concept" was held by the members of the Supreme Soviet of Belarus. They demanded from the Government of Belarus to revise the suggested State Programme on Liquidation of the Consequences of the Chernobyl Accident in Belarus proposed by the Belorussian Government [19].

According to the members of the Belorussian Parliament, this programme developed on the basis of the "350 mSv concept" was aimed at only a small part of the residents of the strict control zones of Belarus.

The XI Session of the Supreme Soviet of Belarus became into a real public hearing on the Chernobyl problems in Belarus. This Session was broadcast by the Belorussian television. Besides, speeches of the People's Deputies were published by the republican press. Thus, all citizens of Belarus could hear very strong criticism of the authorities of the USSR and the republican authorities. Much was said about insufficiency of protective measures implemented in the affected areas of Belarus. An excerpt from the speech of the Chairman of the Gomel Regional Executive Committee, Member of Parliament N.Grinew: "One needs to recognise that for three years we have been trying to realise wrong plans. The attempt to stabilise the situation by means of decontamination, agricultural methods, organisation of a service of residents of the strict control zones has given nothing. If one takes into account the fact that the majority of the affected population lives in rural settlements, one will understand that these measures could not have given any positive results." [20]

Participants of the Chernobyl hearings delivered many facts on the actual situation in the contaminated territories at the XI Session of the Supreme Soviet. For example, it was said that agricultural activities were still being carried out in areas with very high radioactive contamination levels, and even in the 30-km zone. Members of Parliament demanded to stop this dangerous practice because it led to production of contaminated foodstuffs and increased the potential danger for the health of the people living and working in the affected areas.

Very strong criticism was also expressed at the Session of the Supreme Soviet in regard to the inefficient social and medical support of the affected population, as well as to the inefficient organisation of health improvement by children living in the contaminated areas.

The revised State Programme on Liquidation of the Consequences of the Chernobyl Accident in Belarus [21] was heard at the XII Session of the Supreme Soviet of Belarus of the XI Convocation in October 1989. This programme was developed on the basis of the assumption that living in the affected territories, where it is impossible to produce clean agricultural and animal products, has no sense, even in case all possible protective measures have been taken.

The revised programme foresaw relocation of 118,276 inhabitants of the affected areas in comparison to relocation of 11,600 inhabitants suggested by the Government of Belarus in July 1989.

The relocation had to be carried out in three stages. In the first stage planned for 1990-1991, 17,083 inhabitants of the 112 settlements of the contaminated areas had to be relocated to clean areas of Belarus. The second stage was planned for 1991-1992. During this stage 4,685 persons had to be resettled to clean areas. The third stage foresaw resettlement of 96,508 inhabitants of 353 contaminated settlements after 1992 [21].

The new version of the Belorussian State Programme on Liquidation of the Consequences of the Chernobyl Consequences in Belarus also foresaw a number of social benefits and privileges for the inhabitants of the affected areas [21]. It decreased the pension age of the citizens living and working in the strict control zones by women from 55 to 50 years, and for men from 60 to 55 years. It also foresaw an increase in the annual vacation to 30 calendar days. In some cases, it could reach 42 calendar days. The residents of settlements with caesium-137 contamination levels of 185 to 555 kBq/m^2 (5-15 Ci/km^2) received the right for a vacation of 24 calendar days. An increase was foreseen in the pensions for invalids from their childhood and non-employed pensioners. The state planned to pay 30 roubles monthly to each member of the family living in such affected areas, where clean foodstuffs could not be obtained.

Significant attention was paid in the State Programme to the improvement of medical assistance to people living in the affected areas, improvement of their health in rest homes and sanatoriums, development of an infrastructure of public health care and improvement in the supply of medicines and equipment to medical establishments.

The State Programme took into account practically the whole bulk of problems existing in the affected areas of Belarus, for example, problems of production of clean agricultural and animal products, construction of clinics and other medical establishments in the affected areas, supply of ecologically clean fuel (natural gas) to the residents of contaminated settlements, construction of water pipes, etc.

Without any doubts, a conclusion may be drawn that realisation of this extensive programme could mitigate the problems caused by the Chernobyl accident to a significant degree.

In order to reach this goal, however, the Republic needed significant material and financial support of the Centre. According to the decision of the Supreme Soviet of Belarus adopted at the XII Session on the 25th of October 1989, all financial expenditures (16.9 billion roubles) related to implementation of the Belorussian State Programme, had to be provided by the budget of the USSR. This was possible only in case the Supreme Soviet of the USSR had approved the Belorussian State Programme.

Changes in the Official Soviet Policy

The hearing of the Belorussian State Programme was carried out by the Supreme Soviet of the USSR at its Session on the 25th of April 1990. The Ukrainian and Russian programmes were also heard at this Session. Both of them differed strongly from the Belorussian Programme because they were based on the "350 mSv concept". Besides, the Russian Programme took into consideration only the Bryansk region, despite the fact that 16 regions of Russia were affected by the Chernobyl accident [22].

As a result of the hearing, the Supreme Soviet issued a special decision in regard to mitigation of the Chernobyl consequences [23]. This document recognised protective measures taken in the USSR after the Chernobyl accident as insufficient, especially in relation to medical and social assistance to the affected residents.

The decision of the Supreme Soviet proposed to the Government of the USSR to develop a united programme of mitigating of the Chernobyl consequences in Belarus, Russia and the Ukraine on the basis of a concept of safe living in the affected areas acceptable for the population. It required from the governments of Belarus, Russia and the Ukraine to correct their programmes considering the comments made by the experts of the Supreme Soviet of the USSR and by the parliament members during the hearing.

In addition, the Decision of the Supreme Soviet of the USSR proposed to the Government of the USSR to develop a project of a special law on the Chernobyl catastrophe and to present it to the Supreme Soviet of the USSR before the end of 1990. The Supreme Soviet also demanded from the Government to elaborate in 1990 scientifically based criteria of safe living in the contaminated areas.

This Decision indicated also the necessity of a more substantial and urgent relocation of residents from the affected areas to clean areas of the USSR and a need for an improvement in the living condition of the people living in the affected areas.

This was the first document that demanded from the authorities to develop a state system of compensations and privileges for residents living in the affected areas, relocated from these areas, and for those residents who had abandoned these areas themselves. This also pertained to the military personnel involved in the liquidation of the Chernobyl accident and of other Soviet citizens involved in the liquidation of different categories.

The first step in the mitigation of the consequences of the Chernobyl accident, proposed to the Government of the USSR by the Decision of the Supreme Soviet, was to develop an urgent programme foreseen for the period of 1990-1992 and to allocate financial resources from the budget of the USSR to urgent measures in 1990 required by the radiological situation in the contaminated territories of Belarus, Russia and the Ukraine.

The document mentioned above indicated the difference in the positions of the highest legislative body of the USSR and the executive authorities. The latter insisted on implementation of the "350 mSv concept" although they attempted to correlate their position. So, in October 1989 under the influence of the events in Belarus, the Council of Ministers of the USSR and the All-Union Central Committee of Trade Unions had approved the decision aimed at improvements of the medical and social assistance to the residents of the affected areas [24].

The latter document included a number of points of the Belorussian State Programme approved by the Supreme Soviet of the BSSR. However, the scope of the necessary measures established by this document was practically in the frames of the "350 mSv concept" that had to be implemented from the 1st of January 1990.

The Government of the USSR used all possible means to limit its expenditures for mitigation of the Chernobyl consequences because of the very complicated economic situation in the country. On the 19th of October 1989 the Government sent a letter to the International Atomic Energy Agency (IAEA) with a formal request for a an assessment by international experts of the "350 mSv concept" and countermeasures undertaken in the USSR after the Chernobyl accident [25].

This letter had initiated the International Chernobyl Project which was carried out in 1990 under the aegis of the IAEA. Conclusions of international experts that took part in this project are well known [25]. The experts recognised the medical consequences of the Chernobyl accident as relatively small in contrast to the socio-economic consequences of this accident for Belarus, Russia and the Ukraine. The experts approved the countermeasures taken in the USSR after the accident and rejected the necessity of resettlement of the inhabitants of the heavily affected areas. In principle this meant support of the "350 mSv concept" and attempts of the USSR Government to implement this concept at any price.

However, the Government could not reach this goal because of the political situation in the USSR caused in the process of *glasnost* and *perestroika* initiated by M.Gorbachev.

Elaboration of a Legislative Basis for Mitigation of the Chernobyl Radiological Consequences

Due to democratisation of the Soviet Union and new information possibilities, the Chernobyl problem became the main political factor in Belarus. In spring 1990 the new parliament was elected in the republic. All candidates to parliament promised during their election campaign to do their best for mitigation of the consequences of the Chernobyl accident.

On the 19th of July 1990 the Supreme Soviet of the Belorussian SSR declared the republic as a "zone of national ecological disaster" [26]. From this time the republic started to carry out an extensive programmeto liquidate the consequences of the accident at the Chernobyl NPP.

The legal basis for implementation of this programme was founded by the Law "On Social Protection of the Citizens Affected by the Chernobyl Catastrophe" approved by the Supreme Soviet of the Belorussian SSR on the 22nd of February 1991 [27]. This law was enforced in accordance with the Decision of the Supreme Soviet of the BSSR on the 22nd of February 1991 [28]. However, according to the Decision [28], a number of paragraphs and articles of this Law had to be enforced only after the agreement with Moscow because their implementation required allocation of financial resources from the budget of the USSR.

The postponed paragraphs and articles of the Belorussian Law [27] gave a wide spectrum of social benefits, privileges and compensation to all categories of the people affected by the Chernobyl accident (including residents of areas contaminated with caesium-137 in the range of 37 to 185 kBq/m^2 (1-5 Ci/km^2)).

By development of the Law on Social Protection parliament members used many positions of the Belorussian State Programme approved by the Supreme Soviet of Belarus in October 1989 and many positions of the Decision of the Council of Ministers of the BSSR and the Belorussian Republican Council of Trade Unions that supposed a number of measures for improvement of medical and social assistance to liquidators [29].

The Belorussian parliament established two kinds of radiological criteria for social and other benefits, privileges and compensations: level of territory contamination with caesium-137, strontium-90 and plutonium isotopes, as well as doses of irradiation.

According to this criteria all contaminated areas of Belarus were divided into 5 zones:

- the zone of evacuation or the territory around the Chernobyl NPP (30 km zone) and the territory with levels of contamination with strontium-90 higher than 111 kBq/m^2 (3 Ci/km^2) and plutonium higher than 37 kBq/m^2 (1 Ci/km^2);
- the zone of immediate resettlement where the surface contamination by caesium-137 is above 1,480 kBq/m^2 (40 Ci/km^2), by strontium-90 above than 111 kBq/m^2 (3 Ci/km^2), or by plutonium above 3.7 kBq/m^2 (0.1 Ci/km^2);
- the zone of subsequent resettlement where the surface contamination by caesium-137 is in the range 555-1,480 kBq/m^2 (15-40 Ci/km^2), by strontium-90 in the range of 74-111 kBq/m^2 (2-3 Ci/km^2), or by plutonium in the range 1.85-3.7 kBq/m^2 (0.05-0.1 Ci/km^2) and where the irradiation dose may be higher than 5 mSv (0.5 rem) per year;
- the zone with the right to voluntary resettlement with a housing guarantee where the surface contamination by caesium-137 is in the range 185-555 kBq/m^2 (5-15 Ci/km^2), by strontium-90 in the range 185-74 kBq/m^2 (0.5-2 Ci/km^2), or by plutonium in the range 0.37-1.85 kBq/m^2 (0.01-0.05 Ci/km^2) and where the irradiation dose may be higher than 1 mSv (0.1 rem) per year;
- the zone of residence with periodic radiation control with surface contamination of 37-185 kBq/m^2 (1-5 Ci/km^2) and where the irradiation dose is below 1 mSv (0.1 rem) per year.

The Law on Social Protection [27] established rules for compensations to all victims of the accident depending upon the category of the affected population. The broadest privileges and benefits were given by the Law to those who participated in the liquidation of the Chernobyl accident (liquidators). Their compensation included salary bonuses, access to free health care and free health improvement in rest homes, additional pension payments, etc. The lowest benefits were given by the Law to people living in the zones of periodic radiation control. The inhabitants of such zones received only some additional payment (about 30 roubles monthly in early 1992).

Chernobyl Activities in Independent Belarus

In December 1991 the Belorussian Law on Social Protection was amended in order to consider the new political and economic situation caused by the collapse of the USSR. As a result of this collapse Belarus came to a situation where it had to finance all expenditures required in the frames of the Chernobyl mitigation programme. In the preceding period (July 1990 — October 1991) a significant part of the needed financial and material means was covered from the budget and resources of the USSR.

In order to finance the Chernobyl programme the Supreme Soviet of Belarus set an special 18 percent wage tax (agricultural activities were granted a tax exempt) since 1992 [30]. In 1992 it gave about 60 percent of financial means directed to mitigation of the Chernobyl consequences. In 1994 the extraordinary tax was decreased to 12 percent and in 1996 to 10 percent.

Despite a very complicated economic state the Government of Belarus could allocate a significant part of the budget for mitigation of the consequences of the Chernobyl accident: 16.8% in 1991; 12.6% in 1992; 9.6% in 1993; 6.9% in 1994 and 7.3% in 1995 [30].

The specified expenditures of Belarus for 1997 [31] have to be 7,199 billion Belorussian roubles from the total sum of state expenditures at 72,645 billion roubles or about 9.9 percent of the state budget. As can be seen from this data, the government allocated about 10% of the budget for mitigation of the Chernobyl catastrophe consequences in the period from 1991 to 1997.

The main part of the state expenditures in 1991-1997 was directed in Belarus at implementation of the relocation programme. In the course of realisation of this programme 58,100 residential houses and apartments have been built for resettled families in Belarus [30]. All these houses and apartments were constructed in clean areas of the Republic. Over the same period different measures have been undertaken in the affected areas in order to improve the social-economic conditions in settlements where people had not moved away.

These measures include construction of 4,621 km of roads in the contaminated territories with hard covering, 1,099 km of water-pipe networks, 310 km of water drain, 1,072 km of gas networks, etc. [30]. A number of secondary schools have also been built with 28,000 places; pre-school establishments with 2,900 places, hospitals for 1,900 places, clinics and medical establishments for 10,700 visits per shift, etc. [30].

However, the real financial means used yearly during this period for the Chernobyl Programme decreased permanently because of decreasing of the state budget as a result of constant worsening of the economical situation in Belarus (the GNP of Belarus decreased by 40 percent in 1990-1996 !). This is the reason for rather small financial compensations of the state to the affected population of Belarus that have to live and work in the areas affected by the Chernobyl accident.

According to the Decision of the Council of Ministers of the Republic adopted on the 26th of May 1997 [32], the following compensations were established for each member of families living in the affected areas:

- 16,800 Belorussian roubles monthly in the zone of periodic radiation control;
- 21,800 Belorussian roubles monthly in the zone with the right for voluntary resettlement;
- 33,500 Belorussian roubles monthly in zones of subsequent and immediate resettlement.

This Decision also established an increase in salaries for employed persons, and payments for non-employed, pensioners, people living on social assistance, students and school children defined by the Law on Social Protection. This sort of financial assistance fluctuates from 13,800 Belorussian roubles in case of school children living in areas with periodic radiation control to 165,600 Belorussian roubles in case of persons working in the zone of evacuation.

One can imagine how small these compensation are, taking into account that $1 costs about 27 thousand Belorussian roubles (official rate for summer 1997).Considering this fact one needs to understand that inhabitants of the affected areas of Belarus have to confront radiological consequences of the Chernobyl accident practically without assistance of the state.

Another important point is that these people form a rather large fraction of the Belorussian population. The total number of citizens in Belarus was 10 million 276 thousand people in 1996. The number of people living in areas with ceasium-137 contamination density of 37 kBq/m^2 (1 Ci/km^2) and higher was 1 million 625 thousand people (Table 1) or 15.8% of the total population in 1996. This number includes 426,591 adolescents and children (Table 2). The data on the number of settlements in contaminated territories of Belarus are given in Table 3.

Analysis of the data presented in Tables 1-3 shows that in 1996 no people have been living in areas contaminated with caesium-137 to levels higher than 1,480 kBq/m^2 (40 Ci/km^2). All of them have been resettled to clean areas of Belarus.

Table 3 also indicates that the total number of settlements in the affected areas has dropped within the period of 1995-1996 from 3,221 to 2,930. Correspondingly the number of inhabitants in the contaminated territories dropped from 1,840,951 in 1995 to 1,625,981 in 1996 (see Table 1) or by 11.7%. The number of adolescents and children in the affected areas changed within the same period from 483,869 to 426,591 (see Table 2) which is 11.9%. These changes have mostly been a result of a contamination levels revision performed in Belarus in 1995 [33].

However, even this revision did not change significantly the fact that a very large fraction of the Belorussian population has to live and work in abnormal conditions of long-term irradiation as a result of the Chernobyl accident. The inhabitants of the affected areas are exposed to additional external and internal irradiation. The irradiation is especially serious in the case of inhabitants of rural settlements who consume foodstuffs produced in private sector that very often have high concentration of caesium-137 [34].

Practically, people living in the contaminated areas of Belarus have become a material of a scientific experiment being carried out to investigate the harm that can be inflicted by an accident at a NPP to heterogene population comprising pregnant women, infants, children, adolescents, old people, and the people suffering from different somatic diseases. It is evident that data established in the course of such an experiment are very important for the whole international community. However, one needs to understand clearly that Belarus is not able to detect all these harmful effects of the Chernobyl radionuclides on hundreds of thousands of people without efficient assistance on the part of the international community. Belarus has simply no means to solve such a problem. The country had to make very large expenditures for implementation of the State Programme on mitigation of the Chernobyl consequences. But these expenditures are only a fraction of the material and financial losses of the republic. Belorussian specialists assess the total material financial damage caused by the Chernobyl accident in Belarus up to 235.4 billion USD only for the years 1986-2015 [30]. The largest share (81.6%) of this damage will be incurred by expenditures connected with the support of production and realisation of protective measures including resettlement. 12.6% will be direct and indirect losses and 5.8% will arise from the lost profit.

Summing up the information given in our paper one can imagine how large could be the economic damage caused by an accident at a nuclear power plant similar to the accident at the Chernobyl NPP.

The very important lesson of the Chernobyl accident, that needs to be considered by planning of countermeasures in case of a nuclear accident at a

Table 1 Number of residents living in the affected settlements of Belarus with levels of caesium-137 contamination 37 kBq/m^2 and higher [33].

Contamination level, kBq/m^2	Years				
	1991	1993	1994	1995	1996
37-185	1,489,630	1,488,350	1,490,545	1,485,193	1,302,971
185-555	281,309	322,425	317,301	314,193	298,584
555-1,480	79,066	43,198	41,928	41,282	24,426
Higher than 1,480	2,944	353	251	283	—
Alltogether	1,852,949	1,854,326	1,850,026	1,840,951	1,625,981

Table 2 Number of children and adolescents living in the affected settlements of Belarus with levels of caesium-137 contamination 37 kBq/m^2 and higher [33].

Contamination level, kBq/km^2	Years				
	1991	1993	1994	1995	1996
37-185	—	409,267	409,154	395,309	347,748
185-555	—	80,162	79,870	78,721	72,970
555-1,480	—	9,134	9,125	9,821	5,873
Higher than 1,480	—	34	27	18	—
Alltogether	—	498,597	498,176	483,869	426,591

Table 3 Number of settlements in the affected areas of Belarus with level of caesium-137 contamination 37 kBq/m^2 and higher [33]

Contamination level, kBq/km^2	Years				
	1991	1993	1994	1995	1996
37-185	2,206	1,935	1,937	1,933	1,752
185-555	999	1,112	1,100	1,102	1,091
555-1,480	307	191	186	176	87
Higher than 1,480	58	13	11	10	—
Alltogether	3,370	3,251	3,234	3,221	2,930

nuclear power plant, is that any lack of objective information and every attempt to downsize the scale of the accident will aggravate the social and economic consequences caused by this accident.

Summary

The information given in the present report demonstrates clearly that the central authorities of the former USSR had known since the very beginning that the Chernobyl accident had a catastrophic scale. However, an attempt was made to play down the scale of the accident because of the very serious economic difficulties and due to political reasons such as the traditional Soviet policy of concealing all information about heavy accidents in the country.

Only the collapse of the USSR has given the possibility to undertake serious countermeasures aimed at decreasing the harmful impact of radiation. However, these measures could not have been carried out in full-scale due to the deep economic crisis in the country and because a very significant fraction of the Belorussian population has to live and work in conditions of long-term external and internal irradiation. Thus, the international community has a chance to study the consequences of a large nuclear accident. Such experience might be very useful in the use of nuclear energy for electricity generation on a wide scale. In order to obtain reliable data related to such accidents the international community has to render Belarus adequate assistance.

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Problems of Social Assistance to the Chernobyl Sufferers in Russia

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1. Assistance to the Chernobyl sufferers from the government

1.1. In the period of the USSR

By the time of the world's largest civil nuclear accident at the Chernobyl nuclear power station (ChNPS) in April, 1986 NOT A SINGLE legislative act existed in the USSR that could protect victims of possible nuclear accidents and incidents. Such was the Soviet Union despite of the fact that it was literally stuffed with both nuclear weapons and nuclear reactors for military industry, as well as with hundreds of research reactors all over the country. Thus, when the accident at the ChNPS happened, the government of the USSR had no available legislative base to provide assistance for sufferers — personnel of ChNPS, volunteer-liquidators, and the population affected by the accident. During the first five years after the accident the Supreme Soviet of the USSR had made no attempts to adopt any laws to protect the citizens affected by the accident at ChNPS and to give them rights for certain benefits and compensations. How can we understand this situation? The Soviet communist regime could not allow to disclose the scale and contamination levels of the accident, as well as the number of affected persons. During the first five years after the accident, various decrees of the Central Committee of the CPSU (Communist Party of the Soviet Union), which were directed to republican and regional party organs for execution, functioned the role of "laws". Quite often they were issued, as joint decrees both of the Central Committee of the CPSU and of the government of the USSR. As a matter of course, they were secret. When these decrees appeared in open documents, they had no concrete information on the number of sufferers, their needs.

The first actions by the authorities to rescue lives of the ChNPS personnel and fire-fighters were of emergent nature without preparation. Coordination of liquidation work was not effective because the authorities were not ready for such a large-scale nuclear accident. This is indicated by the fact that medics did not carried out iodine prophylactics in due time (within the first eight days after the accident). Although a large amount of chemical and engineering corps, special military materiel and transport equipment of the Ministry of Defence of the USSR and Civil Defence forces were mobilized in dosimetric and decontamination activities, the authorities did not manage to carry out quick and effective evacuation of 116 thousand people from the 30-km zone around Chernobyl. Without doubt, the reason of such failure was related with the deep secretiveness of the communist regime which did not need open the truths about the accident at all. The party and government leaders discussed the tragedy only behind closed doors.

Evacuation of residents from the villages in the 30-km zone was executed without detailed planning. Nothing definite was explained, except that people had to leave their villages for some time, for two-three weeks, and then would come back again. Nevertheless, some executives of the contaminated districts recall having a feeling, that these residents would never return to their homes (see A.Yaroshinskaya. "Chernobyl. Top Secret", Moscow. 1992).

In 1989 the author of this article was elected a People's Deputy of the USSR from one of the most affected regions — the Zhitomir region. She came to Moscow and visited the Bureau for Fuel and Energy Resources at the Council of Ministers of the USSR with documents proving the necessity of resettlement from the Narodich and Lugin districts of the Zhitomir region. The Bureau was involved in the problems of liquidation of the Chernobyl accident consequences at that time. Notwithstanding this fact, the leaders of the Bureau refused even to hear about any resettlement. However, after the author had reported these facts at the First Congress of the People's Deputies of the USSR, a decision was made immediately to resettle 12 villages. This points to only one fact that until 1989 there was no scientifically developed government programme to aid the people affected by the ChNPS accident. This was not due to lack of scientific brain-power necessary for its elaboration. This is related with *glasnost*. A closed society and *glasnost* of the Chernobyl events were ideologically incompatible each other.

During the first five years after the Chernobyl accident the co-ordination of measures to liquidate the accident consequences and aid to the population was subject to the strict command system of administration. For this purpose a special operative group was established in the Politburo of the Central Committee of the CPSU and it continued to function in the course of several years. At first the group meeting was held daily, but afterwards more and more infrequently. The operative group received reports from republics, the government, Ministries of Defence and Health, gave hearings to operative group members' reports, and immediately took decisions on ALL problems: hospitalisation, discharge from hospital, increase in the maximum acceptable doses for vegetables and fruit consumption in the affected territories, population resettlement, aid to personnel of the ChNPS, introduction of benefits for compensation payments to the population, medical assistance to the affected persons, etc.

The secrecy and uncoordinated character of the actions by the authoritative bodies on different levels led at times to misuse of authority power. For instance, in the Narodich district of the Zhitomir region, officials who were distributing flats for the resettled people in Kiev, L'vov, Zhitomir, etc. were taking several flats for their own, disallowing them to the people in real need.

The efficiency of taken decisions was low for one more reason: at that time the foodstuffs in the USSR were in short supply not only in affected villages, but in big towns and cities as well. Thus, the decisions of the CPSU to improve the situation of foodstuffs supply to the ChNPS victims were practicably impossible. According to the party decision, residents in the affected zones were receiving 30 roubles (people called them "coffin money") for "clean" food. However, "clean" food was not found in village shops. The shops were practically empty. The sum itself was simply ridiculous. Three different programmes, which were not interconnected each other, for liquidation of the ChNPS accident consequences existed until 1989 — the Ukrainian and the Belorussian programmes, and the programme of liquidation of the consequences of the accident at the ChNPS in the Bryansk region (Russia) for the period of 1988 to 1990. In April 1990 a state-union programme of liquidation of the ChNPS accident consequences in RSFSR (Russian Soviet Federated Socialist Republics) for 1990-1992 was made.

Only in 1990 were held THE FIRST open public parliament hearings on the Chernobyl accident. At these hearings the Supreme Soviet of the USSR adopted the first decree to liquidate the consequences of the accident at ChNPS and to elaborate a comprehensive state programme and a concept of living in the affected districts. A State Expert Commission at the Government of the USSR was also founded (the author of this report was a member of this commission as a People's Deputy of the USSR), which had to elaborate an all-union programme of liquidation of the consequences of the Chernobyl accident.

Three new programmes of the accident consequences liquidation were presented to the Expert Commission — the Ukrainian, the Belorussian and the programme for Bryansk region (RSFSR). Only the Belorussian programme had more or less integral and compact contents with attempts of scientific approach. This programme contained the most important issues about the criteria of benefits to the population and residents in the affected territory — the issues that were not mentioned on the governmental level for years. The Ukrainian programme was not even signed. So, its author was unknown. It was evident that different "parts" of this programme were merged into a single document in a machine-like manner. The programme of the ChNPS accident consequences liquidation for RSFSR turned out to be the strangest . It involved only one region, the Bryansk region. However, at that time it was already known that other regions of Russia had been contaminated, for example, in the Orlov-Bryansk-Tula spot.

In April 1991, after numerous discussions in the parliament and the government, "Concept of Living in Districts Affected by the Accident at the Chernobyl NPS" was adopted at a session of the State Expert Commission. According to this concept, the main criterion to make decisions on protective measures, their scales and compensations for damages to the population had become irradiation dose induced by the Chernobyl accident. A dose of irradiation was considered acceptable if it resulted in an average annual effective equivalent dose not exceeding 0.1 rem (1 mSv). Persons living in "dirty" territories or having lived there for a defined minimal period, had the right for loss recovery by way of benefits, compensations, guarantees, and systems of social and medical assistance.

A system of social guarantees to Russian population was worked out only in May 1991 in the Law of RSFSR "On Social Protection of Citizens Exposed to Radiation as a Result of the Catastrophe at the Chernobyl NPS". As a matter of fact, in order to launch the mechanism of the Law, more than 40 normative bylaws were elaborated and adopted. Nevertheless, this law was inefficient, especially as compensation payments to the population were concerned. In June 1992 modifications and amendments were introduced to the Law.

Thus, if one was to sum up the government assistance to the population affected by the ChNPS accident within the Soviet period (1986-1991), not taking into account its quality and efficiency, the following directions of this assistance could be distinguished:

- recovery and decontamination measures, aimed at decrease in the radioactive contamination of territories;
- implementation of social protection of citizens living in the affected territories: resettlement from the contaminated to the "clean" territories, compensations for loss of housing, compensations for "clean" foodstuffs, medical assistance benefits.

At that time medical brigades visited the districts affected as a result of the accident at the ChNPS in order to perform in-depth examination of the population and determine the changes of health status. Unfortunately, all information was classified secret not only to the population, but (according to E.B.Burlakova) to some of Russian scientists.

During this period, however, the material and technical bases of local health care were significantly improved; a network of diagnostics and medical-recreation centres was established, advanced training of medical personnel was carried out, etc.

According to the data of the State Committee of the Russian Federation on Liquidation of the Consequences of the Accident at the ChNPS, medical observation of health status of the Russian population was performed both by local medical establishments and by 25 leading research institutes. A Russian state medical-dosimetric registry was established. Its database contains information on 137.6 thousand people affected by radiation effects as a result of the Chernobyl accident; 97 thousand of so-called liquidators, about 3 thousand of the people evacuated from the affected zone, more than 35 thousand of the people living in the affected zone, and more than 2.6 thousand of children born from participants of the accident consequences liquidation.

In the first years after the accident at the ChNPS the Government of the USSR allocated budget funds for housing construction for the resettled. However, even in such case ideology played its role as well. In order to conceal the scale of the accident a decision was taken to build new houses for the victims of the catastrophe even on contaminated territories. For example, about 200 million roubles (in prices of that time) were invested only in the Zhitomir region in construction of 50 apartment blocks in the "dirty" territory of the Narodich district. It should be noted that the resettled did not live there, knowing this was a deceit on the part of the authorities.

As far as the Russian Federation is concerned, decontamination of 412 settlements in the affected territories was carried out. About 13 thousand people were resettled from the zones of radioactive contamination in the Bryansk region, 5.5 thousand of them from the zone of obligatory resettlement. 18 settlements were entirely resettled. Until 1993 about 50 thousand people have been resettled or have voluntarily left the affected territories of the Russian Federation.

It is interesting to note that special agrochemical studies were conducted in the affected territories in order to decrease accumulation of radionuclides in agricultural production. In some districts of the Bryansk, Orlov, Tula, Kaluga regions, sowing of forage crops was extended, while grain crops were reduced; buckwheat and rape were not sown. As some specialists (e.g. ex-Chairman of the State Committee on Liquidation of the ChNPS Accident Consequences V.Ya.Vozniyak) state, the taken measures resulted in improvement of soil fertility and a 1.5-4 times decrease in the radionuclide accumulation in plants. Personally, I strongly doubt such numbers, especially when such information comes from V.Ya.Vozniyak who himself took part in classifying the information about the Chernobyl accident during the Soviet period. The same doubts arise about the very necessity to plant something in fields that are known to be radioactive, as foodstuffs for people or even as forage for animals. I cannot perceive and accept such logic of a Moscow cabinet official who determined how the people had to live in a zone of permanent health risk.

1.2. After the collapse of the USSR

After the collapse of the USSR, every of the three most affected republics had to deal with its problems on one's own. At the time of the Commonwealth of Independent States foundation (late 1991) the area contaminated with caesium-137 as a result of the accident at the ChNPS with a density of 1 Ci/km^2 and higher has totalled in Russia, the Ukraine and Belarus more than 100 thousand square kilometres. The main problem of every newly formed state remained the same — social protection to victims of the ChNPS accident: resettlement from the so-called radioactive "B" zones (according to the Chernobyl laws of Russia, the Ukraine and Belarus) which are nominally areas with a contamination density of 15-40 Ci/km^2 or even higher.

Already 11 years passed since the accident at the ChNPS! A sad fact should be stated: neither the Soviet government nor the democratic governments have managed so far to provide their citizens with the minimum which is set by the Chernobyl laws adopted by their parliaments. Moreover, the state assistance to the resettled nowadays tends to decline. In 1993, for example, 4,410 persons were resettled from the zones of obligatory and guaranteed resettlement (Gomel and Mogilev region) in Belarus (according to A.Dumnov, E.Vos'mirko), and in 1995 — only 1,723. 2,790 persons were resettled in 1993 from the zones of obligatory and guaranteed resettlement (Bryansk, Kaluga, Tula and Orlov regions) in Russia, and in 1995 — only 1,370. The same picture is to be seen in the Ukraine.

According to preliminary data, 410.4 thousand people are living in the affected territory in the zones of obligatory and guaranteed resettlement in Russia (Bryansk, Kaluga, Tula regions) in early 1997, in Belarus — 323 thousand people, in the Ukraine — 673 thousand people (furthermore, 479 people are living in the restricted zone of the Kiev region). Simple mathematics shows that with the existing trend preserved, the resettlement of people from the zones of obligatory and guaranteed resettlement in these countries may be prolonged for decades.

According to the Federal Law of Russia "On Social Aid to Citizens Subject to Effects of Radiation as a Result of the Catastrophe at the Chernobyl NPS", the status of such citizens is defined. In the Section 3 of the Law, 12 categories of citizens are defined, which can be used as bases of compensations and benefits by the Law. All benefit and compensation rates available to the victims of Chernobyl are described in detail in the mentioned law. Below are listed some of them:

1. Citizens who contracted radiation syndrome, other illnesses, and invalids as a result of the catastrophe are granted gratuitous medical treatment (hospital and ambulatory), gratuitous acquisition of medicines on a physician's prescription, gratuitous dentistry and construction of dentures, gratuitous annual sanatorium-resort therapy or payment at the average cost of the corresponding travel voucher, etc. Working invalids are granted disablement benefits up to four continuous months or up to five months within a calendar year with 100 percent payment of the average salary. A gratuitous one-time grant of house-room equipped with modern conveniences is provided, regardless of the period of residence in the given settlement, within three months from the submission of a corresponding application under the condition that the applicants are recognised to need improvement in the housing conditions or residing in shared apartments with an additional separate room. Also are granted 50-percent discounts in accommodation payments to the citizens named above, including members of their families residing together with them, as well as 50-percent discount in payments for telephone, radio, shared TV-aerials and their installation; 50-percent discount in payments for gas, heating, water and electricity; gratuitous travel on the territory of Russia on all types of urban and suburban passenger transportation, as well as once every year — all over Russia; relief from income-tax and all other types of taxes, etc.

2. Citizens who are permanently residing (working) on the territory of the zone with the right for resettlement can receive monthly compensation depending upon the period of residence (in percent to the minimal salary defined by the Law):

- from 26th of April 1986 — at a rate of 40 percent;
- from 1st of January 1987 — at a rate of 30 percent;
- from 1st of January 1991 — at a rate of 20 percent.

Today the minimal salary in Russia constitutes 84,000 roubles per month. This means that the above citizens in this zone receive a compensation of 33,600 roubles, 25,200 roubles, 16,800 roubles respectively.

3. Citizens who are permanently residing on the territory of the zone of resettlement can receive a monthly compensation until resettlement to other regions, depending on the duration of residence (in percent to the minimal salary defined by the law):

- from 26th of April 1986 — at a rate of 60 percent;
- from 1st of January 1987 — at a rate of 50 percent;
- from 1st of January 1991 — at a rate of 30 percent.

Thus the monthly compensation to the citizens residing (working) in the zone of resettlement until resettlement to other places constitutes from the 1st of January 1987, for example, 42,000 roubles.

The citizens of above-mentioned categories also have the right of monthly pension and benefits for unemployed pensioners, invalids and disabled children at higher rates depending on the duration of residence (in percent to the minimal salary defined by the law):

- from 26th of April 1986 — at a rate of 300 percent;
- from 1st of January 1987 — at a rate of 200 percent;
- from 1st of January 1991 — at a rate of 100 percent.

As well, fellowships are granted to 100-percent of postgraduate students and students of state primary, secondary and higher professional educational establishments on the territory of the zone of resettlement. The state scholarship to students of state higher educational establishments of Russia is the same as the minimal salary, 84,000 roubles. Thus, students of state higher educational establishments on the territory of the zone of resettlement receive a scholarship from the state at a rate of 168,000 roubles. Citizens of the named categories are also guaranteed other benefits by the Law.

The Law also makes a provision for compensations (Section 5) for the harm inflicted to health as a result of the Chernobyl catastrophe. For instance, invalids of the 1st and the 2nd group receive an annual compensation at a rate of five minimal monthly salaries, defined by the law. Thus, with a minimal monthly salary of 84,000 roubles invalids of the 1st and the 2nd group must receive an annual compensation of 420,000 roubles for loss of health.

The law also covers compensations to other categories of citizens, whose health has been harmed as a result of the accident at the ChNPS.

Due to the severe state of the economy, the payments and compensations to the citizens, who suffered as a result of the accident at the ChNPS, have been more and more often delayed by the state bodies.

An important indicator of the state care about the population living in the contaminated territories is a sum of special investment for construction of housing, social and cultural facilities for the resettled, as well as establishment of industrial facilities to employ them. The expenditures for liquidation of the consequences of the Chernobyl accident in the budget of each country is a separate item. However, in recent years these sums tended to shrink. The reason for such a phenomenon is general financial recession, inflation processes, the bulk of new transition-period problems in the economy of the newly-independent states. Investment in the economy of every country has been recently dropping at a rate of 10-30 percent a year in comparable prices. The real amount of Chernobyl investment has dropped at an even bigger rate. The expenditures of Belarus for Chernobyl investment in dollar equivalent was last year (1996) 120 million dollars, of Russia — 60 million, and of the Ukraine — 185 million. The cutback in housing construction in the framework of the "Chernobyl" programmes in three states altogether constituted 40 percent in comparison to 1995. As compared with 1995, only 27 percent of housing were completed in Russia, in Belarus — 62 percent, and in the Ukraine — 75 percent (A.Dumnov, E.Vos'mirko).

After the commencement of the war in Chechnya, the construction of 150 houses in the Potchip district of the Bryansk region (settlement Moskovsky), run by the Moscow government, was withheld, leaving the houses unfinished. Practically no clinics, hospitals and secondary schools, which are very important elements of the infrastructure for residents and the resettled, have been put into service in Russia last year. Problems are accumulating with the people who had resettled to "clean" areas but could not find work places there. Nearly no jobs are created for the resettled. Quite often the resettled, being unable to adjust to new living conditions, return to their "dirty" homes and gardens. In this relation the Russian government adopted in January 1997 a decree on elaboration of a mechanism to reimburse funds allocated for housing for the resettled who had returned back.

Budget complications have affected not only the problems of adult population rehabilitation, but children rehabilitation as well. A special multipurpose presidential programme "Children of Russia" has been functioning in the Russian Federation for several years already. One of its divisions is called "Children of Chernobyl". Although the programme is a presidential one, it was not fully financed last year. Within 9 months of 1996, 24 billion 907.3 million roubles have been allocated for implementation of the programme "Children of Chernobyl". This investment for the programme has constituted only 13 percent of the annual plan.

The problem of consumption of "dirty" foodstuffs grown in private gardens by residents of contaminated areas is still acute. In the first place, it relates to milk and milk products, meat, wild-growing fruit, berries, and mushrooms. While at least some control of such products was performed in the first years after the accident, there is practically no control at present in these areas.

Also unresolved is the problem of clean foodstuffs supplies to the population living in the contaminated territories. For example, only 8-20 percent of "clean" milk, butter and vegetable oil, meat, vegetables, and sugar have been supplied to these territories in the Ukraine in 1995 as compared with 1991. In comparison with 1994, supplies of vegetables, meat, vegetable oil and different cereals have decreased by a half, and supplies of milk and sugar — by more than two-thirds. The same relates to Russia and Belarus in a number of regions.

Considering the problems of state assistance to the Chernobyl victims, one cannot but touch upon misuse of authority, as well as corruption in this sphere. It is long known that in some districts subject to radiation effects as a result of the accident at the ChNPS, the budget money allocated to solve the problems of Chernobyl victims was spent for other purposes. For instance, in the Bryansk region of the Russian Federation the local authorities have used this money for construction of a local airport, in the Zhitomir region (the Ukraine) some money has been spent to build country-houses for officials. Several years ago in Kiev in the Ukraine a corruption was disclosed in connection with transfer of "Chernobyl" money from the sate budget to a private foundation of top-ranking officials. This corruption involved members of the Cabinet of Ministers.

Thus, the state assistance to the people affected by the accident at the ChNPS over the last years in newly-independent states has been subject to new tests in the course of rebuilding of the socio-economic system, adjustment of economic policies and decisions of new national priorities. Due to these reasons many "Chernobyl" problems remain unsolved. The primary problems in the Russian Federation are:

- Comprehensive monitoring of contaminated settlements is not accomplished;
- Not all residents are provided with personal protection means and special clothes;
- Home-made "dirty" milk and milk products, as well as home-grown vegetables and fruit with increased radiation levels are still consumed;
- Inflation and price increase do not allow residents of contaminated territories to obtain "clean" foodstuffs and even essential goods;
- Due to general economic recession, many Chernobyl victims are deprived in recent years of their benefits provided by law — compensation payments and gratuitous acquisition of medicines in drugstores;
- 100-percent clinical observation of the adult population living in the affected territory is not achieved;
- Personnel is still scanty in medical establishments, especially in remote villages;
- Medical institutions are not fully equipped with all necessary medical facilities;
- Housing construction for the resettled has been withheld;
- Construction of social and cultural objects has been

brought to a halt;

- Jobs are not being created for the resettled.

A fact is evident — the governments are not able to tackle with even the most acute social problems related to resettlement of the population from the most dangerous radiocontamination zones during 11 years after the Chernobyl accident. It is also obvious that the tendency of the central governments to shrink the assistance is likely to remain. Apparently, the major burden of assistance to the victims of Chernobyl will be carried in future by local administrations and by the resettled themselves.

2. Public movement to assist the Chernobyl sufferers

The first official public action was the announcement of a "Chernobyl" account #904 some time after the accident. Citizens of the USSR were informed about this account by officials of the party and Soviet ruling circles. The account number and all account information were broadcast on all radio and television channels, and printed in all party, Soviet, trade-union and official newspapers. The authorities invited people to mercy. The Soviet citizens were proposed to send money to this account for victims of Chernobyl. Nothing else could have happened at that time. No one except the authorities had the right to set up a special account (no matter what kind of account, not even the "Chernobyl" one) in a bank. Citizens of the USSR had no accounts in ordinary banks, only in state savings-banks. Except for the central state bank, there were no other banks in Russia.

When the deputies of the USSR started to speak publicly about the Chernobyl problems in their first Congresses and Sessions of the Supreme Soviet of the USSR, the USSR government asked so-called "independent" experts of WHO and IAEA to come to the Soviet Union and conduct so-called "independent" study of the Chernobyl NPS accident consequences. This commission was headed by a Japanese scientist, I.Shigematsu. The conclusion of this commission appeared perplexing to many: the Chernobyl accident had posed no danger to human health and no change in the health of people was found by the international experts. Soon it became known that the Soviet government had financed the visit of the international experts, their stay, the best hotel accommodation and everything else from the "Chernobyl" account #904 according to a direction of the Chairman of Council of Ministers of the USSR, N.I.Ryzhkov. That brought the first official public action of mercy towards the victims of the accident at the Chernobyl NPS to an inglorious end.

Until 1989 no public association or organisation was allowed in the former USSR except the communist ones. Thus, any public movement for assistance to the victims of Chernobyl was out of question. Only the liquidation of Article 6 of the USSR Constitution by the People's Deputies of the USSR, abolition of the communist party monopoly, adoption of a new article on a multiparty system and public organisations, adoption of the law in 1990 on public organisations and movements thrust the establishment of different civil movements and organisations, including those aimed at assistance to victims of Chernobyl.

It should be specially noted that the unofficial "green" movement in the former USSR emerged in different aspects owing to many publications about the consequences of the Chernobyl accident, appearing in press in late 80's after the first, more or less, free elections of the People's Deputies of the USSR. The elections gave a rise to real liberalisation of political life in the country. According to some data, 38 non-government ecological organisations (and all of them were without doubt controlled by the line of the CPSU) existed in the country in 1987. In 1991 the number of newly-formed non-government ecological organisations increased by more than 5 times and their total number exceeded 1,000 organisations.

The first non-registered (i.e. illegal) non-government public organisations (at that time, the registration system under the condition of the CPSU monopoly did not yet exist) concerned in the consequences of the Chernobyl accident emerged in late 1986 — early 1987. In particular, the non-registered (illegal) political club "*Perestroika*" founded by the editor of journalist agency "*Novosti Zhitomirschiny*", Yakov Zaiko and the author of this report in the town Zhitomir. One of the tasks of the club was to spread by all possible means true information about the life of the people in the affected territories. Because of the taboo on such information in the official communist press, it had to be printed on a type-writer and illegally distributed among the population. Since 1988 the club "*Perestroika*" had been illegally publishing using primitive equipment the newspaper "*Stenogramma*" (Shorthand) with a circulation of 100 copies. The newspaper critically touched upon political topics and the situation in the northern districts of the Zhitomir region affected by the Chernobyl accident. At that moment *glasnost* was the most important task: nobody in the country knew about the real developments in the fourth reactor of the Chernobyl NPS, and about the scale of the accident consequences. Besides, the people who remained in the affected territory found themselves in a total information blockade — no one knew about them, their sufferings, ailments, deaths. Thus no help could be rendered to these people.

In 1988 the author of this report had the first chance to publicly talk at a meeting with workers of the plant "*Promavtomatika*" on what was going on in the "Chernobyl" territories. Further, with democratisation of life in the USSR, the first meetings in support of the rights of the people affected by the Chernobyl accident have been organised by the "National Front of Assistance to *Perestroika*". This Front had "grown" out of the small club "*Perestroika*" and was officially registered by local authorities by that time. Thousands of people came to these meetings. People of Zhitomir expressed their solidarity with the victims of Chernobyl, demanded resignation of the government of the Ukraine, truth about the consequences of the accident at the Chernobyl NNP, and efficient help of the authorities to the affected. A wave of meetings against stifling of *glasnost* about the consequences of the Chernobyl accident had moved over all districts of the Zhitomir region affected by radiation, as well as in Belarus (e.g. a "crusade" rally of people from the affected territories to Minsk in 1990).

This is how started the public movement of citizens for truth about the consequences of the Chernobyl accident and for assistance to the victims. Only in 1991 appeared the first non-government organisations that were officially registered and acknowledged by the authorities and the society. The major purpose of these organisations were to help the immediate victims of Chernobyl, especially children. They emerged at first in Kiev, Minsk and Moscow, and acquired the status of all-union and republican organisations. At that time the "Chernobyl" 24 hours TV charity was popular and efficient as a means to collect money for the affected.

In 1989 dozens of foreign journalists gained access to the affected territories. Articles about the complicated situation of the affected appeared in the Western press. As a result, hundreds of organisations for assistance to the victims of Chernobyl emerged in the West, Japan and the United States. Domestic non-government organisations began to associate with the Western ones, thus merging into international non-government organisations. In order to overcome the bureaucratic barriers on the way of humanitarian aid to the Chernobyl victims from Western and Japan, it was better to work together. The enormous humanitarian aid, generosity and heartiness of the Japanese towards the people affected by the Chernobyl accident should be especially noted.

The years of 1989-1991 were the peak of the "Chernobyl" movement in the USSR and abroad. With the collapse of the USSR the "Chernobyl" movement of mercy and aid to the victims of peaceful atom significantly weakened. The problems of Chernobyl were thrust aside by problems of building up the independent states and solution of national problems. According to the data of the present author, there are currently more than 50 non-government anti-nuclear domestic organisations in Russia that in one way or the other, directly or indirectly, render help to the people affected by Chernobyl. There are several international non-government organisations (in co-operation with Russian organisations) as well.

The number of non-government organisations in Russia involved exclusively with "Chernobyl" matters is 25 (the list is supplemented). As a rule, their activities are aimed only at various help to the victims of the Chernobyl accident, from lobbying of necessary laws in the Council of the Russian Federation and scientific projects related to the consequences of the accident at the ChNPS, to assistance to concrete organisations, especially to children's homes, hospitals, families and people.

The author of this report is also the president of yet single in the Russian Federation private Charity Foundation with a statutory objective to render assistance to children-orphans victims of Chernobyl. The Foundation regularly helps 150 orphans living in two children's homes in the radiocontaminated territory (Russia), as well as to the children's hospital, the old, the invalids, the families with many children in the town Zhitomir and the village Bazar of the Narodich district of the Zhitomir region (the Ukraine) — so far as the customs barriers and the facilities of the Foundation allow. Humanitarian actions of mercy by the Charity Foundation include purchase and delivery of food, different mixtures, juices for destitute children-nurselings (unparented children live in children's homes from birth till the age of 12), as well as medicines, syringes, footwear, books, toys, candies, biscuits, colour-TV's, etc.

The Foundation addressed the Moscow mayor, Yu.M.Luzhkov requesting to assist in the construction of a new children's home in "clean" area in order to resettle both of the children's homes from "dirty" territory of the town Klintsy. A location for the new children's home was found, the engineering data were prepared, and the design of the house was drawn. However, with the commencement of the war in Chechnya all work was brought to a standstill.

As far as the abilities allow, the Foundation renders help to a Zhitomir children's hospital which is treating the children from the affected territories, finances heart operations for children of families with low income living in the "dirty" areas, as well as allocates one-time money grants to the old and the invalids from the affected territories of the Zhitomir region (the Ukraine).

The Foundation has several holders of fellowship as well — it pays for education of gifted students from Zhitomir in higher educational establishments.

Additionally, the publishing department of the Foundation edits, publishes, and distributes ecological and antinuclear literature (free of charge for the people affected by the Chernobyl accident). All benefits are spent solely for the purposes to help the people affected by the Chernobyl accident. The Foundation carries such authority that its stuffs are invited to take part as jury-members in different national meetings and festivals of "green" and other organisations, as well as in different international conferences. The Foundation established a special prize and awards the participants of various international and national contests of "green" organisations and "green" press.

The Foundation has reliable partners in the West and Japan. Co-operation is especially close with the Japanese "Chernobyl" organisations headed by Akiko Wada (Tokyo) and Ikuo Kusaka (Ishinomaki). In recent years they and their organisations have several times provided via the Foundation significant support to two children's homes patronised by the Foundation, as well as to the old of Zhitomir. The Foundation also maintains close co-operation with Japanese scientists from the Research Reactor Institute of the Kyoto University, T.Imanaka, H.Koide and K.Kobayashi, who are members of the authors for a collective of a fundamental publication launched by the Foundation — the first "Nuclear Encyclopaedia" in the world.

One should mark among the "Chernobyl" non-government organisations the ones that comprise victims of the Chernobyl accident living in the affected territories, and struggling for their survival, as well as non-government organisations of the participants of liquidation of the accident who had as consequence became invalid. The association "Chernobyl — Moscow State University" and the Moscow State University Scientific Association of Chernobyl Invalids, officially registered in 1991 and 1994, respectively, have been more and more active lately.

The main objectives and tasks of the Moscow State University Scientific Association of Chernobyl Invalids are charity actions aimed at social-psychological, informational, legal, medical assistance and material support to persons affected as a result of the Chernobyl accident or exposed to radiation due to other reasons; material, medical and social assistance to people, their families, children, women, invalids, families of perished and deceased; arrangement of payment for travel and medical treatment for children, women and invalids, including medical treatment abroad; provision of work places to the association members by making new enterprises of the association; provision of measures (within the framework of international co-operation) on rehabilitation of territories affected by the catastrophe at the Chernobyl NNP; financial support of scientific studies related to different aspects of the consequences of the accident at the ChNPS (social-psychological, legal, medical, economic, ecological aspects), etc.

The research experience of these associations presents certain interest. Since 1991 they have performed research studies on almost 20 topics directly or indirectly touching the consequences of the accident at the Chernobyl NNP. These topics include: "Radionuclide content in the forestry products in the conditions of radiation contamination", "New medical-biological criteria of life-standard influence on the health state of the people in radiocontaminated regions", "Development of methodology of immunological monitoring for examination of aviation specialists — liquidators of the consequences of accident at the Chernobyl NPS", "Development of technique to form resistance to stress factors" (within the framework of the programme "Children of Chernobyl").

In addition, the Moscow State University Scientific Association of Chernobyl Invalids takes part in the "1997 Comprehensive Target Programme of Social Assistance to Invalids, as well as Persons Injured as a Result of the Accident at the Chernobyl NPS", authorised by the government of Moscow.

One of the latest projects developed by the Moscow State University Scientific Association of Chernobyl Invalids is teaching children who came to Moscow from the affected zones and encounter difficulties in entering higher and secondary professional establishments. It is planned to provide additional help to 500 children of former "Chernobylers".

While analysing the question of public organisations of help to victims of Chernobyl, one cannot bypass another aspect of this problem. Sometimes organisations or people who hampered publishing of true information about the events at the ChNPS after the accident and intentionally published false information about the situation of the population in the contaminated territories, had started after the breakthrough of the *glasnost* to found organisations of assistance to victims of Chernobyl and declared themselves their best friends.

Such cynical case happened in Zhitomir in 1987. The editor of the newspaper "*Radyanska Zhitmorischina*", D.Panchuk had not permitted the author of this report (at that time a correspondent of the newspaper) to visit the affected villages of the Narodich district of the Zhitomir region. After the author had, nevertheless, travelled to these villages and written an authentic article — the editor had not published it. Instead, an untruthful article of another correspondent was published stating that everything was fine in the affected areas. However, when the Chernobyl topic became not dangerous to be written, D.Panchuk jointly with other journalists of such sort had quickly established within the regional organisation of journalists a foundation for assistance to victims of Chernobyl. A fact is striking such that this pseudo-foundation found connections in Japan. The Japanese people, not knowing with whom they were actually having contact, came to Zhitomir with humanitarian aid (many thanks for that), met those who had been unhesitatingly implementing the party decisions on classifying of the events in the affected territories and who had been in real guilty of stresses, illnesses, and deaths of their fellow citizens. The people who admitted the classifying of Chernobyl were invited and visited Japan, met the Japanese public and told how bravely they were writing truth about Chernobyl, and gave interviews to the Japanese newspapers. A greater cynicism more than this story can not be imagined. The author of this report had to explain the real state of things twice in the all-union and the Ukrainian republican newspapers.

This Zhitomir story is, however, not alone. There are a lot of other similar examples that oppressors of the truth of Chernobyl had afterwards not only turned into "advocates" of this truth at the level of public organisations, but occupied the highest positions in the government of the independent states.

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1. "SOS" Chernobyl -— Obninsk division of the international association. Obninsk. Moscow region.
2. "Children of Chernobyl" -— division of the Belorussian Committee. Moscow.
3. Public Association of Persons Affected as a Result of the Catastrophe at the Chernobyl NPS. Moscow.
4. Division of the International Foundation for Assistance to Victims of Chernobyl. Moscow.
5. "Raduga-XXI" -— division of the international non-government humanitarian organisation "Foundation "Chernobyl - help" of North America. Moscow.
6. Foundation "Social Protection and Medical Provision of the Chernobylers". Moscow.
7. "Spec.Chernobyl" Foundation. Moscow.
8. Foundation of assistance and rehabilitation of invalids, orphans, refugees and victims of Chernobyl. Moscow
9. "Chernobyler" -— social protection foundation. Moscow.
10. Union "Chernobyl" of Russia. Moscow, with divisions over the country.
11. "Chernobyl" -— association of the Union. Moscow.
12. "Chernobyl-Help" -— the international humanitarian organisation. Moscow.
13. "Chernobyl, Children of Chernobyl" -— division of the international association. Ul'yanovsk.
14. "Union of Chernobyl Workers" -— Russian association. Voronezh region, settlement Ramon.
15. "Chernobyl-Atom" -— international association of unions. Moscow.
16. "Chernobyl-Hospital" -— foundation. Moscow.
17. "Chernobyl-Hope" -— foundation for assistance to invalids, injured, ill, overirradiated as a result of Chernobyl catastrophe. Moscow.
18. Chernobyl Safety Foundation. Moscow.
19. "Chernobylenergozaschita" -— association for social protection of citizens who took part in liquidation of the consequences of the accident at the Chernobyl NPS. Moscow.
20. Chernobyl Mission" -— public organisation. Moscow.
21. Operative department at the Siberia regional division "Chernobyl". Novosibirsk.
22. "Chernobyl" -— public association of invalids of war and Chernobyl. Moscow.
23. Private Charity Foundation of Yaroshinskaya (assistance to people affected by the accident at the ChNPS). Moscow.
24. Association "Chernobyl -— Moscow State University"
25. The Moscow State University Scientific Association of Chernobyl Invalids. Moscow.

Legal Regime of the Chernobyl Problems in the USSR, Belarus, Russia and the Ukraine

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Introduction

In the night from 25th to 26th of April 1986, an accident with human casualties occurred at the fourth unit of the Chernobyl nuclear power plant (the Ukraine) with RBMK-1000 reactor, which has been working for three years. The consequences of this accident will produce negative effects on the ecology of the planet for many hundreds of years to come.

Despite the fact in the USSR that the capacities of the nuclear power plants were being increased year by year, and active nuclear weapon tests were conducted, the USSR was the only nuclear country in the world without its own laws regulating the use of nuclear energy and its safety. Meanwhile, in other countries such laws have been adopted a long time ago: in France in 1945, in the USA and Great Britain in 1946. At present all developed countries have nuclear legislation. The project of such legislation was drafted in the USSR two years before the accident at Chernobyl, however, even after the accident had happened, it was not implemented due to bureaucratic routine. There was no legal basis to be claimed in spite of dozens of accidents in nuclear objects both military and civil that occurred every year and caused human casualties too, as for example, in the Leningrad NPP in 1979. Nobody ever bore responsibility for these accidents. Besides, the authorities kept all of them top secret, in order not to let its own people, as well as the world community, know about such accidents.

It was natural that, after the explosion at the Chernobyl nuclear power plant, neither the USSR government nor the local authorities were ready to take legal action for the ecological, social and other problems caused by Chernobyl. The scale of the accident consequences and the changes that had taken place in the society by that time made simply impossible to keep silence about the fact of the catastrophe. The people in the affected territories continually demanded from the government legal settlement of their health problems, ecological problems in the affected territories, and compensation of material losses on the basis of legislative provisions.

In April 1990, the USSR Supreme Soviet reviewed the situation concerning liquidation of the Chernobyl accident consequences and noted: "The accident at the Chernobyl NPP in its consequences is the heaviest and nation-wide disaster of the present time, affecting destinies of millions of people residing in a vast territory. The ecological effect of the Chernobyl accident made the country face the necessity to solve new, exceptionally complex, large-scale problems, affecting virtually all spheres of social life, many aspects of science and manufacturing, culture, ethical values and morality."

First legislation during the period of USSR

The first attempts in the USSR to find legal settlement of the ecological and other problems caused by Chernobyl were bylaws adopted jointly by the CPSU (Communist Party of the Soviet Union) Central Committee and the Council of Ministers of the USSR (the CPSU Central Committee was considered an authority). A Decree of the CPSU Central Committee and the Council of Ministers of the USSR, adopted 12 days after the accident - on the 7th of May 1986 - "On terms of payment and material provision of employees of enterprises and organisations in the Chernobyl NPP zone" has become the first document regulating the relations between the USSR government and the Chernobyl NPP.

For the first time since nuclear energy was put into use in the USSR some decades ago, the Ministry of Nuclear Power was founded. Along with its creation a legal subject had appeared, which could bear the responsibility for the activity in the sphere of "peaceful atom" implementation.

A number of other joint decrees by the CPSU Central Committee and the Council of Ministers of the USSR have been adopted in 1987-1988, that were aimed at solving various problems to liquidate the consequences of the severe accident. Only four years after the catastrophe, on the 25th of April 1990, the first decree on Chernobyl has been adopted directly by the legislative body of the country - the Supreme Soviet of the USSR - "On a comprehensive programme to liquidate the consequences of the accident at the Chernobyl NPP, and the situation related to this accident." This decree also authorised the first State Union-republican programme of immediate measures to liquidate the consequences of the accident for 1990-1992. The decree assigned the Council of Ministers of the USSR for a duty "to draft the Law on the Chernobyl Catastrophe and put it in to the Supreme Soviet of the USSR in the fourth quarter of 1990. To define in the Law the legal status of the catastrophe victims, the participants of the accident consequences liquidation and persons involved in the activities in the affected area, as well as those subject to involuntary resettlement; legal regime of the disaster area; discipline of population residence and activities;

military service; formation and functioning of state administrative bodies and public organisations in the affected area".

However, none of these measures have been implemented in time. A year later, in the next decree by the Supreme Soviet of the USSR from the 9th of April 1991, "On course of implementation of the decree by the Supreme Soviet of the USSR from the 25th of April 1990 'On a comprehensive programme to liquidate the consequences of the accident at the Chernobyl NPP, and the situation related to this accident'", it was mentioned that "there has been no possibility at present to adopt the Law on Chernobyl Catastrophe and the Law on Nuclear Energy Use and Nuclear Safety due to the delay in submitting the drafts of these laws."

Only in 1991, five years after the accident in Chernobyl, fully adequate legislative acts regulating the responsibility of the government for the damage inflicted to the citizens as a result of the activities of a nuclear enterprise have been adopted in the USSR. These are: the Law of Belorussian SSR - "On Social Protection of Citizens Affected by the Catastrophe at the Chernobyl NPP" from the 12th of February 1991, the Law of the Ukrainian SSR - "On Status and Social Protection of Citizens Affected by the Accident at the Chernobyl NPP", the Law of Russian Federation - "On Social Protection of Citizens Affected by Radiation in Consequence of the Accident at the Chernobyl NPP" from the 15th of May 1991, as well as the federal Law - "On Social Protection of Citizens Who Suffered in Consequence of the Chernobyl Catastrophe" which was adopted on the 12th of May 1991. These laws applied to the affected population as can be seen even from the names. They tackled with ecological problems only indirectly. However, in comparison to the legal vacuum that in fact existed during five years after Chernobyl, these laws were a significant step forward.

The scales of the Chernobyl catastrophe and the ecological damage were the initial motivation, especially for scientists and lawyers, on the base of which the first laws were adopted in Belarus, the Ukraine and Russia, allowing to solve the social and ecological problems of the Chernobyl. This is all the more important event as nobody has ever faced this kind of problems so far. Dozens of other nuclear accidents in the United States of America (Three Mile Island), England (Windscale), and in other states by no means could be compared to the global consequences of the release in Chernobyl.

Legal status of contaminated territories in the Ukraine

The first Law, "On the Legal Regime of the Territories Exposed to Radioactive Contamination in Consequence of the Catastrophe at the Chernobyl NPP" was adopted in the Ukraine on the 27th of February 1991 (with further alterations and amendments introduced by the Law from the 17th of December 1991 and the Law from the 1st of July 1992). This law has given definitions to the territories affected by radioactive contamination after the explosion at the Chernobyl NPP for the first time, as well as the definition of the territory radioactive contamination zone categories.

Depending on the landscape and geochemical properties of soils, the values of excess of natural pre-accident radionuclide accumulation level in the environment, rates of possible negative effect on the health of the population, requirements on implementation of population radiation protection and other special measures, considering the general industrial, social and domestic relations, the territories affected as a result of the Chernobyl catastrophe are divided into zones. According to the Law, such zones are:

1. Restricted zone - residents have been evacuated from this territory in 1986;
2. Zone of unconditional (obligatory) resettlement - a territory subject to intensive contamination with long-lived radionuclides, with soil contamination density in excess of the pre-accident level by caesium isotopes from 15 Ci/km^2 and higher, or by strontium from 3 Ci/km^2 and higher, or by plutonium from 0.1 Ci/km^2 and higher, where the evaluated individual effective equivalent irradiation dose may exceed 0.5 rem/year in excess of the pre-accident dose;
3. Zone of guaranteed voluntary resettlement - a territory with soil contamination density in excess of the pre-accident level by caesium isotopes from 5 to 15 Ci/km^2, or by strontium from 0.15 to 3 Ci/km^2, or by plutonium from 0.0.1 to 0.1 Ci/km^2, where the evaluated individual effective equivalent irradiation dose may exceed 0.1 rem/year in excess of the pre-accident dose;
4. Zone of intensified radio-ecological control - a territory with soil contamination density in excess of the pre-accident level by caesium isotopes from 1 to 5 Ci/km^2, or by strontium from 0.02 to 0.15 Ci/km^2, or with plutonium from 0.005 to 0.01 Ci/km^2, where the evaluated individual effective equivalent irradiation dose may exceed 0.05 rem/year in excess of the pre-accident dose.

Legal status of contaminated territories in Belarus

The Republic of Belarus was next after the Ukraine to adopt a special Law, "On Legal Regime of Territories Exposed to Radioactive Contamination in Consequence of the Catastrophe at the Chernobyl NPP" on the 12th of November 1991. This law is aimed at decreasing of radiation impact on the population and ecosystems, at realisation of environment-recovery and protective measures, and at efficient use of natural, economic and scientific potential of these territories.

The Law regulates the regime of the contaminated territories, conditions of residence, economic and scientific-research activity in these territories.

According to the Law, the territories are divided into the following zones depending on the density of soil radionuclide contamination and impact on the residents (make note of the fact that the zone division in the Belorussian Law is different from that in the Ukrainian. The zoning has been carried out on the basis of the damage inflicted to the public by radiation.):

1. Zone of evacuation (restricted zone) - a territory around the Chernobyl NPP, from which the population has been evacuated in 1986 according to the existent safety regulations (the 30 kilometre zone and the territory subject to additional evacuation due to strontium-90 soil contamination density exceeding 3 Ci/km^2 and plutonium-238, 239, 240, 241 contamination higher than 0.1 Ci/km^2);
2. First priority resettlement zone - a territory with soil contamination density by caesium-137 over 40 Ci/km^2, by strontium-90 over 3 Ci/km^2, or by plutonium-238, 239, 240, 241 over 0.1 Ci/km^2;
3. Zone of subsequent resettlement - a territory with soil contamination density by caesium-137 from 15 to 40 Ci/km^2, or by strontium-90 to 3 Ci/km^2, or plutonium-238, 239,240, 241 from 0.05 to 0.1 Ci/km^2, where the annual average individual effective equivalent dose may exceed 0.5 rem/year, and other territories with lesser contamination density by the abovementioned radionuclides, where the annual average individual effective equivalent dose may exceed 0.5 rem/year;
4. Zone with right for resettlement - a territory with soil contamination density by caesium-137 from 5 to 15 Ci/km^2, or by strontium-90 from 0.5 to 2 Ci/km^2, or by plutonium-238, 239, 240, 241 from 0.02 to 0.05 Ci/km^2, where the annual average individual effective equivalent dose may exceed 0.1 rem/year, and other territories with lesser contamination density by the abovementioned radionuclides, where the annual average individual effective equivalent dose may exceed 0.1 rem/year;
5. zone of residence with recurring radiation control - a territory with soil contamination density by caesium-137 from 1 to 5 Ci/km^2, or by strontium-90 from 0.15 to 0.5 Ci/km^2, or by plutonium-238, 239, 240, 241 from 0.01 to 0.02 Ci/km^2, where the annual average individual effective equivalent dose may not exceed 0.1 rem/year.

Legal status of contaminated territories in Russia

The ecological problems of Chernobyl have affected 16 regions of the Russian Federation. Unfortunately this fact has become known to the general public only seven years after the accident . (In the first years after the explosion the republican programme of Chernobyl accident consequences liquidation dealt only with the Bryansk region and Kaluga-Tula-Orlovsk spot.)

A special Law on status of territories, affected by radiation after the explosion at the Chernobyl NPP was not adopted, although it has been drafted already in 1993. However, one should note that there exists a Government Decree from the 25th of December 1992, "On Regime of Territories Exposed to Radioactive Contamination in Consequence of the Accident at the Chernobyl NPP".

The ecological problems of the contaminated territories are also regulated by a special article of the Law, "On Social Protection of Citizens Exposed to Radiation Effects in Consequence of the Catastrophe at the Chernobyl NPP", which was adopted by the Supreme Soviet of the Russian Federation on the 15th of May 1991 (with further alterations and amendments). The name of the article is: "Regime and Ecological Rehabilitation of Territories, Exposed to Radioactive Contamination in Consequence of the Catastrophe at the Chernobyl NPP".

The Law defines the zones of radioactive contamination. (They are also different from the Belorussian and Ukrainian zones. Every republic adopted the legal norms according to the ecological damage it has suffered due to the Chernobyl accident). The Law defines four zones of radioactive contamination: the restricted zone, the evacuation zone, the residence zone with the right for resettlement, the residence zone with privileged social-economic status.

Article 7 of the Law states that "the borders of these zones and the list of residence place within them are reviewed according to the changes in the radiation situation and other factors at least once in every five years".

1. The restricted zone (that was called the 30 kilometre zone in 1986-1987, then called the evacuation zone from 1988 until the adoption of the Law) is the territory around the Chernobyl NPP, as well as a part of the territory of the Russian Federation, contaminated by radioactive substances in consequence of the catastrophe at the Chernobyl NPP. The population has been evacuated from these territories according to the norms of radiation safety in 1986 and in subsequent years.
2. The resettlement zone - the part of the territory of the Russian Federation outside the restricted zone, with soil contamination density by caesium-137 higher than 15 Ci/km^2, or by strontium-90 higher than 3 Ci/km^2, or by plutonium-239, 240 higher than 0.1 Ci/km^2.
3. The residence zone with the right for resettlement as well is determined with the density of soil contamination. This territory of the Russian Federation outside the restricted zone and the evacuation zone with soil contamination density by caesium-137 from 5 to 15 Ci/km^2. Additional criteria for determination of the zone borders are established by the Government of the Russian Federation according to the density of radioactive contamination by other (except

caesium-137) long-lived radionuclides.

4. The fourth zone is the residence zone with privileged social-economic status. This is the part of the territory of the Russian Federation outside the restricted zone, the evacuation zone and the residence zone with the right for resettlement with radioactive soil contamination density by caesium-137 from 1 to 5 Ci/km^2.

Social aspect of the Chernobyl legislation

The Chernobyl legislation of the Ukraine, Russia and Belarus comprise two approaches to solve the global problems connected with the consequences of the catastrophe. The first is the abovementioned territorial approach, the second is the social approach. The laws designed for the social-economic protection of the citizens of Russia ("On Social Protection of Citizens Affected by Radiation in Consequence of the Accident at the Chernobyl NPP"), of the Ukraine ("On Status and Social Protection of Citizens Affected by the Accident at the Chernobyl NPP"), and of Belarus ("On Social Protection of Citizens Affected by the Catastrophe at the Chernobyl NPP") have been adopted in these republics of the USSR practically a year before its disintegration. The laws, designed for social protection of citizens in the three former republics of the USSR actually supplement the laws of these republics connected with the status of territories.

Privileges and compensations are determined according to the levels of the radioactive contamination density in the territories. Contamination with chemical and other toxic substances is taken into account.

The size of compensations and premiums is based on different principles in the Laws of Russian, the Ukraine and Belarus: in Russia it depends on the minimum salary, in Belarus it is a monthly premium of a certain size with further indexation, in the Ukraine it depends on the basic pay and salary. Other privileges and compensations are similar to a significant extent. In the Ukraine additional privileges and compensations are set for employees of health care, education and culture establishments.

The amounts of compensations and premiums in zones with right for resettlement and zones of obligatory evacuation indicate the fact that, in the system of social protection, resettlement in Russia of residents from the affected territories was given more importance than in the Ukraine and Belarus.

Criticism to the current Chernobyl legislation

After ten years from the Chernobyl accident, as a result of many diversified investigations of the catastrophe consequences and compensation of the damage inflicted to the affected people, various scientists, specialists and ecologists began to question the correctness of the "Chernobyl" laws of Russia, Belarus and the Ukraine in regard to the social protection of the population. A great number of studies exposed the current system of social-economic and medical protection to harsh and, from the author's point of view, reasonable criticism. The main point is related to the problem of dose evaluation delivered to the population, according to which the decision on compensations and aid should be made. The analysis of the current Chernobyl legislation on the social protection testifies to the fact that it does not take into consideration several crucial aspects of this problem which is in fact the basis of all "Chernobyl" legislation. The problems in question here are the methods how to evaluate delivered dose, as well as to determine the consequences, in consideration of peculiarities of release and migration of radionuclides, irradiation duration, dose rate, etc.

According to Yu.O. Zitzer (a leading specialist of the State Committee on Environment Problems of Russia), the estimates of dose delivered to the population, underlying the existing legislation, are imperfect due to the following reasons:

1. The radiation risk of the population may vary largely.
2. Through the experience to evaluate the average individual dose for a certain group of the population, it is established that the reliability of dose value calculated in this way is very low due to a high spread in values; the number of inspection per one territory should be increased.
3. Although long-term investigations have been carried out up to now by the Institute of Biophysics, the Institute of Radiation Hygiene and other establishments of the Ministry of Health Care of the former USSR and Russia, the scope of dosimetric and epidemiological data is absolutely insufficient to specify the model parameters such as dose distribution in various regions; parameters of social-related biological effects e.g. mortality; differentiation of people's sensitivity to radiation, etc.
4. The last point — the differentiation of people's sensitivity to radiation is a very important factor influencing the total outcome of irradiation in regions. The radiation-sensitive part of the population shows an extremely high population morbidity.

Taking into account the facts given above, the following conclusions can be made: the evaluation of territory contamination according to the density of radionuclide deposition and, correspondingly the evaluation of individual dose — the so-called "zone" approach, which is being used today due to absence of another, is imperfect. Radionuclides migrate, are adsorbed and transform in the environment, thus changing both into less and significantly more dangerous elements.

"The Concept of Radiation, Medical and Social protection of the Population Exposed to Radiation Effects" was adopted by the Russian Commission on

Radiation Protection, and recommended by the Government of the Russian Federation for the revision and specification of the "Chernobyl law" provisions. In accordance to this concept, the "dose" approach is intended to replace the current "aerial" approach.

The problem of the "Chernobyl" legislation revision in the Russian Federation is also connected with another important social factor: a number of legislative acts and Government decrees have been adopted in Russia regarding social protection of citizens from different regions of the country affected by radionuclides as results of radiation accidents at industrial and military enterprises, or nuclear tests. The existing trend to spread the "Chernobyl law" onto other regions of Russia that have been affected by radiation impacts (activities and accident situations at the Industrial Association "Mayak" in Chelyabinsk region and Semipalatinsk Polygon) practically does not consider the peculiarities of radioactive contamination and radiation dose formation to the population. A direct application of the articles of the "Chernobyl law" for these situations is inadmissible.

The political aspect of the "Chernobyl" legislation also should be also noted. Very often the problem of social protection of citizens residing in the affected territories becomes exchangeable coins for the people who have been striving to power, especially in the period of various election campaigns. In many cases speculations to get confidence of the electorate in the Chernobyl zones becomes a pass for such people to get into big politics.

In 1994-1995 the Russian Duma (the Lower House) was involved in protracted struggle with the position of both the Government and the President in relation to the revision of the current law on social protection of citizens, residing in the affected territory. The Duma tried to change the Law aiming to worsen the status of such citizens, despite the fact that during the election campaign the deputy candidates promised to advocate them. The President of Russia had to apply to the Constitutional Court of the Russian Federation in connection with the fact that the law adopted by the Duma in 1995 discriminated the constitutional rights and freedoms of citizens. Then the President and deputies agreed to make an amendment to the Law without decision of the Constitutional Court. The work for the amendment is not going up to now. Major point of the struggle between them is related with a question about the criteria that should be the basis to provide privileges to inhabitants living in the contaminated territories, the level of soil contamination or the value of irradiation dose. The President considers that, in any case, interests of inhabitants should not be reduced. Some deputies who are concerned with this Law try to decrease the number of the people receiving these privileges regardless of the fact that they are living in "dirty" zones. The final resolution of this problem is not yet obtained.

The Laws adopted in the former republics of the USSR - Russia, Belarus and the Ukraine have without doubt produced their positive effect in the society. However, due to the social and political situation which emerged in the republics after the disintegration of the USSR, these Laws are not implemented into reality always and everywhere. The scale of the catastrophe requires significant financial expenditures from every state affected by Chernobyl. In the given specific situation these states do not possess such financial means. Consequently, the Laws are often left unclaimed and millions of people are suffering in the affected territories under conditions that protection measures for the environment are not carried out in necessary scales, and the ecosystems are not rehabilitated to the full extent.

Nevertheless, we can be optimistic by the fact itself that the first fully functional acts aimed at legal solution of ecological problems of the global catastrophe at the Chernobyl NPP and social protection of citizens have been adopted in the former republics of the USSR. We can expect that in case of situation stabilisation in these countries, the adopted Laws will be revised and improved, will function to the full extent of their power, and will protect the Nature and people from the severe consequences of the most grave anthropogenic accident in the history of the Earth.

Collection of Interesting Data Published in Various Documents

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This report is merely a collection of interesting data that Imanaka noticed during the course of the collaborative work. When readers are interested in more details, please look into original materials or have a contact to Imanaka.

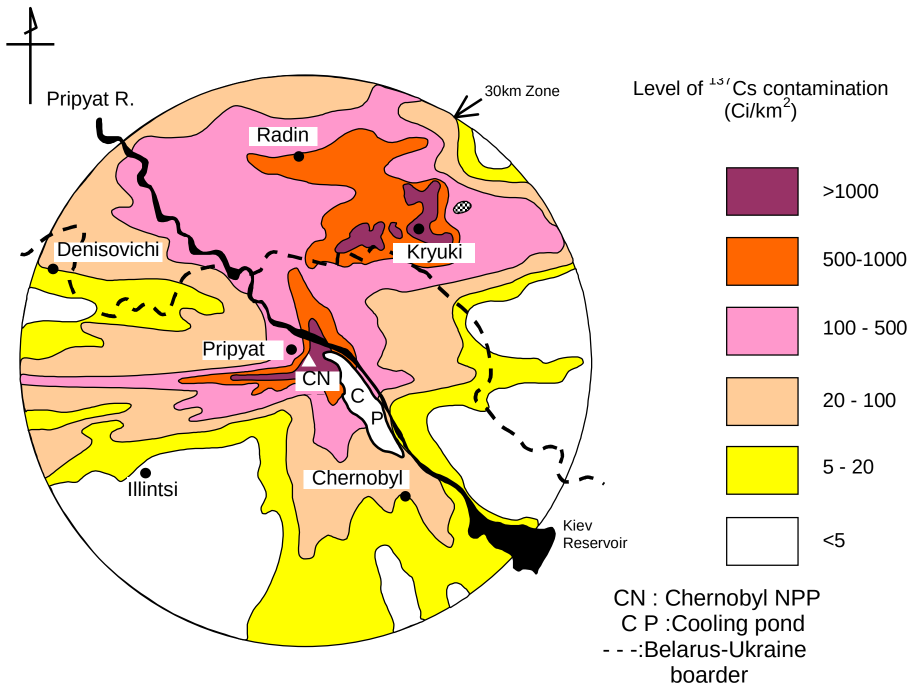

Fig. 1. Contamination map of ^{137}Cs within the 30 km zone around the Chernobyl NPS [1].

- Redrawn by Imanaka from the original map, ^{137}Cs levels of which are divided into 12 classes.

note: Imanaka visited near village Kryuki in the summer of 1993, and measured an exposure dose rate of 44 μSv/h above the ground with a scintillation spectro-surveymeter. This value is evaluated to correspond to the initial ^{137}Cs deposition density of about 1,200 Ci/km^2, based on the relation between the deposition density and exposure rates obtained from other measurements.

Table 1. Level of ^{137}Cs contamination in the alienation zone belonging to Ukraine [2].

Level of ^{137}Cs contamination (Ci/km^2)	Area (km^2)
over 1,000	21
500 - 1,000	59
200 - 500	112
100 - 200	187
50 - 100	364
20 - 50	892
10 - 20	114
5 - 10	41
2 - 5	172
1 - 2	63
0.5 - 1.0	19
Total	2,044

remarks:

- Alienation zone is defined as the area around the Chernobyl NPS from where inhabitants evacuated in the first weeks or months after the accident. This zone does not necessarily coincidence with the 30 km circle around the site, and is somewhat larger than the circle.

- Total activities of ^{137}Cs, ^{90}Sr and ^{239,240}Pu in soil within the alienation zone in Ukraine are reported to be 110,000, 100,000 and 800 Ci, respectively. Besides, Activities in storage/disposal sites within the alienation zone reportedly amount to 410,000, 56,000 and 1,400 Ci of ^{137}Cs, ^{90}Sr and ^{239,240}Pu, respectively [2].

- The area of the alienation zone belonging to Belarus is reported to be 1,700 km^2 [3].

Table 2. Excerpts of description about the health state of inhabitants from the secret protocols of the Operative Group of the Politic Bureau of the Central Committee of the Communist Party of the Soviet Union [4].

<Date of protocol>	<Description about the health state of people>
/1986/ April 29, April 30:	No description.
May 1:	To impose him (*remark:* Mr Shchepin, the first Deputy Minister of Health of the USSR) a task to report to the Operative Group the data on the numbers of hospitalized, including children, and of patients with radiation disease.
May 3:	No description.
May 4:	By the situation on May 4, 1,882 people are hospitalized in total. Total number of examined people reached 38,000 persons. Radiation disease of various seriousness appeared with 204 persons, including 64 infants.
May 5:	Total number of hospitalized people reached 2,757 persons, including 569 children. Among them, 914 persons have symptoms of radiation disease. 18 persons are in very serious state and 32 persons are in serious state.
May 6:	By the situation at 9:00 on May 6, the total number of hospitalized reached 3,454 persons. Among them, 2,609 persons are in hospital for treatment, including 471 infants. According to confirmed data, the number of radiation disease are 367 cases, including 19 children. Among them, 34 persons are in serious state. In the 6th Hospital in Moscow, 179 persons are in hospital, including two infants.
May 7:	During the last day, 1,821 persons were additionally hospitalized. At 10:00 May 7, the number of persons in hospital for treatment is 4,301, including 1,351 infants. Among them, diagnosis of radiation disease was established with 520 persons, including staffs of Ministry of Internal Affairs of the USSR. 34 persons are in serious state.
May 8:	During the last day, the number of hospitalized persons increased by 2,245, including 730 children. 1,131 persons left hospital. By the situation at 10:00 May 8, the total of 5,415 persons are in hospital for treatment, including 1,928 children. Diagnosis of radiation disease was confirmed with 315 persons.
May 10:	During the last two days, 4,019 persons were hospitalized, including 2,630 children. 739 persons left hospital. In total 8,695 persons are in hospital, including 238 cases with diagnosis of radiation disease, among which 26 are children.
May 11:	During the last day, 495 persons were hospitalized and 1,017 persons left hospital. In total, 8,137 persons are in hospital for treatment and examination, among which 264 persons with diagnosis of radiation disease. 37 persons are in serious state. During the last day 2 person died. Total number of death by the accident amounted to 7 persons.
May 12:	During the last day, 2,703 persons were hospitalized, most of which were in Belarus. 678 persons left hospital. 10,198 persons are in hospital for treatment and examination, among which 345 persons have symptom of radiation disease, including 35 children. Since the time of the accident, 2 persons perished and 6 persons died of diseases. 35 persons in serious state.
May 13:	During the last day 443 persons were hospitalized and 908 persons left hospital. 9,733 persons are in hospital for treatment and examination, including 4,200 children. Diagnosis of radiation disease was established with 299 persons, including 37 children. During the last day, one person died. In total two persons perished and one died in hospital.
May 14:	During the last day 1,059 persons were additionally hospitalized and 1,200 persons left hospital. The number of patients with diagnosis of radiation disease was reduced to 203, among which 32 are in serious state. 3 persons died during the last day.
May 16:	The number of persons in hospital is 7,858, including 3,410 children. Diagnosis of radiation disease is established with 201 cases. The total number of deaths is 15, including 2 deaths on May 15.
May 20:	During the last 4 days the number of hospitalized persons increased by 716. Radiation disease was confirmed with 211 cases, including 7 children. The number of death is 17, and 28 are in serious state. Symptoms of radiation disease were established only with persons who were directly at the zone of the scene and development of the accident.
May 22, May 26:	No description.
May 28:	5,172 persons are in hospital for examination and treatment, including 183 persons with established diagnosis of radiation disease (among them one infant). During the last week, one person died. The total number of death on May 28 is 22 (plus 2 victims at the beginning of the accident).
June 2:	3,669 persons are in hospital for examination and treatment, including 171 persons with established diagnosis of radiation disease. The number of deaths amounted to 24 (besides, two persons perished at the beginning of the accident). 23 persons are in serious state.
June 4, June 9:	No description.
June 12:	2,494 persons are in hospital for examination and treatment, including 189 persons with established diagnosis of radiation disease. The number of death until June 12 is 24 persons (plus 2 victims at the beginning of the accident).
June 20, June 25, July 2, July 7, July 10, July 23, July 31, August 13, August 22, September 5, September 19, October 17, November 15, /1987/ January 4,March 16, July 13, /1988/ January 6:	No description

remark: The total number of 40 protocols are included in the secret document, all dates of which are shown above.
The above numbers of deaths and serious states almost correspond to the numbers of cases with firemen and plant staffs.

Table 3. Number of death after the accident among persons who survived the initial period of acute radiation syndrome and among 500 liquidators specially followed-up in a EC/CIS study.

	I Patient of acute radiation syndrome [5]		II Follow-up study of 500 liquidators [6]		III Japanese adult (male, 35-45 years old)
	Group A	Group B	Belarus	Russia	
Sample size	106 persons	103 persons	494 persons	474 persons	-
Number of death	9 cases	5 cases	5 cases	17 cases	-
Cumulative death rate after the accident*	8.5 %	4.9 %	1.0 %	3.6 %	~2 %

* Durations of observation are 10 years, about 7 years and 10 years for I, II and III, respectively

Remarks:

1. - According to the first detailed report about the accident by the USSR government [7], the number of deaths by the accident was reported to be 31 cases. The number of persons who suffered acute radiation syndrome (ARS) was reported to be 203 persons, all of whom were firemen and staffs of the station. Among them, 28 persons died in three months related with ARS. Two persons died on the day of the accident: one staff was missing within the destroyed reactor and the other died of severe burns. One death was from other reason.

- In November 1986, the number of ARS was revised to be 237 cases [8]. That is, 209 (= 237 - 28) persons were alive at that time.
- Later on, 103 cases out of 237 were excluded from the category of ARS [5].
- Group A in the above Table consists of 106 patients with whom diagnosis of ARS was confirmed. Group B consists of 103 patients with whom diagnosis of ARS was given in 1986, but later canceled. The period for observation is for 10 years (1986-1995).
- Death causes of Group A: 3 coronary heart diseases, 2 myelodysplastic syndrome, 1 lung gangrene, 1 lung tuberculosis, 1 liver cirrhosis, and 1 fat embolism.
- Death causes of Group B: one cases of car accident, hypoplasia of haematopoiesis, encephalitis/encephalomylitis, sarcoma (thigh), and coronary heart disease.

2. This study was carried out within the frame of the EC/CIS collaborative project [6], in order to check the traceability of contingents in the Chernobyl registries. 500 liquidators were randomly selected from the Registries in Belarus and in Russia. As a result of special efforts to ascertain their states, 4 persons remain unknown and 2 persons emigrated abroad in the Belarussian group. These numbers in the Russian group were 4 and 22 persons, respectively. The time of state ascertainmemt was not exactly mentioned, but the time of address ascertainment was described to be 01.10.1993 and 31.12.1992 for Belarussian and Russian groups, respectively.

- Death cause of 5 Belarussian liquidators: 1 acute mycardial infarction, 1 cerebrovascular disease, 1 fracture of the skull, 1 fracture of the back bone and 1 Hpdgkin’s disease.
- Death cause of 17 Russian liquidators: 4 hangings, 2 cancers (one pharynx, one stomach), 2 haemorrhages (one internal, one pancreas), 2 internal brain trauma, 1 gangrene of the intestine, 1 carbon monooxide poisoning whilst intoxicated, 1 car crash, 1 ischemic heart disease, 1 heart insufficiency and 2 unknown causes.

3. - Death rate of Japanese male are taken from the Vital Statistics in Japan in 1986.

Table 4. Population size of the Chernobyl registries carried out in each affected country.

Group	Ukraine [2] (State Registry of Ukraine)	Russia [9] (Russian National Medical-dosimetric Registry)	Belarus [10] (Chernobyl Registry)
Total number of registered person (date)	474,095 (96.1.1)	435,276 (95.9.1)	204,982 (95.1.1)
including:			
A. Liquidators	184,672	152,325	53,192
B. Evacuees and resettlers	62,711	12,889	~10,000*
C. Inhabitants in contaminated areas	189,518	251,246	~90,000*
D. Children of A-C groups	37,194	18,816	?

* These numbers were obtained by a private communication with Matsko in Minsk.

Table 5. Characteristics of liquidator population in the Registry of each country.

	Ukraine [2]	Russia [9]	Belarus [11]
Population size of primary cohort	174,812 persons	143,032 persons	45,674 persons
Fraction of persons with dose record	59 %	80 %	26 %
Average recorded dose	160 mSv	107 mSv	57 mSv

- Primary cohorts consist of liquidators who are subjects of following-up study; principal information about places and period of their working at Chernobyl are known.

Table 6. Dose distribution of liquidators registered in Ukraine [12].

	Number of persons	Recorded external irradiation (mSv)					
		no record	<50	50-99	100-249	250-500	>500
Workers in 1986-87	135,800 100 %	65,300 48.1 %	8,000 5.9 %	20,900 15.4 %	34,100 25.1 %	7,300 5.4 %	270 0.20 %
Workers in 1988-90	39,000 100 %	6,600 17.0 %	26,200 67.2 %	5,500 14.2 %	510 1.3 %	90 0.23 %	0 0 %

Table 7. Distribution of observed and expected numbers of cancers in 1993-1994 among male

Fig 2. Dynamics of disabled rate among liquidators registered in Russia [13] and Ukraine [12].

liquidators registered in Belarus by duration of work in the 30 km zone [11].

ICD-9	Site	Duration of work in the 30 km zone							
		Less than 30 days				1-6 months			
		O	E	SIR	95%CI	O	E	SIR	95%CI
151	Stomach	7	12.1	58	23-119	5	7.3	69	22-160
153	Colon	7	2.9	241	97-497	2	1.7	117	14-423
162	Lung	14	22.1	63	35-106	9	12.0	75	34-143
173	Skin	2	4.4	45	5-163	0	2.7	0	0-139
188	Urinary bladder	5	3.0	167	54-390	4	1.6	245	67-628
189	Kidney	3	3.4	88	18-257	4	2.1	189	52-485
193	Thyroid grand	1	0.7	151	4-844	3	0.5	625	129-1826
204-208	Leukemia	3	2.7	111	23-325	6	1.8	342	126-746
140-208	All sites	61	85.2	72	55-92	41	50.4	81	58-110

- Expected number (E) is obtained with age standardization based on the incidence data of the general population in Belarus.

Table 8. Incidence of leukemia among Ukrainian liquidators [12].

Year	Incidence rate (per 100.000 persons)	
	Workers in 1986	Workers in 1987
1987	13.33 ± 4.71	-
1988	6.42 ± 3.21	6.32 ± 4.47
1989	14.06 ± 4.69	4.41 ± 3.12
1990	14.50 ± 4.59	5.32 ± 3.07
1991	18.13 ± 4.84	7.74 ± 3.46
1992	12.59 ± 3.98	12.02 ± 4.25
Total	13.35 ± 1.80	7.04 ± 1.57

- During 1987-1992, 141 cases of hemobalstoses disease were observed among registered liquidators, 86 cases among which were leukemia.

Table 9. Morbidity of acute leukemia in children under 15 years old in Belarus in 1979-1992 [10].

Region	Incidence per 1 million children		Total number of cases (1979-1992)	Chemical contamination level in the environment, ton/km^2
	1979-1985	1986-1992		
Brest	42	44	208	2.80
Vitebsk	42	47	186	10.40
Gomel	34	43	210	4.60
Grodno	42	39	147	3.20
Minsk	37	41	195	2.20
Mogilev	50	42	184	7.60
Minsk city	49	47	234	735.40
Total	42.0	43.3	1,364	-

Remarks: The Blood disease registry in Belarus was began in 1988 at the Research Institute of Heamatology and Blood Transfusion of the Health Ministry. So, the old data are supposed to be obtained by retrospective analysis.

Table 10. Average annual indices of hemoblastoses morbidity in the Bryansk region of Russia from 1979 to 1993 [14].

	Annual indices per 100,000 persons, (number of cases during the period)		
	1979-85	1986-90	1991-93
Acute lymphoid leukemia:			
6 contaminated districts	0.56±0.17(11)	1.55±0.34(21)	1.33±0.42(10)
Bryansk city	0.48±0.12(14)	1.59±0.26(37)	1.86±0.36(27)
Other districts	0.70±0.11(38)	1.14±0.18(42)	2.56±0.34(56)
Hemoblastoses total:			
6 contaminated districts	10.54±0.73(209)	12.79±0.97(173)	15.43±1.43(116)
Bryansk city	12.79±0.65(387)	18.73±0.90(437)	18.22±1.12(265)
Other districts	11.24±0.46(610)	13.17±0.60(485)	19.23±0.94(421)

- 6 contaminated districts are districts of Gordeevsk, Zlynkovsk, Klimovsk, Klineovsk, Krasnogrsk and Novozybkovsk.
remarks: The special registry of blood disease in the Bryansk region was established in 1987 at Haematological Research Center of RAMS. So, the old data are supposed to be obtained by retrospective analysis.

Table 11. Malignant cancer incidence in the contaminated territories of Belarus: before and after the Chernobyl accident and by ^{137}Cs levels (Annual standardized incidence per 100,000 persons) [10].

Contamination level with ^{137}Cs Ci/km^2	Gomel region		Mogilev region	
	before the accident 1977-1985	after the accident 1986−1994	before the accident 1977−1985	after the accident 1986−1994
>15	194.6±8.6	304.1±16.5**	221.0± 8.6	303.9± 5.1**
5-15	176.9±9.0	248.4±12.5**	241.8±15.4	334.6±12.2***
<5	181.0±6.7	238.0±26.8	248.8±14.5	306.2±18.0*

: Significant increase (; p<0.05, ** ; p<0.01, *** ; p<0.001) as compared with the period before the accident.
- Cancer morbidity is based on the data of the Belarussian Cancer Registry during 1977 -1994.

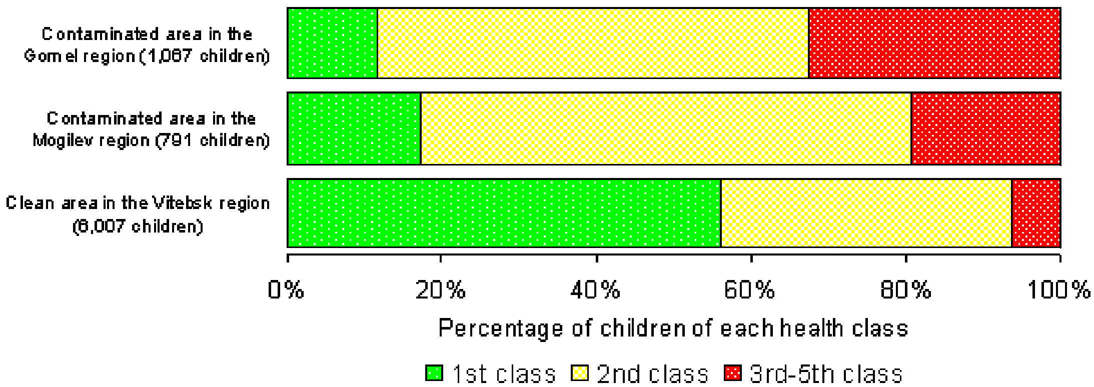

Fig. 3. Distribution of children by health groups obtained by a special study in the WHO/IPHECA program [14].

Health indices: 1st class - healthy children from all indices of health, 2nd class -children with functional disturbances, risk for occurrence of chronic pathologies and high morbidity
3rd, 4th, 5th classes - ill children with chronic pathologies of different degrees

Table 12. Morbidity of Belarussian children included in the Chernobyl Registry [15]. (1992, per 1,000 children)

- The number of children contained in the Chernobyl registry is 33,488. Among them, 6.9, 81.4 and 11.7 % are

Diseases	Children in the Register (A)	Whole Belarus (B)	Ratio (A/B)
Neoplasm	4.08	1.75	2.3
including: Malignant neoplasm	1.84	0.35	5.3
Thyroid cancer	0.82	0.05	16
Endocrine, metabolism and immune system disorders	133.78	33.66	4.0
Blood and hematopoetic tissue diseases	56.46	12.00	4.7
Blood circulation diseases	39.58	12.92	3.1
Otolaryngologic diseases	95.89	19.47	4.9
Digestive organ diseases	162.91	125.84	1.3
Psychic diseases	27.64	24.49	1.1

evacuees from the 30-km zone, residents or emigrants from the zone over 15 Ci/km^2 and children born with registered parents, respectively.

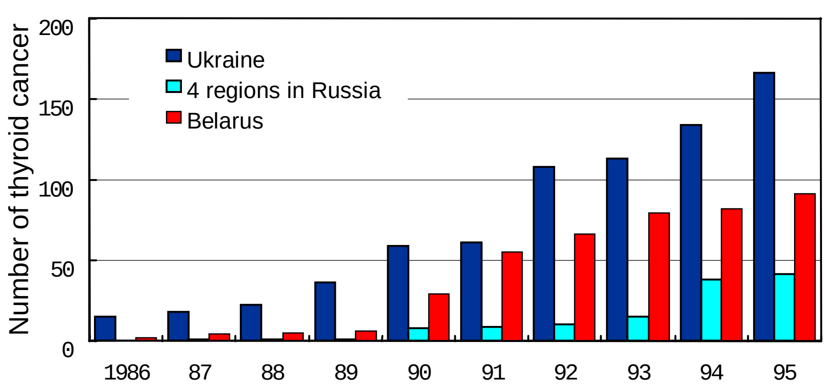

Fig. 4 Annual incidence of thyroid cancer in children and adolescents in Ukraine [16], 4 regions of Russia [17] and Belarus [18].

- 4 regions in Russia are the Bryansk, the Kaluga, the Tula and the Orel regions.
- **Children's age of Ukraine and Russia is *0 - 18 years old at the time of the accident*.**
- **Children's age of Belarus is *0 - 14 years old at the time of their cancer operation*.**

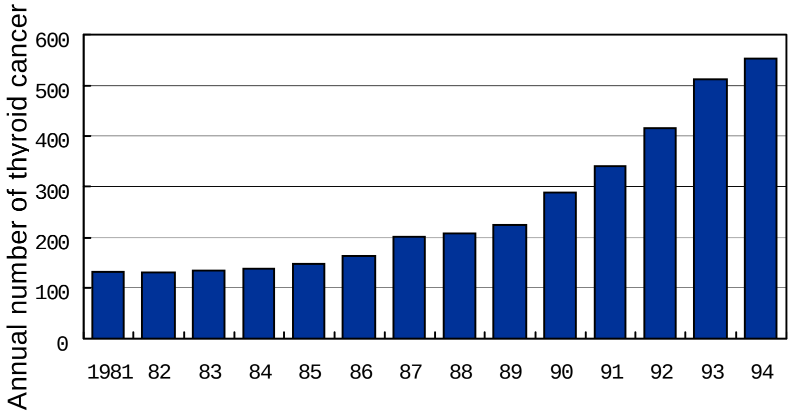

Fig. 5. Annual incidence of thyroid cancer in adults of Belarus [19].

Table 13. Estimates of economic loss due to the Chernobyl accident in Belarus for 1986-2015 [10].
unit: Billion US Dollars (at the price in 1992)

Item of loss	Period		
	1986-1995	1996-2015	1986-2015
Deterioration of people's health and related countermeasures	0.98	0.89	1.87
Manufacturing industry	0.19	0.44	0.63
Social circumstances: school etc.	7.77	6.47	14.23
Construction industry	1.40	1.28	2.68
Transport and communication	2.13	1.26	3.39
Houses and public facilities	0.52	2.94	3.46
Agricultural industry	38.31	33.70	72.00
Forest industry	1.26	2.85	4.11
Resettlement	4.36	0.72	5.08
Implementation of the Law to help the sufferers: compensation, privilege etc.	15.48	70.84	86.32
Contamination of mineral and water resources	2.12	0.55	2.67
Construction of monitoring	4.23	32.60	36.83
Monitoring works	0.26	1.46	1.72
Total	79.00	156.00	235.00

- Estimation was carried out at the Institute of Economy, Academy of Sciences of Belarus.
- All items consist of loss categories: direct and indirect loss, loss of profits, and additional expenditures.
- 235 billion USD corresponds to 32 times of the national budget of Belarus in 1985 or 21 times of it in 1991.

Table 14. Expenditures to implement countermeasures for the Chernobyl problems in Ukraine [2].

Year	Expenditure from the LCA Fund* (Billion Krb.)	Percentage to the national budget of Ukraine (%)	Percentage to general national production (%)
1991	6.2	-	2.1
1992	97.4	6.4	1.9
1993	1,966	6.3	1.3
1994	23,788	5.1	1.8
1995	94,199	5.8	1.8

*: LCA Fund: Fund for Liquidation of the Consequences of the Chernobyl Accident. Until September of 1991, works to liquidate the consequences of the Chernobyl accident and to help the sufferers were implemented directly by the budget of the former USSR. Thereafter, the finance has been given from the budget of Ukraine through the LCA Fund.
- Krb. is the currency unit used in Ukraine until 1996.

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