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

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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Research Reactor Institute,
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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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CONTENTS

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.

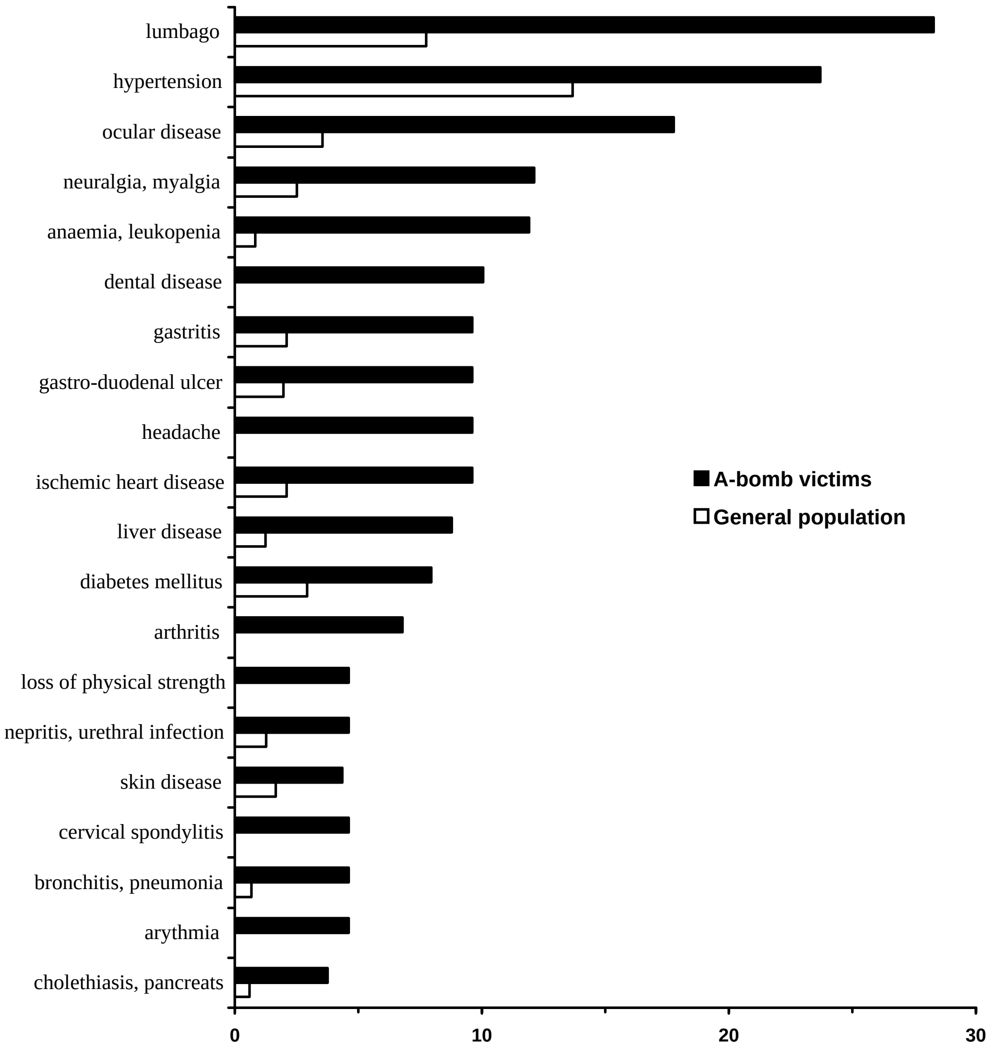

Fig. 1 Comparison of morbidity rates (%) of the A-bomb victims and of the general Japanese population [33].

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).
5. Buglova E. E., “Formation of Internal Radiation Dose Dependent on Peculiarities of Cesium Radionuclide Transfer along Food Chain and Efficiency of Protective Measures”, Abstracts of Intern. Conf. “Science and Medicine For Chernobyl”. Minsk, 10-13 Nov. 1993, pp.3-4 (in Russian).
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7. Ilin V. P., Gudak S. P., “Characterization of Radionuclide Migration in the Aeration Zone of South-East of BSSR”, Vodnye resursy. 1990, No.6, pp.56-60 (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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14. Mazur V. A., Ustinovich A. K., Zubovich V. K. et al., “Health State of Pregnant, Bearing Women and New-Born Children in BSSR Regions Exposed to Radioactive Pollution in 1981-1989”, Vestnik Akademii Meditsinskikh Nauk SSSR. 1991, No.11, pp.22-24 (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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8. ZAKHAROV V.M. and KRYSANOV E.YU. ed., "Consequences of the Chernobyl Catastrophe: Environmental Health", Center for Russian Environmental Policy, Moscow, 1996.
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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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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:

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

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, $\overline{H}_{\tau,\text{ext}}$ **,** and internal, $\overline{H}_{\tau,\text{int}}$**,** doses:

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

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:

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

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

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 $\overline{H}_{\tau,\text{ext}}$ is much easier than that of $\overline{H}_{\tau,\text{int}}$**.** The mean external equivalent dose, $\overline{H}_{\tau,\text{ext}}$, can be determined by means of the equation:

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

where

$\overline{H}^{*}_{\tau,\text{ext}}$ = 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:

$$\overline{A}^{0}_{s}\,(^{137}Cs) = \frac{Q_0}{S} \quad (6)$$

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: $\overline{H}^{*}_{\tau,\text{ext}}$, 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, $\overline{H}^{*}_{\tau,\text{ind}}$, 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:

$$D_{\tau} = C_1 \cdot P_{\tau} \quad (7)$$

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:

$$H_{\tau} = C_2 \cdot D_{\tau} \quad (8)$$

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:

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

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:

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

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**:

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

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]:

$$K_L = a_1\cdot\exp(-l_1\cdot t) + a_2\cdot\exp(-l_2\cdot t), \qquad \textbf{(12)}$$

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.

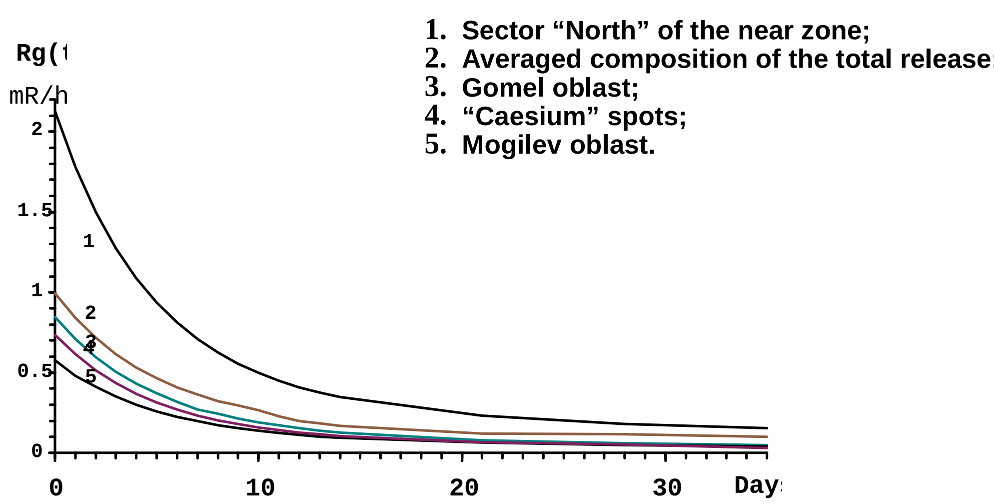

Fig. 1 Exposition dose rates in air at a height of 1 m during the first weeks after the Chernobyl accident in different areas of Belarus (normalized to the contamination level of caesium-137 equal to 1 Ci/km^2).

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:

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

$$P^*_\tau = K_S \cdot \int_0^\tau K_L(t) \cdot \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma^0_i \cdot \exp\left(-\frac{0.693}{T^i_{1/2}} \cdot t\right) \qquad (14)$$

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:

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

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:

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

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:

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

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:

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

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:

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

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.

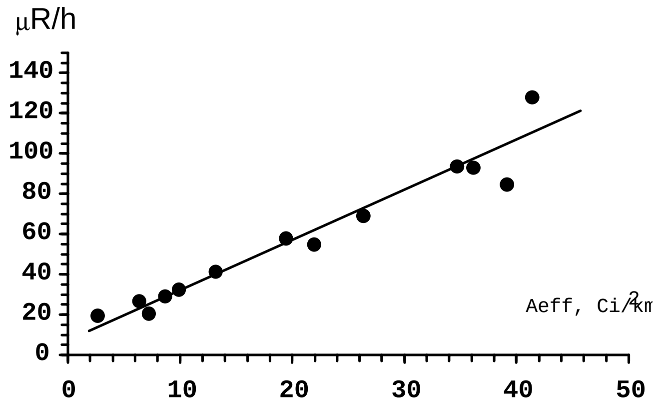

Fig. 2. Exposition gamma dose rates at a height of 1 m outside the buildings as a function of Aeff

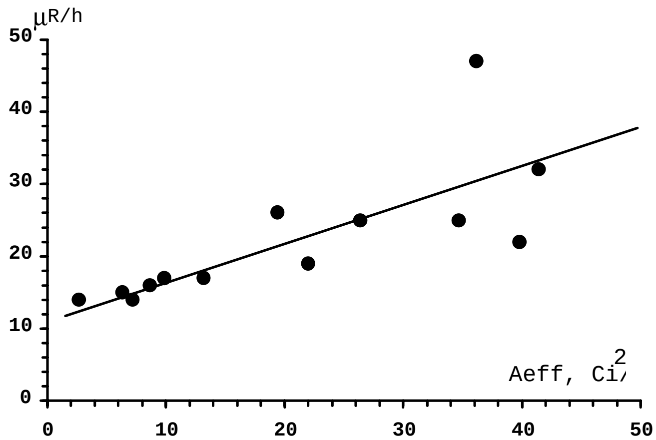

Fig. 3. Exposition gamma dose rates at a height of 1 m inside buildings as a function of Aeff

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:

$$F\,(t) = \sum_{i=1}^{n} K_{i,\gamma} \cdot \sigma_i^0 \cdot \exp(-\frac{0.693}{T_{½}^i} \cdot t). \qquad \textbf{(21)}$$

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,

$A\,eff(90)$ = 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

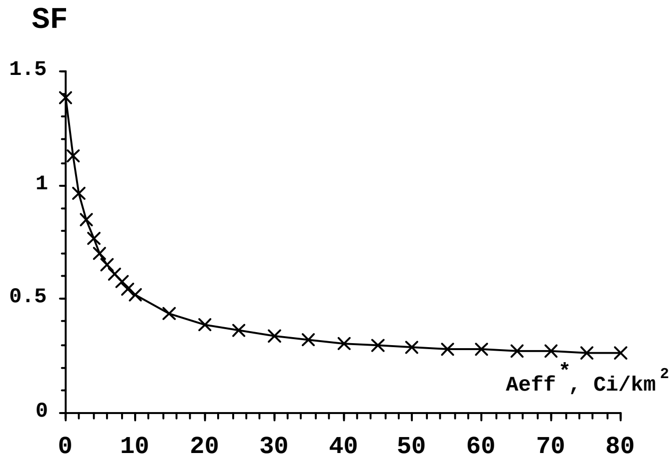

Fig. 4 Shielding factors as a function of contamination levels

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:

$$F_3 = \frac{0.836 \cdot Aeff^*}{3.944 \cdot Aeff^*} = \frac{0.836}{3.944} = 0{,}212 \qquad \textbf{(41)}$$

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:

$$\overline{H^*_{\tau,\text{ext}}} = 0.247 \cdot P_\tau . \qquad \textbf{(42)}$$

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:

$$\overline{H^*_\tau} = \frac{\overline{H^*_{\tau,\text{ext}}}}{0.6} . \qquad \textbf{(43)}$$

Combination of the two last equations gives:

$$\overline{H^*_\tau} = 0.412 \cdot P_\tau . \qquad \textbf{(44)}$$

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	$0.1\bullet10^{-3}$	$0.8\bullet10^{-3}$	3%
^{239}Pu	$0.1\bullet10^{-3}$	$0.7\bullet10^{-3}$	- " -
^{240}Pu	$0.2\bullet10^{-3}$	$1\bullet10^{-3}$	- " -
^{241}Pu	0.02	0.14	- " -
^{242}Pu	$0.3\bullet10^{-6}$	$2\bullet10^{-6}$	- " -
^{242}Cm	$3\bullet10^{-3}$	$2.1\bullet10^{-2}$	- " -

*) 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;

$\overline{A_{s,i}^0}$ = 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:

$$Q_0 \approx S \cdot \sum_{i=1}^{N} \frac{\overline{A_{s,i}^0}}{N} = S \cdot \overline{A_s^0}, \qquad (48)$$

where:

$\overline{A_s^0}$ = 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 $\overline{A_s^0}$ is determined by the equation:

$$\overline{A_s^0} = \sum_{i=1}^{N} \frac{\overline{A_{s,i}^0}}{N}. \qquad (49)$$

The last equation was used for the calculation of the averaged levels for areas with the level of contamination $A_s^0 \geq 1 Ci/km^2$. Results of the calculation performed on the basis of the experimental data on $\overline{A_{s,i}^0}$ 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 $A_s^0 \leq 1 Ci/km^2$. 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

$$\overline{A_s^0} = \frac{A_{s,\min}^0 + A_{s,\max}^0}{2}. \quad \textbf{(50)}$$

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:

$$H_\tau^{coll} = N \cdot \overline{H_\tau^*} \cdot \overline{A_s^0} \quad \textbf{(51)}$$

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	$5.5 \cdot 10^4$	$4.4 \cdot 10^4$	$6.6 \cdot 10^4$
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:

$$q_{th} = q_{th,7} \cdot \frac{\rho}{\rho_7}, \quad (56)$$

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 $160\cdot10^{-4}Sv^{-1}$ and $16\cdot10^{-4}Sv^{-1}$, 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 $8\cdot10^{-4}Sv^{-1}$. 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 $16\cdot10^{-4}Sv^{-1}$ (DDREF=1). From here one can receive the lifetime morbidity risk coefficient $160\cdot10^{-4}Sv^{-1}$ 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 $16\cdot10^{-4}Sv^{-1}$ from the value $1{,}090\cdot10^{-4}Sv^{-1}$ estimated by the UNSCEAR. One can receive on this simplified way the value $1{,}074\cdot10^{-4}Sv^{-1}$ 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 $110\cdot10^{-4}Sv^{-1}$ 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

$$^{131}I = 14.58 \cdot \left(^{137}Cs\right)^{0.605} \quad (2)$$

and

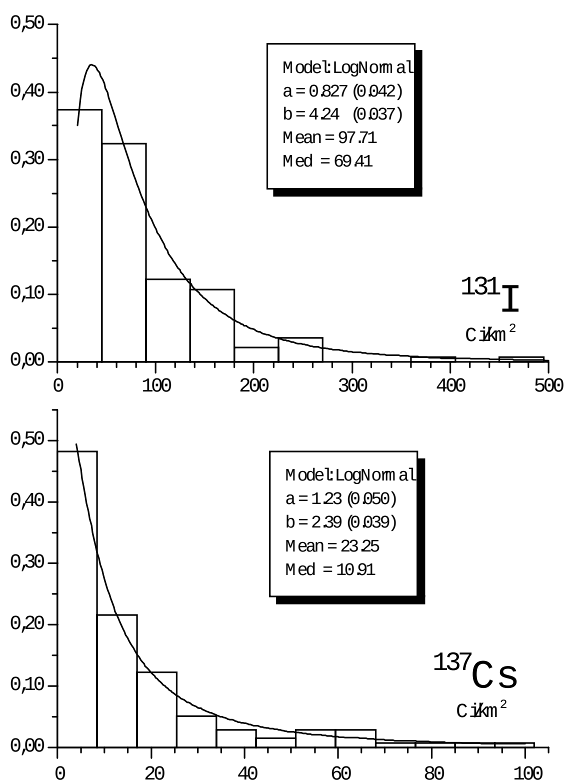

Fig. 2 Distribution of ^{131}I and ^{137}Cs activity concentration in soil of the southern area of Belarus.

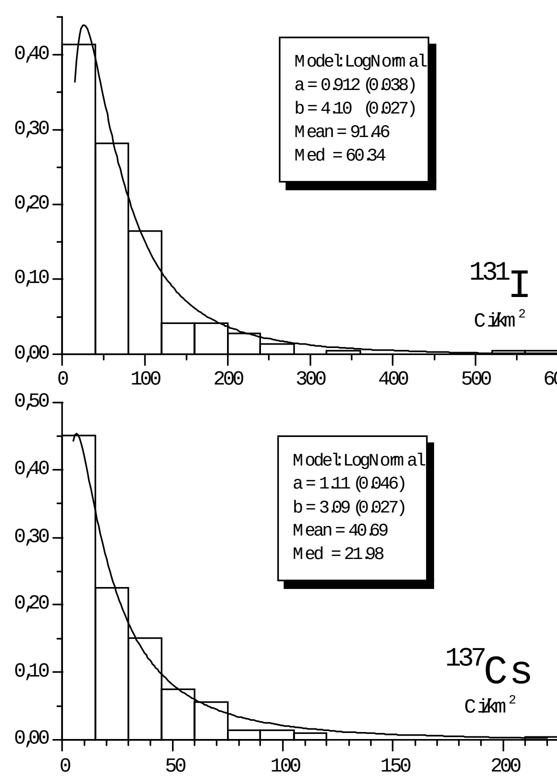

Fig. 3 Distribution of ^{131}I and ^{137}Cs activity concentration in soil of the eastern area of Belarus.

$$^{131}I = 8.85 \cdot \left(^{137}Cs\right)^{0.627} \qquad (3)$$

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.

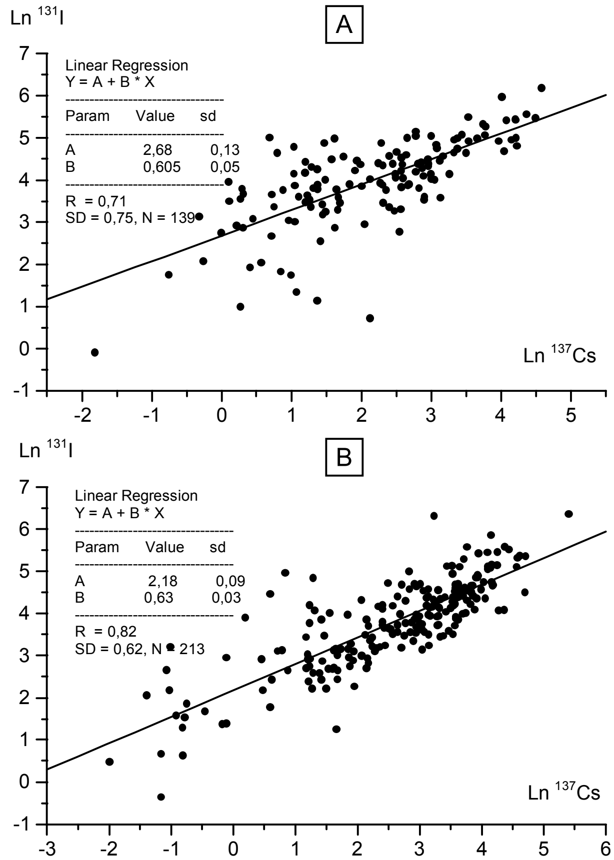

Fig. 4 Relationship between ^{131}I and ^{137}Cs activity concentration (Ci/km^2) in soil of the southern (A) and the eastern (B) areas of Belarus.

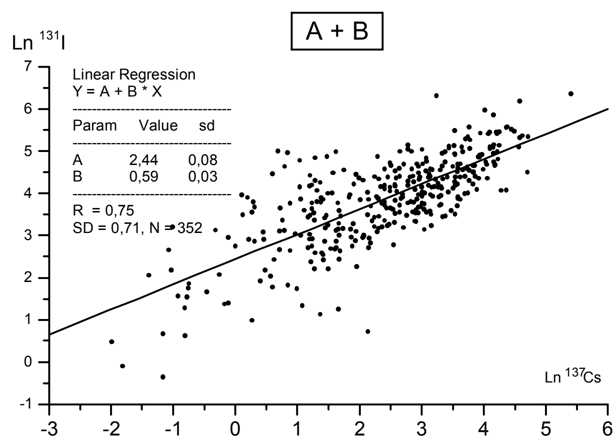

Fig. 5 Relationship between ^{131}I and ^{137}Cs activity concentration (Ci/km^2) in soil of the Belarus territory including both the southern (A) and the eastern (B) areas.

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