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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