Health Effects of Chernobyl and Fukushima: 30 and 5 years down the line

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CONTENTS

GENERAL ABBREVIATIONS, UNIT ABBREVIATIONS, AND TERMINOLOGY

AMS – Academy of Medical Sciences.

ACS DB DEMOSMONITOR - Automated control system of data bases of monitoring of medical and demographic consequences of Chernobyl catastrophe.

ARS - Acute Radiation Syndrome.

ATR - Attributive risk.

BSSR - Belorussian Soviet Socialistic Republic.

Bq (kBq) - Becquerel ($Bq \cdot 10^3$), radioactivity unit, in the SI system.

CER - Clinical and Epidemiological Register.

CFS - Chronic Fatigue Syndrome.

CLL - Chronic lymphoid leukaemia.

CI - Confidence Interval.

$Ci \cdot km^{-2}$ - level of radioactive contamination of the territory, outdatednon-system unit (1 $Ci \cdot km^{-2} = 37\ kBq \cdot m^{-2}$)

CNS - Central Nervous System.

DCS - Diseases of the Circulatory System.

DS – Department of Statistics of Ukraine.

CMU - Cabinet of Ministers of Ukraine.

EAR - Excess Absolute Risk.

ERR - Excessive Relative Risk.

ED – Effective Dose.

FGI - French-German Initiative for Chernobyl.

Gy - Grey, absorbed dose unit, in the SI system.

GR - Growth Rate.

IAEA - International Atomic Energy Agency.

ICD - International Classification of Diseases.

IChP-1991 - International Chernobyl Project.

ICRP – International Commission on Radiological Protection.

IPHECA - International Program on Health Effects of the Chernobyl Accident.

IQ - Intelligence Quotient.

JSDF - Japan Self-Defense Force.

$kBq \cdot m^{-2}$ - level of radioactive contamination of the territory, in the SI system.

ME - Ministry of Ukraine of Emergencies and Affairs of Population Protection from the Consequences of Chernobyl Catastrophe.

MH - Ministry for Health.

MIAU - Ministry of Internal Affairs of Ukraine.

NAMSU - National Academy of Medical Sciences of Ukraine.

NASU - National Academy of Sciences of Ukraine.

NCRPU - National Commission on Radiation Protection of Population of Ukraine.

NPP - Nuclear Power Plant.

NRER - National Radiation and Epidemiological Registry.

OR - Odds Ratio.

PTSD – Post-traumatic Stress Disorder.

RADRUE - Realistic Analytical Dose Reconstruction and Uncertainty Analysis.

RCR – Radioactively Contaminated Rayon.

RCT – Radioactively Contaminated Territories.

Rem - roentgen equivalent in man, the biological equivalent of Roentgen, outdatednon-system unit for effective expose dose, 1 rem=0.01 Sv.

RF - Russian Federation.

RR - Relative Risk.

RSFSR – Russian Soviet Federation Socialistic Republic.

RSSU_97 - Radiation Safety Standard of Ukraine_97.

NRCRM - State Institution «National Research Centre for Radiation Medicine of NAMS of Ukraine».

SIR – Standardized Incidence Ratio.

SRU - The State register of Ukraine of the persons survived after the Chernobyl catastrophe», State Registry of Ukraine.

Sv (mSv) - Sievert (milliSievert) - effective dose unit, in the SI system.

TEPCO - Tokyo Electric Power Company.

UACOS – Ukrainian-American Chernobyl Ocular Study.

UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation.

USSR - The Union of Soviet Socialistic Republics.

UkrSSR - The Ukrainian Soviet Socialistic Republic.

WHO - World Health Organization.

Clean-up workers (liquidators, recovery operation workers, Chernobyl emergency workers) - citizens of the USSR including the UkrSSR who has participated in any activities connected with damage control and mitigation of the catastrophe and its consequences in the exclusion zone regardless of number of working days in 1986-1987, and at least 30 calendar days in 1988-1990. Citizens temporarily sent on mission to work in the exclusion zone, including servicemen, employees of state, public and other enterprises, establishments and organizations irrespective from their departmental relation, and also those who worked at least 14 days in 1986 at functioning points of population sanitary treatment and decontamination of technical devices or at their building are also attributed to the clean-up workers

Radioactive contamination - presence of radioactive substances in or on a material or the human body or elsewhere being undesirable or potentially harmful. Units of measurements are: $Bq \cdot l^{-1}$, $Bq \cdot kg^{-1}$, $Bq \cdot m^{-2}$, $Ci \cdot l^{-1}$, $Ci \cdot kg^{-1}$, $Ci \cdot km^{-2}$.

Radiation effect - effects, for which a causative role of radiation exposure is proven; there are deterministic and stochastic effects.

Radioactively contaminated territories (RCT) – territories in Ukraine (Law of Ukraine, 1991a) with a stable contamination of environment by radioactive substances above a pre-accidental level, that with due regard for the natural-climatic and complex ecological characteristics of specific territories could result to irradiation of population to above 1.0 mSv (0.1 rem) per year, and which requires measures of radiation protection of population. Territories subjected to radioactively contamination, are divided in zones:

1) *exclusion zone* is a territory, which has been radioactively contaminated after the Chernobyl catastrophe, and from which the population has been evacuated in 1986.

2) *zone of obligatory (compulsory) resettlement* is a territory exposed to intensive long half-life radionuclide contamination with density of soil deposition at a threshold values of 15.0 $Ci \cdot km^{-2}$ (555 $kBq \cdot m^{-2}$) and above for isotopes of caesium, or 3.0 $Ci \cdot km^{-2}$ (111 $kBq \cdot m^{-2}$) and more for strontium, or 0.1 $Ci \cdot km^{-2}$ (3.7 $kBq \cdot m^{-2}$) and over for plutonium. As a result the average by-settlement radiation dose of an equivalent human irradiation dose in a view of factors of radionuclides migration to the plants and other factors can exceed 5.0 mSv (0.5 rem) per one year is above the dose levels, been received in the pre-accident period;

3) *zone of guaranteed voluntary resettlement* is a territory with soil contamination density by isotopes of caesium from 5.0 up to 15.0 $Ci \cdot km^{-2}$ (185 up to 555 $kBq \cdot m^{-2}$), or strontium from 0.15 up to 3.0 $Ci \cdot km^{-2}$ (5.55 up to 111 $kBq \cdot m^{-2}$), or plutonium from 0,01 up to 0.1 $Ci \cdot km^{-2}$ (0.37 up to 3.7 $kBq \cdot m^{-2}$), where the average settlement of an equivalent human irradiation dose in a view of factors

of radionuclide migration to the plants and other factors can exceed 1.0 mSv (0.1 rem) per one year above the doses, been received in the pre-accident period;

4) *zone of strict radio-ecological control* is a territory with soil contamination density by isotopes of caesium from 1.0 up to 5.0 $Ci \cdot km^{-2}$ (37 up to 187 $kBq \cdot m^{-2}$), or strontium from 0.02 up to 0.15 $Ci \cdot km^{-2}$ (0.74 up to 1.85 $kBq \cdot m^{-2}$), or plutonium from 0.005 up to 0.01 $Ci \cdot km^{-2}$ (0.185 up to 0.37 $kBq \cdot m^{-2}$) provided that the average settlement of an equivalent human irradiation dose in a view of factors of radionuclide migration to the plants and other factors exceeds 0.5 mSv (0.05 rem) per one year above the doses, been received in the pre-accident period.

Resettlement - because of possible exceeding of a life dose over 350 mSv in the inhabitants of the RCT the Government of the USSR in 1990 has accepted the decision to resettle from these districts in UkrSR, BSSR and RSFSR more than 200.000 people. About 50.000 persons had to be resettled to the clean districts in UkrSSR. The resettlement had to be carried out in 1991-1992. Further, in Ukraine the resettlement proceeded from zones of obligatory (compulsory) resettlement, guaranteed voluntary resettlement and strict radio-ecological control.

Chernobyl catastrophe survivors. The following population groups in Ukraine are recognised as the Chernobyl catastrophe survivors:

1) evacuees from the exclusion zone (including persons who at the moment of evacuation were at a fetal life period, later they have been born and become the adult persons nowadays) and person who had moved from zones of obligatory (compulsory) resettlement and guaranteed voluntarily resettlement;

2) individuals been permanently resident within the territories of obligatory (compulsory) and guaranteed voluntarily resettlement zones at the moment of the catastrophe, or having resided at least for two years on the territory of obligatory (compulsory) resettlement zone as of January 1, 1993, or at least for three years within the territories of guaranteed voluntarily resettlement zone, and individuals relocated or migrated themselves from those territories;

3) individuals been permanently resident or working in zones of obligatory (compulsory) and guaranteed voluntarily resettlement under condition that they have lived or worked there in the zone of obligatory (compulsory) resettlement for at least two years as of 1, January, 1993, and in the zone of guaranteed voluntarily resettlement – for at least three years;

4) individuals been permanently resident or working within territories of strict radio-ecological control zone under the condition that they have lived or worked there for at least four years as of January 1, 1993;

5) individuals having worked temporary since the moment of the catastrophe till July 1, 1986 for at least 14 calendars days or at least 3 months during 1986-1987 on the territory of obligatory (compulsory) resettlement zone under the condition that they were sent to that zone by an order of ministries, establishments, executive committees of oblast Councils of Peoples' Deputies;

6) children with thyroid irradiation doses exceeding the threshold levels established by the MH of Ukraine.

Notes

1. Units of measurement used in the report are those presented in submitted documents. Recalculation in the International system units is stated in brackets behind them.
2. Territory of and Ukraine and of Belarus consists of several provinces (called "oblasts"), in turn each "oblast" consists of several districts (such district is called "rayon" or region).
3. The name for the city of Kiev in Ukrainian is "Kyiv", and for the city of Chernobyl is "Chornobyl". The spellings "Kiev" and "Chernobyl" are used in this report being known and recognised internationally.

CONCLUSIONS

A. 30 years later, using Ukraine as an example we can draw the following conclusions about the Chernobyl catastrophe and its consequences.

1. The Chernobyl catastrophe has led to radioactive contamination of large territories of Ukraine. Practically the whole territory of Ukraine was polluted by ^{137}Cs above twice pre-accident level. It has also led to deterioration of the environmental life-quality in the affected areas. Dangerous and unsuitable for the human habitation areas appeared and remain in the zones adjacent to the accident site. They have become also unsuitable for the production and support of life. Last years the improvement of the radiological situation and decrease in radiation exposure to the people are noted.

By the results of dosimetric passportization (2011-2012) as of the end of 2011 the passport dose in 1851 settlements was less than 0.5 mSv·year^{-1}, and in 101 of them varied from 0.5 up to 1.0 mSv·year^{-1}. According to the national criteria the settlements with a dose under 0.5 mSv·year^{-1} cannot any more to be regarded as radioactively contaminated. The 25 settlements where the doses make range from 1 up to 5 mSv·year^{-1} can be referred to as zone of guaranteed voluntary resettlement, the 101 settlements with dose range from 0.5 up to 1 mSv·year-1 - as zone of strict radio-ecological control. There are no more settlements where the doses exceed 5 mSv·year^{-1}, i.e. such that should be attributed to a zone of obligatory (compulsory) resettlement. Zone of the strict radio-ecological control and settlements located within it are excluded from the list is radioactively contaminated ones since January 1, 2015.

The rest of the contaminated territories are stigmatised with destruction and degradation. With this consideration the maintenance of emergency response concerning the radioactive contamination will be persisting for many years. A new strategy for radiation protection and health care of the population in the remaining radioactively contaminated areas is required.

Social and health protection of survivors as important measures for preserving their health should be continued. In 30 years after catastrophe the exclusion zone remains highly dangerous because of intensive releases of radioactivity and fallout.

2. Taking into account the content and amount of accidental release of radionuclides as a result of the Chernobyl catastrophe the Ukrainian population has been exposed to external and internal irradiation in low doses following the combined, complex and synergistic action of acute exposure, stress and other factors. As a result all that increased an impact of ionizing radiation. Exposure to ionizing radiation resulted in health effects involving the whole body, organs and tissues.

3. At the same time, the Chernobyl catastrophe consequences, obviously, cannot be attributed to the radiation only. The dramatic social changes, inadequate governmental informational and social insurance policy, psychosocial impact and stress-related disorders (PTSD, depression, anxiety, somatoform and psychosomatic disorders, psychoactive substance abuse, suicides) following radiation emergencies are of great importance.

4. 3,364,475 citizens in Ukraine were categorized as the Chernobyl catastrophe survivors. There are 376,639 clean-up workers of the Chernobyl catastrophe and 2,985,231 other survivors including 1,264,329 children among them. Data on irradiation doses to them are contradictory thus being mainly represented as averaged for groups (clean-up workers) or by settlements (in the inhabitants

of RCT). Individual total irradiation doses in the clean-up workers were partially reconstructed by the 25th anniversary of the catastrophe in the framework of cohort studies within international projects. Among the 376,639 liquidators the radiation doses have been estimated for about a half of them. Inhabitants of the RCT have been provided the worst dosimetric assessment. Density of soil contamination by radionuclides has been accepted as safety criteria instead of the real radiation dose since May, 1986 till 1991. The radiation doses were estimated then on the basis of the ^{137}Cs contamination density. These criteria dated by 1986 concerning the ^{137}Cs contamination exceeded the pre-accident values 277 times, regarding the ^{90}Sr contamination 500 times, and for the plutonium isotopes - in hundreds times. These criteria were extrapolated also to the territories with natural radiation background due to the caesium contamination with density up to 100 kBq·m^{-2}. The individual radiation doses have been calculated for the 131,450 persons from more than 1,800,000 RCT inhabitants in 2015. An absence of individual radiation doses for evacuees and inhabitants of the RCT in the SRU results in limitations of epidemiological research concerning the Chernobyl catastrophe health effects.

5. The following radiological health effects have been proven by the epidemiological studies in Ukraine:
- there is a radiation dose related risk of thyroid cancer in population groups exposed to radioiodine in children age;
- there is an increased thyroid cancer risk due to irradiation in the Chernobyl catastrophe of clean-up workers;
- results of studies of the thyroid cancer risk in groups of an adult population with irradiated thyroid evidence to the urgent need of extended monitoring to obtain the reliable results;
- the dose-dependent leukaemia radiation risks in the Chernobyl catastrophe of clean-up workers correspond to the Hibakusha radiation leukaemia risks;
- in contrast with Hibakusha the study results in the Chernobyl catastrophe clean-up workers evidence to the dependence of chronic lymphocytic leukemia risk on the radiation dose; the stated inconsistence may be due to some genetic differences between two populations;
- available data on inhabitants of contaminated territories suggest the absence of increased risk of the radiation-induced leukemia;
- the breast cancer incidence rates female Chernobyl catastrophe clean-up workers exceeded in 1.6 times the level of respective mortality of female population in Ukraine;
- taking into account the long latency periods of the development of radiation-induced cancer of many organs and systems there are urgent needs to continue the monitoring of this disease in a remote post-accident period;
- there is an excess of cardiovascular mortality in the clean-up workers;
- there is a decrease of cognitive function in the clean-up workers;
- the excess of radiation cataract cases is specific to the clean-up workers.

6. There is an international consensus concerning the severe long-term mental health adverse consequences of the Chernobyl catastrophe. These catastrophes were, are and will be the greatest medical and social burden to the society and public health.

There is also an international consensus concerning some major mental/neuropsychiatric problems following the Chernobyl catastrophe:
- PTSD, depression, anxiety, somatoform and psychosomatic disorders, alcohol abuse; there is a full coherence of expert opinions here; life-span studies are recommended, psychological-psychiatric monitoring and care are strongly necessary;
- effects on the developing brain (cognitive impairment, emotional-behavioural disorders, attention deficit and hyperactive disorder, neurodevelopmental disorders); there is extensive discussion with

contradictions going on in this issue; effects are to be investigated further, the life-span studies are recommend with interventions if necessary;
- organic brain damage in liquidators (cerebrovascular disease, neurocognitive deficit, demyelinating diseases of the nervous system, paroxysmal states etc.); the problem is at issue; further research is required with life-span studies being recommend; constant neuropsychiatric monitoring and care are necessary;
- suicides; there is a full coherence of expert opinions here; further studies are necessary, specific approaches on suicide prevention are urgent.

Such mental health/neuropsychiatric problems as the Chronic Fatigue Syndrom, psychosis, stroke, multiple sclerosis, epilepsy, attention deficit and hyperactive disorder, etc. are still at issue. Further research is needed here. The biological mechanisms of cerebral effects due to the impact of low radiation doses are of great importance and are to be explored. All further studies should be conducted together with advanced biophysical (dosimetric) support on the base of analytical epidemiology.

Radiation exposure has multiple effects on the brain, behaviour and cognitive functions. These changes depend largely on the radiation dose. Points of view on the genesis of the Chernobyl neuropsychiatric aftermath are extremely controversial. Cerebral effects of low-dose ionizing radiation especially the cerebrovascular disease and cognitive impairment are in the focus of research interest worldwide. An increasing pool of data supports the radiosensitivity of the central nervous system, mainly through hippocampal neurogenesis. The cortical-limbic system is a target for radiation brain damage where a dysfunction of hippocampal neurogenesis is crucial.

There is a strong necessity to improve the system for neuropsychiatric care for the Chernobyl catastrophe survivors. This system should include the brews/teams of intensive neuropsychiatric, emergency psychological and psychiatric care, networks of crisis and rehabilitation centres, neuropsychiatric outpatient and inpatient units in general hospitals.

7. The Chernobyl catastrophe in Ukraine has resulted in the loss of territories for living, territorial redistribution of residents from contaminated territories to the clean i.e. not contaminated ones, deteriorated age and gender structure of the remaining inhabitants of the RCT, reduction of the fertility, increased mortality, demographic losses, and decreased viability. Number of disabled (category #1) survivors increased from 9,040 in 1992 to 116,758 in 2013, and in 2015 was 113,268. Their share in all the survivors is increasing and now reaches 5.59%. The leading place in the structure of morbidity and mortality belongs to the DCS. Their prevalence is dramatically increasing in survivors of a different age, and the development of complications leads to early disability and mortality. The early retirement in 3-10 years and disability in survivors have a negative impact on the productive capacity of the country.

8. Deterioration of children's health is one of the most unfavourable biomedical issues under the contemporary circumstances. Its reasons, nevertheless, remain debatable and role of ionizing radiation due to the Chernobyl catastrophe is contradictory. No consensus is reached yet on the issue of health effects. This is mainly due to the contradictory epidemiological data and imperfect dosimetric support of both epidemiological and clinical studies. At that, according to the data from papers published in recent years it is entirely possible that the function of some organs and systems in children becomes in general abnormal as a result of radiological contamination and low-dose radiation impact after the Chernobyl catastrophe.

9. The challenging issue of genetic effects in both first and second generations of descendants of the exposed parents is intricate and yet unsolved. The pilot epidemiological research in children born in

contaminated territories of Rivne oblast of Ukraine indicates to the highest incidence rate of neural tube malformations, blastopathy, microcephaly, and microphthalmia in Europe. It is assumed that a phenomenon of genomic instability that can cause elevation of cancer and congenital malformation risk appears in children born to exposed parents. Possible pathways of the trans-generation instability are studied and broadly discussed now. With this consideration in mind the genetic effects of Chernobyl require further research.

10. A large volume of works on liquidation of consequences of the Chernobyl catastrophe was implemented in the affected countries. The experience of Ukraine shows that the curtailment of countermeasures leads to an increase of soil radioactive contamination to the level of previous years and increasing exposure to population. This indicates the need to continue the monitoring of radioactive contamination and radiation doses in population. In Ukraine due to the inadequate functioning of the SRU is not reached and there is no generalisation of the results of health monitoring in survivors. In this regard the national and world science is missing the ability to assess objectively the health consequences of the Chernobyl catastrophe in the country where there the epicentre of catastrophe is. Further use of the exclusion zone and resettled part of the zone of obligatory (compulsory) resettlement is an unsolved problem too. The national strategy is necessary on elimination of the Chernobyl catastrophe consequences in the following years.

11. Russian Federation and Belarus seem to have achieved significant success in reducing the consequences of the Chernobyl catastrophe. Especially in the field of socio-economic and radiological rehabilitation of contaminated areas, health protection of exposed individuals, scientific analysis and forecasting of radiological and medical consequences of the catastrophe. The joint governmental Programs of the Russian Federation and Belarus also contribute significantly to the elimination of Chernobyl catastrophe consequences.

However but on the basis of the data obtained from Ukraine, Belarus and Russian Federation it can be concluded that Chernobyl catastrophe consequences have not yet been eliminated for the last 30 years in these countries.

12. The international efforts are required to continue the liquidation of the Chernobyl catastrophe aftermath and studying the impact of radiation on population. Firstly, it is important that the international community should recognise and consider far more extensive data on health effects of the Chernobyl catastrophe, including those presented in this report that promote making valid conclusions about their scale and overall impact. In particular, it should be investigated urgently because of wide discrepancies between the estimates that have been adopted by the IAEA and WHO. Secondly, in the absence of properly coordinated international approaches to the monitoring of cancer cases and non-cancer diseases in population within RCT (with special emphasis on the most intensively contaminated territories) in Ukraine, Belarus and RF, the opportunity has been missed to explore the full long-term effects of the catastrophe.

13. 5 years later we can draw the following conclusions about the nuclear catastrophe in Fukushima.

13. The catastrophe at the NPP in Fukushima (Level 7 on INES) has been the subject of a careful study by scientists and specialists around the world. In comparison with the Chernobyl disaster, almost 20 times less employees participated in liquidation of the catastrophe at the Fukushima NPP. The external and internal exposure doses recorded were several times less too. High thyroid irradiation doses (in the range from 2 to 12 Gy) from radioiodine were received by 12 employees. They have been carefully studied later on. Due to the loss of infrastructure there was a delay of the

start of ^{131}I measurement in the thyroid gland, therefore the reconstruction of thyroid irradiation doses is needed. No deterministic radiation effects were registered among the workers. Epidemiological research in longer period is required to evaluate the health effects in the workforce. In quantitative terms the evacuation of people from the 20-km zone was close to that in Chernobyl. The total radiation doses to the thyroid gland were less in the total population. As in Chernobyl, the incidence of thyroid cancer began to increase in Fukushima 4 years after the catastrophe. Higher incidence of thyroid cancer at lower radiation doses was unexpected and surprising. Other diseases that are compared in Chernobyl and Fukushima catastrophes i.e. the radiation cataracts, cardiovascular disease, cerebrovascular disease, cognitive dysfunction, and benign thyroid abnormalities are still analysed and it is expected that the hazardous effect of radiation in Fukushima may be lower.

It is extremely necessary to:
- conduct the longitudinal follow-up studies of traditionally recognized health effects due to ionizing radiation in workers, evacuees from the 20-km zone, persons with high-dose exposure of the thyroid gland, females pregnant at the moment of exposure and children;
- deliver special attention to non-cancer diseases, cognitive dysfunction during the prenatal period, radiation and vascular cataracts;
- consider non-radiation factors of the catastrophe as possible substantial risk modifiers.

14. The health effects 30 years after the catastrophe in Chernobyl are not confirmed by the IAEA and WHO in the materials of the Chernobyl forum (2006), as allegedly there was no danger from radiation to the survived population's health. A catastrophe of almost the same magnitude occurred again 25 years later in Japan at the Fukushima NPP. After 5 years the health effects of Chernobyl seem to repeat in Fukushima.

The consequences of this catastrophe will adversely affect the lives and health of many generations. The dramatic experience of mankind testifies to the possible risk of radiation catastrophe at any NPP.

In this regard further discussion is necessary on measures to protect the environment and health of people under the continuing use of nuclear energy to produce the electric power.

(N. Omelianets, D. Bazyka, A. Prysyazhnyuk, K. Loganovsky, E. Stepanova, S. Igumnov, D. Afanasev)

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AUTHORS

Omelianets Nikolai, MD, Prof., SI «NRCRM of NAMS of Ukraine» - Chief research worker of the Laboratory of medico demography, omelyan2006@yandex.ua.

Bazyka Dmitry, MD, Prof., Associate Member of the National Academy of Medical Sciences of Ukraine, SI «NRCRM of NAMS of Ukraine» - Director, bazyka@ yahoo.com.

Igumnov Sergey, MD, Prof., Institute of Management and Social Technologies of the Belarusian State University - Department of Social Work and Rehabilitology Professor, sigumnov67@gmail.com.

Loganovsky Konstantin, MD, Prof., SI «NRCRM of NAMS of Ukraine» - Head of the Department of Radiation Psychoneurology, loganovsky@windowslive.com, loganovsky@mail.ru.

Prysyazhnyuk Anatoly, MD, Prof., SI «NRCRM of NAMS of Ukraine» - Head of the laboratory of cancer epidemiology, anatoly.prysyazh@mail.ru.

Stepanova Eugenia, MD, Prof., SI «NRCRM of NAMS of Ukraine» - Head of the Department of radiation paediatrics, inherent and hereditary pathology, profstepanova@i.ua

Afanasev Dmitrij, SI «NRCRM of NAMS of Ukraine» - Radiation Endocrinology Dpt., Leading research associate, otradny@gmail.com.