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·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·km^{-2} - level of radioactive contamination of the territory, outdatednon-system unit (1 Ci·km^{-2} =37 kBq·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·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 had 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.

1 INTRODUCTION

The fifth anniversary of the 3.11 Fukushima nuclear accident i.e. the meltdowns at Fukushima Daiichi nuclear power plant (NPP) in Japan and the 30th anniversary of the 4.26 Chernobyl NPP accident in Ukraine (former USSR) will be in 2016. Both events are the largest manmade radiation accidents in the history of humankind. A sudden power output surge during a system test caused the reactor vessel rupture leading to a series of blasts, caused the Chernobyl accident. A magnitude 9.0 earthquake followed by a tsunami caused the cooling systems to fail, followed by series of fuel generated hydrogen explosions, in Units 1, 2, 3 and 4 at the Fukushima Daiichi NPP. Both accidents resulted in an intensive release of radioactive substances into environment with subsequent radioactive fallout. In both cases, it has had a serious impact on nature, society, and people. Due to the Chernobyl accident, radioactive contamination occurred at a large part of the globe and many billions of people were irradiated at a wide dose range (Atlas, 1998). The Fukushima disaster has been officially recognized as the “second Chernobyl” (Fukushima Daiichi NPP, 2011; Fukushima. Report of IAEA, 2011).

In the former USSR, the scale and aftermath of the Chernobyl catastrophe have been downplayed for many years. At the end of first quinquennium upon the disaster the international community has shared this point of view (IChP, 1991). Disagreements with the latest were expressed by Omelyanets (1992). The international community is grateful to the International Atomic Energy Agency (IAEA), World Health Organization (WHO) and other international organizations and societies for the compilation and preparation of the Chernobyl forum papers (2005, 2006) on the catastrophe consequences to environment and human health (Report, 2005; Health, 2005; Chernobyl’s Legacy, 2006, WHO, 2006, etc.). However, the conclusions of these reports resulted in disagreement and criticism concerning the underestimation of disaster aftermath (Ruff, 2007; Yablokov *et al.*, 2009).

Findings received at the research institutes in Ukraine both with results of national and international follow-up studies have proved the fact that irradiation after the Chernobyl NPP accident resulted in radiation-induced health disorders and diseases. The acute radiation syndrome (ARS), radiation cataract, thyroid cancer in clean-up workers and evacuees, leukemia in clean-up workers, and breast cancer in female clean-up workers are among the health effects. An increase in frequency of other forms of solid cancers could be expected. The fundamental data were obtained showing that the Chernobyl catastrophe and its consequences have become a source of both direct and indirect effects of ionizing radiation on the human body, its organs and systems, and cell population (Bazyka, 2014).

Excess incidence of thyroid cancer among children due to exposure to radioactive iodine has become a tragedy for Ukraine, Republic of Belarus and Russian Federation (RF). The current number of thyroid cancer cases is 33-fold higher vs. the pre-Chernobyl annual level (60-fold among children and 14-fold in adolescents). As of 2009 there were 6,049 cancer cases operated in Ukraine among persons exposed to ionising radiation aged under 18 years old (Tronko *et al.*, 2012). As of 04.01.2014, their number has reached 10,432 (Information NRCRM, 2014). The rate of non-cancer diseases, especially of diseases of the circulatory system (DCS) has increased. There are many deteriorated demographic indicators. In general, the new scientific knowledge proves that the Chernobyl disaster and its consequences have caused and will still induce the long-term adverse health effects.

Despite some differences between the Chernobyl and Fukushima radiation catastrophe they are at the same time quite similar from radiological point of view. However the Fukushima meltdown is inferior in scale than the Chernobyl disaster.

The period of 30 years is around a half-life of the most hazardous radionuclides. These 30 years are also about a half of lifetime of persons born in 1986. On the eve of the two anniversaries it is very important to review and consider the health effects of both catastrophes.

The objective of this Report is to summarise the accumulated knowledge for the future.

Authors take full and complete responsibility for the content of this Report, authenticity of publications, discussion, and conclusions.

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2 CHERNOBYL: HEALTH EFFECTS ASSOCIATED WITH THE NUCLEAR CATASTROPHE

2.1 Radiation Exposure 30 years later

Data collected in the past 30 years after the explosion of a nuclear reactor at the Chernobyl NPP testify to some unusual health consequences due to the impact of ionising radiation. Considering the declared levels of radiation doses in survivors as low, one could think no such consequences should occur (Report, 2005; Health, 2005). Therefore it is important to estimate once again the scale and consequences of the largest in human history nuclear accident.

2.1.1 The number of victims of the Chernobyl catastrophe

As a ground for estimations we have retrieved the data on individual radiation doses of more than 3.3 million citizens of Ukraine who according to the national legislation have received the status of the Chernobyl catastrophe survivors. According to the national legislation the survivors are included to the «The State Register of Ukraine of the persons who had survived after the Chernobyl catastrophe» (SRU) and annually undergo the health check-up i.e. the so-called "dispensary supervision" (Law of Ukraine, 1991). The follow-up control of health and study of the immediate and remote health consequences in all Chernobyl catastrophe survivors is the objective.

Data shown in Table 2.1 demonstrate the number of the Chernobyl catastrophe survivors over the last years. It was the least just after catastrophe and the largest in 1998-2000 (3,364,475-3,361,870 persons). As of 2015 it exceeds 2 million. The number of children who had received the status of survivor is 1,264,329 (National Ukrainian Report, 1996; 2001; 2006; 2011). It is worth noting that until 1990 the maps of radioactive contamination and radiation doses in population were classified both in USSR and UkrSSR (National Ukrainian Report, 2011).

Table 2.1 - Number of the citizens of Ukraine assigned the status to the Chernobyl catastrophe survivors, as of beginning of a specific year

Indices	1987	1991	2000	2005	2010	2015
Survivors in total from them:	264,587	1,536,270	3,361,870***)	2,646,106	2,254,471	2,025,141
- clean-up workers	83,327	180,144	376,639	358,459	260,807	222,498
- other survivors except children*)	179,799	1,269,553	2,985,231	2,287,647	1,993,664	1,802,643
- children**)	43,645	350,223	1,264,329	643,030	498,409	442,343

Notes: *) the group of survivors includes evacuees and inhabitants is of RCT;
**) age of children is 0-14 years till 2005, and 0-17 years after that;
***) the maximum number of certified survivors was 3,364,475 in 1998

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2.1.2 Radiation exposure of clean-up workers

For the first years after accident the levels of radiation exposure in the clean-up workers were reviewed on a sample of about 200,000 persons from those involved in emergency works from the entire USSR (Baryakhtar, 1997; Omelianets *et al*., 2004; Omelianets *et al*., 2015a). There were 83,327 of them from Ukraine (former UkrSSR). It was estimated that in 126,000 clean-up workers of 1986-1987 years of participation the external radiation doses were within 150-180 milliSievert (mSv) (154 on average), in more than 177,000 subjects (1986-1988 years of participation) doses were 120-126 mSv, and at about 34,000 ones involved in work in 1988-1990 doses were 37 mSv dose in average. Finally in 28,400 clean-up workers the doses could exceed 250 mSv.

Ahead of the 25th anniversary of the Chernobyl catastrophe (National Ukrainian Report, 2011) certain projects were conducted in Ukraine on reconstruction of individual radiation doses in the clean-up workers. With the use of a RADRUE method (Realistic analytical dose reconstruction and uncertainty analysis) the individual whole-body and red bone marrow radiation doses were reconstructed in 1,010 clean-up workers who were the subjects of the Ukrainian-American research project on leukaemia in Chernobyl catastrophe liquidators. The dose values turned out to be from about zero up to 3.2 Sievert (Sv) with 90 mSv arithmetical mean and 12 mSv geometrical mean.

The highest average individual radiation doses were received by professional staff of NPP i.e. the nuclear industry staff members (381 mSv), workers of Ministry of Internal Affairs of Ukraine (MIAU) (203 mSv), and clean-up workers of 1986 year of participation (105 mSv). The average dose values varied from 31 up to 78 mSv in all other clean-up workers. According to the results of these works it is stated marked in the National report that the sample of subjects in this study was representative and therefore dose values established are enough meaningful and can characterize the radiation doses of Ukrainian clean-up workers in general.

The individual beta-radiation doses on crystalline lens were reconstructed for 8,607 participants of the Ukrainian-American Chernobyl Ocular Study (UACOS) (Sergienko and Fedirko, 2002; Chumak *et al*., 2007). Is was shown that highest doses (median 502 mSv) were received by the clean-up workers of the first days and weeks of participation in emergency works. The military clean-up workers had received 121 mSv dose in average. The median value of radiation dose in all groups surveyed emergency workers was 123 mSv. The 1,600 individual doses of the NPP employees and persons temporarily assigned to the NPP staff were assayed in 1986-1996 using the calculation method. Individual doses of about 43,000 military clean-up workers were verified also. Under at the 100%-coverage of the described cohort dosimetry control its results were shown being of the lowest accuracy.

That is why by the 25th anniversary of Chernobyl catastrophe the individual whole-body radiation doses were reconstructed in Ukraine for more than 54,000 clean-up workers with red bone marrow doses reconstructed for 1,010 of them, and beta-irradiation doses on crystalline lens in 8,607 subjects. Doses were reconstructed mainly by the staff of the State Institution "National Research Centre for Radiation Medicine of National academy of Medical Sciences of Ukraine" (NRCRM) using modern dosimetry methods.

However for the 30 years anniversary almost no progress was made in the field of individual internal radiation dose and thyroid irradiation doses reconstruction in the clean-up workers. Dose reconstruction is still required for more than 44,000 clean-up workers, who after an acute exposure to ionising radiation during the emergency activities lived within radiologically contaminated territories. According to our records as of 1997 the dosimetric data were available for only 110,618 (67.45%) of 164,000 clean-up workers registered in the SRU. From them 51.9% participated in clean-up works in 1986-1987, and 83.0% in 1988-1990 respectively. Radiation doses in 95.63% of cases (from those in whom dose values were available) were less than 250 mSv. Data comparison resulted in the conclusion that a share of the clean-up workers having recorded dose values exceeding 250 mSv in the SRU it is less than stated in scientific publications (Health status, 2001;

Health status, 2001a). As of 2011 it was only specified that about 95% of the dose records in the SRU are attributed to the military clean-up workers (National Ukrainian Report, 2011).

The works on identification and verification of individual doses is underlined in all analyzed sources.

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2.1.3 Radiation exposure of evacuees

According to data available (Baryakhtar, 1997; Likhtarev *et al.*, 1994; Repin, 1996) the external radiation doses in evacuees (persons evacuated within about 10 days after the accident) made up to 50 mGy in 48,659 persons (98.58%) of 49,360 inhabitants evacuated from the Prypiat city and in 34,673 persons (86.17%) of 40,239 ones evacuated from other settlements of the 30-km zone (now – the exclusion zone). About 1,300 subjects had received doses more than 100 mGy, 40 persons - more than 250 mGy, and 12 persons - above 500 mGy. The average individual dose is 13.4 mGy in Prypiat city inhabitants, and 24.0 mGy in population of the 30-km zone.

The calculated values of internal radiation doses and radiation on specific body organs and tissues are available only for the evacuees but not other groups of survivors. The median dose values are 30 mSv to a lung, and 8 mSv to a lower small intestine. Total doses of external gamma- and beta-irradiation were 70 mSv to the skin epidermal epithelial cells, and 20 mSv to a crystalline lens.

Later with the use of stochastic imitation modelling simulation based on the direct measurements of dose rates and personal interviewing data from 12,632 inhabitants of the Prypiat city the average effective external radiation doses were established. Up to the moment of evacuation they have received 10.1 mSv. Doses of more than 25 mSv were recorded in 534 persons, and over 50 mSv in 18 of them. The 75 mSv dose was the maximal recorded dose in this group. The individual effective doses in 14,084 evacuees as for the moment of evacuation were available for about 25% of them amounting to 15.9 mSv. Radiation doses of more than 50 mSv were recorded in 1,260 persons, more than 100 mSv in 120 of them, and over 200 mSv in only one subject.

Thus the average effective dose (ED) value of 15.9 mSv here was 14% lower vs. the dose established in previous studies (18.2 mSv). The researchers consider that doses were reconstructed in the cohort of interviewed survivors being representative for the inhabitants of 104 settlements within the exclusion zone if not including the cities of Prypiat and Chernobyl. The whole-body and thyroid gland radiation doses are known for evacuees at the routes of their evacuation (Likhtarev *et al*., 2013; Tronko *et al*., 2014). As it is marked in the National Ukrainian Report (2011), the levels of the latter exceeded the dose values received up to the moment of evacuation. Contribution of a dose under evacuation to a total radiation dose was about 50% and this fact strongly changes general pattern of radiation exposure in evacuees. Data on external doses and thyroid irradiation doses in evacuees are available at the SRU only for about 1,000 persons.

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2.1.4 Radiation exposure of population

The problem of radiation dose reconstruction and registration in population of RCT is especially serious in Ukraine. Intensity (density in Ukrainian terminology) of soil contamination with radionuclides was accepted instead of radiation dose as a criterion of radiation safety in May, 1986. Territories with intensity of soil contamination by ^{137}Cs at 555 $kBq \cdot m^{-2}$ and more, or by ^{90}Sr at 111 $kBq \cdot m^{-2}$ and more, or by $^{238,239,240}Pu$ at 0.37 $kBq \cdot m^{-2}$ and more were designated as radioactively contaminated areas. With this background there were 686 settlements within contaminated territories with a population of 640,000 in Belarus, Russia and Ukraine. These territories were designated as rayons of strict radiation control and only there the arrangements of radiation protection were applied. There were 8 such regions in Ukraine in 1986, and 6 since 1987.

The density of ^{137}Cs and ^{90}Sr deposition on the territory of Ukraine before the accident varied from 0.74 to 3.7 kBq·m^{-2} with an average value of 2.2 kBq·m^{-2}, and of $^{239+240}Pu$ was 0.037 kBq·m^{-2} in average (Baranovskaya *et al.*, 1966). Taking into consideration the available maps of radioactive contamination (National Ukrainian Report, 2011; Atlas of Ukraine, 2008) and having accepted the double excess of radioactive contamination density vs. pre-accident level as a criterion we have calculated the parameters of the extent of RCT in the country. Data shown in tables 2.2-2.4 testify that the all oblasts of Ukraine (237,400 km^2 from the area of the whole country 603,628 km^2) is contaminated by ^{137}Cs at a level twice exceeding the pre-accident one, whereas a doubled level of ^{90}Sr and $^{238+239+240}Pu$ deposition is characteristic for the 21 oblasts.

Table 2.2 - Levels and scales of contamination of the territory of Ukraine with ^{137}Cs as of 10.06.1986 over the level before accident

Excess over the pre-accident level	2-fold (>4 kBq·m^{-2})	10-fold (>40 kBq·m^{-2})	25-fold (>100 kBq·m^{-2})	277-fold (>555 kBq·m^{-2})	740-fold (>1480 kBq·m^{-2})
Number of oblasts with contamination	all oblasts, 237,400 km^2	14 oblasts, 28,800 km^2	8 oblasts, 8,800 km^2	2 oblasts and exclusion zone, 1,000 km^2	2 oblasts and exclusion zone, 600 km^2

Table 2.3 - Levels and scales of contamination of the territory of Ukraine with ^{90}Sr as of 10.06.1986 over the level before accident

Excess over the pre-accident level	2-fold (>2 kBq·m^{-2})	10-fold (>4 kBq·m^{-2})	50-fold (>10 kBq·m^{-2})	500-fold (>100 kBq·m^{-2})	735-fold (>1480 kBq·m^{-2})
Number of oblasts with contamination	21 oblasts, 156,400 km^2	21 oblasts, 43,200 km^2	10 oblasts, 10,000 km^2	1 oblasts and exclusion zone, 200 km^2	exclusion zone, 200 km^2

Table 2.4 - Levels and scales of contamination of the territory of Ukraine with $^{238+239+240}Pu$ as of 10.06.1986 over the level before accident

Excess over the pre-accident level	2-fold (>0.08 kBq·m^{-2})	10-fold (>0.4 kBq·m^{-2})	25-fold (>1-2 kBq·m^{-2})	250-fold (>10.0 kBq·m^{-2})
Number of oblasts with contamination	21 oblasts, 129,300 km^2	3 oblasts and exclusion zone, 4,170 km^2	3 oblasts and exclusion zone, 3,750 km^2	exclusion zone, 840 km^2

Data shown in the tables along with authorized adopted criteria show that 277-fold excess of ^{137}Cs soil deposition, 500-fold excess of ^{90}Sr deposition, and the hundreds time excess of plutonium isotope deposition over the pre-accident levels was approved by MH of the USSR as a criterion of safe living of the population.

The restrictions of modes of life, work, agricultural industry, conducting of animal livestock management, and forest management were to be introduced only under the high levels of wood, land etc. contamination. Prohibition of use of foodstuffs of local industrial production and produced in the individual farms, change of public nutrition to consumption of clean i.e. non-contaminated and imported products, and the free-of-charge three-time a day nutrition for children in preschool institutions and schools were introduced (Omelianets *et al.,* 2014).

Levels of ^{137}Cs contamination over 1,480 kBq·m^{-2} and of ^{90}Sr more than 111 kBq·m^{-2} were the criteria for the decision-making about evacuation (resettlement). Levels of ^{137}Cs contamination over 2,960 kBq·m^{-2} - were the reason to phase down the agricultural production. According to the data generated for the Ministry for Health (MH) of the Union of Soviet Socialist Republics (USSR) (they were under seal with a signature stamp "«confidential") till 1991 there were about 10 settlements in Ukraine, and a hundred settlements in Belarus where the contamination density of soil by caesium exceeded 3,700 and 5,500 kBq·m^{-2}. However, not any additional arrangements on population protection were introduced. The situation in RCT of Polesiye region in Ukraine was also a challenge because due to an increased transition of caesium from soil into the plants the radiation doses in population there had reached value of several mSv despite a relatively low soil contamination density of 37 kBq·m^{-2}.

To prevent the excess of irradiation of the population, the following dose thresholds were established by the MH of the USSR: up to 100 mSv in 1986, 35 mSv in 1987, and 20 mSv in 1988-1990. Hence, integrally until 1990 the inhabitants of RCT of Ukraine could receive up to 195 mSv radiation dose. However, no comparison of the received doses to criteria was conducted further in subsequent studies.

In connection with incomplete application of measures on radiation protection that resulted in protests of the RCT inhabitants and to resolve the issue of the return of the population to the traditional (preceding the accident) way of life and activity in rayons of strict radiation control, the MH of the USSR adopted in 1988 the «Radiologic concept of constant permanent safe residing of the population was of territories of RSFSR, UkrSSR and BSSR, which have undergone to the radioactive contamination as a result of accident on at the Chernobyl accident» (protocol # 36-1 from 21.10.88). Two periods setting references for irradiation of the population were established i.e. the emergency period (from 26.04.1986 till 01.01.1990) and the recovery period (from 01.01.1990). Individual maximal life-span doses in the population of the regions under control were set in both periods equal to 35 rem (350 mSv) including a dose received for the period since 26.04.1986 for till 01.01.1990 due to the Chernobyl NPP accident.

Taking this into account the rayons of strict radiation control were distributed in 3 groups: 1) where the population could be subject to a life-span irradiation at a dose of up to 350 mSv (437 settlements with 181,100 population), 2) where population could be subject to the life-span irradiation at a dose of 300-500 mSv (141 settlements with 43,900 population), and 3) where the population could be exposed to the life-span irradiation at a dose of 500 mSv and more (108 settlements with 22,200 population). No limitations of population lifestyle or labour activity were introduced in the first group of settlements. In the second group the restrictions could be rejected under the circumstances of centralised implementation of certain complex of agricultural and agromeliorative modifications and providing the non-contaminated fodder to the cows at private farms. Under the maintenance and preservation of existing protective measures system and restrictions the proposed dose level still could be exceeded. Limit of the life-span dose could be exceeded in Ukraine in settlements with a population of about 50,000. According to the USSR program on 1990-1991 the latter population should be resettled to the non-contaminated regions (Union-Republ. program, 1990). Resettlement however is not completed until now and radiation doses in the migrants are unknown.

Transition to the dose criteria for estimation of catastrophe consequences appeared one of the important results of this concept. However, it was not the last concern about individual radiation doses.

Until 1997 any information on radiation doses in population of contaminated territories was inconsistent and established for the specific groups through recalculation from the values of ^{137}Cs soil density contamination (National Ukrainian Report, 1996; National Ukrainian Report, 2001). In the National reports to the 20th and 25th anniversaries of the Chernobyl catastrophe the doses on separate population groups were provided in an integrated manner.

Data on reconstructed radiation doses of the RCT population were published in Ukraine only in 1998 (Collection 7, 1998). The dose levels were represented in average by settlements, from 1986 untill 1997 by years, and after 1997 till 2056 (for 70 years of life) by periods. Review of the submitted dose values provided the basis for the National commission on radiating protection of population of Ukraine (NCRPU, 2006) to consider them biased and underestimated. The radiation doses within the first year after catastrophe in particular were considered underestimated by a factor of tens and hundreds. Doses for 1986 were estimated as few percents from a total dose for 70 years, although they should make up to 50-90% of it, and the dose levels of 1986 were by factor of ten less vs. the 1987-1997 period. All that was considered the background for reconsideration of doses for 1986. In the Report of the Chernobyl forum (Report, 2005), the situation with doses in Ukraine was reflected inadequately, as the Forum based on the data, which were prepared at a national level, with no critical analysis[1].

No review was carried out. Using the published data on Collection 7 (1998) we have calculated the average radiation dose levels in population of the most intensively contaminated rayons for the first 12 years after the catastrophe. Data are shown in Table 2.5.

These dosimetry data as well as previous ones were neither registered in the SRU nor actually used in epidemiological research of health effects of the Chernobyl catastrophe.

According to the Concept (1991) the calculated settlement ED of extra irradiation to the critical population group (children born in 1986) in Ukraine due to the Chernobyl catastrophe should not exceed 1.0 mSv (0.1 rem) per one year and 70.0 mSv (7.0 rem) for the whole life (over a dose received by population before the accident in specific natural environmental conditions).

The RCT were divided into the 4 zones (see of General abbreviations, unit abbreviation, and terminology) in line with levels of radioactive contamination according to the official legislation (Law of Ukraine, 1991; Law of Ukraine, 1991a). We have carried out the review of data sets of dose values indicating that in 1991 from 2,302 settlements, the dose data were available only in 541 (23.5%) of them, where doses of the whole population amounted to or exceeded 1 mSv. There were 136 such settlements in 1997.

Dosimetric passportization of the settlements is implemented in Ukraine since 1991 and will be carried out onward. It is a standardised system of estimation and assigning of a passport dose to the settlement according to the results of radio-ecological and dosimetric monitoring of the territory and inhabitants of the settlement. The passport dose of the settlement is an ED which can be received within one year by each of its inhabitants from all the sources of both Chernobyl and any other industrial origin. It is not an individualized radiation dose due to the Chernobyl catastrophe and is used only under the administrative decision-making on planning of measures of public radiation protection.

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[1] NCRPU, 2006. The National Commission of Radiating Protection of the Population of Ukraine to the Prime Minister of Ukraine from 31.01.2006 N° 01/01-04 (in Ukrainian).

Table 2.5 - Individual average annual total radiation doses in 1986-1997 in population of the most intensively contaminated rayons, mSv·year^{-1}

Parameters	Average doses by years:											
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Zhitomir oblast												
Narodichy rayon. Number of settlements: 61												
Average	8.16	4.32	3.09	2.43	1.91	1.55	1.30	1.11	0.96	0.83	0.75	0.66
Luginy rayon. Number of settlements: 48												
Average	5.77	5.09	3.69	2.87	2.24	1.78	1.48	1.24	1.07	0.91	0.80	0.70
Ovruch rayon. Number of settlements: 150												
Average	5.15	4.67	3.39	2.67	2.06	1.65	1.36	1.14	0.98	0.83	0.74	0.64
Kiev oblast												
Ivankov rayon. Number of settlements: 81												
Average	2.98	1.42	1.04	0.84	0.67	0.55	0.48	0.42	0.36	0.32	0.29	0.26
Polesskoe rayon. Number of settlements: 31												
Average	1.61	0.89	0.65	0.51	0.40	0.32	0.27	0.23	0.20	0.17	0.16	0.13

Activities on dosimetric passportization were carried out mainly by the NRCRM staff and their results were generalized in the special Collections of papers. The passportization results testified to a decrease of the radioactive contamination levels and passport dose values. Passportization activities in 2011 (Collection 14, 2012) were especially important, specifically as of the end of 2011 the passport dose in 1851 of 1977 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 (Law of Ukraine, 1991a), the settlements with a dose under 0.5 mSv·year^{-1} cannot be regarded as radioactive contaminated any more. The 25 settlements in Zhitomir and Rivne oblasts where the doses ranged from 1 to 5 mSv·year-^{1} can be referred to 'zone 3', the 101 of them with 0.5 to 1 mSv·year^{-1} doses - to 'zone 4'. There are not any settlements now where the doses exceed 5 mSv·year^{-1}, i.e. such that should be attributed to 'zone 2'. This lay of the land was confirmed by the results of year 2012 (Collection 15, 2013). Over the results of these two dosimetric passportization have formed the background for elimination of the zone 4 (zone of a strict radio-ecological control) from the RCT scope with subsequent repeal of benefits both with all privileges and indemnifications to survivors (clause # 23 excluded in the Law of Ukraine, 1991).

A rather challenging scenario with radiation doses occurs during the last years in the RCT. Study results by Vasylenko *et al.* (2012); Vasylenko *et al.* (2013); and Bilonyk *et al.* (2014) testify, that because of economic crisis in the country and increased consumption of local food products by population, the annual exposure doses have increased by 30-80% since 1994. In some settlements the internal radiation doses after 1996 exceeded values of the first years after the Chernobyl catastrophe. Children in particular have received doses higher as compared to adults.

Restricted funding of the measures on radiologic protection of the population and environmental rehabilitation within the RCT (table 2.6) can result in an increased irradiation of population from now onwards. Almost complete termination of monitoring of both contamination levels and radiation doses is also a challenge in Ukraine (Gunko *et al.*, 2010; Information materials, 2013; Annual report, 2014).

As to the issue of applicability of dosimetric passportization instead of radiation dose estimation specified by Prister *et al.* (2011) one should agree with this critical review of the unlearned lessons of the Chernobyl disaster. We also believe that the consequences of the catastrophe to assess the levels of radiation doses of the population.

Table 2.6 – Expenditures of the State budget of Ukraine in 2012-2014 on realization of measures on radiological protection of the Chernobyl catastrophe survivors, million UAH

The name of the State budget program	2012	2013	2014
Radiologic protection of population and ecological rehabilitation of territory, which has undergone radioactive contamination	4.8	4.3	2.2
Maintenance of environmental safety in zones 1 and 2	32.4	32.4	16.2

During the last years, the NRCRM staff has carried out work on reconstruction of individualized internal, external, and total radiation doses in inhabitants of the RCT registered in SRU (Likhtarov *et al*., 2014; 2014a). The individualized internal irradiation doses are reconstructed already for the 28,711 inhabitants of Rokitny rayon of Rivne oblast, 18,790 inhabitants of Ivankov rayon of Kiev oblast, 41,585 inhabitants of Ovruch rayon of Zhitomir oblast, 27,811 inhabitants of Koselets rayon, and 14,553 - ones of Repki rayon of Chernigov oblast. On average the data by regions are received for 50-60% of survivors from those registered in the SRU. Results of dosimetry are given as average dose values for the period of 1987-2012.

Distribution of inhabitants of various oblasts is lined up by dose intervals (absorbed doses from both internal and external exposure for all the survey period). The received data are passed for inclusion to the SRU.

Thus, in a view of the carried out works in last years the individualized doses are reconstructed in 131,450 persons from more than 1,800,000 people having the status of a survivor.

Data comparison of doses reconstructed as of 1988 (Collection 7, 1998) and as of 2014 (Likhtarov *et al*., 2014) within one of the most intensively contaminated Zhitomir oblast, testify that the dose in 2015 was only 1.09 mSv more than in 1986. For all next years the nowadays-reconstructed annual doses are actually in 1.5, and the absorbed doses - in 1.4 times lower vs. reconstructed earlier.

Data review from the main peer-reviewed publications by the foreign scientific experts indicates that after 2011 the researchers only have repeated all the data, which were generated in proceedings of the Chernobyl Forum in 2005. No new data are available on radiation doses in the Chernobyl catastrophe survivors in Ukraine.

To some extent it can be explained by the aspect that according to the requirements of the clause #11 of the Law of Ukraine (1991a) all scientific information and research of scientific institutions which are received within RCT are the property of Ukraine and can be used only under a special licence (approval) by the Cabinet of Ministers of Ukraine (CMU). Therefore, since 2012-2013 the Ukrainian scientists were obliged to terminate all the contracts with foreign experts and institutions in the field of Chernobyl problems (Nasvit, 2015).

(N. Omelianets)

2.2 The recognised consequences

Looking at general trends in the data on cancer incidence and tendencies of its variation pattern after almost 30 years after the Chernobyl catastrophe and evaluation of cancer radiation risks are not only of a practical but also of a theoretical interest. Such studies are performed not only in the three countries most severely affected due to the Chernobyl catastrophe i.e. Ukraine, Republic of Belarus and RF but in other countries as well. It has to be pointed out that the majority of them are descriptive, devoted mainly to study of the distribution of variables, for example the disease frequency level, its time trends and territorial differences. In addition, there are ecological studies in which the units of analysis are populations or groups of people rather than individuals. Analytical studies are dedicated to identifying and measuring the impact of risk factors on health. They are cohort and case-control studies directed to assessing the disease risk being studied in exposed vs. unexposed groups of the population. Due to its significant financial expenditures, they are performed jointly with scientists from abroad and supported by their national and international organizations. For example, some collaborative projects are performed in Ukraine jointly with scientists from the USA in order to study the leukemia and thyroid cancer risk in Chernobyl catastrophe clean-up workers (Romanenko *et al*., 2008; Zablotska *et al*., 2013; Ostroumova *et al*., 2014), thyroid cancer in a cohort of subjects whose age at the time of accident did not exceed 18 and who inhabited the most radioactively contaminated territory of Ukraine (Tronko *et al*., 2012). Such collaboration is performed in Belarus as well (Zablotska *et al*., 2011).

2.2.1. Thyroid cancer

Among the specific forms of malignant tumours, thyroid cancer is of special concern because of dramatic incidence increase soon after the accident in the youngest age group residing in districts closely adjacent to the Chernobyl NPP. Based on results of long-term monitoring of the population exposed to external radiation (Jacob *et al*., 2006), it is expected that thyroid cancer cases related to the Chernobyl catastrophe will be registered for many years.

The ecological study performed in children and adolescents ageing from 1-18 years and residing in three regions (oblasts) of Northern Ukraine most heavily contaminated with radioactive iodine within the 1990–2001 observation period (Likhtarov *et al*., 2006), allowed to evaluate some basic indices of thyroid cancer risks, namely the excess relative risk per Gy ($ERR \cdot Gy^{-1}$) – 8.0 (95% confidence interval (CI): 4.6-11.0) and excess absolute risk per 10^4 person-years Gy – (EAR 10^{-4} person-years) 1.5 (95% CI: 1.2-1.9). In the estimation of coefficients of radiation risk, it is assumed that the observed increases in thyroid cancer incidence are due to radiation exposure.

Comparative analysis of thyroid cancer incidence rate 20 years after the Chernobyl catastrophe in Ukraine with consideration of the thyroid irradiation doses average per oblast absorbed by children and adolescents (accounting an age at the time of accident) showed a significant correlation between factorial (dose) and resulting (incidence) parameters (Fuzik *et al*., 2011,2013). Special attention was drawn to the youngest subcohort at exposure i.e. individuals born in 1982-1986. Upon the applied correction for the screening effect (through the comparison of thyroid cancer incidence rate in this subcohort and another one with persons born after the accident - i.e. in 1987-1991), a significant radiation excess in the subcohort exposed in age 0-4 years was suggested. At attained age of 10-14 years, the thyroid cancer incidence rate in the exposed subcohort was 9.7 times higher vs. unexposed one, and at the attained age of 15-19 such excess was 3.4-fold. Along with it, during the observed period an excess of the age-specific thyroid cancer incidence rates was spread to the adult age groups. In 1991 an excess of thyroid cancer incidence was registered in the group aged 0-34 and in 2001 at age range of 0-54 (at the moment of the Chernobyl accident). A special situation was observed in the female age group of 40-49 at the time of Chernobyl catastrophe i.e. the age-specific thyroid cancer incidence rates were significantly higher in the “high exposure” regions vs. “low exposure” ones during all the years of observation within 1989-2009.

The analytical Ukraine–American project deserves attention here (Tronko *et al*., 2012) as its main objective was to quantify the risks of thyroid cancer in the framework of a classical cohort study, comprising subjects who were aged under 18 years at the time of the catastrophe, in whom the direct measurements of thyroid gland ^{131}I radioactivity taken within two months after accident were available, and who were residents of three severely contaminated northern regions of Ukraine (Zhitomir, Kiev, and Chernigov oblasts). Four 2-year screening examination sessions were held from 1998 till 2007 to study the thyroid cancer risks due to the iodine incorporation caused by the Chernobyl catastrophe. The arithmetic mean of an individual thyroid absorbed dose over the entire cohort was 0.79 Gy. At the stage of cohort formation between 1998 and 2,000 the 13,243 subjects were screened. As a result of the four session of screening examination, 110 cohort members were operated for the thyroid cancer. The excess relative risk per Gy (ERR Gy^{-1}) was estimated at $5.25 \cdot Gy^{-1}$ (95% CI: 1.70-27.5) during 1998-2000. In 2001-2007 the $ERR \cdot Gy^{-1}$ was estimated to be 1.91 Gy^{-1} (95% CI: 0.43-6.4) and excess absolute risk - EAR was estimated to be 2.21 per 10^{-4} person-years (95% CI: 0.04-5.78). This result especially in terms of excess relative risks differ somewhat from the results obtained in above mentioned (Likhtarov *et al*. 2006) ecologically study and may be the consequence of different study design.

In another ecological study (Tronko *et al*., 2014) dedicated to the epidemiology thyroid cancer in Ukraine among exposed children and adolescents (aged 0-18 years at the time of accident), a higher incidence rate was observed in 6 most contaminated regions in comparison with 21 low-contaminated regions for all post-accident study period (1990-2010). By age at diagnosis, the peak incidence in childhood and adolescent groups was observed in 1995-1997 and 2000-2002, respectively. Since 2002, there were no exposed subjects (including the in utero cohort) in the childhood group and since 2006 in the adolescent group. Thus, in these age categories all childhood and adolescent cases of radiogenic thyroid cancer have been realized. In corresponding groups of unexposed subjects aged 0-14 and 15-18 years at the time of diagnosis, the thyroid cancer incidence is comparable to the average rate in European countries.

Unlike thyroid cancer incidence increase in exposed children and adolescents, the effect of irradiation in adult age remains not enough clear. Studies of thyroid cancer morbidity in adults suggest an insignificant increase of thyroid cancer incidence due to ionizing radiation. According to the conclusion of UNCSEAR (2006) report there is a little suggestion in various exposed population groups to the increased thyroid cancer incidence among those exposed as adults in general population. Among adults the most meaningful evidence comes from the studies of clean-up workers. An elevated rate of this disease vs. the general population has been reported, but no clear association with external radiation dose has been found. Moreover, no estimates have been carried out of the thyroid irradiation doses from the inhaled radioiodine to those who worked on the Chernobyl site in April-June 1986. Thyroid doses only exist for a very small number of workers; it is not possible to give a valid average value for the whole group (UNSCEAR, 2008). The influence of annual screening and active follow-up of these cohorts make comparison with general population problematic. Therefore, there is some evidence of a detectable effect in the group of clean-up workers, but this is far inconclusive.

In contrast to the abovementioned, another study by Shalimov *et al*. (2006) and Prysyazhnyuk *et al*. (2007) performed in the framework of the French-German Initiative (FGI) in adolescents and adults in territories of Chernigov, Kiev and Zhitomir oblasts with different levels of ^{131}I deposition from the fallouts, a dependence was revealed of the thyroid cancer incidence rate on a level of radioiodine contamination. Effect of exposure to this radionuclide tends to increase in time. The sufficient statistical power of this study allowed making quite an important conclusion that an increased exposure to ^{131}I results to increase in thyroid cancer incidence rate.

The Chernobyl catastrophe clean-up workers received the highest radiation doses. It motivated the participants of the Ukrainian-American project to study the thyroid cancer frequency in a cohort of 150,813 male Chernobyl clean-up workers from Ukraine by calculating a standardised incidence ratio (SIR) using national cancer statistics (Ostroumova *et al*., 2014). Follow-up of clean-up workers with the SRU was launched in 1986 and continued through 2010. There were 196 incident thyroid cancer cases in the study cohort with an overall SIR of 3.50 (95% CI: 3.04-4.03). A significantly elevated SIR estimate of 3.86 (95% CI: 3.26-4.57) was calculated for the clean-up workers who had their first clean-up mission in the Chernobyl zone in 1986, when there were highest levels of external and internal exposure to radiation. SIR estimates for later calendar years of the first clean-up mission, while significantly elevated, were lower than for the first year. SIR estimates were elevated throughout the entire follow-up period but were especially high 10-18 years the after catastrophe, namely 4.62 (95% CI: 3.47-6.15) and 4.80 (95% CI: 3.78-6.10) for the periods of 1995-1999 and 2000-2004, respectively. These findings support the growing evidence of increased thyroid cancer rates among the Chernobyl clean-up workers. Although this could be partially attributed to an increased medical surveillance, the observed pattern of SIR increase substantiate further investigation of a potential contribution of radiation exposure to the elevated thyroid cancer rates in this large population.

In a collaborative case-control study nested within cohorts of Belarus, Russian and Baltic countries an evaluation of the radiation-induced risk of thyroid cancer was performed (Kesminiene *et al.*, 2012). A statistically significant dose-response relationship was found with total the thyroid irradiation doses (external and internal). The ERR per 100 mGy was 0.38 (95% CI: 0.10-1.09). Risk estimates were similar when doses from internal ^{131}I and external radiation were considered separately, although for external radiation the ERR was not statistically significantly elevated. In the estimation of coefficient ERR, it is assumed that the observed increases in thyroid cancer incidence are due to radiation exposure.

In conclusion it should be pointed out that research devoted to thyroid cancer risk in children and adults in the Chernobyl post-accident period are mainly descriptive and describe the incidence time-trends. A small number of studies are of a cohort or case-control design. Along with evidence of an increased risk of thyroid cancer in children and adolescents exposed to radioactive iodine, there is doubt as to the thyroid cancer risk in adults and particularly to the clean-up workers. However, separate studies in survivors primarily those who took part in eliminating the consequences of the Chernobyl accident provide a basis for further analytical studies referring to the long-term observation of adult cohorts.

(A. Prysyazhnyuk)

2.2.2 Leukemia

Leukemia is associated with exposure to ionizing radiation in different populations, including the A-bombing survivors in Hiroshima and Nagasaki, patients subjected to radiation therapy, and population groups subjected to occupational radiation exposure in health care and nuclear industry (Report, 2005). Leukemia risk increases 2-5 years after exposure with the ERR per unit of radiation dose being one of the highest (especially in children) among any other radiation-induced malignancies (BEIR VII, 2006). Leukemia incidence and mortality are being often considered as a "marker" of radiation effects in exposed population. Risks from acute exposure to high doses of ionizing radiation for the most leukemia types are well known, but risks associated with protracted exposures and association between radiation impact and chronic lymphocytic leukemia (CLL) are not clear.

Results of studies in residents of territories contaminated with radionuclides after the Chernobyl accident concerning leukemia risk in children and adolescents were not enough convincing (Davis *et al.*, 2006). Hatch *et al.* (2015) have analyzed for the period 1998-2009 the incidence of nonthyroid cancers during the post-Chernobyl period in a well-defined cohort of 13,203 individuals who were <18 years of age at the time of the accident. No evidence was found of a statistically significant elevation in cancer risks in this cohort of subjects exposed at radiosensitive ages, although some cancer trends, particularly for leukemia (SIR=1.92, 95% CI: 0.69-4.13), should continue to be monitored.

Recent reports suggest an increase in incidence of leukemia among the clean-up workers from the Belarus, the RF, Ukraine and Baltic countries. The limitation of these studies include low statistical power, uncertainties in dose reconstruction, and internal inconsistencies that suggest a potential bias or confounding factors that are difficult to address (UNSCEAR, 2008).

This limitation was avoided in the large-scaled Ukrainian-American project for study of leukemia risk in clean-up workers, exposed to radiation when they worked in the Chernobyl zone (Romanenko *et al.*, 2008). A cohort of 110,600 participants of the clean-up works in 30-kilometer zone in 1986-1990 was formed. During the period of observation (i.e. 1987-2000) a calculated ERR value was $3.44 \cdot Gy^{-1}$ (95% CI: 0.47–9.78, P<0.01). A follow-up study in 2001-2006 showed a diminution of this value to $1.26 \cdot Gy^{-1}$ (95% CI: 0.03-3.58) (Zablotska *et al.*, 2013). It should be pointed out, that the revealed tendency corresponds with results of studies of the clean-up workers of the RF (Ivanov *et al*., 2012) and A-bombing survivors in Japan (Hsu *et al.*, 2013).

Study of the risk of chronic and non-chronic lymphocytic leukemia under a protracted exposure to low-dose ionizing radiation in Ukrainian clean-up workers in the last period (2001-2006) of Ukrainian-American project gave the reason to conclude the significant increase of risk of these leukemia types as both are radiosensitive (Zablotska *et al*.,2013).

In conclusion, it should be pointed out that epidemiological studies of leukemia risk as a result of radiation exposure due to the accident at the Chernobyl NPP are mostly descriptive and focused on children and adolescent contingents. In general, taking into account the low-dose radiation exposure, there is a low probability of high risk of childhood leukemia according to the results of Ukrainian and Belarusian studies. In contrast, the analytical study in clean-up workers of the accident indicates the existence of an increased risk of leukemia in this group of survivors in Ukrainian and Russian studies. The first established in Ukraine fact of radiation dose dependence of chronic lymphocytic leukemia in clean-up workers draws attention here.

(A. Prysyazhnyuk)

2.2.3 All cancers

In the papers by Shalimov *et al.* (2006) and Prysyazhnyuk *et al.* (2007, 2007a) the main results are presented concerning cancer incidence in the main group of affected population of Ukraine. Those are the Chernobyl catastrophe clean-up workers who had participated in the clean-up works in 1986-1987 (a 100,000 cohort), evacuees (50,000 subjects), and residents of territories most heavily contaminated with radionuclides (180,000 subjects). In these three groups the incidence of cancer (of all sites of the body) exceeded the national level (SIR=117.2%, 95% CI: 114.1-120.3) only in the clean-up workers, whereas in evacuees and residents of contaminated territories those rates were lower than national one.

Kashcheev *et al.* (2015) presented the results of retrospective cohort study of cancer incidence and mortality for the 1992-2009 follow-up periods among the Russian emergency workers at the Chernobyl catastrophe. A statistically significant increase in solid cancer incidence in emergency workers was found. The average excess over the entire follow up period was 18%, SIR=1.18 (95% CI: 1.15-1.22). This value is the same as a figure in Ukrainian emergency workers (Prysyazhnyuk *et al.*, 2007, 2007a). Values of excess relative risk of cancer incidence and mortality per Gy ($ERR \cdot Gy^{-1}$) are 0.47 (95% CI: 0.03-0.96, P=0.034) and 0.56 (95% CI: 0.002-1.25, P=0.049) respectively, the attributable risk is 5.8%. The estimated ERR value are in a good agreement with results published by this team in previous years (Ivanov, 2007; Ivanov *et al.*, 2009) and with results obtained in the life span study cohort of atomic bomb survivors (Preston *et al.*, 2007).

As to another cohort exposed in consequence of the Chernobyl catastrophe i.e. Baltic emergency workers the conclusions are in contrast: no consistent evidence of an increase in radiation-related cancers was observed. Results here are to some extent uncertain because of known impact of health examination approaches including thyroid screening among the clean-up workers (Rahu *et al.*, 2013).

Thus, given the results of malignant tumour risk studies due to the radiation exposure as a result of the Chernobyl NPP accident there is an increased risk of this disease in Ukrainian and Russian clean-up workers. Among the other groups of survivors, namely evacuees from the exclusion zone and residents of RCT the cancer incidence rates do not exceed the national level.

(A. Prysyazhnyuk)

2.2.4 Breast cancer

After the Chernobyl catastrophe the breast cancer also draws attention because of vulnerability of breast to carcinogenic effect of ionizing radiation. Breast cancer incidence after the Chernobyl catastrophe was studied mainly in descriptive epidemiologic studies aimed to reveal any possible stochastic effects in affected groups of population. A significant increase (in 1.6 times) of breast cancer incidence was registered in female clean-up workers in 1986-1987 years of participation (Prysyazhnyuk *et al.*, 2007b, 2008).

Epidemiological analysis of combined data of Belarusian and Ukrainian population showed a statistically significant 2-fold increase of breast cancer incidence in 1997-2001 in female residents of the most heavily contaminated with radionuclides territories vs. residents of less contaminated areas (Pukkala *et al.*, 2006). In districts of Ukraine with average accumulated dose in population of 40 mSv and more, the relative risk (RR) was 1.78 Sv^{-1} (95% CI: 1.08–2.93). These results confirm the necessity of profound investigation of possible role of radiation in breast cancer incidence rate in the entire population and in separate population groups most affected after the Chernobyl catastrophe.

Thus the fact of impact of radiation on the increased risk of breast cancer for the first time revealed in a Japanese cohort also confirmed in the study of female clean-up workers at the Chernobyl NPP. Separate studies of breast cancer incidence rate in women primarily those who took part in eliminating the consequences of the Chernobyl accident provide a basis for further analytical studies referring to the long-term observation of affected people.

Summing up the data from listed publications one can conclude.
Significant excess of thyroid cancer in main groups of affected population that might be caused by radiation exposure of thyroid due to radioactive iodine fallouts. Excess of thyroid cancer incidence was observed not only in children and adolescents but in adults as well. Effect of radiation exposure was manifested by extra thyroid cancer cases and trended to increase during the time.
Exposure to low and medium dose radiation was associated with significant increase of leukemia incidence rate in recovery operation workers which is consistent for Russia liquidators as well as Japanese atomic bomb survivors. Last performed in Ukraine study gave evidence radiosensitive origin of chronic lymphatic leukemia.

As to total cancer incidence rate only in recovery operation workers 1986-1987 these figures exceeded national level. Significant increase of breast cancer incidence rate was registered in female participated in recovery operation works in 1986-1987. Moreover, this review suggests the significant difficulties in evaluation of carcinogenic effects of the Chernobyl catastrophe. Clear estimation of radiation doses and comprehensive data on number of cancer cases in main groups of exposed population are required to receive some more substantial arguments.

Principal conclusions from the reviewed articles are as follows:
- there are radiation-dose related thyroid cancer risks in population groups exposed to radioiodine in children age;
- there is an increased thyroid cancer risk due to irradiation in the Chernobyl catastrophe clean-up workers;
- results of studies of thyroid cancer risk in adult population groups with irradiated thyroid evidence to the need of extended monitoring to obtain the reliable results;
- the dose-dependent leukemia radiation risks in the Chernobyl catastrophe clean-up workers correspond to the radiation leukemia risks in A-bomb survivors (Hibakusha);
- in contrast with Hibakusha the study results of the Chernobyl catastrophe clean-up workers evidence to the dose dependence of chronic lymphocytic leukemia; the stated inconsistence may be due to the genetic differences of these two populations;
- data on inhabitants of RCT suggest the absence of increased risk of radiation-induced leukemia;
- breast cancer incidence rate in female Chernobyl catastrophe clean-up workers in 1.6 times exceeded the level of morbidity of female population in Ukraine;
- taking into account the long latency periods of development of radiation-induced cancer of many organs and systems there is an need to continue the monitoring of this disease in a remote post-accident period.

(A. Prysyazhnyuk)

2.2.5 Radiation cataract

The crystalline lens in the human eye appears to be more radiosensitive than it was previously assumed. In 2013, the International Commission on Radiological Protection (ICRP) (IAEA, 2013) established a new dose limit to the lens for occupational exposure of 20 mSv per year (former limit was 150 mSv). The reduction of the limit for the dose to the lens of the eye to 20 mSv per year has been passed in the current Euratom Directives (2013) (Bruchmann *et al.*, 2015). Accumulated evidence from the Japanese atomic bomb survivors, Chernobyl liquidators, US astronauts, and various other exposed groups suggests that cortical cataracts may be also associated with impact of ionising radiation, although there is little evidence that nuclear cataracts are radiogenic. The dose-response appears to be linear (Little, 2013).

However, there are critical opinions concerning radiation cataractogenesis following exposure to low doses of ionising radiation (Yeltokova, 2013; Seals et al., 2015). There are many factors, including genetic, metabolic, nutritional, and environmental involved in cataractognesis. At the same time nowadays the tissue of the lens is considered radiosensitive, thus, lens opacities are possible late effects of exposure to ionising radiation (Belyy et al., 2015).

An analysis of research results for 30 years since the Chernobyl catastrophe testifies that an eye is one of basic targets of radiation influence (Buzunov and Fedirko, 1999; Fedirko, 2000, 2001, 2002).

Radiation cataract, which is examined as a deterministic effect, was traditionally considered a basic consequence of radiation effect on the eye (Fedirko, 2000).

Examinations performed after the Chernobyl catastrophe proved that radiation cataract is observed upon exposure at the doses significantly less than it was early considered (Fedirko, 1999, 2000 2001, 2002). Results of the UACOS studies are an evidence of possible presence of a threshold but at the level about 0.1 Gy for some age groups, i.e. significantly lower than 2 Gy (Chumak et al., 2007); a threshold is dependent on cataract form and can be higher than 0.7 Gy (Worgul et al., 1999, 2007). A dose threshold for radiation cataract was not fixed in any other study. A latent period can exceed 24 years. Data of studies and mathematic modelling are indicative in favour of the view that radiation cataract is a stochastic effect of radiation exposure (Fedirko, 2002).

It has been shown that such appearance of non-typical changes in the lens of children and adolescents is possible as partial opacities and changes in optic infiltration without decreasing of visual acuity by certain time and are only diagnosed under the purposeful examination as a chronic radiation effect. Presence of the dose dependence was proved for this disease (Fedirko, 2002).

(N. Omelianets)

2.2.6 Mental health

The long-term mental health consequences have been recognized by the UN Chernobyl Forum and supported by further evidence-based International studies as one of the main medical and social problem of the Chernobyl catastrophe aftermath. First of all, they are the stress-related disorders, effects on the developing brain, organic mental disorders in clean-up workers, and suicides (WHO, 2006; Bromet *et al.*, 2011; Bromet, 2012–2015; Havenaar, 2015; Igumnov, 2015; Loganovsky, 2013–2015). The UN Chernobyl Forum also suggested the excesses of mortality, due to cardiovascular disease (including cerebrovascular), in the clean-up workers of the Chernobyl NPP accident. At the same time, the effect of low doses of radiation on the brain are among the research priorities for exploring of non-cancer effects of radiation, however, they are still at issue (Loganovsky, 2009, 2012, 2013; Bazyka *et al.*, 2013a, b, 2014). This sub-chapter is an overview of the recent *peer reviewed* publications and proceedings of international conferences of the evidence-based studies on mental health aftermath of the Chernobyl accident recognized by the International community.

Effects on the developing brain as well as organic mental disorders in the clean-up workers are explained in subchapter “2.3.9.3. Neuropsychiatric effects”. Among them there are both recognised consequences and those not fully recognised by the International community.

Radiation accidents, radiological terrorist attacks, as well as nuclear conflicts and nuclear war are substantially different from natural disasters and wars without use of weapons of mass destruction. Clinical features here include the major criteria of post-traumatic stress disorder (PTSD) - "immersion" in the experience, "avoidance”, "hyperexcitability”, and "social functioning deficit" (Rumyantseva *et al.*, 2007; Rumyantseva and Stepanov, 2008). Psychological stress about the future (the risk of oncological and other diseases, congenital malformations in the descendants etc.), long-term radioactive contamination, evacuation and resettlement, as well as incomplete and imperfect legislation regarding social benefits to the victims all make a significant contribution to the development of psychopathological responses (Rumyantseva *et al*., 2007; Loganovsky *et al*., 2014).

The male Chernobyl liquidators who met the DSM-III-R criteria for current PTSD group scored significantly higher than the non-PTSD group on all the measures of PTSD and general psychiatric symptomatology, state and trait anxiety, depression. There is a determining role of individual perception and assessment of radioactive hazard in the development of post-traumatic stresses placing this problem among the most important ones in studying of psychological consequences of radioactive threat experiencing. The real working conditions and the level of information also affected the workers' estimate of the severity of the radiation hazard in Chernobyl (Tarabrina *et al.*, 1996).

We have conducted standardised psychiatric interviews using the Composite International Diagnostic Interview with 295 clean-up workers and 397 controls 16-18 years after the catastrophe and report on common psychiatric disorders, suicide ideation and severe headaches. Prior to the Chernobyl catastrophe being consistent with healthy worker effect, the clean-up workers had significantly lower rates in anxiety and alcohol disorders. The clean-up workers had significantly higher rates of depression (18.0% vs. 13.1%) and suicide ideation (9.2% vs. 4.1%) after the catastrophe, but not alcoholism or intermittent explosive disorder. In the year preceding the interview, the rates of depression (14.9% vs. 7.1%), PTSD (4.1% vs. 1.0%), and headaches (69.2% vs. 12.4%) were elevated. The affected liquidators with depression and PTSD had lost more working days vs. controls. Exposure level was associated with current somatic and PTSD symptom severity. Thus, the long-term consequences of Chernobyl catastrophe on mental health were observed in the clean-up workers (Loganovsky *et al.*, 2007, 2008).

Recent studies show that the rates of depression and PTSD remain elevated two decades later. Very young children and those been in utero who lived near the plant when it exploded or in severely contaminated areas, have been the subjects of considerable research, but the findings are inconsistent. Recent studies of prenatally exposed children conducted in Kiev, Norway and Finland point to the specific neuropsychological and psychological impairments associated with radiation exposure, whereas other studies found no significant cognitive or mental health effects in exposed children grown up. General population studies report the increased rates of poor self-rated health as well as clinical and subclinical depression, anxiety, and post-traumatic stress disorder. Mothers of young children exposed to the disaster remain a high-risk group for these conditions, primarily due to the lingering worries about the adverse health effects on their families. Thus the long-term mental health consequences continue to be a concern (Bromet *et al.*, 2011).

The UN Chernobyl Forum (WHO, 2006) has defined the suicides in the clean-up workers as one of important issues within the post-accident period. Suicide is a leading cause of death in the Estonian liquidators (Rahu *et al*., 2006) and in Lithuania the suicide mortality among the clean-up workers has exceeded the population level (Kesminiene *et al*., 1997). The major finding of epidemiological studies in the Estonian clean-up workers mortality is an increased risk of suicide (Rahu *et al*., 2013a, 2015). Whereas exposure to low radiation doses is the risk factor of suicidal behavior, or this is a socio-psychological phenomenon only, is still at issue (Loganovsky, 2007).

The toll of cleanup work was evident 24 years after the Chernobyl catastrophe among the Estonian clean-up workers indicating the need for focused mental health interventions. The strongest difference was found for somatization being three-fold more likely in the cleanup workers vs. controls to score in the top quartile (odds ratio (OR)=3.28, 95% CI 2.39-4.52), whereas for alcohol problems the difference was half as large (OR=1.52, 95% CI 1.16-1.99). Among the cleanup workers and arrival at Chernobyl in 1986 (vs. later) was associated with sleep problems, somatisation, and symptoms of agoraphobia (Laidra *et al.*, 2015). These data are the same as in Ukraine concerning current alcohol abuse among liquidators (Postrelko *et al.*, 2013).

Mental health drives physical health. Research on mental health has led to development of new terminology to describe the health problems associated with stress (chronic fatigue syndrome, health anxiety). Radiation risk perception is the primary risk factor for health anxiety related to the accident. Mothers of young children and former liquidators are at the highest risk of developing mental health effects (Bromet, 2015).

Arkhangelskaya and Zykova (2003), Zykova and Arkhangelskaya (1999a, b), Zykova *et al.* (2000) used the term “radiation anxiety” to determine the psychological effects of the catastrophe, that include emotional disorders inadequate to the real radiation hazard, concern about their own health, the health of their children and their future. There is a change of values, personal and social motivation, decreased personal activity until complete indifference. Among 519 residents of the contaminated Narovlya rayon in Gomel oblast of Belarus the health state is worrisome for 94.8% of them, the level of radioactive contamination for 91.3% of them (of which 64.2% are extremely concerned), and 86-90% are disturbed by various aspects of the future existence. The study of radiation risk perception among young people within Gomel oblast of Belarus showed that 84% of students believe that the Chernobyl catastrophe consequences have had a negative impact on their health and will continue to influence it. In addition the 98% of girls and 70% of boys are concerned about possible violations of the health in their future children. High level of radiation anxiety is associated with low level of public awareness about ionizing radiation and its effects on human health. In 2005 the socio-psychological monitoring was carried out of various groups of population living in contaminated areas of Bryansk, Kaluga, Tula and Orel oblasts of Russia, as well as Gomel oblast of Belarus. The monitoring results showed that 45% of respondents living in the evacuation zone had no knowledge of radiation and peculiarities of life in the radiation-contaminated areas. Doctors, other experts and representatives of the authorities were most informed (Marchenko *et al.*, 2006).

Thus, despite 30 years of studying the consequences of the Chernobyl catastrophe, the information on harm of radiation is controversial. The conflicting information about the radiation danger, which are disseminated by the mass-media, only exacerbate the situation and provoke in population the development of radiation anxiety and psychosomatic disease not directly related to ionizing radiation. There are concerns about the quality of medical care, use of non evidence-based diagnostics and treatments, and lack of knowledge in the population about the signs of both physical and mental disorders (Samet and Patel, 2011). Unfortunately, there is lack of studies on effective interventions to deal with these problems at an individual and population level (Bromet *et al.*, 2011). This situation needs further prospective long-life investigations of mental health of people suffered as a result of radiation disasters.

It is necessary to develop and improve the system of emergency and long-term psychological and psychiatric care under radiological catastrophes. At present these studies must be focused on the long-term mental health consequences, neurocognitive deficit, emotional-behavioural and psychotic disorders with advanced biophysical (dosimetric) support on the base of analytical epidemiology. A further study is needed that should endeavor to collect more objective measures of exposure and physical health, consider possible cognitive impairment and psychotic symptoms, and conduct more rigorous psychiatric evaluations (Bromet, 2015; Havenaar 2015; Igumnov, 2015; Loganovsky, 2015).

(K. Loganovsky)

2.3 Obvious, but not recognized consequences

Our analysis shows that assessment of health effects of the Chernobyl catastrophe in Ukraine is now almost impossible. Following termination of funding the MH halted publication of the annual statistical book “Indicators of health and providing medical care to victims owing to accident on the Chernobyl NPP” since 2006. Until 2009 this document was however still available on electronic media. No data summarisation on annual statistical reporting forms # 15 “Report of the medical service of the population that was exposed to radiation in connection with the accident at the Chernobyl nuclear power plant and to be included in the State registry distributed for ____ year" and # 16 "Report of the disease and the causes of disability and death of population, which is subject to inclusion in the State register of Ukraine of the persons survived after the Chernobyl accident for ____ year" of the MH is conducted in subsequent years. Since 2007 the DS has cancelled the annual statistical reporting by forms # 1 (Chernobyl) "Report on the resettlement of residents of settlements victims by the Chernobyl catastrophe", # 2 (Chernobyl) "Report on admission to non-contaminated zones of residents from settlements affected as a result of the Chernobyl catastrophe" and # 3 (Chernobyl) "Report on population living in zones of radioactive contamination after the Chernobyl catastrophe". In this regard there is no information about the inhabitants of the contaminated territories in recent years. It is almost impossible to obtain information in the country on the number of citizens who have the status of victims of the Chernobyl catastrophe. SRU is still not functioning in Ukraine. As a result, the country and world community lose highly relevant data on health effects of the Chernobyl catastrophe in Ukraine.

Data stated above testify that the catastrophe and its consequences became a cause of health deterioration in irradiated persons. The above-mentioned radiologic effects were proven in the cohort studies. Hereinafter we will review some parameters, which confirm the negative impact of the Chernobyl catastrophe on health of the population of Ukraine. For the last 10 years there are in general a limited number of scientific publications about the groups of victims and population of the country. Among them there are monographs (Vozianov et al. 2007; Serdiuk et al., 2011; Tronko et al., 2014; Omelianets et al., 2015), collections of scientific works (Problems of radiation medicine, 2012-2014), and conference proceedings (Radioecology-2014; Radioecology-2015).
Hereinafter we will focus on the results of population studies. They were based on the analysis and evaluation of medical and demographic situation in Ukraine for 5 years before and 29 years after the Chernobyl catastrophe. Studies have covered all territories of the country classified according to the national law as radioactively contaminated with population of about 22,000,000 people. Research accounting a wide range of health and demographic indices was performed for each territories separately and also for territories grouped with other of contamination zones, population groups (all population, urban population, rural population), groups of victims (clean-up workers, evacuees, residents of contaminated territories and children), genders (males, females, both sex), ages (19 age groups), and main causes of death. «Automated control system of data bases of monitoring of medical and demographic consequences of Chernobyl catastrophe» (ACS DB DEMOSMONITOR) was the informational base of research established under our leadership by order of the ME of Ukraine (Omelyanets et al., 1997; Omelyanets, 2000; Buzunov et al., 2011). State statistical reporting from Ministry of Statistics was the source of studied parameters. All the studied parameters were subjected to statistical and mathematical analysis.

2.3.1 Loss of territories for residence

As of 1991 according to the national legislation the 53,454 km2 of soils (4.8% of territory of the country), 4,600,000 hectares of agricultural land (12% of the total area) and 25,357 km2 of woods (40% of the total area) in Ukraine were contaminated with ^{137}Cs at intensity exceeding 37 $kBq \cdot m^{-2}$. 2,293 settlements, 74 administrative rayons and 12 oblasts are recognised as contaminated. They are divided in radiation hazardous (include of the exclusion zone and zone of obligatory (compulsory) resettlement) and radioactively contaminated (include zone of guaranteed voluntary resettlement and zone of strict radio-ecological control) (Law of Ukraine,1991a).

The exclusion zone (an area of 1,210 km2) and the zone of absolute (obligatory) resettlement (area of 6,490 km2) are referred to radiation hazardous territories. Permanent residing of people and main kinds of activity there are forbidden. They are in 11 administrative rayons of seven oblasts. The 91,600 inhabitants were evacuated in 1986 from the exclusion zone. Today there are no inhabitants in 76 settlements in exclusion zone and in 92 in absolute (obligatory) resettlement. Those populated places are excluded from the list of settlements. However, for all years few thousand so-called squatters constantly lived there. In 1991-1992, about 50,000 of people had to be resettled to the clean districts from the zone of absolute (obligatory) relocation. However, resettlement is not completed until now. As of 2015, the 170 people still live in 10 villages of this zone. The territory of both zones is secured. Various measures on minimisation of distribution of radioactive substances are constantly carried out; works on construction of new safe shelter and transformation of zones in ecologically safe state are actively conducted. However, because of insufficient funding such measures are carried out not to full extent. Fires often occur. Due to the levels of contamination they remain being an unsafe source of human irradiation.

In recent times the issues of the future of exclusion zone and absolute (obligatory) resettlement zone are discussed in the country. Return of population there is a most important issue. Meanwhile it is also proposed to organize the Chernobyl biosphere reserve in these zones. The future of these zones was discussed this year at the Parliament hearings (Recommendations, 2015).

Zones of guaranteed voluntary resettlement and of strict radio-ecological control are attributed to radioactively contaminated ones. First zone of 23,620 km2 covered the territories of 33 administrative rayons and 8 oblasts. About 600,000 people with more than 150,000 of children lived in 835 settlements in it. Second zone of 22,480 km2 covered 68 rayons and 12 oblasts. There were 1287 settlements in it with more than 1,600,000 population including more than 300,000 children. As previously mentioned about 25 settlements can remain in a zone of guaranteed voluntary resettlement according to results of dosimetric passportization 2012. The zone of strict radio-ecological control and settlements located on it are excluded from the list is radioactively contaminated since January 1, 2015 (Law of Ukraine, 2014).

Thus, 30 years after the explosion of a nuclear reactor on the Chernobyl NPP in Ukraine, 7,700 km2 of radioactively contaminated soil remain unsuitable for residing of people. An area of 45,000 km2 is still radioactively contaminated. As the scope of state arrangements on radiation protection in the country is considerably reduced, these territories will remain dangerous to the people even for many decades.

Inhabitants of these zones were subject to the greatest emergency exposure. By way of exposure prevention only evacuation was effective. However, irradiation of evacuees remained after their domiciling in territories with high levels of contamination, from which after 1991 they were again moved to non-contaminated districts.

Hence, the Chernobyl catastrophe resulted in radioactive contamination of huge territories and some of them are still unsuitable for residing of the people. It is an indisputable proof of danger of the Chernobyl catastrophe and its consequences for life and health of the people.

(N. Omelianets)

2.3.2 Territorial redistribution of population

About 200,000 people were evacuated, resettled or independently migrated for 29 years from contamination zones to the clean (uncontaminated) regions. According to our sources (figure 2.3.1), most of all resettlements were in 1986 and in 1987-1989. Since 1991, the resettlement from zone of absolute (obligatory) resettlement was carried out. After 2004 it was limited and till now is not completed. Evacuated and displaced persons in 1987-1989 were settled in areas throughout the country, but since 1991 mainly within the confines of oblasts. Evacuated and resettled persons were necessarily provided with free-of-charge habitation and the employment was guaranteed to them. As of 2013 the 37,768 families were on the waiting list for housing, from them 9,822 were families of the Chernobyl invalids and 14,943 of voluntary resettlement from the contaminated territories (Information materials, 2013).

According to data of vital statistics generated by us (statistical books of the Ministry statistics of Ukraine, nowadays Department of statistics (DS) of Ukraine), the population in radioactively contaminated territories decreased since 1986 till 1990 by 46,400 persons (by 3%) in Zhitomir oblast, by 26,600 persons (by 1.36%) in Kiev one, and by 63,200 persons (by 4.46%) in Chernigov oblast.

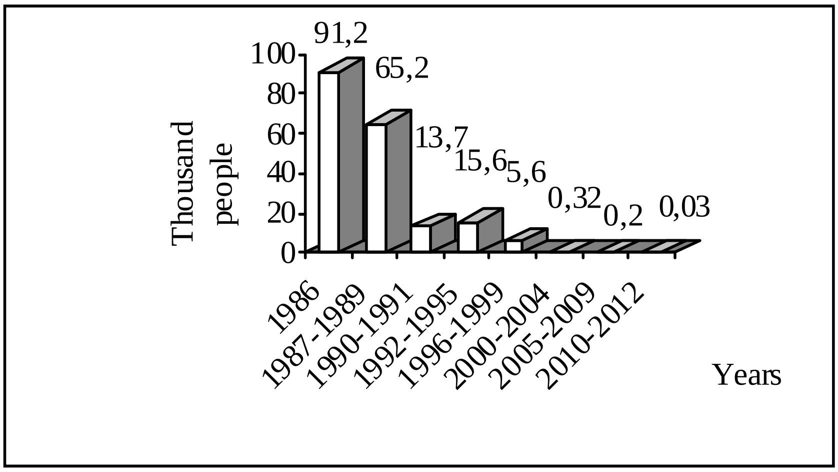

Figure 2.3.1 - Scope of population resettlement from radioactively contaminated territories in Ukraine within 1986-2012, thousand people

In the control Poltava oblast contrariwise there was a gain of population (by 17,200 persons). Number of rural population was especially reduced i.e. by 18.4% in Zhitomir oblast and by 20.6% in Chernigov oblast. In the control Poltava oblast a decrease has made 9.6%. In Kiev oblast where the evacuees mainly are living the decrease has made only 6.9%. In 1991-2012 the number of rural population in Kiev oblast was reduced by 23.9%, in Zhitomir oblast by 22.2%. On this evidence the countryside of these areas can be reasonably named a zone of accelerated depopulation. Depopulation was statistically significant in the most contaminated Ovruch (-24.43%), Ivankov (-26.65%), Luginy (-27.98%), Narodichy (-45.2%), and Polesskoe (-76.56%) rayons.

Hence, the Chernobyl catastrophe has caused a departure of about 200,000 people from radiation hazardous territories and RCT of Ukraine. Thirty years later a depopulation of radioactively contaminated zones goes on. It is more intensive than in not contaminated districts.

(N. Omelianets)

2.3.3 Degradation of population structure within radioactively contaminated territories

Families having children up to 14 years old, pregnant women, and persons with medical contraindications were given the right to independently leave from RCT in the post-accident period. Together with evacuation it immediately has had an effect on the structure of the population. The number of males in the population structure has decreased in Zhitomir oblast by 17.4%, of females - by 16.9%, in Kiev oblast - by 9.9% and 13%, in Chernigov oblast - by 17.4% and 19.3%, respectively. In the control Poltava oblast the decrease was 2-3-fold less (5.6% and 10.9% accordingly). Share of women of childbearing age and children of younger age groups decreased considerably in population suffered from radiation exposure and those living in the controlled territories. It has had an effect on reproduction of population in the future. It has already an affect on reproduction of population in the radioactive contaminated areas in the past and will affect in the future.

(N. Omelianets)

2.3.4 Birth rate

Down to recent times any possible occurrence of unfavourable consequences of the Chernobyl catastrophe on fertility was completely denied. However, the results of our research show otherwise. So, Omel'anets *et al.* (1989) showed that in the first and second years after the accident there was a decrease in birth rates within most intensively radiologically contaminated zones of Ukraine (Figure 2.3.2).

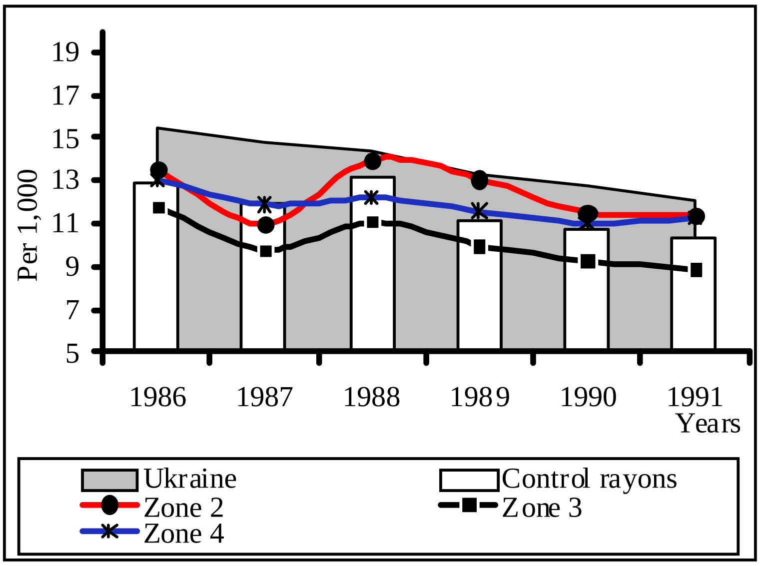

Figure 2.3.2 - Birth rate in population of radiologically contaminated zones in Ukraine since 1986 till 1991, per 1,000 population

Review of a set of parameters characterizing birth rates (fertility rates by maternal age, rates of stillbirth, medical abortions, spontaneous abortions, deaths of infants aged 0-6 days) and radiation dose values afforded a ground to believe that fertility rate drop in 1987 was due to impact of excessive within first year after the catastrophe. Of course, it was still under the influence of many other factors that could play a role, such as evacuation, stress, etc.

Degree of birth rate reduction depended on the category of contamination zone i.e. the highest one was peculiar to the zone of obligatory (compulsory) resettlement (‘zone 2’) and zone of guaranteed voluntary resettlement (‘zone 3’). Decline of birth rate was also in the control rayons. These birth rates were as described above the levels of radioactive contamination and radiation doses of the population.

Review of the birth rate trend over the 1991-2012 periods showed its significant changes (figure 2.3.3). From 12.1 per 1,000 in 1991 it decreased to 7.7 per 1,000 in 2001. For the three years this level was the lowest since records began in the country. Recent years it was within 11 per 1,000.

Integrally the birth rate declined in Zhitomir oblast with annual growth rate (GR) of 0.02 per 1,000 in 1991-2012. In Kiev, Volyn and Rivne oblasts it on the contrary increased i.e. annual GR were 0.08, 0.04, and 0.02 per 1,000 respectively. These differences, however, were not statistically significant ($p>0.05$). Statistically valid reduction at that was in Luginy and Narodichy rayons of the Zhitomir oblast. In other nine studied rayons the changes of fertility rate were not statistically significant vs. control and average for the country.

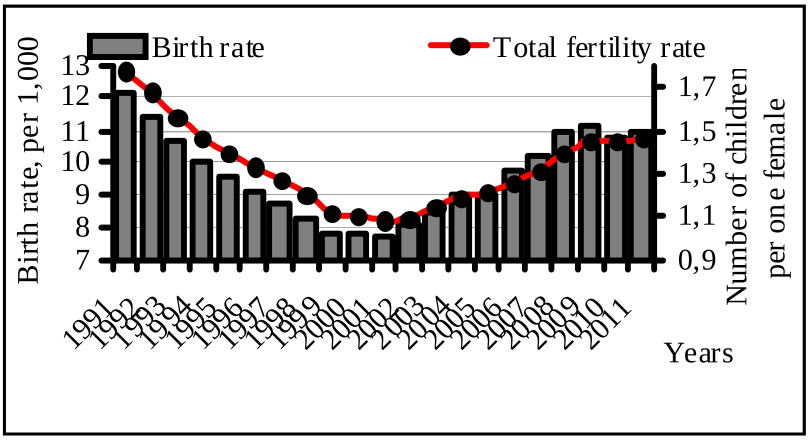

Figure 2.3.3 – Time pattern of birth rate and total fertility rate in Ukraine in 1991-2012

Reproductive activity in Ukraine also continues to decline. Just total fertility rate in the country decreased from 1.77 (1991) to the lowest value in the history of 1.09 child per female of childbearing age in 2001-2012. Value of the total fertility rate decreased by 6.2% in Rivne, 9.4% in Volyn, 17.6% in Zhitomir, and 2.6% in Kiev oblasts. In Rivne and Volyn oblasts the elevated total fertility rate is attributed, first of all, to the prevalence of the rural population, which is characterized by a greater intensity of births and tradition of having many children associated with religiosity.

Revealed changes in fertility were confirmed by international research under the French-German initiative for Chernobyl (FGI) (Dzikovich et al., 2004; Omelyanets et al., 2004, 2004a). It was proved due to dependence on existing levels of radiological contamination, thyroid and the whole body radiation doses.

Gender disproportion in newborns is one of the negative consequences of the Chernobyl catastrophe. It is generally stable in populations accounting 104-105 boys per 100 girls. The value is under impact of many factors including ionizing radiation. Pattern of gender change after the irradiation is believed being resulted from damage of sex chromosomes, mainly of X-chromosome.

The result depends on the gender of the irradiated person. There will be more boys in gender ratio of newborns upon irradiation of male genital organs. Death of embryo leads to miscarriages and stillbirths. The born children may have different abnormalities and damages occurred during fetal life. In turn, there will be fewer boys in gender ratio of newborns upon irradiation of female genital organs. Upon irradiation of gonads of both parents, of mother's body during pregnancy, and of foetus the male embryos die predominantly and proportion of boys among newborns is reduced.

There were no significant fluctuations of gender ratio at birth both at the national level and in radiologically contaminated rayons for the entire period of our observations. At the same time, the variability of parameter at a rayon level was quite noticeable. In the most severely contaminated rayons it ranged within 110-120 boys per 100 girls. There were also some rayons with predominance of girls in the birth structure.

(N. Omelianets)

2.3.5 Mortality

Mortality indices will be analysed on a selected population sample split in two groups. The population of radioactively contaminated territories represents the first group, the second one includes survivors of the Chernobyl catastrophe.

2.3.5.1 Mortality in population of radiologically contaminated territories

According to our data (Omelianets *et al.*, 2007, 2011, 2011a, 2015, 2015a; Dubova *et al.*, 2011), the mortality increase began in Ukraine since 1991. In fact, it is ongoing. Its value in the population of RCT was statistically significance higher ($p<0.05$) than in control. In 2012 the mortality in Ivankov rayon was 24.55±2.70 per 1,000, in Polesskoe – 26.42±4.56, in Luginy – 19.86±2.26, in Narodichy – 26.17±3.28 and in Ovruch - 19.32±2.11 per 1,000. These levels are significantly higher vs. average in Ukraine (15.14±0.95 per 1.000).

Our comprehensive and in-depth research revealed a number of important regularities, trends and new facts about the impact of radiation from Chernobyl on mortality, for example regarding the mortality values depending on levels of radiological contamination (by category of contamination zone) and adopted regulations of secure residence (criteria for radiation dose levels). As can be seen from Figure 2.3.4 the highest mortality rates are in population living in 'zone 2' i.e. zone of obligatory (compulsory) resettlement. Mortality rate is also high in 'zone 4' (zone of strict radio-ecological control. The high mortality rate in 'zone 2' we attribute high individual doses of radiation (more than 5 mSv·year^{-1}). Large mortality rates in 'zone 4' compared to 'zone 3' can be attributed to differences in the levels of collective dose. In 'zone 4', where the calculated level is 800 man-Sv·year^{-1}, the mortality is higher than in 'zone 3', where its level is 600 man-Sv·year^{-1}.

We attribute the establishment of heterogeneity phenomenon to new knowledge. It manifests itself as an effect of selection (Michalski *et al.*, 2008) in which the most vulnerable individuals die earlier and over time the population becomes "more stable". In demography it is when the rate of mortality increase in the oldest ages (75+) is reduced and in the epidemiology of cancer when the cancer incidence is declining among the geriatric population (75+).

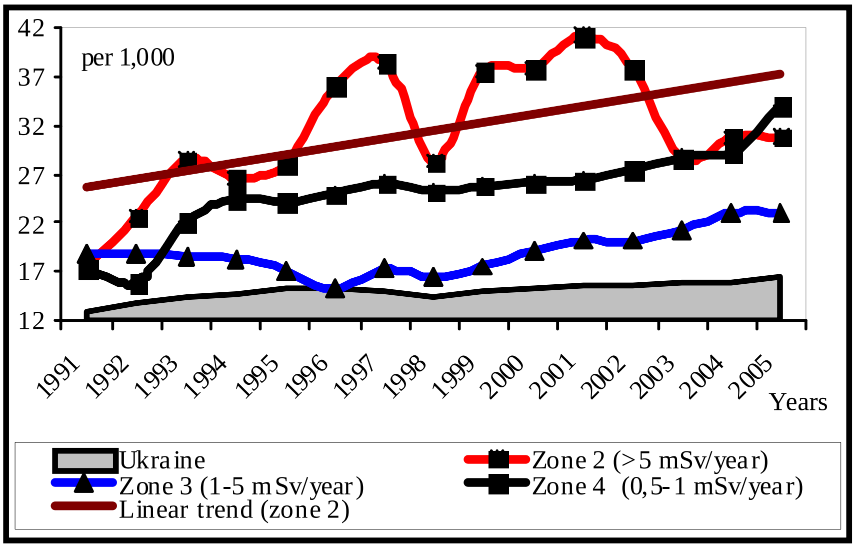

Figure 2.3.4 - Mortality rates depending on category of contamination zone and total irradiation dose level set by the law in 1991-2006, per 1,000 population

It is confirmed by the data shown in Figure 2.3.5 meaning that mortality rates began to rise already from the age of 15 and have been great to 65-69 years in inhabitants of five most intensively contaminated territories vs. unexposed population. At the age of 70+ the mortality rate was over 22 per 1,000 of the population less vs. before the accident. There were almost no such trends in mortality rates in population of Ukraine. Modest increase in mortality rate in 2009 vs. 1986 occurred in this group only beginning from age of 35 years. Mortality rates of those aged 70+ were almost equal (108.3 and 108.9 per 1,000).

Death rate from neoplasms increased in the first years after the catastrophe. During 1981-2000 it increased to 0.03 per 1,000 in RCT, whereas only to 0.02 in controls and to 0.01 in Ukraine as a whole. It was statistically significant ($p<0.05$) in comparison with pre-accident period. In all studied territories the highest increase of this mortality rates was accounted for the second quinquennium since catastrophe with prevalence of males in its structure. Subsequently there was an increase of mortality rate from non-cancer diseases with Diseases of the Circulatory System in their structure.

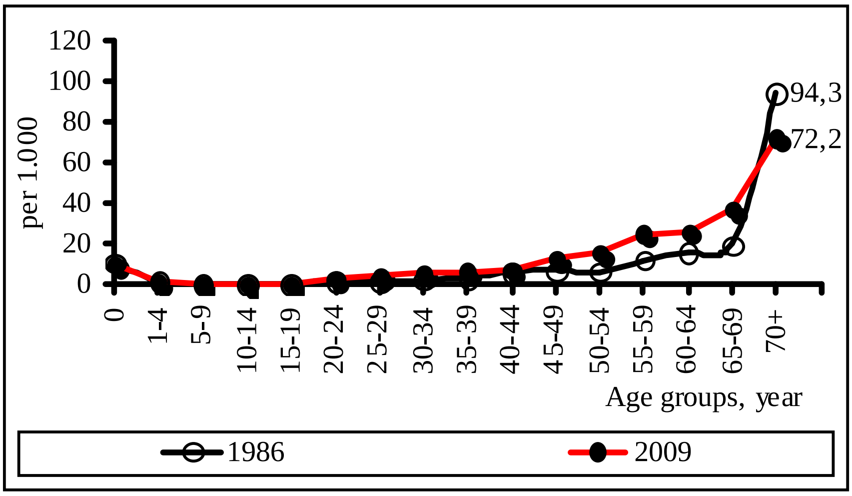

Figure 2.3.5 – Age-specific mortality rates in residents of five the most intensively RCR in 1986 and 2009, per 1.000 persons of the relevant age group

Females appeared being prevalent in mortality structure ($t>2.8$, $p<0.05$). These features of mortality were confirmed by calculations of standardised indices and RR. Risk analysis of individual causes of death has testified to its increase at the expense of mortality in both genders from somatic diseases and in males from external causes.

(N. Omelianets)

2.3.5.2 Mortality of the Chernobyl catastrophe survivors

There were two classifications of survivors used in Ukraine after 1991 (Buzunov et al., 2011; Omelyanets et al., 2011a). First one was introduced in the former USSR in 1986 for persons exposed to radiation as a result of the Chernobyl NPP accident. Survivors were subdivided into 4 accounting groups and 5 categories of observation. First group of accounting included the accident and its consequences clean-up workers in the controlled zone. Second group comprised the evacuees, third one spanned the inhabitants of territories of observation and migrants out of there. Fourth group included children born from irradiated parents. Another i.e. second classification was approved by the national legislation in 1991 (see List of the designations, abbreviations and terms). By 1991 the number of registered persons has increased almost 6-fold and as of 1998 more than 11-fold. After that their population decreased due to deaths, change of residence, and the exclusion from the group of survived children after they reach the adulthood.

After 1991 the first classification continued to be used in the healthcare statistical reporting forms #15 and #16 and in the SRU. Data of forms #15 and #16 for the most part were each year summarised and published by the MH in statistical reference data books. The last one was issued in 2007 (Statistical handbook, 2007). The first classification is also used as a building block in SRU. The second classification was of countrywide application being applied for registration of citizens recognised the Chernobyl catastrophe victim as in accordance with the law. It was the basis for planning of arrangements on liquidation of consequences of catastrophe, financing and provision of social, health, and radiological protection of victims and general population. According to this accounting the number of survivors exceeded the number registered in healthcare system by more than 600,000. Having regard to the above we have repeatedly expressed the opinion that existence of these two incompatible classifications of survivors and respective reporting forms is the source of confusion both at the national and international levels regarding data on their number in the country and estimates of health effects (Omelyanets et al., 2011b).

Today the health assessment in survivors (except for cohort studies) can only be based on the MH data before 2007. Health estimates in survivors by the groups established by the national legislation cannot be made.

Figure 2.3.6 shows the highest mortality rate in inhabitants of the RCT which were exposed to relatively high doses of acute irradiation in 1986 and to low-dose chronic irradiation later for 19 years (Statistical handbook, 2007).

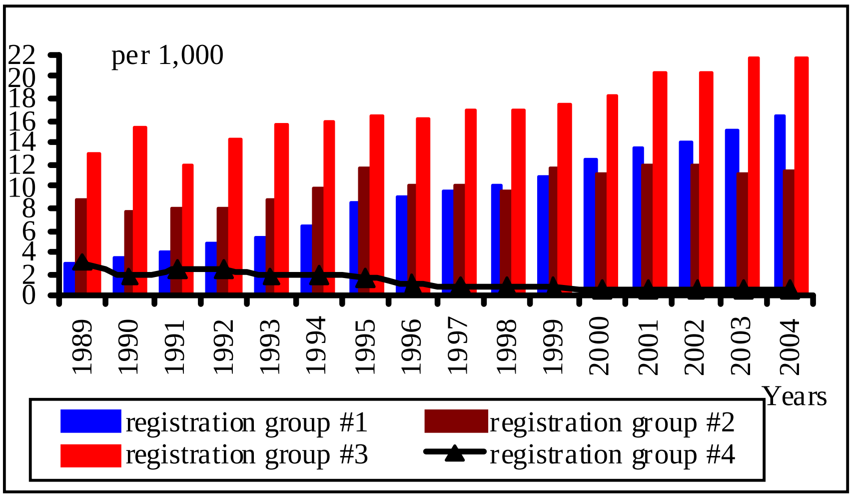

Figure 2.3.6 - Mortality rates in survivors of the Chernobyl catastrophe by groups of registration in 1989-2004 per 1,000 persons of the relevant registration group

The clean-up workers who were exposed to acute irradiation at high doses when they participated in the emergency works especially in 1986-1987 the trend of increasing mortality are on the second place. Evacuees i.e. those who were briefly exposed to increased levels of radiation until evacuation are third in descending order of mortality rates. Children born from irradiated parents occupy the fourth place. Particularly intense mortality increase occurred upon 2000 i.e. 15 years after the onset of exposure. Mortality of children born from irradiated parents was highest among all the observed paediatric population (i.e. evacuees, living in the RCT, and born from irradiated parents). Until 1994 its level was 6-fold higher vs. mortality in evacuated children.

The analysis shows that DCS, cancer, diseases of respiratory and digestion organs are the leading causes of death in adult and adolescent survivors. The most dramatic increase of mortality from diseases mentioned above was within 15 years after the catastrophe.

Some changes in mortality structure occurred by the 20-th anniversary of the catastrophe. Increase of mortality rate due to DCS (116.5-131.3 per 10,000 survivors vs. 68.0-71.0 in total population in 2000-2004) was a main feature. Share of DCS in the structure of causes of death reached 67.9%. Mortality rate due to diseases of digestive organs increased by 46.8%. Mortality rate due to cancer almost has not changed for this period. Levels and proportion of mortality due to diseases of respiratory and endocrine systems decreased at that. Consequently the increase of mortality rates occurred in the entire group of the survived adults and adolescents mainly due to diseases of DCS and digestive organs. Mortality due to DCS in survivors was nearly twice the mortality in population.

Injuries and poisonings were the leading cause of death (33.8%) in survived children. Congenital malformations were at the second place (16.2%). In a due course however the death rates from them have decreased (from 0.24 per 1,000 in 1992 to 0.11 in 2004). Mortality from diseases of the nervous system in 2004 appeared at the third place. Fourth place in mortality rates was shared by cancer and certain disorders originating in perinatal period (8.8%). Mortality from former decreased and from latter increased. No significant differences in mortality rates between the survived children and paediatric population of the country were found.

In the absence of data on radiation doses it is impossible to establish any link between the mortality rates in survivors and impact of ionising radiation.

Not any other new peer reviewed publications on this problem are available.

In virtue of the already published data (Omelyanets et al., 2011a; Omelyanets et al., 2015) we can conclude that 30 years later:
1) more than 1,800,000 survivors representing more than two thirds of their total number still live in the zones of radiological contamination in Ukraine; there are more than 400,000 children among them; there are no data on their radiation doses which diminish the validity of estimates of health effects of acute and long-term radiation exposure;
2) mortality rates in population of RCT are higher vs. in population of Ukraine in general;
3) share of non-cancer diseases and of DCS in particular increased in the structure of causes of death;
4) the worst mortality rates among all survivors including the affected children are peculiar to those born from irradiated parents.

(N. Omelianets)

2.3.6 Demographic losses

It is well known that various natural and social disasters (earthquakes, epidemics, wars, revolutions, catastrophes) give rise to the human or demographic losses. Both last mentioned are estimated in demography by the changes in number and composition of population. Taking into consideration the scale of the Chernobyl catastrophe it was important to determine an impact of its consequences on this parameter.

The only research on the analysis and assessment of demographic losses after the Chernobyl catastrophe was conducted in the NRCRM concerning at that only data available for Ukraine (Omelianets *et al.,* 2015). Level of losses was assessed by the number of unborn children, premature deaths and migrated outside in zones of radiological contamination since 1979 till 2004. Values for the most heavily contaminated territories were compared vs. control and vs. average values for oblasts and the entire country.

It was established that demographic loss is from the birth rate decrease, excessive mortality, and forced migration of population after the catastrophe in Ukraine. Since 1986 till 2003 urban areas in radioactively contaminated rayons born less on average 8 newborns per one thousand population and in rural areas on average 11 of them. There were on 4 and 2 newborns less, respectively, in control populations. The rate of loss due to unborn children per 1,000 females of childbearing age increased from 8 in 1986 to 76 in 2001, i.e. in 9.5 times. In 2003, 17 years after the catastrophe it amounted to 41.1 per 1,000 females of childbearing age. Values in the control rayon and the

national average were the same and amounted to 14.2 per 1.000 females, i.e. been 3-fold lower. Contribution of females aged 20-29 years to the total value of losses due to unborn was most pronounced. There was "not received" from 39 children (Poltava oblast) to 215 kids (Narodichy rayon) per every thousand in the post-accident period. In Ukraine this index was 15.5.
The post-accident period in Ukraine was characterized by high mortality rates (Omelianets *et al.*, 2007, 2011). Excessive mortality evolved mainly in population of 60 and more years old (86% of total losses). At younger ages, on the contrary, there was a slight increase in saved lives. The greatest decrease in absolute number of deceased children was observed at the age of 1 year (about 3.0 % of total losses). Through 1986-2003 the loss of population of working age (15-59 years) ranged from 7.5 % (Zhitomir oblast) to 12.3 % (Kiev oblast) of the total amount of losses and was lower than in the control rayon (16.8 %) and Ukraine as a whole (18.7 %). This lower level of losses can be associated with a lower proportion of persons in this age group in the population of the affected oblasts.

The greatest loss of population was due to deaths from non-cancer diseases, primarily from diseases of circulatory system. They are responsible for about 40.0 % of female and almost 24.0 % of the male losses. Neoplasms have occupied the second place in structure of losses especially in contaminated rayons. Their contribution to the total loss of population in 1986–2003 accounted for 35.1 % while being 15.9 % in the country as a whole. The major part of human losses from neoplasms occurred in the age group of 45-75 years old. The scale of mortality from external causes became threatening in the post-accident period. Population size and structure have worsened due to the migratory losses. They were within entire period of observation in Zhitomir oblast, at most since 1994 in Kiev oblast, and since 1996 in the control Poltava oblast. In the rayons of radiological contamination losses ranged from 10,400 to 28,300 being only 2,400 in the control population. As a result of intensive outflow of young people, mostly female, the demographic basis of population reproduction was radically compromised in rural areas. Features and peculiarities of demographic losses identified in the most heavily contaminated oblasts suggest to the increasing depopulation there and loss of their labour potential both with deterioration in social, economic and household fields. To resolve these issues the continued recovery of radiologically contaminated territories is required up to the pre-accident condition by the radiation factor. This will provide an opportunity to mitigate social and psychological stress in survivors, strengthen demographic setting for childbearing, and stop chronic exposure to low radiation doses being a basis for the formation of destructive changes in organisms of humans and excessive mortality.

(N. Omelianets)

2.3.7 Vital index of the population

Vitality index i.e. birth-death ratio was used in our research as an integral indicator of health in the RCT population. It is calculated as ratio of births to deaths within a population during a given time. When the value of the index is over five over a year the population is considered viable and has a good ability for reproduction. In case of an index value less than one the population is considered inviable.
Table 2.3.7 shows that since 1990 population of the most intensively contaminated Zhitomir and Kiev oblasts had begun to lose vitality. A year later the overall Ukrainian population had become inviable. The lowest values of vital index were observed in 2001 i.e. on the fifteenth year after the catastrophe. In Zhytomyr and Kiev oblasts this decrease is primarily the result of the drop of birth and increasing of mortality in the most radioactively contaminated rayons as result of the Chernobyl catastrophe. Until the end of 2012 it had never reverted. In Volyn and Rivne oblasts far-field from the accident site the vital index under one occurred since 1995 and 1999 respectively. Years with lowest registered values were virtually the same as nationwide. Twenty years after the disaster it began to return to pre-accident level.

Table 2.3.7 – Vital index of population in the most intensively contaminated oblasts and in Ukraine overall in 1986-2012

Years	Zhytomyr oblast	Kiev oblast	Ukraine	Volyn oblast	Rivne oblast
1986	1.29	1.30	1.40	1.73	1.97
1989	1.04	1.11	1.15	1.49	1.67
1990	0.92	0.95	1.05	1.36	1.49
1991	0.89	0.83	0.94	1.16	1.35
1995	0.68	0.58	0.62	0.92	1.08
1996	0.68	0.57	0.60	0.93	1.03
1997	0.65	0.55	0.58	0.89	1.05
1998	0.60	0.51	0.58	0.89	1.03
1999	0.54	0.46	0.53	0.80	0.94
2001	0.49	0.43	0.50	0.78	0.88
2002	0.50	0.46	0.52	0.79	0.86
2005	0.52	0.51	0.54	0.79	0.88
2006	0.56	0.55	0.60	0.88	0.98
2007	0.59	0.58	0.62	0.91	0.98
2008	0.62	0.65	0.67	0.99	1.05
2009	0.69	0.72	0.73	1.05	1.13
2010	0.69	0.69	0.71	1.03	1.14
2011	0.74	0.75	0.76	1.06	1.24
2012	0.75	0.77	0.79	1.12	1.28

Note. Cell shading delineate areas of population invitality; figures in bold show minimum values during the observation period.

Among the all 74 RCRs a vital index value of more than one in 1986 was in 26% of rayons (Gunko and Dubova, 2012). In 1999 their number decreased almost 3.5-fold. In the eleven RCRs where co-authors and we conduct a research at NRCRM (table 2.3.8) the vital index value in 2012 ranged from 0.47 (Narodichy rayon) to 2.35 (Rokitny rayon).

It was the worst in rayons of Zhitomir and Kiev oblasts. Since 1991 till 2012 the decline was statistically significant ($p<0.05$) in six of them. In Kamin-Kashyrsky, Ivankov, Zarichne, Rokitny and Sarny rayons the decrease was insignificant. The worst indices were in the most intensively contaminates Narodichy and Polesskoe rayons.

Table 2.3.8 – Vital index of inhabitants of radiologically contaminated rural rayons and Ukraine by the size of grouping in 1986-2009

Years	Distribution of rayons according to vital index, %						Vital index
	<0.51	0.51-1.0	1.01-1.5	1.51-2.0	2.01-3.0	>3.0	
Ukraine							
1986	1.9	57.8	24.9	9.4	5.6	0.4	1.04
1990	16.9	61.1	16.4	4.4	1.2	0.0	0.81
2000	65.5	30.2	3.5	0.8	0.0	0.0	0.49
2009	43.5	50.0	5.5	1.0	0.0	0.0	0.64
RCR							
1986	4.1	69.9	9.6	8.2	6.8	1.4	0.98
1990	31.5	52.1	9.6	2.7	4.1	0.0	0.69
2000	78.1	13.7	4.1	4.1	0.0	0.0	0.47
2009	61.7	30.1	4.1	4.1	0.0	0.0	0.57

The data received indicate that there are not only ill-being in population regarding birth rate and mortality rate indices but also the reduction of its vital index due to oligonatality and high mortality.
(N. Omelianets)

2.3.8 Disability

The disability of survivors is a main peculiarity of the health consequences of the Chernobyl catastrophe.

After the Chernobyl catastrophe the examination to evaluate the disability in connection with exposure to ionizing radiation was introduced in the former USSR. In Ukraine the law regulates an establishment of a causal link with the disease and the Chernobyl catastrophe impact (Law of Ukraine, 1991) and the Order of MH (Order MH, 1997; Order MH, 1997a). The list of diseases for which a causal link can be identified with the impact of ionising radiation or other harmful factors in survived adults and children was set by Order (1997a). The Law stated that the relationship of disease and disability is determined regardless of the radiation dose to a survivor. According to the State classification these survivors are attributed to #1 category of Chernobyl disability.

Unfortunately, the problems of disability due to exposure to ionising radiation was considered or concerned neither in national nor in international studies on Chernobyl health effects for 30 years. Most fully this problem is addressed only in the Statistical handbook (2007) and National Ukrainian Report (2011).

Published data suggest the following conclusions:
1. Over the last 29 years there was a constant increase in the number of disabled people from 9,040 in 1992 to more than 100,000 (Table 3.2). Their share among survivors is increasing and now reaches 5.59%.
2. Among persons with disabilities the proportion of survivors, namely evacuees and residents of contaminated territories is increasing in recent years.
3. Among persons with disabilities up to 3,500 disabled children are registered annually. In 2013 there were almost 2,700 of them.

Table 3.2 – Time pattern of the number of Chernobyl catastrophe survivors and persons assigned the #1 category of Chernobyl disability

Parameters	2009	2011	2013	2015
All survivors	2,317,147	2,210,605	2,132,257	2,025,141
Including:				
clean-up workers:	268,003	255,862	243,456	222,498
of these, #1 category (disabled)	66,613	66,489	67,509	63,210
other survivors:	2,049,144	1,954,743	1,888,801	1,802,643
of these, #1 category (disabled)	43,895	46,240	49,249	50,058
Total #1 category (disabled)	**110,508/4.76*)**	**112,729/5.09*)**	**116,758/5.47*)**	**113,268/5.59*)**

Note. *) in the denominator - percentage share in the total number of survivors

4. For all the period after the catastrophe a large number of emergency workers and evacuees live within contaminated territories. Radiation doses to them are not known. Health effects from long-term chronic exposure have not been studied.

5. In recent years the primary tumours, the DCS, and diseases of the nervous system are the considerable cause of disability.
6. Disabled survivors aged less than 40 years are characterised by a large proportion of cases due to malignant neoplasms, DCS, and diseases of the nervous system vs. unexposed disabled persons of this age.
7. The problem of disability in children is insufficiently taken into account within system of evaluation of the Chernobyl NPP accident health affects. The pattern of their disability by cause is different from that in children in Ukraine as a whole.
8. In the national classification of survivors there was one other category – a person being the legal guardian of a child whose parent had died because of the Chernobyl catastrophe impact. We imply here the deaths from diseases caused by the Chernobyl catastrophe or its consequences. According to the government statistics there were 24,024 such cases in 2009; 26,862 in 2010; 28,588 in 2011; 30,599 in 2012; 32,406 in 2013; and 35,033 in 2015. I.e. from 2009 to 2015 their number increased by 11,009 people. Given that cancer is a cause of disability in more than 50% of cases it can be assumed that this disease (cancer) might be the cause of more than a half of all deaths.

(N. Omelianets)

2.3.9 Non-cancer Health Effects

2.3.9.1 Children's health

Health deterioration of the child population is one amongst the most unfavourable biomedical consequences of the Chernobyl catastrophe (Fetisov *et al.*, 2008; Yablokov *et al*., 2009; Stepanova, 2011a). Despite intensive efforts and arrangements on its preservation and restoration, there is a decrease of proportion of the apparently healthy subjects among all population groups of the survived children. There is also a 3.12-fold increase of the crude incidence rate of all diseases in children 0 through 14 years old since the Chernobyl catastrophe (Stepanova, 2011a; Stepanova *et al*., 2011b).

The true reasons of children's health deterioration remain debatable with controversial role of radiation. Largely it is due to a limited application of epidemiological research tools for the available data analysis and improper dosimetric support of both clinical and just epidemiological studies.

Further prospective and retrospective radio-epidemiological studies using the refined whole-body count (WBC) measurements and ecological model dose estimations in conjunction with findings from animal toxicological studies should help to elucidate the possible radiogenic health effects associated with chronic low-dose internal exposure to ^{137}Cs (Jelin *et al.*, 2015). Some epidemiological studies were conducted recently in the field of low-dose radiation impact on the specific body systems in children.

The available data show a statistically significant reduction in red and white blood cell count, platelet count and haemoglobin content along with the ^{137}Cs soil contamination density increase at the place of residence. Over the six-year observation period the hematologic indices were improving. This improvement was more pronounced for the platelet count and less for the red blood cell count and haemoglobin content in children exposed to higher radiation doses born before the catastrophe. There was no interaction with exposure time for the white blood cell count in the 702 children who were born after the catastrophe. The initial exposure gradient persisted in this sub-sample of children. Another study has provided the first longitudinal data analysis for a large cohort of children after the Chernobyl catastrophe. Findings suggest the persistent adverse haematological effects associated with residential ^{137}Cs exposure (Stepanova *et al.*, 2008).

According to study findings, the other research project was expedient using more comprehensive exposure assessment including the individual WBC measurements of ^{137}Cs ($Bq \cdot kg^{-1}$). The cross-sectional study sample examined within 2008-2010 included 590 children in the age of 0-18 years old. Children with higher individual (radio)activity in the body (WBC data) had a significantly decreased haemoglobin content with both lowered erythrocyte and platelet count. Effect of high-incorporated activity on a decreased platelet count was only seen in children over 12 years old. Average by village activity value of ^{137}Cs ($kBq \cdot m^{-2}$) in soil was only indirectly associated with a decreased blood count with accounting the ^{137}Cs body content as an intermediate variable. Children in this study were born at least 4 years after the catastrophe thus being exposed to low doses of ionising radiation from the ^{137}Cs. This cross-sectional study indicated that low levels of radiation exposure might be associated with a decreased blood count. However, we cannot exclude that these results are due to impact of some residual confounding factors (Lindgren *et al*., 2015).

Epidemiological analysis on serum concentration of the main classes of immunoglobulins (IgG, IgA, IgM) in children living in the settlements with different density of ^{137}Cs soil contamination showed a strong correlation of residential soil contamination in 2008 with individual body burden by the ^{137}Cs. Serum IgG and IgM concentrations had increased between 1993 and 1998. Children from the locations with higher ^{137}Cs soil exposure had lower serum IgG levels, which however was increased in a small cohort surveyed between 1997 and 2010. Children within the fourth quintile of ^{137}Cs soil exposure (266-310 $kBq \cdot m^{-2}$) had higher IgM serum concentrations between 1993 and 1998 however with further decline between 1997 and 2010. These findings indicate to the radiation-related alterations of immunoglobulin content, which by itself is not an adverse health effect. Further investigations therefore are necessary to understand how these deviations affect the health status (McMahon *et al.*, 2014).

Decreased content of the main classes of immunoglobulins, imbalance of immunoregulatory T-cell subpopulations, and depressed phagocytic activity of neutrophilic granulocytes with secondary immunodeficiency onset in children living on contaminated territories were stated by various researchers (Sheikh Sajjadieh *et al.*, 2010; Sheikh Sajjadieh *et al.*, 2011; Kolpakov *et al*., 2011; Stepanova *et al.*, 2010; Baleva *et al.*, 2011)

Taking into account a significant protective role of IgA at the respiratory mucous membranes the children and adolescents with low level of IgA were considered at a high risk of respiratory diseases with an appearance of pulmonary disease which steady increase was observed along the post-accident period (Stepanova *et al.*, 2003).

Predisposition to prolonged natural history of a disease is noticeable along with an increased incidence of respiratory disorders in the survived children. Bronchial hyperresponsiveness, abnormal function of pulmonary surfactant system, activation of free-radical reactions, and depression of local protective factors in respiratory organs revealed in child population of contaminated territories is the basis for that. Assay of the fatty acid content by the gas liquid chromatography in an expired breath condensate (EBC) revealed the lipid peroxidation process against a background of a depressed antioxidant properties of pulmonary surfactant and metabolic disorders of polyunsaturated fatty acid at the stage of the bioregulator-eicosanoid formation (Parkhomenko *et al.*, 2012).

Epidemiological analysis showed that children living in villages with soil ^{137}Cs contamination at the highest quintile were 2.6 times more likely to have a forced vital capacity (FVC) <80% of predicted value [95% confidence interval (CI), 1.07-6.34] and 5.08 times more likely to have a ratio of forced expiratory volume in 1 sec (FEV1) to FVC <80% (95% CI, 1.02-25.19). We have found a statistically significant evidence of both airway obstruction (FEV1/FVC %, peak expiratory flow, and maximum expiratory flow at 25%, 50%, and 75% of FVC) and restricted forced vital capacity correlating with an increasing soil ^{137}Cs contamination (Svendsen *et al.*, 2010).

In 2008-2010, a consecutive cross-sectional study conducted in the same pediatric population used whole body burden of ^{137}Cs as a refined measure of the individual exposure. The decrements in percentage predicted the FEV1/FVC ratio and an increased odds of bronchodilator responsiveness, restrictive impairment, and FVC less than lower limit of normal were associated with a log increase in weight-adjusted ^{137}Cs whole-body burden. Thus, children in the region just outside of the Chernobyl contamination zone continued having radiation-related respiratory disorders as recently as in 2010 (Svendsen *et al.*, 2015).

These disorders were combined with some abnormal indices of non-respiratory lung function such as reduction of respiratory moisture and aerosol excretions from respiratory organs being accompanied by a falling concentration of superficial active substances from pulmonary surfactant and by a decrease in phospholipids and total lipids in its content. Intensification of oxidative free-radical processes in the EBC was revealed. It is evident from the rise of a light sum indices and amplitude of instantly flash-initiated chemiluminescence of EBC. Inhibition of antitrypsic EBC activity indicating a decrease in the local respiratory protection was established (Parkhomenko *et al.*, 2008; 2009; 2010).

Functional abnormalities of cardiovascular system were revealed in the 40.0% of children exposed to ionizing radiation on the contrary to the 14.5% ($p<0.05$) in the control group. The sinus tachyarrhythmia was registered on the ECG in 32.0% of cases, bradyarrhythmia – in 45.0%, signs of moderate and pronounced metabolic disorders in the heart muscle – in 42.4% and 3.8%, respectively. Data from rheographic studies of the regional hemodynamics were characterised by the signs of dystonia and presence of venous stasis often with blood flow interhemispheric asymmetry, pronounced tendency to increased vascular tone, decreased pulse rate and rate of arterial circulation in the extremity vessels. Decreased stroke and minute volumes of blood, significant incidence of hypotonic (22.3%) and dystonic (31.5%) reactions to a physical loading, more intensive and less efficient work of ventilation apparatus both with reduction of some efficiency indices were established in a "steady condition" by assessing the indices of the central hemodynamics and external respiration using dosed physical load of the average intensity. The increase of oxygen debt (by 14.8%, $p<0.05$), total oxygen inquiry to work (by 22.6%, $p<0.01$), periods of restoring to the initial indices of pulmonary ventilation (by 18.6%, $p<0.02$), and oxygen consumption (by 20.1%, $p<0.01$) after loading were indicative of that (Stepanova *et al.*, 2011b).

Autonomous neural regulation of cardiovascular system in children of both major groups differed by the insufficient input from sympathoadrenal system during a physical exercise that can be attributed to characteristic features of vegetative homeostasis in this period (Kondrashova *et al.*, 2014a).

Some experts consider the abnormal pathways of health deterioration with an increased incidence of multifactor disease from the following points. According to contemporary opinions, the cell nuclei and membranes are the most sensitive targets for ionising radiation. The free-radical pathways are activated under the radiation impact leading to origination of the active toxic oxygen species. Lipid peroxidation is a key link between a radiation impact and damage to membranes with disorders of their structure and functions (Vartanian *et al.*, 2010).

Cellular capacity for a specific function is closely related to the properties of its surface. Radiation exposure induces numerous structural displacements in cellular membranes that remain for a long time upon irradiation episode and lead to the functional cellular disorders (Benderitter *et al.*, 2003).

The red blood cells being ontogenically and phylogenically linked to many tissues originated from mesenchima represent a universal model for evaluation of the impact of a range of factors including radiation on cellular membranes. All that provides considering the superficial erythrocyte membrane as the most available study subject reflecting the state of cellular membranes is the organism.

A decrease of discocyte number with an increase of pre-haemolytic and degenerative forms was observed in children residing in radiation-contaminated territories. A concavo-concave discoid shape of normal erythrocytes i.e. discocytes is optimal for the gaseous exchange. Structural abnormalities of superficial membrane in erythroid cell population were most pronounced in a group of children having the incorporated ^{137}Cs level from 6845 to 16522 Bq (Stepanova *et al.*, 2013a).

Abnormal shape and surface relief of superficial erythrocyte membrane is a sign of membrane destabilisation not only in these cells but a reflection of cellular membrane damage in a body as a whole.

Significant disorders of submicroscopic organisation of intracellular organelles especially of mitochondria in circulating lymphocytes are established. The most expressed abnormalities were found in children having the incorporated ^{137}Cs level exceeding 6845 Bq. Structural and dimensional variability of mitochondria was noted both with an increase of the condensed-type mitochondria number and a decreased number of organelles of a canonical configuration. Appearing of the giant forms was specified. Swollen mitochondria, unclear outer membranes, unclear mitochondrial cristae with their abnormal orientation, and pallor or homogenisation of some organelle matrix were observed. Sometimes mitochondria with an almost disordered structure were found (Stepanova and Litvinets, 2013b).

Impact of ionising radiation gives place to mDNA damage, 80-90% activity decrease of key enzymes of mitochondrial energy metabolism, and leads to enzymatic activity dyscoordination in the Krebs cycle and glycolysis. Secondary mitochondrial failure occurs being attributed to disorders of cellular bioenergetics. Pathogenetic pathways of mitochondrial diseases induced by ionising radiation are represented by the organ and tissue functional incapacity stipulated by the lack of energy (Beregovskaya and Maiboroda, 1995; Gritsuk *et al.*, 2002).

A suppressed activity of cellular succinate dehydrogenase is a cytochemical marker of abnormal mitochondrial energy production, whereas an increased serum lactate level and abnormal ratio of lactate to pyruvate are the biochemical markers here.

Some efforts are applied to elucidate the pathophysiological pathways of these disorders. It is believed that a launch of the free-radical oxidation and lipid peroxydation under the impact of unfavourable environmental factors including radiation are the trigger for such effects. It was shown that the consequences of a low-dose radiation impact on human are of systemic (syndromic) nature possibly sharing some mutual pathogenetic pathways linked to mitochondrial activity (Kovalenko and Kovalenlo, 2008).

Thus, the review of available literature data for the recent years indicates that low doses of ionizing radiation received after the Chernobyl catastrophe can lead to dysfunction of some organs and body systems and give place to deterioration of children health. The latter is characterized by a decreased number of apparently healthy children in population and respective increase of number of children with chronic somatic diseases.

(E. Stepanova, S. Igumnov)

2.3.9.2 Diseases of the Circulatory System

The results of health monitoring in survivors testified the graceful deterioration of their health. According to the annual health check-ups since 1988 till 2010 the number of healthy persons among clean-up workers in Ukraine decreased from 62.0% to 3.1%, among the adult evacuees from 67.7% to 18.7%, and among all the inhabitants of RCT from 41.3 to 12.3%. The proportion of clean-up workers with chronic diseases increased from 12.8 to 83.1%, and of evacuees from 31.5 to 80.3% (Health indicators, 2010).

Studies conducted at the NNCRM (Buzunov et al., 2010, 2011a; Pirogova et al., 2010; Voychulene, 2011; Krasnikova et al., 2013) on survivors registered in the SRU and Clinical and Epidemiological Register (CER) only for NNCRM indicated the increased incidence of DCS in the clean-up workers and evacuees. The highest incidence levels were recorded 12 to 22 years after the exposure. In RCT residents the level had increased within first 10 years.

The epidemiological studies proved a relation between these diseases and external radiation doses in a range of 0.05-1.0 Gy. The greatest risks were established in the clean-up workers who were exposed at the age less than 40 years. Risk levels and RR excess were found at doses of 0.25-0.7 Gy.

A link of an increased incidence of disease in the cohort of RCT residents with accumulated radiation doses in the range of 21-50 mSv for the period from 1988 to 2010 was also credible.

The data obtained are to some extent consistent with the results of health monitoring in Hibakusha i.e. the A-bombing survivors in Japanese cities of Hiroshima and Nagasaki (Shimizu et al., 2010; Preston et al., 2003). Previously an increased incidence of DCS was observed in the clean-up workers residing in Russia (Ivanov et al., 2006).

Using the pooled data on morbidity and mortality we can recognise that impact of ionizing radiation due to the Chernobyl catastrophe was the cause of DCS in the clean-up workers, evacuated adults and adult residents of RCT. Morbidity and mortality occur in survivors at a younger age than in the entire population.

(N. Omelianets)

2.3.9.3 Neuropsychiatric effects

The opinions on the point of genesis of the Chernobyl neuropsychiatric aftermath are extremely controversial. At the same time, the cerebral effects of low doses of ionizing radiation, especially the cerebrovascular disease and cognitive impairment are in the focus of research interest worldwide (Bazyka *et al.*, 2013a, b, 2014; Loganovsky, 2012, 2013). This sub-chapter is an overview of the recent *peer reviewed* publications and proceedings of international conferences and evidence-based studies on neuropsychiatric effects of the Chernobyl. There are recognised ones among them and also those not been fully recognized by the International community.

An increasing pool of data supports the radiosensitivity of the central nervous system (CNS). There are several mechanisms of radiocerebral effects, namely the disrupted neurogenesis in the hippocampus, changes in the gene expression profile, neuroinflammatory response, neurosignaling alterations, apoptotic cell death, cell death and injury mediated by secondary damage, "glial-vascular union", etc. At the same time, the cortical-limbic system is a target for the radiation brain damage where hippocampal neurogenesis dysfunction is crucial (Loganovsky, 2009, 2012; Marazziti *et al.*, 2012; Picano *et al.*, 2012).

It is axiomatic that the developing brain is extremely radiosensitive. The problem of brain damage *in utero* as a result of the Chernobyl catastrophe is highly discussible. An extrapolation of the Japanese atomic bombing experience and the general medical radiological experience on radiological accidents at the Chernobyl NPP and probably at Fukushima Daiichi NPP also is incorrect because of presence of internal prenatal exposure to radioiodine in these nuclear accidents.

The World Health Organization (WHO) in 1992–1995 implemented a pilot project «Brain Damage in Utero» within «International Program on the Health Effects of the Chernobyl Accident» (IPHECA). Analysis of the results in Belarus, the RF and Ukraine showed the following facts: 1) prevalence of mild mental retardation in children exposed *in utero* is higher than the same in the control groups; 2) increasing trend in the incidence of emotional and behavioural disorders in children exposed *in utero*; 3) increased prevalence of borderline neuropsychiatric disorders in parents of prenatally exposed (WHO, 1996). However, these results have not been definitely recognized internationally. Possible relation of neuropsychiatric effects and doses of prenatal exposure remained unstudied, whereas the assessment of mental health of children exposed *in utero* and aetiology of neuropsychiatric disorders revealed in them is still contradictory.

In this regard a thorough research was performed in Ukraine in 1998–2004 within the framework of the French-German Initiative for Chernobyl, looking at potential effects of prenatal exposure on the brain. The 154 children born between 26 April, 1986 and 26 February, 1987 to mothers evacuated from the city of Pripyat to Kiev, and 143 of their classmates were examined. Among children of Pripyat there were 52 (33.8%) persons with equivalent dose to the thyroid gland *in utero* >1 Sv, and 20 (13.2%) of them had a dose of fetal exposure >100 mSv. In the prenatally exposed examined children no cases of severe mental retardation or microcephaly were found. A significantly increased incidence of abnormal psychological development, emotional-behavioural and organic mental disorders and paroxysmal states were diagnosed in them. In prenatally irradiated children the full scale of intellectual quotient (IQ) was lower due to lower values of verbal IQ, which caused higher frequency of disharmonious intelligence. When a disharmony of IQ (nonverbal IQ - verbal IQ) in the prenatally exposed children exceeded 25 points it was correlated with fetal irradiation dose. Mothers of both groups had similar verbal abilities, however, the evacuees experienced a significantly greater real stressful events, having higher level of depression, posttraumatic-stress and somatoform disorder, anxiety, insomnia and social dysfunction (Nyagu *et al.*, 2004).

According to Bromet *et al.* (2011) the very young children and those exposed *in utero* who lived near the plant when it exploded or in severely contaminated areas have been the subject of intensive research, but the findings are inconsistent. Recent studies of prenatally exposed children conducted in Kiev (Nyagu *et al.*, 1998, 2004; Loganovskaja, Loganovsky, 1999; Loganovsky *et al.*, 2008, 2012; Loganovsky, 2015), Sweden (Almond *et al.*, 2007), Finland (Huizink *et al.*, 2008), and Norway (Heiervang *et al.*, 2010) found out the specific neuropsychiatric impairments associated with radiation exposure *in utero* that could increase the risk of neurodevelopmental disorders.

In prospective studies conducted in Ukraine the disharmony of intelligence due to the lowering of verbal IQ appears to be a radioneuroembryological effect of prenatal exposure as a result of accident at a nuclear reactor. We suggested already in our first studies a prevailing violation of the dominant left cerebral hemisphere, especially its cortical-limbic structures, in children irradiated *in utero* as a result of the Chernobyl accident (Loganovskaja, Loganovsky, 1999). Later we came to conclusion concerning a disrupted development of the left (dominant) brain hemisphere after prenatal exposure from the Chernobyl disaster (Loganovsky *et al.*, 2008, 2011; Loganovsky, 2012, 2015; Loganovsky and Loganovskaja, 2013).

In the Ukrainian-American prospective studies in about 300 exposed persons and their 300 non-exposed classmates they have found neither neurobehavioral nor cognitive disorders in persons exposed *in utero* in Ukraine (Bromet *et al.*, 2000, 2011; Litcher *et al.*, 2000; Taormina *et al.*, 2008; Bromet, 2015), as well as in Israel study of the prenatally exposed immigrants from the former USSR to Israel (Bar Joseph *et al.*, 2004). Much more negative self-evaluations of the evacuees were linked to a number of risk factors, including multiple hospitalizations, health risk perceptions, and epidemiologic risk factors. The increased rate of thyroid cancer and other diagnoses no doubt contributed to the evacuees' less positive subjective health. The strong effect of the mothers' perceptions argues in favor of developing of the risk communication programs for families rather than for mothers or adolescents as separate target groups (Bromet *et al.*, 2009). However, neither individual radiation doses *in utero* estimations, nor verbal intellectual abilities assessments were applied in these studies.

In Belarusian prospective mental health studies of the 250 prenatally exposed vs. 250 non-exposed persons at the age of 6–7, the prenatally irradiated children had lower averaged full IQ and low IQ (80–89) rate excess. However, at the age of 10–12 and 15–16 years old there were no statistically significant differences between IQ in exposed and control groups. No statistically significant correlation was found in the exposed group between individual thyroid dose *in utero* as well as individual antenatal external dose and IQ at the age of 6–7, 10–12, and 15–16 years old. However, a sub-group of persons with the highest external antenatal doses (more than 30 mGy) has relatively lower mean full IQ vs. the whole exposed group at the age of 6–7, 10–12, and 15–16 years. An increased risk of emotional disorders also was found in the exposed group. Visual characteristics of electroencephalograms (EEG) in both examined groups did not differ significantly (Igumnov, 1996, 2001, 2009, 2015; Kolominsky *et al.*, 1999; Igumnov, Drozdovitch, 2000, 2002, 2004).

In Belarus they have come to conclusion that a decisive role in the origin of borderline intellectual functioning and emotional disorders in prenatally exposed children was played by the unfavourable socio-psychological and socio-culturological factors (Igumnov, 1996; Kolominsky *et al.*, 1999; Igumnov, Drozdovitch, 2000, 2001, 2002, 2004), although the average IQ of the most exposed ones (with doses to the thyroid *in utero* >1 Gy) was lower compared to all other exposed children (Igumnov, Drozdovitch, 2000). Moreover the neurophysiological abnormalities in prenatally exposed persons in Belarus were normalized and their EEG did not differ from the non-irradiated controls (Igumnov, 2001, 2009). They came to conclusion that the borderline intellectual functioning and emotional disorders in the exposed group of children are due to unfavourable psychosocial and sociocultural factors such as a low educational level of parents, break of microsocial contacts and difficulties of adaptation, which appeared in the wake of evacuation and relocation from the contaminated areas. However, the hyperkinetic disorders, disorders of scholastic skills and borderline intellectual functioning at a junior school age could be regarded as significant predictors of stable conduct disorders at adolescent age (Igumnov and Drozdovitch, 2002). Thus the cognitive and mental disorders in prenatally exposed residents of Belarus are attributed mainly to the social and psychological factors (Igumnov, 2015).

The radiation risks of cerebrovascular disease in liquidators were reported at radiation doses >0.15 Gy (Ivanov, 2007). Radiation risks of mental disorders and cerebrovascular disease including the mortality from stroke in liquidators were found at doses >0.25 Gy (Buzunov *et al.*, 2011a). There is a significantly increased level of mental and behavioural disorders, vascular dementia, alcohol abuse, dysthymia and PTSD in liquidators and evacuees. Liquidators have an increased incidence of organic mental disorders, namely depressive, anxiety, emotional labile (asthenic), and personality ones (Loganovsky *et al.*, 2011). Prevalence of alcohol dependence syndrome and alcohol abuse is significantly increased in liquidators (Postrelko *et al.*, 2013; Laidra *et al.*, 2015). These syndromes develop secondarily as a result of the already arisen mental disorders (Postrelko *et al.*, 2013).

Cognitive impairment induced by ionizing radiation is a paramount neuropsychiatric effect. Experimental exposure to low radiation doses (0.2–0.6 Gy) of rats has proved a resulted severe neurocognitive hippocampus-dependent deficit (Britten *et al.,* 2012). Postradiation cognitive disorders mainly at the level of Mild Cognitive Impairment (MCI) have been constantly reported in liquidators (Zhavoronkova *et al.,* 1998, 2006, 2012; Polyukhov *et al.,* 2000; Turuspekova, 2002; Antipchuk, 2004; Gamache *et al.*, 2005; Antypchuk *et al.*, 2008; Loganovsky, 2009, 2012, 2015; Loganovsky *et al.,* 2009, 2009a, 2015, 2015a; Volovyk *et al.,* 2010; Bazyka *et al.*, 2013a, b, 2014; Krasnov *et al.*, 2015) and the Acute Radiation Sickness (ARS) survivors (Antypchuk, 2003; Loganovsky and Zdorenko, 2012).

The neurocognitive deficit in the Chernobyl catastrophe survivors with PTSD is higher than that in Afghanistan war veterans. The “postradiation” PTSD is characterized by a projection of fear and insecurity about the future (“anticipatory stress”) concerning cancer, congenital malformations in the descendants, etc. The risk of stroke and atherosclerosis is increased in liquidators with PTSD, as well as dysfunction of neocortex, hippocampus, and deep cerebral structures (Loganovsky and Zdanevich, 2013).

A significant number of consistent studies was recently published on the neurophysiological (Zhavoronkova *et al.,* 1995,1998, 2006, 2008, 2010, 2012; Loganovsky and Yuryev, 2001, 2004; Loganovsky *et al.,* 2011; Denisuk, 2004; Mel’nikova *et al.,* 2010), neuropsychological (Zhavoronkova *et al.,* 1998, 2006, 2008, 2010, 2012; Polyukhov *et al.,* 2000; Turuspekova, 2002; Antypchuk, 2004; Gamache *et al.*, 2005; Loganovsky *et al.*, 2009a, b, 2011; Loganovsky and Zdorenko, 2012), neuroimaging (Bomko, 2004; Kholodova *et al.*, 2007; Kholodova, Zhavoronkova, 2011) and neuroimmune (Bazyka *et al.*, 2013a, b, 2014) deviations in liquidators in whom as a whole the organic brain damage was verified. Summarising the results of these studies it should be emphasized that various authors independently found the comparable and/or even the same evidences of neurocognitive deficit, cerebrovascular disease, and accelerated aging of the CNS in liquidators of the Chernobyl accident.

The radiation-induced neuropsychiatric effects include accelerated aging and neurodegeneration (Polyukov *et al.*, 2000; Bazyka *et al.*, 2004; Kholodova *et al.*, 2007) which could be associated with cell senescence and telomere changes (Bazyka *et al.*, 2013a, 2014). Polymorphic disorders in the clean-up workers cohort, which fit into the concept of psycho-organic syndrome, are based on the multifactorial aetiology and specific pathogenesis with the influence of biological, psychological, and social factors. The complex of these factors leads to early onset of cerebrovascular disease that manifests as a variety of symptom-complexes with the core symptom-complex of cognitive impairment (Krasnov *et al.,* 2015). Moreover, the demyelinating disorders of the nervous system including multiple sclerosis in exposed people should be constantly monitored. Preliminary data testify to the excess of multiple sclerosis in population of the most RCT in Ukraine (Kolosinskaja, 2011).

The dose-related cerebral abnormalities following an exposure to >0.3 Gy doses and radiation brain markers at doses >1 Gy (Acute Radiation Sickness) were revealed by the NRCRM staff (Loganovsky and Yuriev, 2001, 2004; Bomko, 2004; Denisuk, 2006; Loganovsky *et al.*, 2011; Loganovsky, 2012, 2015;). We had proposed the cortical-limbic dysfunction in the dominant hemisphere as an important cerebral mechanism of neuropsychiatric effects following exposure to radiation (Loganovsky and Loganovskaja, 2013) that has been independently confirmed by the fact of cognitive auditory event-related potentials impairment in liquidators (Zhavoronkova *et al.*, 2010, 2012). At the same time some other authors (Mel’nikova *et al.*, 2010) believe that dysfunction of the left hemisphere is only the first step in the development of psycho-organic syndrome in liquidators.

Loganovsky and Loganovskaja (2000) suggested a possible role of ionizing radiation in the genesis of schizophrenia spectrum disorders. Exactly due to the left-hemispheric fronto-temporal dysfunction and shizotypal features on the base of the diathesis-stressor hypothesis it was proposed that ionizing radiation could be a risk factor for schizophrenia spectrum disorders (Loganovsky and Loganovskaja, 2000; Loganovsky *et al.*, 2005) that is still at issue. However, recently the radiation exposure of adults was considered a new model of schizophrenia (Iwata *et al.*, 2008) and the same have been shown in experimental radioneuroembryological schizophrenia models (Korr H. *et al.*, 2001) including the nonhuman primates (Schindler *et al.*, 2002; Selemon *et al.*, 2009; Friedman and Selemon, 2010; Selemon and Friedman, 2013).

Loganovsky (2000) first suggested the Chronic Fatigue Syndrome (CFS) as a characteristic after-effect of radio-ecological disaster. Currently, the National Chronic Fatigue Immune Dysfunction (CFIDS) Syndrome Foundation (NCF, USA) has officially the link between CFS and radiation exposure in low doses (http://www.ncf-net.org/PressReleases.htm#nal). A prospective study of personnel working on transformation of the Chernobyl NPP Object “Shelter” into an ecologically safe system showed that exposure to radiological (0–56.7 mSv, M±SD:19.9±13.0 mSv dose) and industrial risk factors may lead to the onset of cognitive CFS characterized by a dysfunction of cortical-limbic system mainly in the dominant (left) hemisphere with an important involvement of hippocampus. An effect of selection of the “radiation resistant worker” was found. That is the individuals who have been earlier exposed to radiation with no any health consequences were more resistant to further irradiation (Perchuk, 2010; Loganovsky *et al.*, 2015, 2015a).

Thus, radiation exposure has multiple effects on the brain, behaviour and cognitive functions. These changes depend largely on the radiation dose.

Summarising, the mental health and neuropsychiatric consequences of the Chernobyl catastrophe could be outlined as follows: 1) psychological and psychosomatic disorders; 2) long-term disturbance in mental health including the alcohol abuse; 3) celebrovascular and other organic diseases of the CNS, 4) cognitive disorders; 5) effects on the developing brain; 6) potential radiocerebral effects, 7) CFS, 8) suicides. Further prospective psychological-psychiatric and neuropsychiatric studies with an advanced dosimetric support on the base of analytical epidemiology are urgent (Loganovsky, 2015).

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

Further studies on biological mechanisms of low-dose related cerebral effects in Chernobyl survivors with the radiation doses verification are necessary.

(K. Loganovsky)

2.3.9.4 Genetic effects

Issue of genetic effects in the first and further generations of descendants of the exposed parents is even more challenging and yet unsolved.
Exposure to radiation in pregnancy after the A-bombing in Hiroshima and Nagasaki had led to no increase of congenital malformations of dysplastic nature in children. However, there was an increased incidence of somatic and mental retardation mainly in those exposed at the gestation

terms of 8 to 15 weeks. Mental retardation was accompanied by a small head size in some children (Otake and Schull, 1998).
No reliable evidence of genetic abnormalities in suffered children population is stated in the conclusions of the Chernobyl Forum (Chernobyl's Legacy, 2006.).
Contrary to the above-mentioned statement the epidemiological study by Wertelecki et al. (2014) has shown one of the highest incidence of neural tube malformations in Europe, blastopathy, microcephaly, and microphthalmia (Yuskiv et al., 2004) in children born on contaminated territories in Ukrainian Northern Polessye (Rivne oblast). The available results are sufficient to justify the continuation and expanding of studies on malformations in regions of chronic low-dose radiation impact in Ukraine.
To assess possible mutagenic and teratogenic effects of environmental factors including ionizing radiation, it is proposed to study the incidence of congenital birth defects, sentinel phenotypes, and minor birth defects as well (Stepanova et al., 2007).
It has been established that the exposure to radiation during organogenesis leads to development of morphogenetic variants with minor birth defects. The younger the gestational age and the higher the radiation dose, the more minor developmental abnormalities are presented in a child (Stepanova et al., 2007).

Results of cytogenetic studies indicate the increased incidence of stable and unstable chromosome-type aberrations in children residing on the contaminated territories of Ukraine. The incidence positively correlated with level of radioactive contamination and radiation dose to the fetal bone marrow (Pilinskaia et al., 2011; Stepanova et al., 2002).

Phenotypes of children born upon father’s participation in the clean-up work after the Chernobyl catastrophe featured multiple small developmental abnormalities in association with a complex of signs characterizing the connective tissue dysplasia syndrome. More than half of them have had the syndrome of heart structures connective tissue dysplasia (HSCTD) with a broad spectrum of minor developmental abnormalities. The prolapse of mitral and tricuspid valves, and abnormal left ventricular chords were most prevalent at that.

Children suffering HSCTD had mainly a dysplastic type of somatic development i.e. the asthenical organization of the body with poor muscular development (Kondrashova et al., 2014).

In the study by Dubrova et al. (1996) the frequency of mutations in children born in heavily contaminated areas of the Mogilev oblast in Belarus after the Chernobyl catastrophe was found twice as high as in the control group. Mutation rate in families from the Mogilev province correlated with the level of ^{137}Cs soil contamination being consistent with radiation induction of germline mutations.

Similar data were received within examination of the family members in the region of Techya River (Dubrova et al., 2006).

Increase in 5.6 times of mutation rate in microsatellite DNA fraction was registered in children born in families of the Chernobyl clean-up workers after the accident vs. their older brothers and sisters born before father’s participation in the Chernobyl catastrophe clean-up works (Weinberg et al., 2001).

Radiation disorders induced in parental germ cells can be revealed in descendants at various stages of ontogenesis. The “small” mutations persisting in heterozygous state and giving place to the hereditary structures destabilization are presumably realized in the postnatal period. Vorobtzova (2006) predicted this phenomenon being the basis of the so-called “physiological inferiority” and decreased vital capacity of descendants of exposed parents. Multiple dismorphic abnormalities, visceral dysplasia, and increased incidence of chromosome aberrations and mutations of microsatellite DNA-fraction can be the consequences of inherited genome instability in descendants of irradiated persons (Barber et al., 2006). All that predispose to disorders of adaptation to existing conditions, increased risk of development and realization of multifactor disorders, and health level decrease in children born from parents exposed to ionizing radiation.

Nowadays the possible pathways of trans-generational instability are studied and extensively discussed. The possibility to predict the genetic consequences of radiation impact on human, the goal of genetics for the last five decades, is however far from reality. Nevertheless, just now they suppose that the trans-generational instability can increase the cancer risk and risk of congenital malformation in offspring. Possibly due to the progress in the new contemporary technologies some answers will be found to the numerous yet unclear questions and issues associated with the development of unfavourable effects in children exposed to low-dose ionizing radiation and children born from the exposed individuals.

(E. Stepanova, S. Igumnov)

3 REHABILITATION

3.1 Ukraine

In recent years the governing authorities of oblasts, which suffered from the Chernobyl catastrophe, have continued to implement the measures to mitigate its consequences. Main attention was focused on radiological, social, and economic rehabilitation of the contaminated territories. The purpose was to return them to a normal life, to provide people with work and create the opportunities for the towns, cities, settlements and citizens to realize their economic potential.

Realisation of the measures mentioned above was conducted in Ukraine according to the «State Program on liquidation of consequences of the Chernobyl catastrophe for 2006-2010» (Program 1 Ukr, 2006). This program was mainly focused on the completing of the process of economic recovery of the inhabited territories outside the exclusion zone and other settlements and locations heavily populated with evacuated people in order to realize further social, medical and psychological rehabilitation and radiation protection. The scheduled measures also included the financing from the state budget, development of legal background for the solution of rehabilitation issues, as well as the increase of the radio-ecological knowledge level and informing/education of population and staff that conduct measures on liquidation of consequences of the catastrophe. The framework of the program also included elaboration of the State program of rehabilitation of contaminated territories.

Unfortunately this program was not fully realized (Recommendations, 2012). It was stated by the Parliament of Ukraine that the Cabinet of Ministers of Ukraine had introduced no projects on the following:
- creation of legal mechanisms to stimulate the steady development of contaminated territories;
- intensification of industrial activity and increase of their investment attractiveness;
- solution of the problems of complex social and economic development of the territories and places of compact residence of evacuated of people;
- launch of agricultural production on these territories;
- providing survivors with housing.

Supplying the radiologically safe agricultural products, restoration and development of traditional branches of agriculture on contaminated territories has not been provided. No work has been done on the budget program "Radiological protection of the population and ecological improvement of sanitary conditions of the territory exposed to the radioactive contamination". Since 2008 no works have been financed on soil lime treatment, and since 2009 – on radiological examination of lands, evaluation of efficiency of counter measures, special programmes in stock-raising, purchasing the equipment for radiological control, its repair and maintenance, fire-prevention measures in forests, dosimetric monitoring. Nowadays the liquidation of the consequences of the catastrophe has been conducted outside the state program framework. The CMU has submitted no draft for the review by the Parliament of the State program of liquidation of the consequences of Chernobyl catastrophe for 2012-2016, and later for 2014-2018. Deadline of the final submission of the project was repeatedly postponed and the last date was in May, 2013. However, there is no Program up to now.

There is no long-term strategy for liquidation of the consequences of the Chernobyl catastrophe in Ukraine yet. Some issues of the further measures on liquidation of the consequences of the catastrophe are outlined in Recommendations (2015). In particular, it was recommended that the CMU should submit for consideration to the Parliament the draft of the State program for

overcoming the consequences of the Chernobyl catastrophe for 2016-2026. The following measures are envisaged for consideration there:
- improvement of health care and sanitary conditions of people survived after the Chernobyl catastrophe as well as providing them with medicines;
- complex social and economic development of the territories, which were exposed to radioactive contamination and places of compact residence of evacuated people;
- providing the catastrophe survivors with housing;
- monitoring the radiological consequences of catastrophe, manufacturing of radiologically safe agricultural products;
- radiation protection of population and ecological improvement of sanitary conditions of territories exposed to the radioactive contamination;
- informing the citizens on the issues of radiation conditions at the territories;
- providing of scientific research works and information systems.

It was also suggested that some amendments should be introduced to the laws in connection with the liquidation of the zone of the intensive radio-ecological control with respect to the requirements of the State hygienic norms “Radiation Safety Standard of Ukraine_97” (RSSU_97) and the results of dosimetric passportization of populated areas. Unfortunately, up to November 1, 2015 no decision has been adopted on the official level of Ukraine on the measures for the 30-th anniversary of the Chernobyl catastrophe.

Taking into account all the stated above it is to be supposed that the liquidation of the Chernobyl catastrophe consequences in Ukraine will take the indefinitely great while.

(N. Omelianets)

3.2 Belarus

The existing health programmes in Belarus, Russia and Ukraine are different for the convalescents of acute radiation sickness, clean-up workers, population of contaminated territories, and the entire population.

To realise these goals the Council of Ministers has adopted two government programs in Belarus. On 11.01.2006 the Council of Ministers of the Republic of Belarus approved the State program for 2006-2010 (Program 1 Bel, 2006). It was aimed at the socio-economic and environmental rehabilitation of radio-contaminated territories, creation of conditions for economic activities without restrictions by the radiation factor and further reducing of the health risks.

The medical part of the Program was aimed at a special healthcare supervision (clinical examination) of about 1,300,000 people affected by the disaster including about 260,000 children. This population is under the control for malignant tumours of the thyroid gland, nodular and multinodular goitre, malignant tumours of respiratory tract organs, breast, and digestive system. The function of the State Register was provided within Program framework by filling it with data on health state of the survived population.

The implemented sub-program "Children of Chernobyl" within the Presidential program "Children of Belarus" covered the health resort treatment and rehabilitation of the survived population.

On December 31, 2010 the Council of Ministers of the Republic of Belarus issued a Resolution #1922 approving a new State Program for 2011-2015 and for the period up to 2020 (Program 2 Bel, 2011). Its objectives are to reduce further the risk of adverse health effects in the Chernobyl catastrophe survivors, facilitate the transition from rehabilitation of territories to their sustainable economic and social development with the obligatory provision of radiation safety requirements.

By the end of 2014 there were 1,600,000 people, including 261,500 children and adolescents (0-18 years old) under a special healthcare supervision (outpatient check-up) in healthcare institutions of Belarus. During the year 2014 the 1,500,000 people were examined, including 261,500 children and adolescents. The costs for the health check-ups of population amounted to 647,8 billion Roubles of the National Bank of Belarus (about 43,200,000 US Dollars at the exchange rate in 2014). The number of citizens involved in the local programs of health rehabilitation is about 89,800 including 81,500 children (Bashilov *et al.*, 2015). The State Registry branches are launched in 207 healthcare institutions of Minsk city and regions with a total number of 278,800 registered people (Program 2 Bel, 2011).

According to the Resolution of the Council of Ministers of the Union State of December 13, 2013, N^{o} 21, the Program of joint activities to overcome the consequences of the Chernobyl disaster for the period until 2016 was approved within the framework of the Union State of Russia and Belarus activities (Program 3 Bel, 2016).

The objective of the Program is to improve the overall policy on life safety of citizens of Belarus and Russia who were exposed to radiation as a result of the Chernobyl catastrophe as well as the quality of life of the people living within contaminated territories; and to ensure a cooperation between Russia and Belarus in case of emergency response at the contaminated territories. For this purpose keeping with the Unified Chernobyl Register of Belarus and Russia the joint study group was formed from citizens of Russia and Belarus with high radiation risk of various radiation-induced diseases. The uniform standards for diagnosis and treatment were developed.

Despite a large scope of work conducted in Belarus, the consequences of the Chernobyl catastrophe are not yet eliminated. As of January 1, 2010 the area of farmland contaminated with ^{137}Cs was 1,021,200 hectares of which 350,600 hectares also contaminated with ^{90}Sr. From 2000 to 2010 the area of such land has decreased by 21% (from 1,297,000 to 1,021,200 hectares). The total area of contaminated territories of Ukraine, Belarus and Russia is 145,000 km^2. The 1,400,000 people including 222,800 children and adolescents affected by the Chernobyl catastrophe are under a special healthcare supervision in the country. Health check-ups covers the 100% of children and 98-99% of adults (Program 2 Bel, 2011).

(S. Igumnov)

3.3 Russian Federation

The regions of the RF most affected by the Chernobyl catastrophe are Bryansk, Kaluga, Orel and Tula. As of January 1, 2011 (Rus. nat. report, 2011) in the areas of radioactive contamination were 4,414 settlements, inhabited by about 1,600,000 people, also in the areas of radioactive contamination of the Bryansk, Kaluga, Orel and Tula regions - about 1,200,000 people. In just 25 years among the liquidators (this is a little more than 190 thousand people) died from all causes of about 40 thousand people. The most common cause of death was chronic ischemic heart disease (1,763 cases), and in the group of solid cancers the greatest contribution was made by malignant tumors of the bronchi and lungs (485 cases). Herewith overall mortality of the liquidators, according to the data of the National Report (Rus. nat. report, 2011) does not exceed the corresponding values or the male population of Russia.

According to the results of monitoring it can be concluded that nowadays in areas contaminated by the Chernobyl catastrophe, the radiation situation has been stabilized (Bruk *et al.*, 2014). By 2014, the population dose due to the Chernobyl catastrophe has been significantly reduced. In 13 of the 14 regions of the RF affected by the Chernobyl catastrophe there are no localities where the average dose of the critical groups of population exceeded 1.0 $mSv \cdot year^{-1}$. Only in 299 settlements of the Bryansk region the average annual radiation dose to the critical group of the population still exceed 1.0 $mSv \cdot year^{-1}$. Wherein the maximum value of the average annual dose of critical groups of inhabitants is 5.9 $mSv \cdot year^{-1}$, and for all the inhabitants of settlements as a whole - 3.1 $mSv \cdot year^{-1}$. However, the maximum radiation dose, which locals could receive in the absence of radiation protection and self-restriction in consumption of local foods (SGED90), is 8.0 $mSv \cdot year^{-1}$.

With RF Government Decree of October 8, 2015 N^0 1074 (Decree, 1074) was approved a new version of the list of settlements subjected to radioactive contamination as a result of the Chernobyl catastrophe. From contaminated areas were excluded 558 settlements, and 383 settlements were converted to a lower level of contamination in connection with a change in the radiation situation. The list of benefits for the citizens living in the contaminated areas has not been changed.

During the period 1992-2010 by the Government of the RF have been adopted and implemented four federal (state) targeted programs for overcoming the consequences of the Chernobyl accident (1993, 1996, 1997 and 2001, respectively), four programs for the protection of the child population (1990, 1993, 1997 and 2000.), and two programs for providing housing for the liquidators of the Chernobyl accident (1995 and 2002). Furthermore, in 1998-2010 was carried out the complex of measures within the framework of the three Russian-Belarusian programs of joint activities to overcome the consequences of the Chernobyl catastrophe within the Union State (1998, 2002 and 2006). About 80% of the total quantity of work has been carried out in the framework of targeted programs, which have been implemented in 1992-1995 (Rus. nat. report 2015). Since 2002 all activities on overcoming the consequences of the Chernobyl accident have been carried out in the framework of the federal target program "Overcoming the consequences of radiation accidents for the period up to 2010". In generally, within the framework of programs of overcoming the consequences of the Chernobyl accident succeeded to perform a significant amount of work: in the 1992-2010 were put into operation more than 1,300,000 m^2 of total area of residential buildings, schools for more than 19,000 pupils, hospitals with 3,827 beds, outpatient clinics for more than 10,000 visits per shift, gas and water supply networks with a total length of more than 4,000 km, roads with total length of over 880 km, and others.

Up for now, had two targeted programs:
- Government of the RF of February 12, 2011 N^0 186-p has adopted the federal target program “Overcoming the consequences of radiation accidents for the period up to 2015” (Fed. Program-2011);
- The Council of Ministers of the Union State on May 24, 2013 N^0 2 has adopted a joint program of “The program of joint activities to overcome the consequences of the Chernobyl disaster within the Union State for 2016” (Union Program-2013).

The objectives of the programs are differed in some ways. The Federal program has focused mainly on social and economic development of the affected regions, while the Union program aimed at harmonizing legislation in the field of security of residents of the affected regions, cooperation between Russia and Belarus to the emergency response, development and effective use of advanced technology medical care and rehabilitation.

The results of the Programs implementation are widely published (Rus. nat. report, 2011; Bel. nat. report, 2011; Analytical report, 2013; Chlistun, 2014). Certain joint actions of Ukraine and Russia were carried out to eliminate the health effects of the Chernobyl catastrophe (Serdiuk et al., 2011a).

Establishment of the National Radiation and Epidemiological Registry (NRER) - was a progressive step in the elimination of the Chernobyl catastrophe consequences in the RF. Its objective is to use the results of medical observation of the registered citizens to provide them with the addressed health care and to make prognosis regarding medical radiological consequences, including the long–term ones. The Medical Radiological Research Center of A.F. Tsyb provides the unified federal database register with the scientific-methodological basis and organizational-technological support. NRER functions since 1986. The Russian State Medical Dosimetric Register has become its basis. It was part of the Soviet Union Distributing Register, established by the USSR MH in 1986, soon after the Chernobyl disaster.

NRER provides supervision to all the subjects living in Russia exposed to ionizing radiation as a result of radiation accidents. It includes 12 categories of those exposed to ionizing radiation resulting from the Chernobyl catastrophe. Among them the following categories exist: Category 1 (CHAES-1): acute radiation sickness, category 2 (CHAES-2): handicapped, category 3 (CHAES-3): clean-up workers 86-87, category 4 (CHAES-4): clean-up workers 88-90, Category 5 (CHAES-5): employed (alienation zone), category 6 (CHAES-6): evacuees, category 7 (CHAES-7): living (zone with the right of resettlement), category 8 (CHAES-8): living (resettlement zone), category 9 (CHAES-9): employed (resettlement zone), category 10 (CHAES-10): those who left, category 11 (CHAES-11): military, Category 12 (CHAES-12): descendants.

At present the United Federal Register database contains information from 9,563,495 forms. The total number of registered in the NRER subjects is 804,597. Of those currently 530,245 people are under the observation.

The particular feature of the NRER is that it is common for Belarus and the RF. Unlike in Ukraine, its data are the basis for majority of international "Chernobyl" Programs. Unfortunately, the data of the NRER in the RF are not fully comparable with Ukrainian ones in SRU due to certain differences in observation categories.

The results of the NRER observation and generalization are regularly published in the Bulletin of the National Radiation and Epidemiological Registry (Radiation & Risk. Bulletin). The latter has been published since 1992 with the periodicity of 4 issues per year. Its publications summarize the major radiological and medical consequences of the Chernobyl catastrophe.

Establishment and maintenance of the International Chernobyl Project Portal (ICRIN) is one of the important achievements of Russia.

(S. Igumnov, N. Omelianets)

3.4 Future of the radioactively contaminated territories

Data stated above show that the Chernobyl catastrophe and its aftermath caused considerable environmental and public health impact. Countermeasures managed by the authorities of affected states expectedly still have not enough result on the Chernobyl catastrophe consequences, i.e. the effects were reduced to some extent.

Even 30 years after the catastrophe the passport radiation dose exceeded 1 $mSv \cdot year^{-1}$ in 541 settlements out of the 2,302 ones where the dosimetric passportization was provide in Ukraine.

Doses in the range of 1-5 mSv·year^{-1} were assessed in 26 settlements. According to the Law of Ukraine as of 1.01.2015 the zone of strict radio-ecological control ('zone 4') was excluded from the list of radioactively contaminated ones. As a result more than 1,287 settlements with population of about 1,600,000 people including more than 300,000 children were qualified as not contaminated ones. However, the government has not approved the list. At the same time, the country has in fact stopped to conduct the radiation protection of population and rehabilitation of RCT with settlements, and monitoring of radioactive contamination levels. Given the fact that natural rehabilitation processes are not sufficient (Kaschparov *et al.*, 2011) and the radionuclides of caesium, strontium, transuranium elements and their fission products will be maintained in contaminated soils for hundreds of years one may expect a very long period until the pre-accident conditions will appear. Actually the contaminated territories have become a radiation geochemical province of anthropogenic origin. Moreover, for all subsequent years its inhabitants and their descendants will be the subjects of post-accident extra exposure to ionising radiation. With humanistic, scientific, and applied points of view the living conditions and health of these people should be the key issue within state activities. Returning of these territories to the pre-accident radiation levels should be an objective here. Scientists should have the opportunity to investigate the effects of such unique phenomena as radiation geochemical province of anthropogenic origin on nature and public health.

To solve these problems Bazyka and Omelianets (2014) have made suggestions on possible concept of elimination of consequences of the Chernobyl catastrophe in Ukraine in the current century. Authors suggest considering zones of radiation hazard, contaminated lands, and radiobiological province among the RCT in Ukraine. Zones of radiation hazard include the territory of the exclusion zone and part of the zone of obligatory (compulsory) resettlement from where the population have been already resettled. Contaminated lands correspond to the part of zone of obligatory (compulsory) resettlement from where the population was not yet resettled and the zone of guaranteed voluntary resettlement where the irradiation doses are greater than 0.5 mSv·year^{-1}. The radiobiological province comprises the territory of zone of guaranteed voluntary resettlement and of a strict radio-ecological control in which the radiation dose will not exceed 0.5 mSv·year^{-1}. In the zone of radiation hazard it is proposed to implement the measures envisaged by the Concept of the exclusion zone of the Chernobyl NPP in Ukraine (Concept, 2012) and the Law of Ukraine on the removal of the Chernobyl NPP from operation and Shelter Object conversion into an ecologically safe system (Law of Ukraine, 2009). As we have mentioned above both experts and practitioners for many years cannot come to a consensus concerning the return of evacuees and possibility of the "Chernobyl tourism" (Chernobyl-tour, 2015). There has been a debate on the establishment of the Chernobyl exclusion zone biosphere reserve i.e. a reserved area (Baryakhtar *et al.*, 2015). The Parliament of Ukraine requested the CMU to accelerate the preparation of proposals for the establishment of the reserve (Recommendations, 2015).

In the zone of radiation contaminated land the liquidation of consequences of catastrophe it is recommended to be continue subject to the provisions stipulated by the requirements of the current Chernobyl legislation. In the zone of radiobiological province it is proposed to abolish any measures of limitation of additional exposure of population, and to create the conditions for secure economic activity, residence and employment of population without restrictions due to the radiation factor if the dose from additional exposure does not exceed 0.5 mSv·year^{-1}, and finally to continue the monitoring of radioactive contamination. Radiation protection of population should be based on the requirements of the Radiation Safety Standard of Ukraine_97 (RSSU_97). Residents of this zone should continue to have the status of the Chernobyl catastrophe survivors and corresponding healthcare supervision. Preferences can be set only to the persons with diseases for which a causal link can be identified with the impact of ionising radiation or other harmful factors. Descendants of irradiated people are of a particular concern. In the absence of funding in the healthcare system after

2008 no information was summarised on the health of children born to persons who were children at the time of the accident. In this regard, the ability to track the stochastic effects of radiation, teratogenic and genetic disorders is lost.

These propositions are put forward for the further scientific justification of objectives and measures to eliminate the consequences of the catastrophe in remote period, and of the State program for overcoming the consequences of the Chernobyl catastrophe for 2016-2026.

(N. Omelianets)

4 FUKUSHIMA: HEALTH EFFECTS ASSOCIATED WITH THE NUCLEAR CATASTROPHE

For the Fukushima part of the report, the authors largely relied on dose information from the IAEA, UNSCEAR and WHO that is publicly available, as well as on findings reported in peer-reviewed scientific articles available to date. In light of the experience with IAEA and WHO data on Chernobyl, there are clear constraints when using available, and rather limited, data on Fukushima. A critique of this information is however not within the scope of this report, but this uncertainty should be considered when assessing future health estimates. We recommend sufficient support for peer-reviewed scientific studies on estimations of dose exposure from Fukushima.

4.1 Radiation Exposure 5 years later

The Chernobyl catastrophe for the first time in the history of mankind provided a vast amount of information on health effects of radiation in a wide dose interval. After almost thirty years of research a lot of answers have been obtained to the key questions in radiation biology and radiation protection. However some issues are still not clear and need more concern and understanding in the future.

The observed health effects of Chernobyl could be divided into major groups: effects due to ionizing radiation (high-dose and low-dose); effects due to a combined action of radiation and confounding factors; and effects due to influence of psycho-social factors (Serdiuk *et al*., 2011). Such division thus providing a background for the assessment of radiation effects is to a great extent an artificial one as the majority of diseases including the stochastic effects exhibit a multifactorial origin and could be triggered by a set of mutations combined with an incapability of the homeostatic systems. Such approach should be applied to the health effects of Fukushima too.

The Fukushima Daiichi nuclear accident on 11 March 2011 was a consequence of the 9.0 magnitude Tōhoku earthquake and the following tsunami. A series of ongoing equipment failures in several units of the power plant led to releases of radioactive material into the atmosphere and the seawater. Based on these emissions, the accident was regarded as a level 7 (major accident) on the International Nuclear and Radiological Event Scale (INES) (Thielen, 2012).

The Government of Japan recommended the evacuation of about 78,000 people living within a 20-km radius of the power plant and the sheltering in their own homes of about 62,000 other people living between 20 and 30 km from the plant. Evacuation of these people was performed between March 12 and mid-June 2011. Later, in April 2011, the Government recommended the evacuation of about 10,000 more people living farther to the north-west of the plant (referred to as the deliberate evacuation area) (UNSCEAR, 2014).

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) experts considered atmospheric releases of iodine-131 and caesium-137 (two of the more significant radionuclides from the perspective of exposures to people and the environment) in the ranges of 100 to 500 petabecquerels (PBq) and 6 to 20 PBq, respectively. These estimates are lower, indicatively, by a factor of about 10 and 5, respectively, than corresponding estimates of atmospheric releases resulting from the Chernobyl accident. Winds transported a large portion of the atmospheric releases to the Pacific Ocean. In addition, liquid releases were discharged directly into the surrounding sea. The direct discharges amounted to perhaps 10 and 50 per cent of the corresponding atmospheric discharges for iodine-131 and caesium-137, respectively; low- level releases into the ocean were still ongoing in May 2013 (UNSCEAR, 2014). Media reports since that date indicate that these releases remain ongoing (Stapczynski 2015, Takenaka 2015), though there are no peer-reviewed publications so far to confirm that.

So, the environmental impact of the Chernobyl accident was much greater than of the Fukushima accident on land. For Chernobyl, a total release of 5,300 PBq (excluding noble gases) has been established, while for Fukushima - of 520 (340–800) PBq. In the course of the Fukushima accident, the majority of the radionuclides (more than 80%) was transported offshore and deposited in the Pacific Ocean. In contrast to Chernobyl, no fatalities due to acute radiation effects occurred in Fukushima (Steinhauser *et al.*, 2014). Recently published estimates suggest total release amounts of 12–36.7 PBq of ^{137}Cs and 150–160 PBq of ^{131}I. (Aliyu *et al.*, 2015).

From the end of March to early April 2011, extremely high activities were observed in the coastal surface seawater near the Fukushima NPP. ^{134}Cs release in the North Pacific Ocean was estimated to be 15.3 ± 2.6 PBq. The amount of ^{137}Cs released by the Fukushima NPP accident increased the North Pacific inventory of ^{137}Cs due to bomb testing during the 1950s and early 1960s by 20%. (Inomata *et al.*, 2015).

In regard to the long-term effects of radioactive contamination in the environment, ^{137}Cs is the most important radionuclide, both in Chernobyl and Fukushima-1. The contaminated area around Chernobyl is more than 10 times larger than Fukushima-1. It is noteworthy, however, that although the Chernobyl NPP is surrounded by land, the eastern half of the surroundings of Fukushima Daiichi NPP is in the Pacific Ocean, and most of the discharged radioactivity from Fukushima-1 is believed to have streamed toward the ocean, blown by the prevailing westerlies over Japan (Imanaka *et al.*, 2015). However, it should be mentioned the higher population density in Japan compared to the population density around Chernobyl, to account for the fact that even though the area of terrestrial contamination may be smaller, this does not mean less people are affected.

The nuclear catastrophe following the Great East-Japan earthquake and tsunami has indicated several important conclusions albeit not final ones. Firstly, the probability of large-scale accidents occurred to be higher than estimated before, thus showing a need for further development of radiation protection. The need for increased international preparedness for the accidents is an important conclusion. Input of the international organizations (IAEA, UNSCEAR, ICRP, WHO etc.) was substantial; reports and recommendations exhibit high levels of expertise (UNSCEAR, 2014).

At the same time, the media has a lot of consistent critical reports of lack of efficacy of the Japanese authorities and the Tokyo Electric Power Company (TEPCO) in preventing and overcoming the consequences of the accident at the Fukushima Daiichi NPP for the environment and health, inadequate information policy and risk communication, hiding, late, contradictory and even falsity of official information about the actual scale of the disaster with the underestimation of its consequences. As well as, it is considered that the radioactive pollution of the Pacific Ocean is significantly higher than expected.
According to the Center for Marine and Environmental Radioactivity Woods Hole Oceanographic Institution (http://www.whoi.edu/cmer), the release of radioactive contaminants from Fukushima remains an unprecedented event for the people of Japan and the Pacific Ocean. In the aftermath of Fukushima - after years of relative complacency - the public and policymakers have expressed renewed concerns about radioactive contamination. In addition, radioactive wastes have piled up without safe places to store them.

In web-media there is information on peculiarities of environmental and health effects. Due to the wind direction to the East, the majority of radioactive release of the Fukushima Daiichi NPP catastrophe fell into the Pacific Ocean, As a result, the ground radioactive contamination was not as severe as it could have been if all of the radioactivity released had fallen on the terrestrial compartment.. We hypothesize that consumption of seafood, which is naturally rich in stable iodine (Shih-Wen Huang, 2005; National Academy Press, 2001; Mason, 2011), may play a significant role in the prevention of the thyroid gland exposure to radioactive iodine. In particular, seaweed consumed may contain up to 2110 µg/g (dry weight) of iodine (van Netten, 2000). Indeed, according to a literature-based analysis (Zava & Zava, 2011), daily iodine intake from edible seaweeds in Japan is amongst the highest in the world and was estimated at between 1,000 and 3,000 µg/day, based on dietary records, food surveys, urine iodine analysis and seaweed iodine content. For comparison, daily recommended dietary intakes of iodine are in the range of 90 µg/day (for children of 1 to 8 years old) to 290 µg/day (for lactating females) (National Academy Press, 2001; Mason, 2011). At the same time, daily iodine intake by the Ukrainian population was reported at 44.7 µg/day and 48.1 µg/day (median and geometric mean, respectively) in a duplicate portion study from 25 regions in Ukraine (Shiraishi *et al*., 2009). Therefore, the traditional Japanese diet provides a high level of iodine intake and resulting saturation of thyroid with iodine. The latter not only avoids the iodine deficiency that otherwise predisposes individuals to higher intakes of radioactive iodine in any nuclear emergency but also may exerts some kind of protective effect. This could be due to a lower capacity of an already partially iodine saturated thyroid to capture the radioactive iodine as compared to a thyroid in an iodine deficient/unsaturated state.

Health effects of the catastrophe can be estimated based on the categories (type) of exposed people and their radiation doses. The exposed groups included the emergency and clean-up workers of the TEPCO, its contractors and subcontractors, and general population. UNSCEAR latest estimate for the global average annual exposure to naturally occurring sources of radiation is 2.4 mSv and the average annual absorbed dose to the thyroid from naturally occurring sources of radiation is typically of the order of 1 mGy (UNSCEAR, 2014).

Workers. By January 31, 2014 the number of workers that had been involved in the clean-up activities after March 11, 2011 was 31,386. Of them, 4,086 represented the TEPCO staff, and the 27,297 were employed by contractors or subcontractors. According to their records the average ED of the 25,000 workers recorded over the first 19 months after the catastrophe was about 12 mSv. About 35% of the workforce received total doses of more than 10 mSv over that period according to the records, while 0.7% of the workforce received doses of more than 100 mSv (U3). According to the MH, Labour and Welfare of Japan there has been no significant internal exposure reported since October, 2011. The average combined internal and external cumulative ED since March, 2011 till December, 2013 was reported to be 23.60 mSv for the TEPCO workers and 10.97 mSv for the contractors (Ministry of Health, 2011).

According to Hasegawa *et al.* (2015) emergency workers seem to have been successfully protected from radiation. According to a 2013 TEPCO report, less than 1% of all such workers were exposed to a radiation dose (effective dose, combined external and internal sources) of 100 mSv or higher; the average dose was 11.9 mSv. However, the findings of this report from TEPCO cannot be verified through reference to peer-reviewed publications. Among 173 workers whose exposure dose exceeded 100 mSv, 149 (86%) were skilled TEPCO workers. The exposure dose of six emergency workers exceeded 250 mSv; however, no worker received a radiation exposure dose of more than the reference level recommended by the ICRP, ie, 1000 mSv, to avoid severe deterministic injuries. Notably, most injuries or illnesses were not related to radiation exposure. The maximum exposure dose among Japan Self-Defense Force (JSDF) personnel and firefighters involved in the emergency work was 81.2 mSv. Thus, no acute effects of radiation exposure such as ARS were reported after the Fukushima Daiichi NPP accident. Emergency workers seem to have been successfully protected from radiation. However, for emergency workers with radiation exposure of more than 100 mSv, a small increase in incidence of cancer attributable to radiation exposure might be expected (Hasegawa *et al.*, 2015).

The thyroid irradiation doses due to the catastrophe vary in a wide range (Serdiuk *et al*., 2011). The UNSCEAR reported on the data of internal exposure for the 12 most exposed TEPCO workers and confirmed that they had received absorbed thyroid irradiation doses in the range of 2 to 12 Gy, mostly from inhalation of ^{131}I (UNSCEAR, 2011). Intakes of the more short-lived isotopes of iodine were not analysed, causing possible dose underestimation. In 5 members of a disaster medical assistance team of Fukui Prefectural Hospital who have worked on March 15-16 at a distance of 40 km from the Fukushima Daiichi NPP the thyroid activity values were from 249 to 1,082 Bq with an inverse relationship between age and thyroid activity (UNSCEAR, 2011). For the 12 workers whose exposure data were scrutinized by the UNSCEAR and in whom the received absorbed the thyroid irradiation doses from ^{131}I intake were estimated separately in the range of 2 to 12 Gy, an increased risk of thyroid cancer and other thyroid disease developing can be inferred. According to the loss of infrastructure there was a delay in the beginning of measuring of the ^{131}I incorporation to the thyroid gland, so the thyroid irradiation doses in a large proportion of TEPCO and contractor companies workers have to be reconstructed.

TEPCO reported about more than 160 additional workers who received an ED over 100 mSv, predominantly from external exposures. Increased radiation-induced cancer risks are suggested for this group. Of course any statistically significant excess can not be registered in a such limited group. However, such prognosis is based on some threshold dose values representing the mean doses in the subjects of analytical studies. The range of doses in cases is broader, i.e. in the NRCRM leukemia study in cleanup workers the doses varied from 3.7×10^{-5} to 3.170 mGy. The experience of Chernobyl demonstrates a need in follow-up examination of all workers, but not only those having the ED above 100 mSv. They will be specially examined, including the thorough annual examinations of the thyroid, stomach, large intestine and lungs for the potential late radiation-related health effects.

Apart from those groups, the *in vivo* monitoring of the 8,380 members of personnel affiliated with the United States Department of Defense was carried out between March 11, 2011 and August 31, 2011. About 3 per cent of those monitored had measurable activity levels with a maximum ED of 0.4 mSv and a maximum absorbed dose to the thyroid of 6.5 mGy (UNSCEAR, 2014).

According to the UNSCEAR white paper (UNSCEAR, 2015) no deterministic effects from radiation exposure have been observed among the workers. Diseases registered during the recovery operations were not related to radiation exposure. As the dose values were in a low-dose range any information on the other effects can only be obtained within epidemiological studies at a longer time period. Follow-up programs would need to be conducted.

General population. The most important early countermeasures after Chernobyl and Fukushima included evacuation of general population (Serdiuk *et al*., 2011; UNSCEAR, 2011; UNSCEAR, 2014). The levels of decision making however were different: after Chernobyl the unprecedented evacuation was performed under the central government decisions, while in Japan the Government had only recommended the evacuation but the decisions required an adoption at prefectural levels. In the first days about 78,000 people living within a 20-km radius around the NPP were evacuated and re-settled mainly within Fukushima Prefecture. For the 62,000 of people living at the distance from 20 to 30 km from the plant the evacuation was preceded by sheltering. Evacuation was performed between March 12 and mid-June 2011. In April 2011 about 10,000 more people living at the contaminated north-west territories were evacuated (UNSCEAR, 2014).

Individual radiation doses in general population as estimated based on various surveys were low or very low. Nagataki *et al.* (2013) reported that the individual external radiation doses, determined by a behaviour survey in the "evacuation and deliberate evacuation area" ("deliberate evacuation areas" were designated as the area excluding restricted area where the annual cumulative dose of radiation was expected to reach 20 $mSv \cdot year^{-1}$ after the accident) in the first 4 months, were <5 mSv in 97.4% of residents (maximum: 15 mSv). Doses in Fukushima Prefecture were <3 mSv in 99.3% of 386,572 residents analyzed. External doses in Fukushima City were <1 mSv during 3 months (September–November, 2011) in 99.7% of residents (maximum: 2.7 mSv). Thyroid radiation doses, determined in March using a NaI (TI) scintillation survey meter in children in the evacuation and deliberate evacuation area, were <10 mSv in 95.7% of children (maximum: 35 mSv). Therefore, all doses were less than the intervention level of 50 mSv proposed by international organizations. Internal radiation doses determined by ^{134}Cs and ^{137}Cs whole-body counters (WBCs) were <1 mSv in 99% of the residents, as was shown by measurements conducted 4 month after the accident (Hayano *et al.* 2014) and 33-49 months after the accident (Hayano *et al.* 2015), and the maximum thyroid equivalent dose by ^{131}I WBCs was 20 mSv (Nagataki *et al.*, 2013).

In June 2011 a health survey of the local population (the Fukushima Health Management Survey) was initiated. Research activities were launched in October 2011. It is planned to be continued for the 30 years and to cover more than 2,000,000 inhabitants. A thyroid ultrasound survey is of key importance in 360,000 children aged up to 18 years at the time of the catastrophe. The increased number of thyroid nodules and cysts was among the first findings at ultrasound investigation. A high level of basic investigation enables avoiding the screening effect that is a point of discussion when analyzing the Chernobyl data.

After the launch of the health survey the ultrasound thyroid screening was performed on all residents of the Fukushima Prefecture aged less than 18 years. The first round of screening included 298,577 examinees, and a second one has began in April, 2014. At the timepoint of 20–30 months after the catastrophe, Watanobe *et al.* did not confirm any discernible deleterious effects of the emitted radioactivity on the thyroid of young Fukushima residents (Watanobe *et al.*, 2014).

Later Tsuda *et al.* (2015) analyzed the prefecture results from the first and second round up to December 31, 2014 in comparison with the Japanese annual incidence and the incidence within a reference area in Fukushima Prefecture. From the 2,251 ultrasound screen-positive cases by the end of December, 2014 the 2,067 cases were examined in secondary examinations, where 110 thyroid cancer cases were detected, as indicated by the presence of cancer cells under cytological tests after the fine-needle aspiration biopsy. Among the 110 cases, 87 ones were operated by the end of December 2014. The 86 cancer cases were histologically confirmed (83 papillary carcinomas and 3 low-differentiated carcinomas). A benign tumor was finally diagnosed in one case. The highest incidence rate ratio at a latency period of 4 years was observed in the central district of the prefecture compared with the Japanese annual incidence (Incidence RR = 50; 95% CI=25, 90). The thyroid cancer prevalence was 605 per million examinees (95% CI=302, 1.082) and the prevalence odds ratio vs. reference district in Fukushima Prefecture was 2.6 (95% CI=0.99, 7.0). In the second screening round even under an assumption that the rest of examinees were disease-free, an incidence RR of 12 has already been observed (95% CI=5.1, 23). An excess of thyroid cancer has been detected by ultrasound among children and adolescents in Fukushima Prefecture within 4 years of the radioactive release, and according to authors is unlikely to be explained by a screening surge (Tsuda *et al.*, 2015).

(D. Bazyka)

4.2 Certain consequences 5 years later

4.2.1 Thyroid Cancer

Evaluation of possible radiation consequences is based on data on the amount of radiation exposure. Attention is drawn to different estimates of radiation emissions. According to Nagataki, Takamura (2014) the amount ^{131} I released to the environment following Fukushima accident was 120 petabecquerel, wich is one – tenth that in the Chernobyl accident. Some other assessment presented in publication of Tsudo *et al.* (2015): radiation released into the atmosphere from the Fukushima accident was estimated to be approximately 900 petabecquerel (^{131}I: 500 petabecquerel, ^{137}Cs: 10 petabecquerel). The radiologic equivalence to ^{131}I International Nuclear Event Scale was approximately one-sixth of the 5,200 petabecquerel calculated to have been released by the Chernobyl accident.. These data evidence possible influence of radioiodine on thyroid cancer incidence rate.

In the longer term an exposure to radionuclides with long half-lives, including ^{137}Cs and ^{134}Cs, with physical half-lives of 30 and 2 years, respectively is of an another concern (Fushiki, 2013).

Another type of childhood cancer related to radiation exposure is childhood leukemia, which was well described in A-bomb survivors. Unexpectedly, there was no increase in childhood leukemia after the Chernobyl catastrophe, indicating that in contrast indicating that in contrast to the internal exposure to radioactive iodine the external radiation exposure had no distinguishable effects in terms of cancer induction in children (Suzuki *et. al.,* 2015).
Ivanov and Tsyb (2013) have developed a prognosis of possible additional thyroid cancer incidence rate in the population residing near the “Fukushima-1” NPP, in relation to age at the moment of exposure and accumulated radiation doses. The Chernobyl epidemiologic data and international standards were taken in account. According to estimations the risk of thyroid cancer in irradiated children is 3-fold higher than in adults.

Yamashita and Suzuki (2013) accentuated that implementation of a prospective epidemiological study on human health risks from low-dose radiation exposure and comprehensive health protection from radiation should be emphasized on a basis of lessons learnt from the Chernobyl catastrophe. In contrast to Chernobyl, the vast majority of population in Fukushima did not receive a high enough dose to expect a discernible increase in cancer incidence and other radiation-induced health effects in the future (Yamashita and Suzuki 2013).However, public concerns about the long-term health effects of radioactive environmental contamination have increased in Japan. Since May, 2011 the Fukushima Prefecture started the Fukushima Health Management Survey Project with the purpose of long-term health care administration and early medical diagnosis/treatment for the prefectural residents.

Review of Fushiki (2013) focuses on what happened after the accidents at the Three Mile Island nuclear power station in 1979 and the Chernobyl NPP in 1986 in terms of the effects of these incidents on human health. The most critical issue when considering the effects of radiation on the health of children was the increase of thyroid cancer, as it was clearly demonstrated among people who were children or adolescents at the time of the Chernobyl catastrophe. Therefore, in early days after a catastrophe the efforts to prevent the exposure of children to radioactive iodine through inhalation and ingestion should be the primary concern, because radioactive iodine is preferentially accumulated in thyroid gland.

As pointed out Nagataki, Takamura (2014), residents near the Fukushima nuclear plant were evacuated within a few days and foodstuffs were controlled within 1 or 2 weeks. Therefore the thyroid irradiation doses were less than 100 mSv (intervention levels for the stable iodine administration) in the majority of children, including less than 1 year olds, living in the evacuation areas. Because the incidence of childhood thyroid cancer increased in those residing near the site following the Chernobyl catastrophe a thyroid screening of all children (0-18 years old) in Fukushima Prefecture was started. To date the screening of more than 280,000 children has resulted in the thyroid cancer diagnosis in 90 children (approximate incidence 313 per million). Thus, although the dose of radiation was much lower, the incidence of thyroid cancer appears to be much higher than that following the Chernobyl catastrophe. This result is partly due to a screening effect. Nevertheless as pointed out Tsuda *et al.* (2015) among those ages 18 years and younger in 2011 in Fukushima Prefecture, approximately 30-fold excesses in external comparisons and variability in internal comparisons on thyroid cancer detection were observed in Fukushima Prefecture within as few as 4 years after the Fukushima NPP accident. The result was unlikely to be fully explained by the screening effect.

As pointed out (Jacob *et al.*, 2014) thyroid cancer is one of the main health concerns after the catastrophe in Fukushima. Ultrasonography survey is being performed in persons residing in the Prefecture at the time of the accident with an age of up to 18 years. The expected thyroid cancer prevalence is assessed based on an ultrasonography survey of Ukrainians, who were exposed at age of up to 18 years to ^{131}I released during the Chernobyl catastrophe, and on differences in equipment and study protocol in two surveys. The prediction of radiation-related thyroid cancer in the most exposed fraction (a few ten thousand persons) of the screened population of the Fukushima Prefecture has a large uncertainty with the best estimates of the average risk of 0.1-0.3%, depending on average dose.

As pointed out by Mabuchi *et al.* (2013) it is important that regulatory bodies and advisory organizations have as complete understanding as possible of the risks according to gender, age at exposure, time since exposure, health status and other related variables to protect the workers and public from harmful effects of radiation exposure. The 2011 catastrophe at the Fukushima complex again alerted the world to the possibility that large groups, including many adults, can be exposed to ^{131}I. It reminds us that it is important to understand the effect of age at exposure on cancer risk to achieve effective radiation protection and to plan the responses to future nuclear catastrophe or terrorist events involving radiation.

The main conclusion of reviewed publications is an excess of thyroid cancer incidence rate which can only partly be explained by wide implementation of screening. Other forms of cancer - leukemia and solid tumors since 5 years after Fukushima accident in the reviewed publications not yet mentioned.

The Chernobyl catastrophe and Fukushima events evidence an existence of radiation accidents risk even in modern industry, where any nuclear technology is involved.

(A. Prysyazhnyuk)

4.2.2. Non-cancer Health Effects of the Fukushima catastrophe

Past nuclear disasters, such as the atomic bombings in 1945 and major accidents at nuclear power plants, have highlighted similarities in potential public health effects of radiation in both circumstances, including health issues unrelated to radiation exposure. Since nuclear disasters can affect hundreds of thousands of people, a substantial number of people are at risk of physical and mental harm in each disaster (Ohtsuru *et al.*, 2015).

There are main health risks of the Fukushima catastrophe as follows: radiation exposure, heat stress, psychological stress, and infectious diseases (Hiraoka *et al.*, 2015). At high doses, and possibly at low doses, radiation might increase the risk of cardiovascular disease and some other non-cancer diseases (Kamiya *et al.*, 2015).

Less than 1% of all emergency workers were exposed to external radiation of >100 mSv, and to date no deaths or health adversities from radiation have been reported for those workers in peer-reviewed publications (Shimura *et al.,* 2015). The individual external doses of 421,394 residents for the first four months (excluding radiation workers) had a distribution as follows: 62.0%, <1 mSv; 94.0%, <2 mSv; 99.4%, <3 mSv. The arithmetic mean and maximum for the individual external doses were 0.8 and 25 mSv, respectively. So, the estimated external doses were generally low and no discernible increased incidence of radiation-related health effects is expected (Ishikawa *et al.* 2015).

No acute effects of radiation exposure such as ARS were reported after the Fukushima Daiichi NPP accident. However, for emergency workers with radiation exposure of more than 100 mSv, a small increase in incidence of cancer attributable to radiation exposure might be expected (Hasegawa *et al.,* 2015). Moreover, the results from medical examinations conducted in 2012 of workers who were engaged in clean-up works in 2012 showed that the prevalence of abnormal findings was 4.21%, 3.23 points higher than the 0.98% that was found prior to the accident (Yasui, 2015).

By the end of September, 2014, 754 workers received medical treatment at the site. Five deaths were reported: three workers had acute myocardial infarction and cardiac arrest; one patient had aortic dissection; and another person had asphyxia caused by a landslide during construction of a pile foundation. In 2011–2014, heat illness increased in May–July. 88 workers had heat illness; however, no severe cases, such as heatstroke, were reported (Hasegawa *et al.*, 2015).

Evacuation-related mortality risks for vulnerable elderly populations are increased. Experiencing the disasters did not have a significant influence on mortality (hazard ratio 1.10, 95% confidence interval: 0.84-1.43). Evacuation was associated with 1.82 times higher mortality (95% confidence interval: 1.22-2.70) after adjusting for confounders, with the initial evacuation from the original facility associated with 3.37 times higher mortality risk (95% confidence interval: 1.66-6.81) than non-evacuation (Nomura *et al.*, 2016).

Among the aged evacuees living in temporary housing after the Great East Japan Earthquake 62.0% residents had chronic pain, including 29.6% those with relatively severe pain, as well as their quality of life was assessed to be significantly lower, when compared with the national standard values (Yabuki *et al.*, 2015).

Residents proximal to the evacuation zone (median age, 64 years) showed significant post-disaster increases in body weight, body mass index, systolic and diastolic blood pressure, blood glucose levels, and triglyceride levels (Tsubokura *et al.,* 2014). Body weight and the proportion of overweight/obese people increased among residents, especially evacuees, in the evacuation zone of Fukushima prefecture after the Great East Japan Earthquake (Ohira *et al*., 2015). The prevalence of atrial fibrillation increased (before: 1.9% vs. after: 2.4%, P<.001) among residents in the evacuation zone of Fukushima prefecture after the Great East Japan Earthquake, with excess alcohol intake and obesity associated with an increased risk of atrial fibrillation (Suzuki *et al.*, 2015). After the disaster, the prevalence of diabetes increased significantly among evacuees than among nonevacuees. Evacuation was significantly associated with the incidence of diabetes (Satoh *et al.*, 2015).

Life as an evacuee after the Fukushima Daiichi NPP accident is a cause of polycythemia: red blood cell count, hemoglobin levels, and hematocrit significantly increased in both men and women evacuees. Common causes of polycythemia are polycythemia vera (myeloproliferative disease), secondary polycythemia caused by diseases such as pulmonary heart disease that induce a chronic lack of oxygen or an erythropoietin-producing tumor, and relative polycythemia or stress-induced polycythemia (Sakai *et al.*, 2014). At the same time, no marked effects of radiation exposure on the distribution of white blood cell counts, including neutrophil and lymphocyte counts were detected within one year after the disaster in the evacuation zone (Sakai *et al.*, 2015).

Non-radiation effects of a radiation catastrophe, such as economical, social and psychological could prevail and be much more important for the community than purely the radiation factor. For the exposed population after Fukushima, the almost total devastation and loss of infrastructure in the area was a powerful factor. The fact that for the first 10 years after the Chernobyl catastrophe the health effects were significantly different from predicted ones is of importance for the estimation of further consequences of Fukushima. Stress, alimentation changes and other negative factors brought a significant contribution to the health decline of all categories of exposed population and form a background for the induction of a wide range of non-cancer somatic and psychosomatic diseases, and also influencing disability and mortality. Lack or drawbacks of the prepared guidelines understandable to population and authorities on protection from this complex of factors have contributed to the induction of the non-radiation health effects.

The non-radiation factors of the catastrophe could be the substantial risk modifiers. Influence of the mentioned non-radiation factors as well as genetic predisposition could be substantial and has to be encountered when analyzing such radiation-induced effects as leukemia or solid cancers in population exposed to radiation doses several times exceeding the natural radiation background.

The longitudinal follow-up studies of traditionally recognized health effects due to ionizing radiation are needed for radiation workers, evacuees from the 20-kilometer zone, persons with high-dose exposure of thyroid gland, females pregnant at the moment of exposure and children. Special attention should be delivered to the non-cancer diseases, cognitive dysfunction, and cataracts.

So, the estimated external doses were generally low and large-scale discernible increased incidence of radiation-related health effects are not expected (Ishikawa *et al*., 2015).

(K. Loganovsky)

4.2.3 Mental health impact

The Great East Japan Earthquake with trio impact (earthquake, tsunami and radiation catastrophe at the Fukushima NPP) provides new challenges to emergency psychiatry. This sub-chapter is an overview of the relevant peer reviewed papers and proceedings of the International Conferences related to the mental health effects of the Fukushima disaster.

Traumatic effects of emergencies were described since the Civil War in USA (1861–1865) as a psychological and psychosomatic aftermath. There is an excess of morbidity from depression, post-traumatic stress disorder (PTSD), and alcoholism, one year post disaster. The rates vary widely i.e. from 25 to 75% during the first year, depending on the magnitude of the event. Both natural and human-made disasters have acute effects. The human-made disasters have more long-term effects. Events involving radiation may have the most prolonged and complex effects, namely not only depression, PTSD, alcoholism and smoking, but also the health-related anxiety taking the form of medically unexplained physical symptoms (Bromet, 2013).

A chronic shortage of mental health resources had been previously reported in the Tohoku region, and the triple disaster worsened the situation. Eventually a public health approach was implemented by providing a common room in temporary housing developments to build a sense of community and to approach evacuees so that they could be triaged and referred to mental health teams. Japan now advocates using psychological first aid to educate the first responders (Yamashita and Shigemura, 2013). The levels of distress and PTSD are higher in Fukushima Daiichi workers. Discriminations/slurs are associated with higher distress (Shigemura *et al.,* 2012).

The risk of radiation-associated health consequences of residents in Fukushima is quite different from that of Chernobyl and is considerably lower based on the estimated radiation doses received during the catastrophe for individuals. A large number of people have received psychosocial and mental stresses aggravated by radiation fear and anxiety and remained in an indeterminate and uncertain situation having been evacuated but not relocated (Yamashita and Takamura, 2015).

According to Bromet (2014) the emotional consequences of NPP disasters include depression, anxiety, PTSD, and medically unexplained somatic symptoms. Preliminary data from Fukushima indeed suggest that workers and mothers of young children are at a risk of depression, anxiety, psychosomatic and post-traumatic symptoms both as a direct result of their fears about radiation exposure and as an indirect result of societal stigma. Thus, it is important that non-mental health providers learn to recognize and manage psychological symptoms and that medical programs be designed to reduce stigma and alleviate psychological suffering by integrating psychiatric and medical treatment in their clinics (Bromet, 2014).
Current mental health outcomes of Fukushima mainly included the PTSD, depression, and anxiety symptoms. Physical health changes, such as sleeping and eating disturbances, also occurred. In Fukushima the radioactive release induced massive fear and uncertainty in a large number of people, causing massive distress among the affected residents, especially among mothers of young children and nuclear plant workers. Stigma was an additional challenge to the Fukushima residents. The disaster emergency workers, children, internally displaced people, patients with psychiatric disorders, and the bereaved persons are the most vulnerable groups (Harada *et al.,* 2015).

One month after the Great East Japan Earthquake the radiation exposure was a concern for the 9.2% of workers of disaster medical assistance teams. The concern was especially increased in men, but did not appear significant in women. The authors came to conclusion that concern over radiation exposure was strongly associated with psychological distress. At the same time reliable and accurate information on radiation exposure might reduce the deployment-related distress in disaster rescue workers (Matsuoka *et al.*, 2012).

Symptoms of depression were found in 28% of mothers having babies in Soso (the region in which the NPP is located), and mothers that had changed obstetrical care facilities. In contrast, mothers in Iwaki and Aizu, regions with relatively low radiation levels, were significantly less likely to be screen-positive for depression (Goto *et al.*, 2015). A higher proportion of Fukushima mothers with fetal loss, especially those with miscarriage and stillbirth, had the depressive symptoms compared to those who experienced normal childbirth (Yoshida-Komiya *et al.*, 2015).

Nuclear disasters can affect hundreds of thousands of people, and a substantial number of people are at risk of physical and mental harm. During the recovery period after a nuclear disaster the physicians might need to conduct screening for psychological burdens and provide general physical and mental health care for many affected residents who might experience a long-term displacement (Ohtsuru *et al.*, 2015).

Five major nuclear accidents have occurred in the past – i.e, at Kyshtym (Russia [then USSR], 1957), Windscale Piles (UK, 1957), Three Mile Island (USA, 1979), Chernobyl (Ukraine [then USSR], 1986), and Fukushima (Japan, 2011). The effects of these accidents on individuals and societies are diverse and enduring. Accumulated evidence about radiation health effects on atomic bomb survivors and other radiation-exposed people has formed the basis for national and international regulations about radiation protection. In addition to health effects of radiation exposure (i.e., acute radiation syndrome and increased incidence of cancer), adverse effects on mental health were reported after the Fukushima Daiichi and Chernobyl NPP accidents. The Fukushima Daiichi NPP accident showed the health risks of unplanned evacuation and relocation for vulnerable people such as hospital inpatients and elderly people needing nursing care, and failure to respond to emergency medical needs at the NPP. Displacement of a large number of people has created a wide range of public health-care and social issues. However, past experiences suggest that common issues were not necessarily physical health problems directly attributable to radiation exposure, but rather psychological and social effects. Additionally, evacuation and long-term displacement created severe health-care problems for the most vulnerable people, such as hospital inpatients and elderly people (Hasegawa *et al.*, 2015).

The evacuees frequently had got chronic pain and lower physical and mental quality of life scores compared to the national standard values (Yabuki *et al.*, 2015). Fukushima might cause social isolation among the elderly, leading to the mental disorders and alcohol use disorder. Early diagnosis and intervention might be beneficial for individuals presenting the above symptoms. Patient health questionnaire 9 (PHQ-9) scores of 10 or greater were found in 12% of the residents proximal to the evacuation zone, indicating that a substantial number had major depression (Tsubokura *et al.,* 2014).

Suicides are a very important problem following the Japan Earthquake (Orui *et al.*, 2014). Devastating disasters may increase suicide rates due to mental distress. Previous domestic Japanese studies have reported decreased suicide rates among men following disasters. In disaster-stricken areas, post-disaster male suicide rates decreased during the 24 months following the earthquake. This trend differed relative to control areas. Female suicide rates increased during the first seven months (Orui *et al.*, 2014).

Mental health problems associated with stress, depression, anxiety, evacuation, loss of loved ones, inability to return home, stigma, and fear of radiation effects for self and children are being recognized as the most serious health consequence of the catastrophe (Matsuoka *et al*., 2012; Shigemura *et al*,. 2012; Bromet, 2013). Indeed, Fukushima disaster mental health effects, on the base of the current radiation dose estimations, at present could be mainly attributed to the severest stresses and their further mental, psychosomatic, and physical health aftermath (Loganovsky and Loganovskaja, 2011, 2013). However, similarly at least 5 years after the Chernobyl disaster, the International community did not recognize any radiological effects from. Thus further health effects studies in Fukushima with radiation dose verifications are necessary.

Bromet (2013) considers the main lessons of Fukushima as follows: 1) given physical/mental comorbidity the mental health measures should be integrated into medical research and surveillance studies (and vice versa); 2) primary care providers should be educated to recognise and manage the health anxiety, depression, and impairment in daily functioning after exposure events; 3) it is necessary to create alliances with appropriate participants (community advisors, community ambassadors, sharing findings directly). E. Bromet is considering from radiological point of view the Fukushima nuclear catastrophe rather closer to the Three Mile Island (TMI) crisis (1979) than to the Chernobyl catastrophe (1986) as the estimated radiation doses in Fukushima were reported to be significantly lower than in Chernobyl. As reported by Bevelacqua (2012), the similarity of TMI and

Fukushima accidents relates to “the fuel damage sequence, release of fission products within the facility, contamination of onsite structures, and onsite recovery actions. However, “since the extent of TMI-2 reactor building damage was insignificant compared to the Fukushima Dai-ichi NPP damage, the required tasks in Japan are significantly more demanding.”

In many ways we share E. Bromet’s point of view. At the same time, there is much common between the Chernobyl and Fukushima, namely the stress-related disorders are practically the same. There is one main psychological-psychiatric lesson of Chernobyl unclaimed in Fukushima: the equally inadequate information policy and risk communication, secrecy, untruthfulness, untimeliness, non-transparence, non-professionalism, contradictory, and politicization/commercialization - all together they are dramatically increasing stress, fear, anxiety and psychosomatic disorders, etc. Moreover, suicides, potential cerebrovascular disease, cognitive deficit, neurodevelopmental disorders, psychosis, and alcohol abuse should be monitored (Loganovsky and Loganovskaja, 2011, 2013).

The most important issues here are the organization, improvements, and support of constant medical and psychologic-psychiatric care and/or interventions. This should include annual general medical and neuropsychiatric examinations, early diagnostic and treatment of physical and mental problems, mother’s mental health care and psychological care for children and their parents, individual relevant educational programs, no separation of children from parents and relatives, radiation risk perception management.

There is a strong necessity to develop and implement the system of emergency and long-term psychological and psychiatric care for the survivors of earthquake, tsunami, and radiation catastrophe in Fukushima. This system should include the emergency psychological and psychiatric crews/teams, networks of crisis and rehabilitation centers, neuropsychiatric outpatient and inpatient units.

Further prospective studies on mental health and potential neuropsychiatric effects in Fukushima disasters clean-up workers and survivors are needed with verification of radiation doses.

(K. Loganovsky)

4.3 Expected consequences

A comparison of the Chernobyl impacts due to radiation and forecasted Fukushima effects are presented in a Table 4.3.1 (Bazyka, 2014),

Table 4.3.1 - Projection of Chernobyl health effects due to ionizing radiation to Fukushima

Parameters	Chernobyl	Fukushima
Level be the IAEA scale	7	7
^{131} I release (Bq)	1.76×10^{18}	1.5×10^{17}
^{137}Cs release (Bq)	8.6×10^{16}	1.2×10^{16}
^{132}Te release to atmosphere (Bq)	1.15×10^{18} (UNSCEAR, 2014)	8.8×10^{16} (Tagami *et al.*, 2013. Tagami et al., 2013)
Acute radiation syndrome cases	134	Not observed

Immunology /Cytogenetics	Marked changes in cleanup workers during first years and population	Could be observed. Additional data needed
Radiation cataracts	Observed to higher extent than expected	Could be observed in exposed to less than 0.5 Gy radiation doses
Non-chronic lymphoid leukaemia (15 years follow-up)	ERR 2.73/Gy	ERR similar with regard to smaller dose & # of exposed people
Chronic lymphoid leukaemia (15 years follow-up)	ERR 4.09/Gy	Uncertain
Thyroid cancer in children	Incidence higher than expected	Risks could be less than in Chernobyl
Thyroid cancer: Screening effect	Observed	Could be minimal due to the early start of ultrasound screening programs
Contribution of stable iodine deficiency	Present	No
Other cancers	Increase in some population groups	Uncertain
Cardiovascular disease	High incidence & mortality	Low incidence in population
Cerebrovascular disease & cognitive dysfunction	High incidence	To be analyzed
Benign thyroid abnormalities	Controversial	Unexpectedly high background rates of thyroid nodules and cysts at the diagnostic ultrasound survey
Mental health changes in children exposed in utero	Analysis in process	Not expected: severe mental retardation, microcephaly and seizures. Potentially expected: long-term psychosocial disadaptation and different neurodevelopmental disorders, cognitive disharmony, maybe mild cognitive impairment, stress-related disorders - psychosomatic disorders – mental and physical diseases

The data presented shows that after the destruction of the four reactors at Fukushima NPP the extent and levels of radioactive contamination are slightly lower than those in Chernobyl. Nearly 20-fold less number of workers were involved in liquidation of the Fukushima catastrophe compared to Chernobyl. Doses from external and internal exposure were several times lower compared to Chernobyl. In quantitative terms the evacuation of people from the 30–km zone was quite similar to that in Chernobyl. External radiation doses and thyroid irradiation doses in the total population were lower in Fukushima. As in Chernobyl, the incidence of thyroid cancer in Fukushima has begun to increase 4 years after the catastrophe. The higher incidence of thyroid cancer under the lower radiation doses are unexpected and surprising. Some 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 being analysed and it is expected that the hazardous effect of radiation in Fukushima may be lower. No deterministic effects of radiation among the workers were registered. Well-designed epidemiological research is necessary to evaluate the health effects in workforce in the remote period.

(D. Bazyka)

5 HEALTH EFFECTS OF CHERNOBYL AND FUKUSHIMA: AN OVERVIEW

5.1 IAEA, WHO, and UNSCEAR reports: methodological issues

At the initiative of the IAEA an UN Chernobyl Forum was created in 2003. It was composed of experts from the IAEA, WHO, several departments of the United Nations, and representatives of the governments of Ukraine, Belarus and Russia. This organisation has the objective of arriving at a clear scientific consensus about the consequences of the Chernobyl NPP catastrophe. The results of the researches are published in reports of the UN Chernobyl Forum (Report, 2005; Health, 2005; Chernobyl's Legacy, 2006).

The positive fact is that the Chernobyl forum declared the Chernobyl NPP catastrophe as "the greatest nuclear disaster in human history". It summarized a large amount of research, which is most important for the human community in answering the question on possible radiation hazards to the health.

The provisions presented in Reports are the following:
(a) For the health of clean-up workers, evacuees, and people who lived in contaminated areas the irradiation is not dangerous, as at most 3,940 individuals could die from cancer due to radiation exposure;
(b) The radiation from the accident is not harmful to people because from many thousands of the thyroid cancer cases there are only 9 documented deaths from this disease in children and adults in the three affected countries at this time;
(c) The radiation from the accident is not harmful to humans because direct radiation-epidemiological studies have not found any association of the exposure with an increase of mortality in the total population, in particular of mortality from leukemia and solid cancers (except the thyroid cancer in children) or growth of the non-cancer diseases vs. the spontaneous level;
(d) The people who received an additional exposure doses of the low level die from the same causes as the people, who are not accident survivors. The actual number of deaths caused by the accident can never be exactly known.
(e) No convincing evidence was revealed of an increased incidence of leukemia among children or adults who reside in the exposed territories in Russia and Ukraine;
(f) The obtained doses were generally small and therefore not harmful to humans; there is no evidence of any radiation effects on Diseases of the Circulatory System and mortality from them;
(g) The cataractogenesis can occur at radiation of lower than those observed before, namely to about 250 mGy;
(h) Among the population that survived after the accident there is no evidence or any possible cases of the decreased male and female fertility as a direct result of radiation exposure. The radiation doses are also unlikely to affect the number of stillbirths, pregnancy outcomes, and complications of childbirth or children's health;
(i) The levels of fertility in contaminated areas can be lower through the fear to have children and high incidence of medical abortions. Because of low risk ratios no significant growth in hereditary effects caused by radiation is expected;
(k) The large number of thyroid cancer cases is the only confirmed result of the radiation impact;
(l) The affected countries unreasonably spent resources to protect the people from radiation.
The experts of the Chernobyl forum recognize only the presence of radiation induced effects, which are associated with acute exposure at the high doses (ARS, thyroid cancer, leukemia, solid cancers).

As for the DCS identified in the clean-up workers in Russia the experts make comments that these data should be interpreted cautiously in connection with possible influence of additional factors such as stress and unhealthy lifestyle.

The methodology of work of the experts was based on the analysis of peer-reviewed literature and some selected international journals. In this time the valuable results of scientific works of researchers from the different countries of the world were ignored.

Evaluation of the radiation effects and calculation of risk were conducted on the data from A-bombing of Hiroshima and Nagasaki. Such approach to calculation resulted in a reduced value of risk from the Chernobyl because there was quite another nature and level of exposure after the A-bombing.

The Chernobyl fallout and radiation doses not observed or registered in any countries except in Belarus, Ukraine and Russia have not been discussed in the reports.

The conclusions of the Chernobyl Forum were opposed by international organisations (Greenpeace, 2006) and scientists (Horishna, 2006; Burlakova, 2006; Yablokov et al., 2009; Masurenko, 2010).

The data of this Report do not confirm the opinion of the experts of the Chernobyl Forum. The epidemiological studies in recent years and conclusions of scientists suggest that:
1) An increased incidence of thyroid cancer is registered not only among children and adolescents, but also in adults, namely in the clean-up workers and evacuees;
2) The increased risk of leukemia development in the clean-up workers is proven. The fact of a dose-dependent nature of chronic lymphocytic leukemia in the clean-up workers was proved for the first time in Ukraine;
3) There is an the increased risk of breast cancer in female clean-up workers;
4) There is an increased risk of malignant tumors in Ukrainian and Russian clean-up workers;
5) There is an increased risk of radiation cataracts.

Taking into account the long latency periods of the development of radiation-induced cancer of many organs and systems, it is necessary to continue the monitoring of this disease in a remote post-accident period.

Various non-cancer health effects in 10-27 years after the catastrophe that have been proven:
- Cardiovascular disease and mortality in the clean-up workers;
- Vascular eye disease in different groups of exposed persons;
- Cerebrovascular disease and cognitive dysfunction in the clean-up workers;
- Thyroid abnormalities;
- Menthal health disorders in children exposed in utero.

Data for the 30 years of observations show that the Chernobyl catastrophe and its consequences have caused harm to the survivors. These data give a reason to believe that estimates made by the IAEA and WHO on the 20th anniversary of the Chernobyl catastrophe were understated.

In contrast to Chernobyl, after the catastrophe at Fukushima on March 11, 2011 in Japan the existing rules of the alert of the national and international authorities and organizations about the catastrophe have been complied (Fukushima Daiichi NPP, 2011). The IAEA joined the cooperation to render help in the investigation of the causes and consequences of the catastrophe. Its report was presented to the Ministers on issues of nuclear safety on the meeting in Vienna on June 20-24, 2011 (Fukushima. Report of IAEA, 2011). Recognition of the fact that the Japanese government, developers and operators of the Fukushima Daiichi NPP have underestimated the danger of tsunamis was the main conclusion of the report. Some more reports followed. A report on the supposed consequences of the catastrophe at Fukushima NPP on the health of the Japanese was prepared in 2013 (Fukushima. Report of IAEA, 2013). In May 2015 the IAEA published a report on liquidation of the consequences of the catastrophe at Fukushima NPP. At the 59th General conference of IAEA in Vienna (September, 2015) a fundamental report was presented about the organisation of liquidation of consequences of the Fukushima catastrophe. The report included five technical tomes of applications (Fukushima. Report of IAEA, 2015).

Taking into account current information technology the experts and public have the unrestricted opportunities to receive information about the catastrophe at Fukushima and arrangements on liquidation of its consequences.

(D. Bazyka, N. Omelianets)

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 $mSv \cdot year^{-1}$, and in 101 of them varied from 0.5 up to 1.0 $mSv \cdot year^{-1}$. According to the national criteria the settlements with a dose under 0.5 $mSv \cdot year^{-1}$ cannot any more to be regarded as radioactively contaminated. The 25 settlements where the doses make range from 1 up to 5 $mSv \cdot year^{-1}$ can be referred to as zone of guaranteed voluntary resettlement, the 101 settlements with dose range from 0.5 up to 1 $mSv \cdot year^{-1}$ - as zone of strict radio-ecological control. There are no more settlements where the doses exceed 5 $mSv \cdot year^{-1}$, 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 $kBq \cdot m^{-2}$. 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 rate in female Chernobyl catastrophe clean-up workers exceeded in 1.6 times the level of respective morbidity 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 crews/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 levels 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.

B. 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 131I 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.

15. In light of the wide discrepancies in IAEA and WHO estimates related to dose reconstruction and predicted radiation-induced health effects from Chernobyl, it is recommended the study of Fukushima's health effects be as open and transparent as possible, recognize the limitations and consider an extensive range of data on the possible impacts of Fukushima in the long-term. This should include the long-term studies of the multi-generational impact of low-level radiation on human and non-human biota. Indeed, the opportunity has been missed to fully understand the long-term impacts of Chernobyl due to the lack of comprehensive and trustworthy data. Additionally, long-term mental health aftermath should be in the focus of research and management.

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.

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