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

Commissioned by Greenpeace
Brussels
2016

CONTENTS

Pages

GENERAL ABBREVIATIONS, UNIT ABBREVIATIONS, AND TERMINOLOGY

AMS – Academy of Medical Sciences.

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

ARS - Acute Radiation Syndrome.

ATR - Attributive risk.

BSSR - Belorussian Soviet Socialistic Republic.

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

CER - Clinical and Epidemiological Register.

CFS - Chronic Fatigue Syndrome.

CLL - Chronic lymphoid leukaemia.

CI - Confidence Interval.

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

CNS - Central Nervous System.

DCS - Diseases of the Circulatory System.

DS – Department of Statistics of Ukraine.

CMU - Cabinet of Ministers of Ukraine.

EAR - Excess Absolute Risk.

ERR - Excessive Relative Risk.

ED – Effective Dose.

FGI - French-German Initiative for Chernobyl.

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

GR - Growth Rate.

IAEA - International Atomic Energy Agency

ICD - International Classification of Diseases.

IChP-1991 - International Chernobyl Project.

ICRP – International Commission on Radiological Protection.

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

IQ - Intelligence Quotient.

JSDF - Japan Self-Defense Force.

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

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

MH - Ministry for Health.

MIAU - Ministry of Internal Affairs of Ukraine.

NAMSU - National Academy of Medical Sciences of Ukraine.

NASU - National Academy of Sciences of Ukraine.

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

NPP - Nuclear Power Plant.

NRER - National Radiation and Epidemiological Registry.

OR - Odds Ratio.

PTSD – Post-traumatic Stress Disorder.

RADRUE - Realistic Analytical Dose Reconstruction and Uncertainty Analysis.

RCR – Radioactively Contaminated Rayon.

RCT – Radioactively Contaminated Territories.

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

RF - Russian Federation.

RR - Relative Risk.

RSFSR – Russian Soviet Federation Socialistic Republic.

RSSU_97 - Radiation Safety Standard of Ukraine_97.

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

SIR – Standardized Incidence Ratio.

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

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

TEPCO - Tokyo Electric Power Company.

UACOS – Ukrainian-American Chernobyl Ocular Study.

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

USSR - The Union of Soviet Socialistic Republics.

UkrSSR - The Ukrainian Soviet Socialistic Republic.

WHO - World Health Organization.

Clean-up workers (liquidators, recovery operation workers, Chernobyl emergency workers) - citizens of the USSR including the UkrSSR who 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.

4 FUKUSHIMA: HEALTH EFFECTS ASSOCIATED WITH THE NUCLEAR CATASTROPHE

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 (Health effects, 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).

So, the environmental impact of the Chernobyl accident was much greater than of the Fukushima accident. 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. It is also emphasized that the features of the Japanese mentality strongly contributes to mental health deterioration, as well as information policy and risk communication inadequacy following the Fukushima Daiichi nuclear disaster (Loganovsky and Loganovskaja, 2011).

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 reduced. Moreover, sea-food eating (with stable iodine) prevents the overexposure of the thyroid gland by radioactive iodine.

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. 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 acute radiation sickness (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 (Health Effects, 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 (Health Effects, 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·y^{-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, 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 Tsudo *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=30[illegible], 1.082) and the prevalence odds ratio vs. reference district in Fukushima Prefecture was 2.[illegible] (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=[illegible].1, [illegible]). 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 (Tsudo *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, which 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.*, 2014).

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 S. (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 doses to a vast majority of population in Fukushima were not high enough to expect any increase in cancer incidence and health effects in the future. 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 S. (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 (2016), 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 of 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 perfect 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 (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 acute radiation sickness (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, 2013a).

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 (Morita *et al.*, 2015). Significant issues that emerged included a crippling radiation anxiety, a considerable stigma toward addressing mental health care, and a shortage of mental health care throughout the region, as well as the ongoing psychiatric symptoms such as insomnia, anxiety, and alcohol misuse (Karz *et al.*, 2014). 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; Ohto *et al.*, 2015). 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, 2011a, b, c; 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 close to the Three Mile Island crisis (1979) than to the Chernobyl catastrophe (1986) as the estimated radiation doses in Fukushima were reported to be significantly lower than in Chernobyl.

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, 2011a, b, c; 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)	8×10^{16} (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	Questionable
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	Questionable
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 cataract, 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)