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ORIGINAL PAPER

# REMEMBER CHERNOBYL. THREE DECADES SINCE THE NUCLEAR ACCIDENT

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**Abstract.** The nuclear accident in Chernobyl will remain one of the most disastrous events of this kind in the history of humanity, which has caused significant fatalities, affected population and environment health in the short and long run, provoked damage of billions of dollars, determined the shutdown of this nuclear power plant and imposed drastic measures for safety improvement in the functioning of RBMK reactors etc. Humankind is not allowed to forget the disaster that occurred in April 1986 and has to make sure that such accidents are prevented in the future. The present article reviews and recollects the events that took place three decades ago in Chernobyl: the causes of the disaster, the immediate and long-term measures taken by the authorities to eliminate some of its consequences, its effects on human and environmental health condition, its social and economic consequences and the current situation in the area strongly affected by this accident etc. The accident may be regarded as (an accidental) large-scale "experiment" concerning the impact of acute and chronic radiation on life and environment, the recovery capacity of the living matter, the manner to act under such circumstances, the measures to be taken to minimize the effects of similar events etc. We ought to learn from such unhappy incident show to avoid similar situations in the future, and if ever experienced again, how to be better prepared to cope with them and reduce their short-term and long-term effects.

**Key words:** Nuclear accident, health, economic, social consequences, current state.

## Introduction

Three decades have passed since one of the greatest catastrophes in modern human history, provoked by an accident which occurred during the nonviolent usage of one of the most controversial forms of energy discovered by man: nuclear energy. More specifically, we refer to the explosion of unit no. 4 from the nuclear power plant in Chernobyl (Ukrain) on 26 April 1986, having as a result the radioactive contamination of a considerable surface of Europe with immediate and long-term economic and social consequences and causing an impact on human and environmental health which is hard to estimate. After this unhappy incident, the world has become reluctant to releasing energy from splitting the atoms to generate electric power and, in some countries, under public opinion pressure, governments have been forced to consider new energetic policies, confining or even discarding nuclear technologies for producing electric power.

In time, nuclear technologies have advanced, safety measures have improved in such plants, people got accustomed with the risks associated with nuclear power exploitation, hence, the building new nuclear power plants has not ceased. The rememoration of the Chernobyl nuclear accident was occasioned by a similar event which occurred in March 2011. Following a devastating earthquake in northeastern Japan that caused a tsunami of apocalyptic proportions on its coast, significant damage occurred in the reactors of Fukushima power plant (reactor no. 2 exploded, while a fire started at reactor no. 4), making the accident here classified at the same level - 7 as the one at Chernobyl.

For remembrance, I felt it useful to evoke the events that occurred in Chernobyl three decades ago (April 26th 1986) and the short and long-term effects of that major nuclear accident, in homage to all the ones who sacrificed themselves or endangered their lives to reduce or mitigate the effects of that terrible incident. I believe that whoever undertakes the misssion of trying such an approach does not have an easy task, given that, within the three decades, there were tomes written about this accident; and yet, most data relies on estimates and are, therefore, unconvincing. Moreover, rigorous statistics on the health of the local population, the social-economic conditions before the accident are missing, while some data are deliberately exaggerated or rather minimized etc. Undeterred by these, I will further assume this risk.

The accident stirred fear and emotion in Romania three decades ago. The population had not faced such a phenomenon before, but knew the consequences of the nuclear bombs launched by the Americans on Hiroshima and Nagasaki in 1945. I can remember that, on the first days after the accident in Chernobyl, common people who did not know the facts but had heard something in the media about radiation-related hazards affecting the population would see signs of radiation everwhere, even in the pollen floating on water pools caused by rain.

## Accident production

“V. I. Lenin” nuclear power plant in Chernobyl (Ukraine) was positioned close to Belarus border (at about 16 km distance), in the vicinity of Pripyat town (3 km) and at about 130 km from the Capital Kiev. Reactors 1-4 (RBMK-1000, thermic, channel-type, high-power reactors) were built between 1977-1983 (each with a capacity of 1000 megawatts), in 1986 having two more reactors under construction. Without getting into details, this type of reactor uses slightly pressurized water as a cooling agent, the fuel is represented by enriched uranium dioxide (2 % U-235), while the moderator of nuclear fission reaction (with the role of slowing down neutron speed, and implicitly, pressure in the system) is graphite (which surrounds the pressure tubes). This type of reactors, in which the nuclear reactions are assisted by graphite, are considered to be less stable (less secure) than the ones using water as a moderator of the nuclear reaction (3). The pellets of nuclear fuel in a RBMK reactor are included in the zirconium tubing. Among the blocks of (flammable) graphite circulates a mixture of helium and nitrogen to prevent oxidation of graphite and improve heat transfer.

The activity in the reactor is controlled by means of rods of boron carbide (with which the neutrons can be absorbed, thereby reducing the fission rate of the nuclear fuel), (Fig. 1), (15). The core (heart) of the reactor has a diameter of 12 m and a height of 7 m.

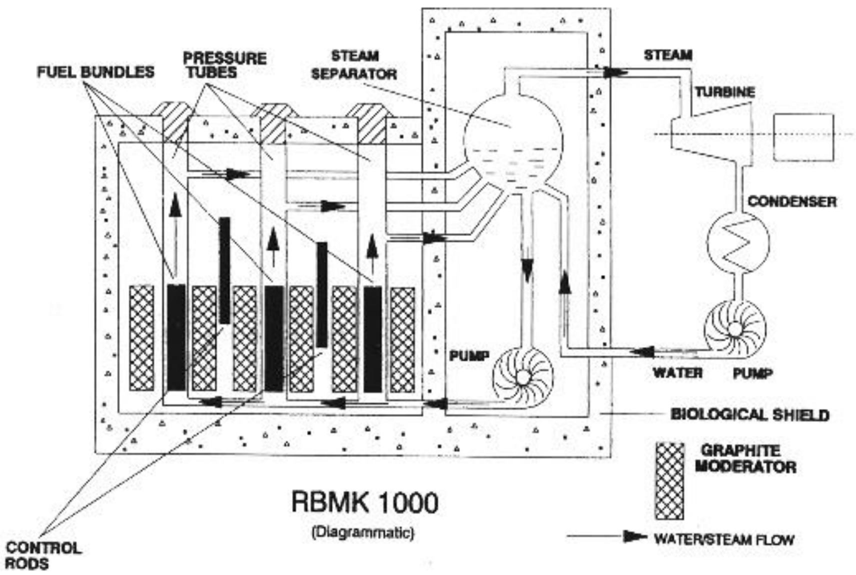


**Figure 1** – Design of time reactor RBMK-1000 (15)

Here is how the events unfolded. On April 26th 1986, there was a test scheduled at reactor 4 in order to verify the functioning of the control unit in case of power failure (if the inertia of the turbine can provide enough electrical power to maintain cooling pumps in operation until emergency generators start functioning), (12, 18). At 1 a.m., the operators started to reduce power in the reactor, which reached 50 % by 2 a.m. The operations carried out caused variations in the temperature of the water located in the reactor, bringing the reactor into an unstable state (2). Reactor power dropped more than necessary (which caused the reactor to produce more Xenon-135 and thus reduce its power even more), (12). Under these circumstances, instead of stopping the reactor and the experiment, the operators tried to increase its power again, by raising the control rods more than admissable.

The test began at 1.22 a. m., under abnormal operating conditions for the reactor. Operators closed the safety mechanism that would have stopped the reactor in emergency situations (in case the steam supply of the turbines was insufficient). At 1.23.01.04, the turbines failed to operate and the cooling pumps stopped, the amount of steam in the pressure tubes increased and the reactor power rather than reduce, increased (which determined the fuel fragmentation and rapid transfer of resulting heat to the coolant). At 1:23:40 a. m., an attempt was made manually shutdown the reactor by releasing the control bars, which could not get to the heart of the reactor because the fuel elements had begun to fragment. After a few seconds (1.23.44 a. m.), the explosion occurred ( 2, 12, 18, 20 ).

The shut down of the reactor cooling system (the cooling of the reactor was ensured by water, the agent generating steam to drive the turbines was also water carried to the central from an artificial lake of about 22 $km^2$, located outside the town of Pripyat) led to enormous pressure accumulating in the reactor and to its final blast. There were two successive explosions at intervals of 2-3 seconds, the first one due to the interaction of very hot fuel with the coolant (which produced a large amount of steam and increased pressure) and the second because of the hydrogen produced from the reaction of zirconium (of which the reactor channels were made) with water vapor. These explosions destroyed the reactor core, its protective layer, and detached the reactor lid (weighing 1,000 tons), causing a breach through which (up to about 1200 m altitude) large quantities of graphite fragments (about a quarter from the 1200 tons of reactor graphite were ejected), radioactive dust and toxic gases were thrown into the atmosphere.

The radioactive material released by the accident would be equivalent to about 200 nuclear bombs (according to other specialists even 400) of the type launched in 1945 on Hiroshima (15, 19). Following the explosion, the hot fragments projected by the reactor produced more than 30 outbreaks of fire around the plant. Note that the temperature reached at the heart of the reactor before the explosion was estimated at about 1400-1600$^0$C; according to other sources, it would amount to even 2000 $^oC$, which led to the melting of the fuel pellets, whereas the graphite surrounding the reactor caught fire and burned for nine days (29). The heat resulted from the decay of uranium and plutonium fission products reached a very high level for several weeks (13, 15). The main causes for the accident are considered to have been: - projecting an unstable and insecure reactor; - lack of solid theoretical knowledge and insufficient staff training; - exaggeratedly confidential measures in the USSR during the cold war (18).

The explosion and the fire caused huge quantities of radionuclides (fission products) to be spread in the atmosphere for about 10 days and their total activity is estimated at about 12 x $10^{18}$Bq (of which, 6-7x$10^{12}$Bq due to noble gases). An air sample taken in 27 April 1986 in the vicinity of the nuclear power plant at altitudes of 400-600 above the soil, contained larger radioactive particles (from a couple to tens of μm), along with a host of small particles (2). The range of radionuclides released after the accident was complex (tab. 1), but a more significant role in the artificial radiation of population and environment was played by isotope $I^{131}$ (whose total activity in Chernobyl was estimated by IAEA at about 1.3-1.8 x $10^{18\ Bq}$), $Cs^{134}$ (approx.0.05 x $10^{18}$Bq) and $Cs^{137}$ (approx 0.09 x $10^{18}$Bq). These values correspond to approx. 50-60 % of radioactive iodine ($I^{131}$) existent in the reactor during the accident and approximately 20-40 % of the two radionuclides of cesium. At the moment of the explosion 3-4 % of the fuel existing in the reactor was released, up to 100 % of noble gases (among which $Kr^{85}$and $Xe^{133}$) and approximately 20-60 % of volatile radionuclides (15). The nuclear cloud formed after the explosion had in its composition some of the isotopes presented in Table 1. (13).

**Table 1** – Isotopes identified in the nuclear cloud formed as a result of the Chernobyl nuclear accident

| Isotope | Radioactivity ($10^{18}$ picocuries) | Radioactivity percentage | Halving time |
|---|---|---|---|
| Iodine-131 | 7.3 | 2.0 | 8.05 days |
| Tellurium-132 | 1.3 | 15 | 78 hours |
| Cesium-134 | 0.5 | 10 | 2.06 years |
| Cesium-137 | 1.0 | 13 | 30.1 years |
| Molybdenum-99 | 3.0 | 23 | 66 hours |
| Zirconium-95 | 3.8 | 3.2 | 65 days |
| Ruthenium-103 | 3.2 | 2.9 | 39.35 days |
| Barium-140 | 4.3 | 5.6 | 12.8 days |
| Cerium-141 | 2.8 | 2.3 | 32.51 days |
| Cerium-144 | 2.4 | 2.8 | 285 days |
| Strontium-89 | 2.2 | 4.0 | 50.5 days |
| Strontium-90 | 0.22 | 4.0 | 28.5 years |
| Plutonium-238 | 0.0008 | 3.0 | 89.6 years |
| Plutonium-239 | 0.0007 | 3.0 | 24.400 years |
| Plutonium-240 | 0.001 | 3.0 | 6.600 years |
| Plutonium-241 | 0.14 | 3.0 | 93 years |
| Plutonium-242 | 0.000002 | 3.0 | 3.8 x $10^5$years |
| Curium-242 | 0.0021 | 3.0 | 162 days |
| Neptunium-239 | 1.2 | 3.2 | 2.35 days |

Table data indicate that the radioactive cloud was carrying huge quantities of I-131, Barium-140, Zirconium-95, Rutenium-103, Molybdenum-99 and Cerium-141.

At the beginning, air currents transported the radioactive cloud to the north-west, then to the north-east, the radioactive fallouts affecting large areas (over 160,000 $km^2$), especially in Belarus, Ukraine and Russia, but it reached

Sweden and even Scotland and Ireland. Areas of approximately 16,500 km$^2$ in Belarus, 8,100 km$^2$ in Ukraine and 4,600 km$^2$ in Russia – located around the plant, recorded excess levels of $Cs^{137}$estimated atabout185 kBq/m$^2$. Three areas were most affected: a central area (spread over about 100 km direction west/northwest from the reactor); Gomel-Mogilev-Bryansk area (stretched over 200 km distance from the reactor to the north/northeast); Tula-Kaluga-Orel region (about 500 km northeast of reactor), (24). Of the three countries, Belarus was most affected by the nuclear accident, 23 % of its territory (53 towns, 3711 villages, 18 % of agricultural land - which were decommissioned) supporting massive release of radionuclide contaminants. This nuclear accident was rated as having grade 7, the highest on the international scale of nuclear events (20).

In the case of the Chernobyl accident, crucial to population radiation were radioisotopes $I^{131}$(the main contributor to the doses at thyroid level – received especially by internal radiation) and $Cs^{137}$ (the main contributor to the doses received by organs and tissues – other than the thyroid, by internal and external radiation). It was estimated that, in the exclusion zone (30 km around the nuclear plant), until the population was evacuated, the doses ranged from 3 to150 mSv. For adults in the area, the doses at thyroid level were estimated between 20 and 1000 mSv, while for one-year olds, were between 20 and 6000 mSv.

For residents later evacuated from this area, the inhaled doses were 50-70 % higher. These internal doses were due in particular to radioactive iodine, and tellurium and radioisotopes of rubidium (21).

Despite the measures taken to eliminate or mitigate the consequences of this accident, it will continue to affect the lives and the environment within a radius of tens of kilometers around the plant in the next few dozens (even hundreds) of years until radiation levels reach normal levels. In Chernobyl exclusion zone, some isotopes have more long-term significance to humans, animals and plants. Among them, are isotopes $Cs^{137}$, $Sr^{90}$ and $Pu^{239}$, which have larger half-lives, respectively 30, 29 and 24,000 years (9). The maximum radiation dose estimated by the International Chernobyl project for residents of the most contaminated territories over the next 70 years (1986-2056) is about 160 mSv (25). Since 1987, the doses of radiation affecting the population in the affected areas have come from deposits on the soil of $Cs^{137}$ and $Cs^{134}$. The average dose received by residents from areas contaminated with the two radionuclides over 10 years after the accident was expected to be 10 mSv, (24). In contaminated areas, $Cs^{137}$ is the most important radioisotope that continues to affect the area in the long run, given that it is located on soil surface, where it can be absorbed by plants, it adheres to clay minerals as it is not mobile in soil, and its removal is only by beta disintegration in short-lived isotope $Ba^{137}$ (15).

A paper published (Ghiorghita and Corneanu, 2002) shows that explosions and nuclear accidents lead to radioactive contamination of soil and water, direct contamination (by depositing radioactive dust on the leaves) and indirect contamination of plants (through absorption of radioisotopes in soil solution) animals and humans (through food). An important role in the contamination of living organisms is detained by three radioactive isotopes – $I^{131}$, $Cs^{137}$ and $Sr^{90}$. The half-life is short for Iodine-131 (8 days) and long for Cesium-137 (30.1 years) and Strontium-90 (28.5 years). In addition, the latter have chemical properties similar to potassium and calcium respectively, so their absorption from the soil by plants depends on the ratio $Cs^{137}$/ K, respectively $Sr^{90}$/Ca in the soil solution (4).

As if the explosion caused by human error had not been in itself a serious enough phenomenon, there was another one, namely the concealment of the nuclear accident by the Soviet authorities of the time. The practice was that events which were detrimental to the projection of "great" achievements in communist countries be silenced (the "law of silence" was enforced unoficially). The level of secrecy was hard to imagine, as it seemed inconceivable to the Communist authorities in Moscow that such a serious and unfortunate event would happen in the USSR, which claimed to be "the bastion of peace and progress" in the world?! It seems that the real situation was hidden for several hours after the explosion by the leader of the country himself, Mikhail Gorbachev.

This reprehensible secrecy led to some measures to protect the population in the affected area (including outside the USSR) being delayed. Even for people near the plant (in Pripyat, for example), the decision and measures to evacuate the area came 36 hours after the accident. We can only imagine the terror and panic of the workers, of the authorities, and of the liquidators of the effects of the accident in a dramatic situation like that. It was probably then that the lack of strict and appropriate measures to protect workers and the local population against radiation became obvious. Public opinion was to find out about the accident only when radioactive dust came and fell over Sweden, the country which gave the alarm. At that moment, the secret could not be kept by the Soviets any longer. Let us remember that in Romania protective measures against the consequences of this dramatic event (including providing the population with pills that contained potassium iodide to avoid contamination with radioactive iodine thyroid) were taken as late as 1-2 May 1986. The level of natural radiation of the population in Romania before the accident was about 2.93 mSv/year, whereas in 1986 it reached 4.17 mSv (12).

## Measures undertaken by the authorities after the accident

A first measure taken by the specialists of the nuclear power plant was temporarily stopping the other three reactors. To limit the effects of the explosion and fire caused by the blast in the first phase (27 April - 5 May1986), the damaged reactor was covered (with the help of more than 30 military helicopters), with about 5,000 tons of lead, sand, boron compounds, dolomite and clay materials designed to absorb neutrons, radiation and aerosols formed. In the space below the tank of the damaged reactor was pumped nitrogen under pressure, which helps to reduce temperature and oxygen concentration. To prevent the base of the tank reactor from melting and to facilitate the penetration of the radioactive mixture deep into the ground, a heat exchanger was installed in the structure of the reactor on a floor made of special concrete (action completed in June), (15 ).

The reactor destroyed was then encapsulated in a metal and concrete sarcophagus, which was completed in October 1986. Under this sarcophagus, there are about 200 tons of nuclear fuel mixed with other materials whose radioactivity is estimated at 700 x 1015 Bq (25), a sarcophagus designed to last between 20 and 30 years (29). Considering that this first sarcophagus proved unreliable, there were some measures taken to make a new one (new safe confinement - NSC), which should be safer. It will have an arch-shaped structure of steel and concrete, of impressive size (110m high, 160m long and 260m-scale, whose cost is estimated at about 1.5 billion euros), and will cover both the reactor destroyed and the old sarcophagus. Its construction began in April 2012, asis a structure made of two pieces, made separately near the reactor damaged, which will be assembled together, and the resulting structure will be transported on rail about 330m to be placed in its final position after the side walls are added. This new sarcophagus will weigh about 31,000 tonnes and is projected to be finished in November 2017 (15). It is the largest movable structure made on Earth and about 1,400 people took part in its being built, with funds from 40 countries and covering the reactor just like a casserole. One night marish day in history 30 years ago (April 26th 1986) meant, among other "costs" difficult to assess, spending several billion dollars (16).

In 1986-1987, the action of removing the consequences of this catastrophe involved about 200,000 people (called "liquidators") that were part of the nuclear power plant personnel, firemen, civil and military troops, medical, civil, military and air force personnel etc., throughout the Soviet Union. They received an average dose of about 100 mSv, about 10% had received a dose of 250 mSv, and a few approximately 500 mSv (natural background radiation averaging 2.4 mSv/year). High doses of radiation received approximately 1,000 people who intervened urgently on the first day after the accident, and dozens of them probably received lethal doses of radiation (several thousands of mSv).

In the coming years, approximately 400,000 more people were among the liquidators of Chernobyl accident consequences, but received lower doses of radiation (2, 15). Of the approximately 600,000 liquidators at Chernobyl (who received liquidator certificates under the law in Ukraine, Belarus and Russian Federation), 240,000 were soldiers. It is estimated that the dose received by 211,000 workers who participated in the first year after the accident was of 165 mSv (16.5 rem), (15). The doses recorded in the area of maximum impact of the accident gradually decreased over time, being of about 170 mSv in 1986, 130 in 1987 mSv, 30 mSv in 1988 and 15 mSv in 1989. It is considered reasonable to admit that during 1986-1987, the accident liquidators received an average dose (derived from external gamma radiation) of about 100 mSv (24). Table 2 (after Bennett et al.) presents external radiation doses received by some liquidators of the accident from 1986 to 1987, (2).

**Table 2** – Distribution of external doses received by emergency workers and liquidators

| Category | No. of people | Percentage in the dosage interval (in mSv) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 0-10 | 10-50 | 50-100 | 100-200 | 200-250 | 250-500 | 500 |
| Emergency workers and accidental witnesses | 820 | - | - | 2 | 4 | - | 7 | 87 |
| Nuclear plant staff, 1986 | 2.358 | 13 | 45 | 24 | 14 | 2 | 2 | - |
| Nuclear plant staff, 1987 | 4.498 | 66 | 42 | 1 | 1 | - | - | - |
| Building workers, 1986 | 21.500 | 23 | 24 | 11 | 18 | 11 | 13 | - |
| Building workers, 1987 | 5.376 | 47 | 23 | 24 | 4 | 1 | 1 | - |
| Military pesonnel, 1986 | 61.762 | 13 | 22 | 16 | 23 | 19 | 19 | - |
| Military pesonnel, 1987 | 63.571 | 15 | 15 | 49 | 15 | 6 | 6 | - |
| Workers brought from other nuclear power plants, 1987 | 3.458 | 78 | 21 | 1 | - | - | - | - |

As shown above, 36 hours after the accident, the authorities began evacuating residents in the vicinity of the plant in Chernobyl, starting on April 27 with those of Pripyat (about 45,000 residents) and Chernobyl – the city inhabited by workers from the power plant and their families (about 10,000 residents). On 3 May, there followed those on a 30-km radius (exclusion zone) around the plant (in total about 116,000 people). The exclusion zone was placed under full control of special units of the Interior Ministry of Ukraine and any civil business or residential activities were banned in the area (28). The action of evacuation for Pripyat population began 36 hours after the explosion of the reactor, but it took days and hours (until May 14) due to lack of transportation, although the mission had been allocated over 1,000 buses.

It is estimated that, out of 116,000 people evacuated, less than 10 % received doses of 50 mSv and less than 5 % received a dose of 100 mSv. Meanwhile, some of those removed from the area which was heavily affected (some hundreds, others speak about 1000) unofficialy returned to their homes. Initially, the area of evacuation around the plant was 2,800 $km^2$ and later was extended to 4,300 $km^2$. After the accident, 220,000 other people were relocated from areas that were beyond a certain level of radioactivity (24). After the evacuation of Pripyat town, a new town was built at about 30 km from the power plant (Slavutich) to host the ones who worked in the area and their families.

Workers in the plant (about 3,000) worked in limited shifts and were closely monitored for radiation doses received (19). According to other sources of information, the number of liquidators in the accident at Chernobyl was about 830,000, the number of people evacuated from the area 30 km around the plant and other areas of high radioactive contamination was 350,400, the population strongly affected by radiation (in Belarus, Ukraine and Russia) of roughly 8.3 million people, and the total number of people in Europe who have been exposed to minor radiation amounted to about 600 million (23).

After the accident, a series of measures weer taken to decontaminate the area around the plant and the buildings, which involved:

- Removing the debris generated by the explosion and contaminated equipment;
- Decontaminating roofs and exteriors of buildings;
- Removing a layer of soil 5-10 cm thick and transporting it (in containers) to the radioactive waste storage;
- Where necessary, concrete floors were raised, or the ground was covered with earth brought from uncontaminated areas;
- Some surfaces (including raised floors) were coated with polymers able to capture dust and to prevent the formation of aerosols, etc (13).

They were designed means of ventilation and disposal of the heat further released by fission compounds trapped in the damaged reactor tank. In this respect, miners were brought (from coal mines in Russia) to dug a tunnel of about 150m under the reactor where they walled off a room of 30x30m designed for a cooling system. In June, after the explosion, hydraulic works were carried out in the area surrounding the Chernobyl power plant in order to lower the groundwater level. It is estimated that urgent action to remove the consequences of this unfortunate accident lasted for five months and they involved at least 600,000 people (according to other sources about 1 million) - soldiers, firemen, civilians, about 4,800 medical personnel (of which 1800 doctors). By the end of October 1986, they had removed some of the consequences of the accident and had built he sarcophagus beneath which lies the remains of Unit 4. The costs of "Operation Chernobyl" as it was called, amounted to about 18 billion rubles (20).

After the accident, the population in the affected area was recommended to respect a set of measures, among which:

- Not using rainwater, consuming drinkable water only from networks of deep wells;
- Controlling the radioactivity in milk and milk products for human consumption;
- Avoiding exposure outside the home, especially in the case of pregnant women and children;
- Distributing potassium iodide tablets to the population (especially young people), etc.

Immediately after the accident, the functional reactors were stopped at Chernobyl nuclear power plant. After the action to stop radioactive emmisions from the damaged reactor and clean the area in the immediate vicinity of the plant, in November 1986, due to dire need for energy, reactors 1 and 2 were turned on again, and in December 1987, there followed reactor 3. However, this serious accident led to the abandonment (in 1989) of the plans for construction of reactors 5 and 6, as initially designed.

After 1990, public pressure and international bodies in the field raised the issue of closing the nuclear power plants which proved unreliable, based on the assumption that it was still difficult to estimate the risks. In 1991, a fire started in the turbine hall of reactor 2 (causing its immediate closure), whereas in 1995, another serious incident occurred at reactor 1. It was then obvious that the situation could no longer continue. Incidentally, in 1992 the Group of 7 developed countries (G-7: USA, Canada, France, Great Britain, Germany, Italy and Japan) drew attention to Russia that RBMK reactors that they are unsafe and should be closed. In December 1995, a memorandum was signed between the G7 and Ukraine providing for the closure of the Chernobyl power plant until 2000, in exchange for substantial financial support (about 3.1 billion US dollars) a memorandum that has been so far respected. Hence, in 1996, reactor 1 in Chernobyl was decommissioned and on 15 December 2000, reactor no. 3 was closed, too (27).

Between 1987 and 1991, there were taken a number of technical and organisational measures to increase the security of RBMK reactors, measures to remedy some design deficiencies, to improve equipment quality, as well as management in nuclear power plants and appropriate staff training etc (15).

**Effects of the accident at Chernobyl on human health**

The short- and long-term consequences of this terrible accident on human health and the environment are difficult to estimate because there is no way to distinguish between diseases and deaths as a result of the nuclear accident and those from other causes (diet, living conditions, stress, ill-health, etc.).

Therefore, the data on the long-term impact of the nuclear accident on health when exposed to radiation, recorded in articles and works investigating to this aspect, are sometimes contradictory. On the other hand, there is no reference data on the state of health in the area before 1986. The effort to assess this aspect was however considerable, not only from the Soviet authorities but also from the international organisations. After 1990, when the Cold War between East and West died out (from March 1990 - June 1991) about 50 international missions were organised in the area to train about 200 experts (from 25 countries, including USSR), 7 organisations and 11 laboratories for evaluating the consequences of this accident on human health, using as control subjects the residents of areas unexposed to radiation (15).

The doses to which the emergency workers were exposed after the accident (about 600) were due more to external radiation (gamma and beta) of the whole body rather than to inhalation of radionuclides (2). On the first day after the accident, the radiation doses reached levels estimated at 28,000 mSv, causing acute radiation syndrome in 134 liquidators, of which 28 (among which six firefighters) died until the end of July 1986 due to exposure to high radiation doses. Three other people lost their lives from causes other than radiation (22, 25, 29). Patients from this lot registered serious gastrointestinal lesions, skin lesions (affecting over 50 % of them) etc. Of the 134 patients investigated, 41 received doses below 2.1 Gy, and 93 received higher doses between 2.2 and 16 Gy (50 patients - between 2.2 and 4.1 Gy; 22 patients – 4.2 - 6.4 Gy, and 21 of them – from 6.5 to 16 Gy). Eight of the patients suffering from acute radiation syndrome received doses of beta radiation at skin level between 400 and 500 Gy, (24).

In 2005, the IAEA and the World Health Organization (WHO) attributed 56 deaths to the nuclear accident (47 liquidators and nine children with thyroid cancer), estimating that more than 9,000 people in the affected area (of those exposed to higher radiation doses) might die in the future due to various forms of cancer (12). There are sources estimating that the accident caused about 25,000 casualties and 65,000 disabled victims, while others assess even 60,000 dead and 165,000 invalids among more than 7 million people exposed to radiation (20). In some works, there are even larger numbers of accident victims. Thus, in a book published in Russian in 2007 by Yablokov et al., translated later into English and published in 2009 in Annals of the Academy of Sciences in New York, entitled "Chernobyl: Consequences of the Catastrophe for People and the Environment" emphasizes that the radioactive emissions caused by the accident spread over a huge territory, they have affected and continue to affect hundreds of millions of people and that the number of premature deaths caused by it between 1986-2004 were estimated at about 985,000 people (most in Belarus, Ukraine and

Russia), mostly due to various cancers (11). These estimates are incomparably higher than the ones advanced by the IAEA and WHO. The accident led to an increase in immune deficiencies and decreased life expectancy. An important conclusion of the book is that it is totally wrong to forget what happened at Chernobyl (6, 10). While it is possible that IAEA and WHO have not presented the whole truth about the catastrophe at Chernobyl, the death toll caused by this accident, as estimated by the authors mentioned above (about 1 million people), seems exaggerated and less credible.

Chernobyl accident certainly increased thyroid cancer incidence among children exposed to radiation in the area affected, the effect being more evident in Belarus than in Ukraine and Russia. The main radionuclide contributing to the doses received by thyroid was $I^{131}$, especially through internal radiation, for several weeks after the accident, (2). Children are more likely to get thyroid cancer due to radioiodine as they receive radiation doses higher than adults at thyroid level, because they have higher metabolism, while their gland is smaller in size (22). The minimum latency period (between radiation exposure and thyroid cancer diagnosis) is about 4 years. At the end of 1995, there were reported about 800 cases of thyroid cancer among children under 15 years (born before or within 6 months after the accident), in the area heavily affected by radioactive fallout, of which 400 in Belarus.

These cases were concentrated in areas where radioactive iodine contamination was higher. Immediately after the accident, some foods, such as milk and vegetables had high levels of contamination with radionuclides and control measures were not sufficiently rigorous (many children consumed milk products from the contaminated area). After 2000, there were identified 4,000 cases of thyroid cancer in children exposed to radiation after the accident. Other sources of information show that between 1986 and 2005, there were over 6000 cases of thyroid cancer (including 15 fatal), (22). It was observed that, in the small children group (under 5 years when the accident occurred), there is a higher risk of thyroid cancer, which requires close monitoring (24).

According to Marples' statement (2004), the connection between radioactive fallout and thyroid cancer was not denied by any medical authority (7). Fortunately, this disease - despite its aggressiveness, responds favorably to treatment procedures available and many patients of thyroid cancer can be saved if the disease is diagnosed on time and treatment is adequate (in this case, 99% of patients were saved). It is difficult to predict the future incidence of this disease in humans exposed to radiation (25), although there are estimates according to which between 1986 and 2056, there will be recorded 92.627 cases of thyroid cancer (calculations do not include liquidators), (2. 3).

Another form of cancer whose incidence was expected to rise after this accident was leukemia. Among approximately 7.1 million residents of the territories "contaminated" and "strict control zones", 470 more deaths were expected in 1996 to register due to this disease, to which there could have added 200 more deaths from leukemia among the 200,000 liquidators, between 1986-1987. According to some sources (18), there were actually identified only 21 cases of leukemia among the liquidators that received a dose of 150 mSv. Other informative materials, however, do not provide clear evidence of increased incidence of leukemia or other cancers among liquidators and the population exposed to radiation (24). According to some prediction models, the number of cancers among the 7.1 million residents in the next 85 years from the accident was estimated at about 6,600. (25).

Studies on the impact of the accident at Chernobyl concerning the incidence of cancer in the population have been conducted in areas farther from the disaster site. Such a study undertaken in Sweden notes about 5% of Cs137 released in the accident fell in their country and led to the population receiving an estimated annual dose from 1 to 2 mSv. Assessments made by Alinaghizadeh et al. (2014) in the population of nine counties in northern Sweden, during two distinct periods (1980-1985 and 1986-2009) showed that the effect of $Cs^{137}$ on the incidence of cancer in the study area is uncertain (1). Despite the fact that the risk dose in cancer is uncertain, this does not mean that the risk has disappeared.

According to some assessments that take into account the collective doses of radiation and risk estimates, the number of deaths from cancer caused by the accident at Chernobyl ranges from 9,000 for the population in the most contaminated areas of former USSR to 93,000 deaths in the rest of Europe (5).

It is possible that the absence of clear evidence of increased deaths, cancers (other than thyroid cancer), other non-malignant (somatic or psychological) disorders in the population from some areas affected by the accident be due to the fact that radiation doses to which they were exposed were relatively small. The accident impact on the cancer incidence should be neither underestimated nor exaggerated. Not each radiation dose can induce undesirable phenomena, but some effects of radiation, including cancer can be just a threshold. According to UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) estimates, in the period from 1986 to 2005, residents of areas of "strict control of radiation" (approximately 216,000 people) received an average dose of 31 mSv, and those “contaminated” areas (about 6.4 million people) had a dose of only 9 mSv (over a period of 20 years). On the other hand, as already mentioned, it is difficult to distinguish, in the exposed population, the effects induced by radiation from those caused by other causes (24). For other organs and tissues than the thyroid, the main radionuclides that will contribute to external and internal radiation of the population in the contaminated areas are primarily $Cs^{137}$, then $Cs^{134}$ and, to a lesser extent, $Sr^{90}$ and aerosols containing plutonium radioisotopes (2, 24). About 100 surviving liquidators of those who spoke immediately after the accident received high doses of radiation and form a group closely monitored and medically examined. The observations made on them are likely to provide important information on the long-term effects of radiationon human beings (2).

In 2003, IAEA (the initiative of the Director General ElBaradei), together with 8 other United Nations organizations and three government organizations from Ukraine, Russia and Belarus established Chernobyl Forum. The main tasks of this Forum were: collecting information on health and environmental effects of exposure to radiation from radioactive materials produced by the accident; providing special remedial programs and health care; analysing the need to continue research to solve disputes. Representatives of the above mentioned organizations, plus observers, meet annually to discuss these problems.

Chernobyl Forum Report 2005 stated the official position that, apart from increasing thyroid cancer "*there is no evidence of a major impact on public health to be attributed to radiation exposure from the accident after 14 years. There is no scientific evidence of an increased incidence of cancer in general, of mortality or non-malignant disorders that could be related to radiation exposure*." Of course that could be the reality, but we must take into account the possibility that things may not be as good as they are presented. International organizations that monitor such events (IAEA, WHO) are in a very uncomfortable situation: on the one hand, they must inform the public correctly about the findings and recommend appropriate measures to minimize the effects, on the other hand, they have no interest in alarming the world and making it averse to using nuclear energy for various purposes.

According to information from this Forum, an increase in morbidity by leukemia among liquidators (who received doses exceeding 150 mGy), death caused by some forms of cancer and cardiovascular disease (approx 5 %) and increased cataract risks etc. are highy possible. The Chernobyl accident has also raised numerous socio-economic problems due to population evacuation and resettlement in the affected area, it produced psychological trauma (stress, panic, fear, anxiety, depression) not only out of concern and fear for people's health, ignorance or erroneous perception of the risk posed to themselves and their children from radiation, but also because of loss of previous social contacts. These conditions also occur in other types of disasters, such as earthquakes, floods, fires etc. Moreover, the accident led to abuse including tobacco and alcohol among the affected population. On the other hand, psychosomatic disorders encountered in the population were caused not only by the accident itself, but also the economic difficulties of the period and the early dissolution of the USSR (25). 10 years after the accident, psychiatric disorders and its consequences persist in the population.

What was really unfortunate was the fact that some doctors in Europe recommended abortion to pregnant women for fear of teratogenic effects of radiation on their fetuses, even when it was not necessary (15).

Chernobyl Forum-6 (2006) made some recommendations concerning the health of the liquidators and of the population exposed to radiation as a result of the Chernobyl nuclear accident, including:

-Continuing the annual check-up program and ensuring health care for emergency liquidators and those who survived ARS;

-Reconsidering monitoring programs for persons who received doses above 1 Gy on the whole body;

-Directing resources more efficiently to reduce infant mortality, tobacco and alcohol abuse, to detect cardiovascular disease and to assess the mental state of the affected population;

-Further screening to detect thyroid cancer among children and adolescents who were living in the contaminated areas in 1986 (26).

In reference materials consulted on Chernobyl, we encountered scarce information on the genetic impact of the nuclear accident on the population exposed to radiation. Some of these signal the incidence of chromosomal aberrations in children born of liquidators exposed to radiation, as well as a significant increase in the frequency of genetic and teratogenic disorders, in the number of abortions, infant mortality etc, not only across the three countries situated within the major impact zone, but also in remote areas of Europe (Scandinavian countries, for example, during 1987-1992 recorded increased infant deaths, with a surplus of 1 209 cases) etc (23). The immediate consequences of the accident included the reduction of the number of births in Europe, changing the balance between the sexes (there were significantly fewer girls born), increased incidence of dead fetuses etc (23). A study undertaken in 1994 in Belarus showed that, in areas where soil contamination with radioactive cesium was 1-5 $Ci/km^2$, the number of birth defects in children have doubled since 1986, and in areas where this contamination exceeded 5 $Ci/km^2$, it rose more than 8 times than normal (7). Among the liquidators of the accident, there was a significant increase in the frequency of diseases that affect the endocrine, nervous, circulatory, digestive, musculoskeletal, systems, cataract frequency, ageing acceleration, increased cases of diabetes among children and adolescents etc. (10, 23).

In the first months after the Chernobyl explosion, the flora and fauna of the exclusion zone were visibly affected. Immediately after the accident, coniferous forests suffered greatly as they were more sensitive to radiation (about 4,000 acres, or about 1620 hectares of pine forest turned red (8, 21, 28). It was noted that the average growth rate of pine (*Pinus silvestris*) fell sharply in 1987-1989 and in the years following the nuclear accident (9). The populations of large mammals shrank visibly, some small mammals and invertebrates in the soil disappeared, the breeding capacity of plants and animals reduced (especially within a radius of 10 km around the plant, where contamination with radionuclides was stronger). Investigations by Mousseau et al. (2013) suggest that radiation inhibited the growth rates of pines in Chernobyl area.

In contaminated areas, there was also recorded a sharp increase in the frequency of mutations in plants. Some tame animals remaining in the exclusion zone, such as horses and cows registered thyroid disorders resulting in death and birth anomalies in animals in the years after the accident increased dramatically (14). Researchers found high levels of radioactive contamination of mushrooms, berries and game (with $Cs^{137}$), and cautioned the authorities to inform the population about this, recommending them to avoid the consumption of these foods. In view of the long half-life period of $Cs^{137}$, the levels of contamination of such products will remain high for several decades. In the fall of 1986, radiation rates dropped by about 100 times, in 1987 radiation was driven especially by radionuclides $Cs^{134}$ and $Cs^{137}$, to a lesser extent by $Sr^{90}$ and an even lesser one by $Pu^{239}$ (25). Assessments are that the area around Chernobyl plant (about 38,000 $km^2$) will be contaminated for about 300 years and remain largely uninhabited (19).

The Chernobyl Forum considers that, by the natural process of reducing the levels of radiation, but also by the measures and actions taken by the authorities after the accident, most of the land contaminated with radionuclides in 1986 are now safe for life and economic activities. Future restrictive measures are still necessary in the exclusion zone and in certain areas (limited) of Ukraine, Belarus and Russia, as well as remedial measures for areas with poor contaminated soils (peat soils) on which the transfer of radioactive cesium from soil into plants is high. Unfortunately, remedial actions are technologically difficult to apply in forests and areas under water (26).

This accident has had significant socio-economic impacts: huge economic losses, economic depression in the affected areas, difficulties in implementing investment programs, destruction of local communities as a result of the relocation of hundreds of thousands of people, developing “Chernobyl victim” complex and so on. The Chernobyl Forum recommended that, in the coming period, the authorities' effort change and priority measures of economic and social recovery of areas affected by the accident be taken. Note that about 7 million people receive some compensation after the accident and that the governments of Ukraine and Belarus annually allocate approximately 5-7 % of their budget to this purpose (18, 24). Further observations regarding the long-term consequences of the accident on human health and the environment, social conditions are required. The accident apparently had political consequences, former president of the USSR - Mikhail Gorbachev considering that it represented a more important factor in the collapse of the USSR than the well-known liberal Perestroika reform, initiated and promoted by him (15).

Accidents such as the one at Three Miles Island – USA (28 March 1979) and Chernobyl (26 April 1986) are undesirable and should be avoided if possible, because they have different incalculable effects, not only immediately but in the long run, too. Unfortunately, they may occur for reasons other than technical or human errors (see the case of Fukushima, 11.03.2011). Despite its negative economic and social consequences, the Chernobyl accident can be viewed from another angle. It represents a kind of larges-scale experiment performed under natural conditions, providing information (otherwise difficult to obtain in laboratory experiments or small scale) on the impact of acute and chronic radiation on life in general and on the living creatures from the affected area in particular, on their strength, their capacity for recovery and survival in such conditions, on how to take effective actions in such situations, the measures required to minimize the effects of such accidents etc. It may sound cynical, but experience gained in such unfortunate events, can be extremely useful for future confrontation with other similar accidents. We learn how to manage to limit their short-term and long-termeffects.

**Current state in the affected area**

In 2010, the government of Belarus decided to repopulate some areas of regions Gomel and Mogilev (where about 137,000 people were relocated in 1986), proposing to develop a national program of socio-economic, industrial and agricultural development of the area. The program includes measures to restore infrastructure, provision of utilities (water, gas, and energy), construction of new housing facilities (instead of the ones destroyed or contaminated, which were demolished), schools, hospitals etc. At the same time, lands where contamination with $Cs^{137}$ and $Sr^{90}$ is low are expected to become arable and some reforestation actions are to be considered. Obviously, these projects mean significant investments and actions. (15).

After the accident, in the exclusion zone (approximately 4200 $km^2$) was observed a clear reduction in populations of wild mammals. Observations show that, in the long run, the situation is not liable to alarm us. The exclusion zone has since become a true national park, where no human activities led, paradoxically, to the proliferation of flora and fauna. Forests took hold everywhere (although they lack biodiversity). Some authors believe that plants have adapted their high levels of radiation by enhancing DNA repair mechanisms and hypermethylation (21). Helicopter flights over the exclusion zone and ground assessments in winter have recently indicated a relative abundance of mammals such as elk, deer, wild boars, wolves – just like in uncontaminated areas. It even signalled the presence of the brown bear. In the exclusion zone of Belarus, the deer population increased

10 times between 1987 and 1996 and wolves 7 times compared to the uncontaminated areas. The increasing wolf population in the exclusion zone is interpreted as an indicator of ecosystem health. In this area, there found shelter other species of smaller mammals like foxes, lynx, rabbits, otters, martens, weasels, various rodents (which seem to have tolerance to high levels of radiation) etc (14, 17, 21, 30, 31). In 2008, there were introduced in the exclusion zone Ukrainian large mammals like bison and Przewalski's horse (which apparently is declining). Hundreds of species of birds also live, feed, nest and raise their young in the region affected by the accident (8)

What are we to make of these observations and findings ?! Obviously we must not accept that radiation is positive, beneficial to life, although low doses of ionizing radiations (their size is different depending on the species) are known to have a stimulating effect on plants and animals (4). They give us reason to be a little more optimistic about the risks of radiation on life in general, although long-term effects are more difficult to estimate. In slightly exaggerating the current situation of wildlife in the Chernobyl exclusion zone, we are compelled to accept that human actions on natural ecosystems are even more harmful than the effects induced by chronic radiation caused by this accident. On the other hand, we cannot fail to see that nature has an incredible capacity for recovery, regeneration, adaptation and that the living can overcome almost any obstacle.

Pripyat town and its surroundings have become tourist attraction lately. The ghost town of Pripyat is "frozen" in time, which inspires both fear and attraction and makes many of our fellows tempted to visit it, despite the risks they face. The atmosphere is certainly desolate, because a city born along with the nuclear power plant, where people lived relatively well before 1989, is now deserted, devoid of the ordinary bustle, a town where vegetation proliferated and only birds of the sky and forest animals make it alive. A town where you find at every step traces of those who have left in a hurry, leaving only memories there, but also a part of their life and their belongings. It is impressive to learn from Bob Simon, one of those who visited the area last year that, 10 years after the accident, workers and firefighters had already erected here a monument in honor of their colleagues whose lives have been destroyed, with the inscription "those who saved the world" (16). Their sacrifice really mattered enormously and allowed many lives to be saved.

**Instead Of Conclusions**

•The Chernobyl accident demonstrated how such an event can destroy in a matter of minutes what man has created for a long while. It shattered people’s confidence in security in general, not only in the nuclear industry but also in other industries;

•The consequences of the accident on human health and the environment, on economy and social life in the area heavily affected by radioactive contamination are incalculable and long-lasting. This is why they require further research efforts on the long-term impact of the accident on human and environmental health, as well as on social aspects;

•The accident has imposed a series of changes to RBMK reactors RBMK which will increase their safety, in order to avoid such events in the future: changes in control rods – by adding neutron absorbents, enriching nuclear fuel (1.8 % to 2.4 % U-235), faster operation of automatic closing mechanisms, improved safety systems (15);

•Although less significant in context, some believe that this accident has had political consequences that triggered a chain reaction of events that ultimately led to the collapse of the USSR.

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