LESSON 5

SOCIAL, PSYCHOLOGICAL AND MEDICAL ASPECTS OF NUCLEAR POWER PLANT REACTOR ACCIDENTS

1. CULTURE OF RADIATION SAFETY

“Safety is one of the most important values in human life. But due to lots of problems of international, national and technogenic safety and violation of labor safety millions of people die, suffer through personal injuries and occupational diseases. Just due to these problems every year humanity sustains losses of hundreds of billions of dollars.

The search for new approaches to prevent wars, accidents, industrial injuries and occupational diseases still goes on. Twenty years ago the International Atomic Energy Agency (IAEA) formed a new conceptual approach to determination of nuclear power plant (NPP) safety as a notion comprising determining factors of universal and occupational culture. The notion of technology and psychology of NPP safety grew into the safety culture concept that nowadays is one of the fundamental safety principles in the nuclear industry. Thus, the IAEA has stepped a bit forward in comparison with other international organizations in the sphere of cultural values use to solve specific practical tasks in the safety provision sphere.

It was soon found out that humanization of the safety system is a manifestation of worldwide tendencies. It is also confirmed by the analysis of the best practices, obtained in the course of the International Year for the Culture of Peace (2000), the International Year of Dialogue among Civilizations (2001), and the Millennium Summit (September 6–8, 2000), on reconsideration of the role and place of culture in the life of a person, family and modern civilization. It was this analysis that gave rise to such terms as "world culture", "international safety culture" and "national safety culture". These word combinations are the evidence that it is man who is called upon for making important decisions that can have serious consequences for safety and who will directly perform dangerous actions or indirectly influence safety, is delegated powers to control safety by means of self-control.”*

* Safety Culture at Ukrainian Nuclear Sites: Methodological Guide / Yu.M. Skaletsky, S.I. Condratov, O.I. Nasvit et al.; under the general editorship of Academician of the National Academy of Sciences of Ukraine, Doctor of Engineering, Professor V.P. Horbulin. K.: PH NVC "Euroatlantikinform", 2007.

The cited text is the first in Ukraine to introduce the new fundamental notion *safety culture* as a specific component of general social culture. It means that the safety problem in any sphere of human activity is raised from the sphere of institutional and occupational problems to the level of higher quality — in the dimension of universal culture. The notion *safety culture* becomes a specific component of *general social culture* closely connected with the latter and thus having as the basis the general culture itself. In the hands of the ignorant and criminals a NPP or an aircraft becomes an instrument of terrible danger.

Safety of powerful technical objects (nuclear, space, aviation, industrial, chemical, mines, railways and highways, etc.) concerns not only saving many thousands of peoples' lives, numerous material and financial resources, but also (and it is even more significant) social peace, trust in scientific and engineering achievements that provide further civilization process.

Culture is a difficult-to-understand notion, thus we can see in different encyclopedias, dictionaries and culturology works a variety of its definitions, which is obviously connected with the multidimensional nature of the notion itself, different professions of the authors of such definitions, and even with their different worldview. The definition of the notion *culture* within the safety aspect differs substantially both in official documents and in "private" ones, which reflects different perception of the problem and its grounds.

Thus, according to the mentioned above, safety culture is a component of culture in general, and this very statement should underlie determination of the term *safety culture.* An obvious fact should be noted: culture, despite all the ways of its definition, is a product of social (collective) and individual psychology. Thus, all the material objects created by man and serving as traits and symbols of culture are nothing more than artifacts of human psyche, individual or collective. The Dome Cathedral Pipe Organ, an aircraft that charms with its perfection, roadside rubbish, roads condition, accident at the fourth unit of Chernobyl NPP — all these are products of human psyche. Epigrammatically it was described by Professor Preobrazhensky: "Ruin dwells not in water closets but in minds" (M. Bulgakov "The Heart of a Dog").

It leads to a conclusion that safety culture is a psychological category and consequently the role of human psychology in safety provision is basic and fundamental. This statement seems incontestable due to the fact that any automated device, machine, or integral powerful technical object is a product of intelligence and psyche of a large group of people from the author/authors of the idea to materialist implementators, thus we must come to an exact, logical and incontestable conclusion that provision of stable and accident-free functioning of powerful technical objects is provided by only one factor — a human being with his intelligence and psyche. A human being as a culture bearer is *almost* the only initial factor of both danger and safety guarantee and thus his role in this is *almost* absolute.

In 1959 brilliant psychologist and psychotherapist of the 20^{th} century that became famous as “one of the most prominent healers of all times and nations” and being at that time 84-year-old Carl Gustav Jung answered in the following way to a journalist's question about his point of view concerning the danger of initiation of the third world nuclear war, “One thing is obvious: a great change of the psychological approach is imminent. It is incontestable. Because we strive for psychlogical know-ledge even more and more. We strive for understanding of the human nature even more. Because the only real danger is the human being itself. And we, unfortunately, do not understand this. We know nothing about the human being, too little. Human psyche should be studied because we are the source of all possible coming evil”.

It is common to claim that in the era of highly automated nuclear technologies and their protection systems the human being remains the *only critical element* in the human — machine system. Due to the diversity of meanings of the word *critical* the statement seems argumentative and uncertain. “*The only critical element”* may mean “the only weak one”. But, in the first place, automated devices also can fail and only due to this fact the human being is not “the only critical element”. In the second place, this statement can be accepted only in a very narrow sense: an automated device really can close or open any contact quicker than man does. But only human being can make right decision so to say in state of emergency. Thus, the “critical state” of the human being in such situation can be connected exceptionally with its ability to find the very right decision and to implement it. On the other hand, the “critical state” of the human being can be connected with uncertainty of its psychological, and even more its psychic state, its possible secret malicious intent. Thus, we again find the evidence: the human being with its psyche and intelligence is *almost* the only source of safety as well as danger and so needs special attention and in this sense the human being is critical.

In reality the human role in the system of supercomplex technical objects control is unique, otherwise man could have been substituted with a supercomlex automated device. All the automated devices just serve the operator, saving his power and time till the moment when it is necessary to make an unconventional decision. In this situation man accepts the burden of responsibility, whose pressure cannot be sus-tained by everyone.

Since the main conclusion of studying the notion *safety culture* proves the unique role of human psyche in provision of safe operation of large-scale technical objects and since the properties of the core of human psyche are to a great extent determined genetically and thus are conservative, i.e. practically are not corrected through training, we should understand that the main factor of safety of such objects is occupational and psychological selection of candidates for positions, whose role is crucial for safety provision. These positions cannot be taken by people who are characterized, for instance, by inclination to risk or excitement, indecision, irresponsibility, etc. The level of cognitive functions and professional training are obviously also important.

The culture of every person is known to be formed, among other things, by the state of the culture of the whole society that in its turn is a manifesttation of collective unconscious. Thus, in a society with problem social culture one should expect problems in safety provision.

Except for the mentioned above, for the sake of truth and human self-preservation one should take into consideration not only the "scantiness of knowledge about human nature" but also the scantiness of human knowledge about the physical and metaphysical principles of organization even of our closest environment. For instance, man cannot foresee the time of earthquakes or tsunami, their intensity and location. Due to this very fact, above there was mentioned *"almost* absolute" role of man in safety provision and technogenic disaster creation. But still man can take preventative measures to counteract negative consequences (or to decrease their level) of catastrophic natural disasters. Thus, fatal does not mean imminent because one can form even his fate if there are human wisdom and will.

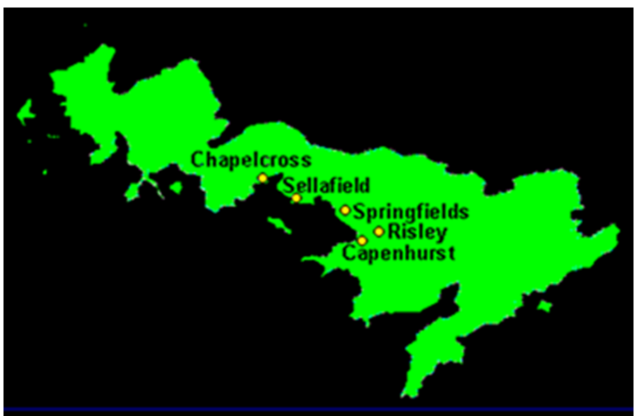
But despite all the efforts of nuclear safety provision one obviously cannot absolutely prevent accidents of different scale and type: at transport, mines, oil deposits and pipelines, chemical productions, and in particular events with possible radiation contamination of the environment.

2. COMPARISON OF SOCIAL, PSYCHOLOGICAL AND MEDICAL CONSEQUENCES AND ANALYSIS OF FACTORS OF NPP REACTOR ACCIDENTS

During a relatively short history of nuclear power industry there have occurred several NPP reactor accidents, with similar technical characteristics but differrent social conditions.

Accident of the reactor of NPP "Windscale" (Great Britain)

The accident occurred on October 10, 1957 at one of the reactors of Windscale (now Sellafield) NPP located at the western coast of Great Britain (fig. 1). The accident had the 5th level of 7 possible in accordance with the International Nuclear Event Scale (INES).

A 

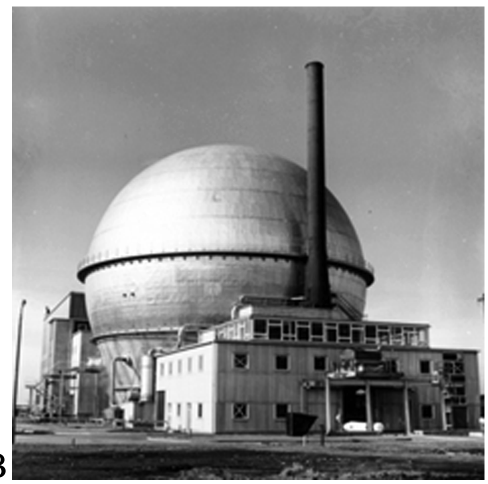
B 

Fig. 1. A) The map of England and Scotland. The city of Windscale (now Sellafield) is in the center. B) NPP "Windscale" photo

After World War II the government of Great Britain not willing to allow the state to be behind in the new worldwide armament race proceeded to realization of the national program to build its own nuclear bomb as soon as possible.

Within the framework of this project a NPP was successfully built for production of plutonium for military purposes. The reactors were built during a short period in large concrete buildings in several hundred foots from one another near a small village Seascale and called Windscale-1 and Windscale-2. Graphite was used as neutron moderator and the air was used for cooling. Hot air of the reactors was directed by means of fans through a pipe into the atmosphere. It meant that any radioactive material from the reactor core had a possibility to get into the environment. Later, at the insistence of Sir John Cockcroft, there were built special filters in the pipe. They were considered an unnecessary waste of money and time and thus called "Cockcroft's Folly". But this "Cockcroft's Folly" prevented the accident from becoming a disaster.

When the reactors were under construction English scientists did not yet have experience concerning graphite behavior under neutron action. Hungarian-American physicist Eugene Wigner discovered that during neutron bombing there occur dislocations in the crystal structure of graphite with potential energy storage. This energy, if not controlled, can spontaneously turn into thermal energy.

Britain planned to engage in nuclear weapon production together with the USA under contract. But for this it was necessary to show technological equality. Windscale was built for production of plutonium for the first British nuclear bomb. At that moment the USA developed and tested a thermonuclear bomb, which needed tritium. In Britain there was no tritium-producing plant, thus there was made a decision to use Windscale for this purpose, too. Tritium can be obtained in a nuclear reactor but this requires temperature to be higher than for plutonium. It was decided to reduce reactor core cooling for its temperature to reach the level necessary for solving of the new problem. All these changes exceeded the projected Windscale power reserve. After successful trial production of tritium the heat problem was forgotten and extensive production started, although at the expense of reactor temperature increase beyond its project specification limits.

As a result of imperfection of reactor construction and an error during operation (operators[5] negligence) the reactor core temperature in one of the plant reactors suddenly increased, which led to fire. Overheating of the Windscale reactor was connected with sudden Wigner energy release. During the accident it was not the graphite moderator but uranium fuel cells that ignited. Metal uranium fuel burns easily in the presence of oxygen as opposed to uranium dioxide that is used in modern reactors. It was promoted by reactor core cooling with the air by means of direct ventilation from the atmosphere. The fire lasted for 4 days. Combustion products with radioactive nuclides admixture came into the environment through a 125-meter pipe. The Cockcroft filters could trap only up to 50 % of radioactive nuclides. All in all 11 tons of enriched uranium burnt. The major portion of radioactive nuclides got into the environment when there were taken attempts to cool the reactor first with the help of air and then with water. Radioactive fallout polluted large territories of England and Ireland. In London (that is 500 km from Windscale) background radiation increased twentyfold. In the evening the next day the radioactive cloud reached Belgium and Denmark, and on October 12 Germany and Northern Norway.

People from the territories adjacent to the NPP were not evacuated though radiation exposure exceeded the admissible level dozenfold.

The accident consequences were studied by the National Radiation Protection Board of the United Kingdom. According to its conclusions there could occur about 30 additional mortal oncological disease cases that meant an increase of death rate from cancer by 0.0015 % over the natural one. Radioiodine-131 was of special concern. The maximum dose of thyroid gland exposure to it was 1 cGy for adults and 10 cGy for children and its risk of additional cancer cases (nonfatal) in accordance with calculations could be 240 cases among all the population of the contaminated territories. In order to decrease internal exposure cow's milk from the contaminated territories (about 500 sq km) was disposed of during 6 weeks (about 2 million liters). About 26 thousand people from Southern Wales located hundreds kilometers further south from Windscale had to keep from eating the local specialty ‘laverbread’, edible seaweed *Porphyra umbilicaris* obtained from the adjacent water area. To provide laverbread admirers the seaweed was delivered by railway from the northwestern sea areas of Great Britain.

British Prime Minister G. McMillan decided to conceal the accident causes being afraid that the information concerning NPP operators negligence and defects in reactor construction would undermine citizens’ trust in nuclear energetics and slow down British nuclear armament program. Concealed data concerning the accident consequences and its influence on the population health were published only 25 years later. British Nuclear Energy Agency renamed the Windscale complex as Sellafield.

In 2010 complex examination of all the workers, who directly took part in the cleaning of the polluted territories in the period after the accident, did not show significant long-term consequences for their health in comparison with control groups of population of unpolluted territories of England.

The accident of the NPP "Three Mile Island" reactor (the USA)

Fig. 2. Photo of NPP "Three Mile Island". Two power units in the concrete containments is in the center (damaged power unit is the further one). Cooling tower systems is in the background

Three Mile Island is an island on the river Susquehanna (Pennsylvania, USA). There is situated a NPP (fig. 2), where on March 28, 1979 a nuclear reactor accident with partial core melting took place. It was the biggest nuclear accident in the United States of America.

At 4 a.m. the water pump in the second circuit of the double circuit reactor cooling system broke down. Automation turned on the reserve one but its valves were left closed shortly before by mistake of the personnel during current check. Due to overheating the pressure in the circuit began to increase, as a result the steam-exhaust safety valve in the special condensation reservoir opened. After pressure decrease the valve should close but this did not happen and the control panel had an indicator that showed that the valve was closed. In reality this light indicator showed just the fact of signal injection for valve closing but the valve state was not controlled. As a result, steam continued to escape and the level of coolant in the reactor decreased. In 2 minutes the emergency water supply system in the first circuit turned on, but due to its frequent false switching the operators did not pay attention to this fact. In about 2 minutes the operator turned off the emergency water supply, thus panel indicators showed that the water level in the reactor increased. But it also was incorrect information due to poor indicator construction.

Only in 8 minutes after the accident began to develop the operator saw that the reserve pump valves were closed and opened them. The second circuit worked normally but the coolant from the first circuit continued to escape through the open valve.

In an hour and 20 minutes the steam began to reach the pumps of the first circuit and they turned off. Then, in an hour, the water level in the reactor suddenly decreased so much that the top part of its core began to melt. Besides, pure hydrogen began to form and accumulate in the protective containment.

In 2 hours and 20 minutes an operator of the new shift noticed that the indicator at the outlet of the safety valve showed too high temperature and closed the reserve safety valve. Till that moment the coolant loss was already over 950 thousand liters. Some part of radioactive water poured out into the plant premises as the reservoir-storage was overflown. Indicators for the first time showed an increase of background radiation in the premises left without special attention. Even hydrogen explosion in the reactor containment during the 9^{th} hour after accident beginning was not noticed by the operators because there were no manifestations of destruction. After 15 hours and 50 minutes the pumps of the first circuit were at last turned on and the reactor core temperature began to decrease.

Till that moment about one third of fuel melted but it did not burn out the reactor vessel and radioactive materials mainly remained inside. It was mostly inert gases that escaped into the atmosphere but the release of dangerous radioactive nuclides, in particular iodine-131, was inessential. The plant territory was contaminated with radioactive water from the first circuit.

After analysis of the circumstances there was made a decision that there were no substantial grounds for population evacuation from the territories adjacent to the plant, but the Pennsylvania Governor still advised pregnant women and preschool children to leave the five-mile territory (8 km) and it was obviously just a political decision not grounded by the real danger that caused quite a panic among the population, lor some of them even with fatal consequences. The average equivalent dose for people in the 10-mile territory (16 km) was estimated as 8 mrem (80 μSv) and did not exceed 1 mSv for any person. For comparison, a dose of 1 mSv equals one third of the total average annual dose for USA citizens from natural background radiation and all the anthropogenic sources.

The accident circumstances were analyzed in detail, which allowed concluding that the plant operators made serious mistakes that were to a great extent determined by incorrect information concerning the state of the reactor cooling system elements. But these circumstances did not cause appropriate reaction of the operators regarding the strange inconsistency of the indications of the reactor and cooling system state, and that became the fatal factor in the accident.

This accident became the reason for introducing changes into the operator training system that is now concentrated on the performance of appropriate technological procedures by an operator in case of any possible situation from a detailed list. The changes also affected the control panel construction and control equipment improvement. At all U.S. NPPs there were introduced plans of emergency action and immediate alerting of population in the 10-mile zone.

Reconstruction of the damaged reactor and elimination of accident consequences were completed in December 1993 and cost 975 million dollars. The fuel was unloaded from the reactor and the plant territories were deactivated. Operation of the other undamaged reactor was renewed in 1985.

Accident of the Chernobyl NPP 4-th reactor (USSR)

Chernobyl Nuclear Power Plant (ChNPP) at the time was the most powerful nuclear power plant of the USSR. It was located on the territory of Ukraine near the town of Prypiat 16 kilometers away from the border with Belarus, 18 kilometers away from the town of Chernobyl and 110 kilometers away from Kyiv (fig. 3). Four reactors with an electric power of 1,000 MW were operated before the accident. Two more similar reactors were under construction. ChNPP provided approximately one tenth of electricity of Ukraine.

Fig.3. Unit 4 of the Chernobyl Nuclear Power Plant after accident (photo)

At night on April 26, 1986 there was an accident at the Chernobyl NPP with the world's largest medical and socio-economic consequences for all the relatively short history of nuclear power, for this reason that accident was called *the Chernobyl disaster*.

On April 26, 1986 at 1:23 am there was an explosion that destroyed the reactor core and part of the building at the 4th unit of ChNPP due to energy release during a failed experiment. The 1,000-ton reactor head was shifted by the explosion. The second explosion ejected fragments of hot radioactive materials outside, and due to air ingress graphite began to bum. During the first day of the accident 25 % of materials were emitted. Intensive emission lasted for 9 days.

The explosion of the 4th unit caused an unprecedented radioactive contamination of vast territories. Due to steady south-east wind at an altitude of 1500 m in the morning of April 27 radioactive materials arrival was registered by the Radiation Safety Authority of a NPP outside the city of Oslo (Norway). Later on changes in meteorological conditions led to contamination of almost all European countries and even the entire Northern Hemisphere. Radioactivity was registered in Japan on May 3, China — May 4, India — May 5, and the day after — in Canada and USA.

The main radioactivity cloud traveled across the western territories of the USSR (Ukraine, Belarus and adjacent lands of the Russian Federative Republic), Eastern Europe and Scandinavia. Up to 60 % of radioactivity fell on Belarus.

Some experts compare this accident with an explosion of a very powerful “dirty bomb”, since the main factor of damage was radioactive contamination.

During the first three months the actual number of deaths was 28 persons. Since the accident had a significant political importance for the USSR, the data on the injured in the subsequent period is hard to determine. According to the estimates of foreign experts the actual number of persons killed by exposure during 20 years was approximately 4,000 persons. Over 200,000 people were evacuated from the area of contamination.

The Chernobyl disaster has become an event of large social and political significance for the USSR, which causes some difficulties in the investigation of its causes and media coverage of the results. Interpretation of the facts and circumstances of the accident changed repeatedly over time, and there is no consensus on this issue so far. And the facts related to the scale of economic losses and health and social consequences are too contradictory according to different sources.

About 300 MCi of radioactive substances was emitted into the environment from the reactor core, and it led to contamination of 50,500 sq km of the territory of Ukraine, where about 2.4 million people lived in 2,218 settlements. The most contaminated areas were the central part of Ukraine, the south-eastern regions of Belarus and some areas of the European part of Russia located close to the accident scene. These territories were inhabited by 17.5 million people, including 2.5 million children aged up to 7 years. In 1986–1989 about 600,000 people were engaged in disaster recovery operations. The magnitude of the collective effective exposure dose of all the population of Ukraine was nearly 50,000 man-Sv over 10 years except for the dose of thyroid gland exposure. The collective exposure dose of the thyroid gland (in 21 regions of Ukraine and Kyiv) was 1.3 million man-Gy, including 607,000 man-Gy of children and adolescents exposure.

Among the power nuclear plant staff and firefighters 145 people had acute radiation sickness of different severity. 31 injured people engaged in disaster recovery operations during the first hours died.

Ecological, medical and psychological consequences of the accident are explained in particular by the influence of the social, economic and political spheres, as well as the weaknesses of the public health system. There was a tendency to ignore exposure effects of the disaster by presenting it as "an ordinary accident", whose health effects are minor compared to daily loss of lives in road accidents. Such tendencies are based on dosimetry ambiguity. The doses of most of 600 thousand participants of disaster recovery operations (emergency workers) and 5 million inhabitants of the contaminated territories of Belarus, Russia and Ukraine are considered to be relatively low and comparable to natural radiation background except for the cohort of several hundreds of the first period emergency workers who were exposed to high doses.

A biodosimetry study of the number of radiation-induced chromosome aberrations in the population of a Russian village, where antiradiation measures had been taken before the evacuation, showed an average dose of 60 mGy, the population of 4 Belarusian villages was exposed to a dose of 180–400 mGy, and people evacuated from Prypiat' town — 200 mGy. These doses do not differ by the order from the average dose for emergency workers of 1986 — 170 mGy.

There are different views on the effectiveness of medical response to the Chernobyl accident. The main conclusions of the International Conference "Fifteen Years after the Chernobyl Accident. Lessons Learned" (2001) concern drawbacks in psychological support and it is indicated that "the lack of special knowledge in radiology did not allow the population to independently assess the presentation of information covered by media, radio and television. As a result, self-perception of possible consequences of the accident exceeded the real state of affairs manyfold. Deterioration of economic situation, collapse of the USSR — all these factors really made the accident a disaster for many people...". However, it is stated that medical service at the time of the accident was not ready to minimize health effects. "Stable iodine prophylaxis was not provided in time and sufficiently, protective measures such as shelter, replacement of contaminated milk with uncontaminated one were slightly used. The countermeasures meant to reduce psychological stress among the population were ineffective. The regional health care institutions at the initial stage of the accident, and later during the first five years, experienced shortage of medical personnel (doctors, nurses, laboratory technicians). Only the leading health care institutions mainly provided high quality treatment at appropriate time and in full".

The conclusions of the next conference "Twenty Years after the Chernobyl Accident. Future Outlook" (2006) include reviews of the countermeasures. It is recognized that the government response to the accident was unprecedented. The flaws are considered to be the following: untimely evacuation of the population, inadequate notification of the population of the accident consequences and failure to replace the milk contaminated with radionuclides with uncontaminated one, ineffective iodine prophylaxis, and unreasonable involvement of large population groups, which were not trained to perform radiation-hazardous work, in the rectification of the accident consequences. The involvement of military personnel, reservists and other groups of population is explained by the lack of sufficient number of trained professionals.

The analysis of countermeasure effectiveness indicates that in general 116 thousand people had been evacuated from 188 settlements by the end of 1986. The population was evacuated hoping that they would come back, however agreed specific criteria for the return of population to the territories with residual contamination have not been worked out yet.

According to the Ministry of Public Health of the USSR about 5 million of iodine pills were distributed, but there is reason to believe that only about 20 % of the distributed pills were used. According to the conclusion of the International Chernobyl Project of IAEA the decision on the intake of potassium iodide pills complied with the established practice of intervention and was justified. 70 % of population, including 60 % on April 26, was subject to iodine blocking in Prypiat'. In total according to the Ministry of Public Health of Ukraine about 5 million people, including 1.6 million children, were subject to iodine blocking. However the regional authorities made a decision on iodine medications distribution only on May 6, that is actually after the termination of intensive emissions of iodine-131 from the reactor.

Analysis of the documents of the first post-accident period also highlights a range of organizational deficiencies:

- the third chief administration of the USSR Ministry of Public Health did not timely inform the Ministry of Public Health of Ukraine about the radiation situation and the measures taken to protect the population on the territories of the town of Prypiat’ and the NPP,
- inadequate health support during evacuation of the population, which led to additional exposure of the NPP workers and inhabitants,
- absence of regulatory documents on the measures taken in case of radiation accidents at the NPP,
- lack of plans of comprehensive measures to support sanitary and hygiene service after emergency evacuation of population,
- inadequate provision of sanitary and epidemiological service and health care institutions with dosimetric and radiation-measurement equipment, noncompliance of the staff structure of the service with the needs to ensure radiological protection of population, radiation control of water and food.

To provide medical support for the rectification of the accident consequences and treatment of the injured in emergency situation all the medical and organizational structures of the health management system of Ukraine (the Ministry of Public Health, medical services of the Ministry of Defense, the Ministry of Internal Affairs, Committee for State Security, research institutions) were used: about 2 thousand physicians, 4 thousand paramedical workers and about 1.2 thousand undergraduate students of medical institutions were engaged in order to carry out medical examinations and provide medical assistance to evacuees and occupants. 230 temporary laboratory-dosimetric mobile teams, about 400 teams of doctors, including 212 teams of special medical aid (to examine children and pregnant women) worked during the initial post-accident period. In total 300 physicians, 600 paramedical workers were additionally involved. By the order of the Ministry of Public Health of Ukraine the mobile teams examined hundreds of thousands of adults and children, new methods of mass screening were promptly developed and introduced.

Twenty years after the accident the Ministry of Emergencies and Affairs on Protection of Population against the Consequences of the Chernobyl Catastrophe of Ukraine and All-Ukrainian Research and Development Institute for Civil Protection of the Population and Territories from Man-Made and Natural Emergencies prepared the National Report “Chernobyl Disaster. 20 Years after” (2006), which summarized the actual data established at that time concerning all the aspects of Chernobyl disaster, and appropriate conclusions were made:

- supernatural forces used in nuclear power require ultra-high education of operators,

- high-level human resources training and retraining system for nuclear power engineering should be set up in any country using nuclear energy,
- nuclear energy as a field of national economy requires high-level management system and scientific and technical society to be available in the state,
- surely, the safety level of nuclear reactors is currently much higher than in the 1980s. However, at the present level of development nuclear energy remains to be a potentially dangerous industry segment. For this reason close cooperation of the Government (decision makers) with the scientific and technical personnel of the state is a necessary and essential condition for effective actions both in case of steady- state normal operating conditions of reactors, and in case of accidents,
- the Chernobyl accident caused inadequate perception of radiation risk by some part of people, which led to psychological discomfort,
- the accident has demonstrated the need to establish and maintain a high level of national response system for cases of possible man-made accidents,
- the accident has pointed to the danger of nuclear energy isolation from public control and showed the necessity of an open and objective dialog with the public concerning all aspects of safe use of nuclear energy,
- the analysis of the experience of response to the Chernobyl accident is a unique opportunity to improve the emergency response system, which should include clear action procedures, well-trained personnel, necessary equipment and instruments, pre-designed criteria and decision-making mechanisms, rescuer training system. This experience should be integrated with international guidelines and methodologies of evaluation, monitoring and response to nuclear accidents.

In the press release “The Chernobyl accident: 20 Years After” (2006) IAEA General Director Mohamed ElBaradei said:

“The April 1986 accident at the Chernobyl nuclear power plant remains a painful memory in the lives of the hundreds of thousands of people who were most affected by the accident. In addition to the emergency rescue workers who died, thousands of children contracted thyroid cancer, and thousands of other individuals will eventually die of other cancers caused by the release of radiation. Vast areas of cropland, forests, rivers and urban centres were contaminated by environmental fallout. Hundreds of thousands of people were evacuated from these affected areas — forced to leave behind their homes, possessions, and livelihoods — and resettled elsewhere, in a traumatic outcome that has had long-lasting psychological and social impacts.

The commemoration of the Chernobyl tragedy is taking place in many forums this month - in Minsk, in Kiev and in other locations.

At the IAEA, it might be said that we have been responding to the accident and its consequences for twenty years, in a number of ways: first, through a variety of programmes designed to help mitigate the environmental and health consequences of the accident; second, by analyzing the lessons of what went wrong to allow such an accident to occur at all; and third, by working to prevent any such accident from occurring in the future.

Building a strong and effective global nuclear safety regime is a central objective of our work. This requires effective international cooperation. The explosions that destroyed the Unit 4 reactor core, and discharged its contents in a cloud of radionuclides, made painfully clear that the safety risks associated with nuclear and radiological activities extend beyond national borders. International cooperation on nuclear safety matters — sharing information, setting clear safety standards, assisting with safety upgrades, and reviewing operational performance — has therefore become a hallmark of IAEA activity, particularly at a time when we are witnessing an expansion of nuclear power to meet increasing energy demands in many parts of the world.

In 2001, after taking note of the conflicting views on the results of the accident, I called for the creation of a Chernobyl Forum, inviting the world's foremost scientific experts to conduct an exhaustive assessment of the health, environmental and social impacts of the accident. As with all IAEA programmes, we emphasized an impartial, fact based approach to the analysis of this difficult and highly charged topic. I was pleased that, after a long period of careful analysis, the parties involved — including the World Health Organization and seven other specialized United Nations agencies, as well as the Governments of Belarus, Russia and Ukraine — were able to achieve consensus on the set of authoritative reports that were issued last September.

But the Chernobyl Forum had another purpose as well. My hope was that, by giving clear, impartial answers about the accident and its effects, we would be able to focus more effectively on present and future needs. Better international cooperation on assistance to the people and regions affected by the accident. Smarter approaches to safe food production and effective health care. Enhanced investments in the people concerned, in ways that would give them control over their own livelihoods.

In short, it was my hope that, by answering questions about the past, we could restore a vision of a brighter future for the regions concerned. And that remains my hope.

We will not soon forget the Chernobyl accident. We will not forget the emergency workers who gave their lives. We will not forget the health and environmental consequences. And we should never forget the lessons we learned regarding nuclear safety and international cooperation. In remembering the Chernobyl accident, we should renew our determination to ensure that such a tragedy will not happen again.

But we must also remember the survivors, the individuals and communities who seek to move forward with their lives and the lives of their children. At this time of remembrance, they too deserve our attention and assistance, so that they will be able to move beyond the shadow of the Chernobyl accident and into a prosperous future."

Accident of NPP "Fukushima-1" simultaneously 4 power units (Japan)

On March 11, 2011 in the north-eastern regions of Japan there was a destructive magnitude-9 earthquake, after what the coast was hit with a tsunami wave over 10 m high. This natural disaster claimed the lives of about 16 thousand people.

Fig.4. Photo of the NPP "Fukushima-1"

In the prefecture of Fukushima at Fukushima-1 NPP (fig.4) the disaster caused damage of nuclear reactors of four power units. As a result of the earthquake the reactor cooling system was deenergized and complete flooding of the plant with tsunami damaged the emergency power generators. There were explosions and fires at the plant, radioactivity leakage from the reactors began. Four of six power units simultaneously got heavily damaged: there happened partial or full melting of the nuclear fuel in them.

In accordance with the analysis of the data obtained by the National Meteorological Service a group of scientists headed by Yasumichi Tanaka from the Meteorological Research Institute drew a conclusion that from 70 to 80 % of radioactive isotopes got into the ocean and not into the soil. " Fukushima-1 NPP is located on the eastern coast of Japan and the winds in March and April blew primarily from the west to the east, and that's why a relatively small amount of radioactive materials got into the soil. A greater amount got into the Pacific Ocean, whose waters, naturally, became polluted," Tanaka explained.

Due to several radioactivity leaks local authorities evacuated the people who survived after the tsunami from the 20-kilometer territory around the NPP and also imposed a ban on flights over the plant within a radius of 30 kilometers. On April 12 Japan announced about an increase of the hazard level at Fukushima-1 to the maximum, equaling the one during the Chernobyl accident.

Some scientists predicted apocalyptic consequences of this accident. Thus, Chris Busby from the Ulster University said that "Fukushima accident is worse than the Chernobyl one because the Chernobyl blew up at once and the Fukushima is boiling". Besides, they took into account the fact that there had been no case of simultaneous damage of four nuclear reactors of high power in the history.

Already at the first stage of the accident the local emergency network got involved and afterwards the country government followed the example. The owner company was responsible for actions at the industrial site of the NPP and the local authorities — for medical care of the population. The cooperation procedure was complicated with disastrous consequences of the earthquake and tsunami for the whole infrastructure. The measures comprised the following:

- evacuation and shelter provision for the population,
- radiation-monitoring evaluation of the situation and introduction of temporary dose standards,
- food and water control measures.

Evacuation of the population from the 3-kilometer territory around the NPP was carried out on the day of the accident; from the 20-kilo- meter territory — on the following day. After 4 days there was introduced the shelter regime for the population of the 30-kilometer territory. On the same day the local emergency authorities decided to conduct iodine preventative measures among the evacuated. The decision on voluntary evacuation from the 30-kilometer territory was made in 2 weeks after the accident.

Direct measurement of radiation doses started on the following day after the accident. All in all there was conducted a radiation survey of over 188 thousand people. Outside the 30-kilometer territory the thyroid radiation dose was measured in 1 thousand children and was lower than 50 mSv.

Cooperation with international organizations was carried out by means of information provision. In accordance with the plans of bilateral cooperation assistance came from the U.S. Department of Energy. Radiation monitoring of the situation was partially conducted by French experts. In accordance with the evaluations of the French Institute for Radiological Protection and Nuclear Safety the expected doses equal significant values, some of them even higher than 200 mSv exceeding the “low dose” range according to the UNSCEAR definition.

According to “La Repubblica”, the rescue operations at the NPP were carried out by hundreds of emergency workers who were called “nuclear samurais” and “kamikaze” in world mass media. “These people consciously take the mortality risk because consider rescuing people from radiation to be their civic duty. Among them there are also those who came to work at the plant following their vocation. They do not communicate almost with anybody in order not to spread unnecessary panic. The American TV-channel Fox News showed a report, during which its correspondent managed to talk with the mother of one of the emergency workers. According to her words, her son and his fellow emergency workers take the fact that they would soon die.”

“No, I am not afraid of radiation,” said 39-year old Kazuma Yokota, who worked at the plant with the others. “We would like to have been supplied with hot meal: we could not eat vitaminized bars and canned food any more.”

Such a request may seem a bit strange if we forget the fact that for many kilometers around the plant tsunami turned the territory into a desert covered with nuclear fall-out.

The chief of a group of volunteers who conducted cooling of the damaged reactors Kazuma Yokota told: “My people lost everything. Now they are living only to be the first in this race with time”.

In the middle of November 2011 mass media informed that to relieve the operations on liquidation of Fukushima-1 accident consequences workers would use exoskeletons that extensively increase human capabilities. The device was based on the development called HAL (Hybrid Assistive Limb) created to help elderly people. The exoskeleton is equipped with servomotors aimed to strengthen the main human joints: of the loin, knees, elbows, and shoulders. This robotized device in the form of a suit doubles strength and protects from injuries. Besides, it helps to increase the weight of personal anti-radiation protective equipment.

In the prefecture of Miyagi that suffered the most as a result of this natural disaster there were built over 22 thousand buildings for the victims in six months. Till the end of November in the prefecture of Fukushima there were built other 15.5 thousand buildings for the evacuated from the 20-kilometer territory around the damaged NPP.

On November 12 journalists in protective suits were for the first time allowed at the territory of Fukushima-1 damaged with the tsunami. Till the end of 2011 the plant was transferred into the cold shutdown condition (reactor temperature below 100 °C) and at the beginning of November of the same year governmental represent-tative Yasuhiro Sonoda in front of the TV-cameras drank a glass of water from the NPP reservoir showing the efficiency of its purification.

The Japanese government estimates that the recovery of the northern east of the country requires at least 300 billion dollars, 74 of which are to be spent on elimination of Fukushima-1 accident consequences.

3. **MEASURES FOR MINIMIZATION OF SOCIAL, PSYCHOLOGICAL AND MEDICAL CONSEQUENCES OF NUCLEAR ACCIDENTS**

Radiation is widely used in medicine, industry, agriculture, power industry, research and in this concern it does not have alternatives as it is of invaluable benefit. But radiation sources can be lost, stolen, etc. not being under appropriate control and this may lead to injury of the people coming into contact with them. Such cases are rare. Over the period from 1944 to 2001 in the world there were registered all in all 420 accidents, which injured about 3 thousand people and killed 133 of them (31 of them died as a result of the Chernobyl accident).

Taking into account the inevitability of accidents a number of international organizations (the International Atomic Energy Agency, the United Nations Organization Office, the United Nations Environment Programme, the United Nations Office for Outer Space Affairs, the World Health Organization, the Pan American Health Organization, the European Atomic Energy Community (EURATOM), the World Meteorological Organization, the United Nations Office for the Coordination of Humanitarian Affairs, the Organization for Economic Cooperation and Development, the Food and Agriculture Organization of the United Nations, the International Maritime Organization, the International Criminal Police Organization, the European Police Office, etc.) agreed on cooperation and assistance in case of nuclear accidents. The activity of this association of organizations is coordinated by the International Atomic Energy Agency (IAEA). The IAEA Secretariat should be ready to react in time, in appropriate and effective manner in any situation that can have substantial or potential radiological consequences for health, property or environment and that needs IAEA participation. Besides, it should be able to react urgently to radiation safety and/or safety-related requests of the member-countries, corresponding international organizations, and mass media.

For arrangement of this responsible work there were created the legal documents Early Notification Convention and Assistance Convention that determine international framework to facilitate the process of communication and effective assistance provision in particular cases of emergency radiation situations in order to minimize their consequences. The plan of Secretariat work in these directions is outlined in the IAEA publication Emergency Notification and Assistance Technical Operations Manual (ENATOM).

In addition to ENATOM the IAEA regularly holds meetings of the International Agency Committee on Radiological and Nuclear Emergencies (IACRNE) in order to discuss the issues of international intergovernmental organizations work coordination in the field of assessment of their readiness to radiological accidents and response to them. Although the Agreements set certain responsibilities of the IAEA and the Parties, according to statutory functions and legal documents (for example, international medical and sanitary norms) different international organizations have their own primary functions and responsibilities that also cover aspects of readiness and response to radiological accidents.

Realizing that a good emergency action plan can substantially improve response effectiveness the international organizations participating in IACRNE have developed, improved and sponsored the new project Joint Radiation Emergency Management Plan of the International Organizations (EPR-JPLAN 2010), which outlines the following issues:

- the principles of planning,
- organizations involved in response,
- their roles and responsibilities,
- their cooperation among themselves and the countries,
- operating concepts, and
- readiness regulation.

These agreements are set forth in the operating emergency response plans of different organizations of the countries.

JPLAN aim is a detailed description of the Intergovernmental action plan on provision of readiness for radiation accident or emergency situation and response to them irrespective of their causes.

Its separate tasks are:

1. Provision of general understanding of the necessity to be ready to emergency and response to it, roles and responsibilities, tasks, powers, possibilities and purpose of each international member organization and all the intergovernmental agreements.

2. Provision of the general concept of cooperation between international organizations that is based on the aims of urgent response, responsibilities, powers, possibilities and profiles of each international member organization and different existing intergovernmental relationships to make it possible to respond in a timely, effective and coordinated manner.

3. Facilitation of agreement conclusion between international member organizations on practical issues, where applicable.

4. Provision of general understanding of the process of improvement and change in intergovernmental relationships.

5. Provision of general understanding of the roles and responsibilities of inter-

national member organization in accordance with: international standards, support of international possibilities through provision with administration and training, appropriate studies, urgent tasks and other preparatory measures.

6. Managerial control over each international member organization that is necessary for provision of all agreements concluded within this organization.

7. Facilitation of well-grounded development, maintenance and preparation of plans and procedures in each organization.

8. Drawing attention of personnel in the countries and international organizations to these agreements and facilitation of development of compatible agreements, where applicable.

Additional possibilities of the IAEA Response System are provided through Response and Assistance Network (RANET). Its main purposes are:

- strengthening the IAEA possibilities to provide assistance and consultating services and/or assistance coordination in accordance with the Assistance Agreement and
- facilitating provision of readiness to emergencies and response to them among the IAEA member countries.

Another mechanism of Response System strengthening is Response Plan for Incidents and Emergencies (REPLIE) that provides the high level basis of Secretariat readiness to emergencies and response to nuclear accidents. This plan is comparable with ENATOM and JPLAN, but it describes details of how the Agency personnel should organize response. Causes of nuclear accidents are usually unknown at first and this Plan provides the way to find timely and reasonable measures in all cases. Plan realization is based on competent and experienced personnel of the Secretariat.

Under the auspices of the IAEA at the Medical Department of Boston University in cooperation with the Medical Department of the University of Massachusetts and Radiological Training Center (Tennessee, USA) there was created the program Medical Training and International Nuclear Accident Readiness Coordination Program that consists of 3 components:

— supervisors training within the standardized program of local training of personnel for care and treatment of radiation-exposed patients,

— teaching the methodology of developing such personnel training courses,

— practical training of supervisors for actions under nuclear accident conditions in regional centers.

The same programs and courses should be available in all nuclear weapon countries.

Response planning is based on the recognition of ultimate responsibility of separate countries for protection of life, health, property, environment, and life standards on their territories. National regulatory bodies are recognized to be responsible for certain emergency plans for their nuclear installations. It is also established that despite numerous different radiation safety measures radioactive material release can cause real, potential and foreseeable radiation emergency in other countries, that's why in such cases appropriate information will be necessary to make consultations on environmental protection and monitoring issues possible. In cases of radiation exposure or emergencies with radiation sources the governmental bodies and international organizations should have reliable information for assessment of possible negative consequences.

In accordance with both Agreements the IAEA as the coordinating organization bears primary responsibility for between organization response system activation. The Agency receives reports on accidents or emergencies from the appointed authorized national body and checks notifications. The Agency establishes initial functional connections with a country or a number of affected countries providing direct communication with their national nuclear accident response organizations. The IAEA also establishes functional connections with the appropriate international organizations that form the Intergovernmental Committee on Radiation and Nuclear Emergencies. These organizations can establish connections with other competent bodies, regional centers and programs that are ready to provide information/consultations or assistance. If a country turns to the IAEA for assistance in accordance with the Assistance Agreement, its realization is coordinated by the IAEA.

The IAEA: 1) informs countries and international organizations that could provide assistance, 2) evaluates the situation in coordination with the appropriate international organizations and can send a group of experts for initial assessment of the situation following the country's request, 3) develops, with the consent of the country provided with assistance, a detailed action and assistance plan. After the plan is accepted by all the interested parties, it obtains authorization to deploy assistance resources by authorized bodies and international organizations.

In Ukraine, in accordance with the Order of the President of Ukraine to the Cabinet of Ministers as of October 7, 1996 there was created the common national system of medical assistance for the population of Ukraine in case of emergency — Emergency Medicine Agency. Then following the Decree of the Cabinet of Ministers of Ukraine No. 1192 as of August 3, 1998 there was also created the Common National System of Prevention and Response to Technogenic and Natural Disasters. The main aim of this system is to prevent technogenic emergencies, reduce costs in case of natural disasters as well as respond to them in a timely and appropriate manner.

In accordance with the 15-year research Ukrainian scientists together with experts of WHO, UNSCEAR, IAEA and other international organizations worked out a forecast and recommendations concerning minimization of the medical consequences of the Chernobyl accident for the following years.

The aim of the Common National Program of Overcoming Chernobyl Accident Consequences for the Period from 2006 to 2010 was radiation protection of people on the polluted territories, preservation of the victims' and their descendants' health, social protection improvement, prevention of radioactive nuclides spread from the alienation zone and recovery of the territories and settlements, strengthening and support of the radiation safety barriers.

Analysis shows efficiency of medical measures applied to minimize medical consequences of the Chernobyl accident, in particular, the measures on reducing the 1986 radiation dose of children, implementation of scheduled health improvement of the affected children. Early detection and treatment of thyroid cancer appeared efficient; it comprised periodic health examinations, surgical treatment with radioiodotherapy of metastases. The UNO Chernobyl Forum (2006) stated that thyroid cancer mortality did not exceed 1 %.

The Chernobyl Forum formulated recommendations on the priority tasks for the health care system. They include:

- to continue monitoring of the persons exposed in childhood,
- to plan health care system measures on the basis of predicted assessment of cancer risks depending on radiation doses,
- to keep cancer register with high-quality data.

These tasks are meant at least for the period till the 50^{th} anniversary of this tragedy.

Radiation is the stars flame giving the weal to us
regard to it with awe so it warms but not incinerate.