Modern technical and software-analytical tools for solving problems of radiation and technogenic-ecological safety of Ukraine

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Abstract. Nuclear energy in Ukraine is provided by the operation of four operating nuclear power plants (15 reactors). For the next decades it is planned only to increase the capacity of this according to the “Energy Strategy of Ukraine until 2035” industry. Nuclear power plants are objects of increased danger. So, conditions should be provided to maintain environmental balance in Ukraine, innovative developments for radioactive waste management should be implemented, methods of wastewater treatment must be developed/improved, prevention and elimination of natural and emergency emergencies should be provided. It is important to create variety of scientific, technical and innovative developments to solve these problems. Their development is carried out by institutions and organizations, including the National Academy of Sciences of Ukraine. The study analyzes and summarizes activities of the State Institution “The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine” on innovative developments to improve nuclear, radiation and technogenic environmental safety. The developments of the Institute are defined, described and systematized. The performed research was aimed to solve problems of sustainable development of nuclear energy, environmental problems of nuclear fuel cycle, handling of radioactive materials at all stages of their life cycle.

1. Introduction
Ukraine is among the top ten countries in the world in the field of nuclear energy. However, along with the prospects for the development of nuclear energy, it is important to solve urgent problems of safe and efficient operation of nuclear fuel cycle facilities. At the same time the principles of ensuring its individual components – natural and man-made and environmental security are laid down at the state level in forming the national security strategy. This is reflected in the Law of Ukraine “On Basic Principles (Strategy) of State Environmental Policy of Ukraine until 2030” [1].

Since 2014 there is a shortage of coal as a result of the military conflict in eastern Ukraine. So, the role of nuclear energy increased significantly. However, another problem is arisen - any
nuclear power plant can become a target for terrorists. Also an important problem in nuclear energy is radioactive waste and spent nuclear fuel which need safe disposal or storage. Not all Ukrainian nuclear power plants (NPPs) have facilities for the processing of radioactive waste. So, it is important to conduct research related to waste management and protection of population and environment from radiation.

Various institutions and organizations (including research institutes of the National Academy of Sciences of Ukraine) function to solve problems related to improve Ukraine’s nuclear, radiation, and technogenic environmental safety. Scientific support of the above tasks is provided by the institutes of the Department of Nuclear Physics and Energy of the National Academy of Sciences of Ukraine [2], including the State Institution “The Institute of Environmental Geochemistry of National Academy of Sciences of Ukraine” (IEG NAS of Ukraine) [3].

IEG NAS of Ukraine is one of the leading scientific institutions of Ukraine in the field of environmental and radiation safety [4]. In 2021 IEG NAS of Ukraine celebrated its 25th anniversary [5]. We will analyze and summarize scientific achievements and innovative hardware and software created by employees of the Department of Nuclear Physics Technologies and the Department of Environmental Protection and Radiation Safety to address current issues of nuclear, radiation and man-made environmental safety of Ukraine.

We analyzed scientific publications and systematized research in the following areas: 1) radiation and technogenic environmental safety [6–14]; 2) environmental monitoring of technogenic-loaded territories [15–22]; 3) introduction of innovative developments in practice and in training and advanced training of specialists in the field of nuclear energy, etc. [23–27]. However, it needs separate analysis and coverage of scientific achievements and innovative hardware and software created by the staff of IEG NAS of Ukraine to address current issues of nuclear, radiation and man-made environmental safety of Ukraine.

**The aim of the work** is to analyze, summarize and highlight innovative developments of IEG NAS of Ukraine to improve nuclear, radiation and technogenic environmental safety of Ukraine.

2. **The research results**

In 2021 Ukraine celebrated 30th anniversary of independence. The analytical publication [28] states that there was a need for intensive development of some modern areas of basic and applied research in a number of fields in the first years of our country’s independence. It includes computer science, nuclear and electronic physics, space and aerospace research, materials science, general and renewable energy, energy saving, geochemistry, ecology. Accordingly, new scientific institutions were established and work of existing organizations was expanded. Some research institutions of the sector were included in the structure of the NAS of Ukraine, and activities of certain institutes were reoriented to scientific and technical support of basic industries and energy.

We should not forget tragic event occurred in our country on – the Chernobyl accident noting the role of scientists in the formation of the Ukrainian state. The Chernobyl disaster affected the environmental, economic and socio-psychological aspects of life not only in the 30-kilometer exclusion zone, but also far beyond. It caused number of complex scientific and technical, medical, biological and environmental problems. It should be noted that participation of scientists of the NAS of Ukraine in overcoming of the Chernobyl disaster consequences began in the first days after the accident and continues today. In addition, the catastrophe scale of the necessitates a scientific assessment of intensity and specificity of the distribution of radionuclides in all chains of natural ecosystems. It is rightly considered the world’s greatest technogenic and environmental catastrophe of the twentieth century Therefore, maximum possible elimination of the consequences of this catastrophe was and remains to this day one of the most important scientific tasks of institutions and organizations of the NAS of Ukraine [28].
New scientific institution was established – the State Research Center for Environmental Radiogeochemistry in order to eliminate the consequences of the Chernobyl disaster and minimize the risks of radiation pollution on humans and the environment. The Institute in 2001 was renamed into IEG NAS of Ukraine. Currently, the IEG NAS of Ukraine conducts fundamental and applied research in the following main scientific areas: scientific support of the nuclear fuel cycle; instrumentation in the field of nuclear, radiation and environmental safety; mathematical modeling and forecasting of natural and technogenic processes. Also, the Institute has state license to conduct geological, hydrogeological, engineering-geological, environmental-geological and laboratory works. The laboratory base of the Institute has state accreditation. It includes set of analytical equipment for the analysis of toxic, heavy and radioactive elements.

There are 4 NPPs operating in Ukraine with 15 power units – 13 of them are WWER-1000 type and 2 WWER-440 type. Measures to improve the safety of existing NPPs are implemented on a systematic basis in accordance with the requirements of national norms, rules and standards on nuclear and radiation safety, recommendations of the International Atomic Energy Agency (IAEA) and taking into account many years of experience and international practice. The activities of the SNRCU (State Nuclear Regulatory Committee of Ukraine) to regulate safety of nuclear installations are aimed to ensure nuclear and radiation safety at all stages of the life cycle of nuclear installations, protection of personnel, population and environment. Main focus was on improving safety of existing Ukrainian nuclear power plants [29]. Results of scientific research of the Department of Nuclear Physical Technologies and the Department of Environmental Protection and Radiation Safety of the Institute are main scientific and technological base of innovative developments of methods, techniques, technologies and means of control of radiation and sanitary environment, cleaning environmental components from man-made pollution [5]. Accordingly, basic and applied researches in recent years were aimed to solve problems of sustainable development of nuclear energy, environmental problems of the nuclear fuel cycle, handling of radioactive materials at all stages of their life cycle.

Systematization of performed scientific researches and innovative developments created by the employees of IEG NAS of Ukraine was carried out in two directions:

1. radiation safety;
2. technogenic and ecological safety.

2.1. Radiation safety
In this area, employees of the IEG NAS of Ukraine created number of technical and software-analytical tools and implemented them in the work of various organizations and enterprises:

- plasma-chemical installation of liquid radwaste treatment generated during the operation of NPPs and NFC (nuclear fuel cycle) facilities (figure 1);
- for control the movement of radioactive materials, a mobile system for detecting neutron and gamma radiation, which works in real time;
- “ASPEC-O” spectrometric complex for radiation detections and monitoring based on an unmanned aerial vehicle (octocopter) (figure 2). More about this development is described in [5];
- system of radiation control and identification of ionizing radiation based on solid-state detector with high metrological and operational characteristics for effective control of specific activity of liquid, viscous, bulk food and non-food samples at permissible concentrations and below, identification of their radionuclide composition;
- “FoodLight” – a portable workstation that allows you to measure the field activity of gamma-emitting radionuclides in the field (figure 3);
Figure 1. Plasma-chemical installation of purified contaminated drinking water by cold plasma.

Figure 2. Spectrometric complex “ASPEK-O” for radiation reconnaissance and monitoring on the basis of unmanned aerial vehicle type octocopter.

- “G-Scrin” – an automated complex that allows you to measure the content of incorporated radionuclides in the human body (figure 4);
- software and modeling complex that allows to determine dynamics of concentrations distribution of radioactive substances in all components of environment as a result of an incident with spillage of liquid radioactive media in radiation-hazardous facility or outdoors, assess health risks personnel and population, determine annual effective doses from all routes of exposure, identify worst-case scenarios of such dangerous events, generate recommendations to support effective management decisions to respond quickly to such emergencies and minimize their consequences, faster and better develop relevant project documentation, to conduct its examination (figure 5).
Figure 3. Portable workstation “FoodLight”.

Figure 4. Automated complex “G-Scrin”.

The developed experimental technical means are recognized in the world. They provide real-time operational search, detection, localization and identification of nuclear radiation materials.

Also, scientists of IEG NAS of Ukraine performed number of research works marked “Secret”. They are related to the prevention of emergencies at critical infrastructure.

Figure 6 summarizes and schematically presents hardware and software created by the staff of the Institute to address pressing issues of nuclear, radiation and technogenic environmental safety.

2.2. Technogenic environmental safety

Environmental security is a component of national security that guarantees protection of vital interests of man, society, state and environment from real or potential threats posed by natural or technogenic factors. In addition environmental component of each of these types of security can be an integrator that integrates them into the national security system. It will help to find their optimal ratio in this system. Moreover, today there is no doubt that any aspect of national security, whether economic, technological or defense loses its meaning in the case of unsuitability of the environment for human life and activity [30].

There is atendency Ukraine to increase number of emergencies of technogenic nature due
Figure 5. Example of the software-modeling complex.

Figure 6. Hardware and software to solve current problems of nuclear, radiation and technogenic environmental safety.
to the use of outdated technologies in many sectors of the economy. Causes of emergencies of technogenic nature include: large amount of transportation, storage and use of hazardous substances; obsolescence of fixed assets, in particular environmental protection; emergency condition of significant part of utilities networks (water and gas pipelines); insufficient investment support for implementation of resource-saving and environmentally friendly technologies in environmentally hazardous industries, namely chemical, metallurgical and energy. For example, nuclear power plants have been operating for over 40 years, new nuclear reactors have not been built and old ones are constantly being extended. Also important is problem of harmful emissions from industrial enterprises into the atmosphere and lack of strict sanctions due to refusal to install special filters to reduce emissions of harmful substances.

The publication [31] emphasizes that status of security problems in modern society is changing due to the impact of different levels of threats: global, regional and national; natural, technogenic and increasingly – socio-ecological. Currently, environmental situation in Ukraine as a whole can be described as tense. Level of environmental safety is defined due to extremely high technogenic load which is constantly growing. Ensuring environmental safety at potentially hazardous sites requires technical re-equipment of production with introduction of the latest resource and energy-saving technologies. It is important to strengthen supervision over the strict satisfaction of industrial safety needs at potentially dangerous facilities, to ensure comprehensive processing, disposal, removal and disposal of industrial waste.

Outlined above problems are paramount importance for conducting research and creating innovative developments which are implemented by the staff of the Institute to improve technogenic environmental safety. As a result of the analysis, the results of scientific research were systematized. We will present the scientific achievements of scientists of IEG NAS of Ukraine and created innovative developments:

- software-modeling system is developed. It allows comprehensive assessment of chemical impact of energy facilities on air and population of adjacent areas with appropriate accumulation, storage, systematization, processing, analysis, exchange and visualization of monitoring data, as well as modeling and forecasting layer of the atmosphere in the controlled areas. More about this development is described in [5];
- mathematical and software tools for optimizing the network of observation posts for air pollution in man-made areas of Ukraine is developed;
- the newest technology of manufacturing of elements of anode and cathode lithium-ion accumulators of the increased capacity for tasks of conversion of peak loadings on power system is created and introduced;
- a new method for the synthesis of highly dispersed nanosorbent has been developed on the basis of magnetically sensitive thermally expanded graphite. This nanosorbent is used to eliminate spills of oil and petroleum products in water bodies;
- indirect method of measuring the concentration of air components on the basis of basic gas laws and taking into account the meteorological characteristics of atmospheric air is developed;
- prototype of the measuring module was developed as an element of the air pollution monitoring system. Figure 7 presents working prototype of the measuring module as an element of the air pollution monitoring system. Such a measuring module may include sensors for measuring the concentration of various pollutants (PM1, PM2.5, PM10, CO2, CO, SO2, NOX, CH2O, etc.) and meteorological parameters (temperature, humidity and pressure) [32];
- new mathematical tools for modeling air pollution due to dust formation on ash and slag dumps were developed. They unlike existing ones take into account particle parameters,
spatial and technogenic surface features, meteorological factors, dust suppression and wind erosion intensities. Ash slag enterprises of the fuel and energy complex on the state of atmospheric air and the population of the surrounding areas. Specialized software and modeling complex was developed on the basis of the mathematical apparatus. It allows to analyze data of atmospheric air monitoring on the territory of ash and slag dumps, to determine the distribution of pollutants in space and time in atmospheric air during dusting of this man-made object, to protect health of personnel and the population, to solve problems of preventive forecasting and generate recommendations to support effective management decisions to respond quickly to such emergencies and minimize their consequences;

- new mathematical models of air and surface water pollution as a result of emissions and discharges from NPPs and mathematical model of soil pollution by chemical emissions from NPPs due to the deposition of impurities from the surface layer of the atmosphere were created. Computer tools were developed for comprehensive assessment of the non-radiation impact of Ukrainian NPPs on the environment on the basis of mathematical software;

- prototype of drinking water treatment plant for persistent organic pollutants by plasma-chemical method was developed. The method of cold plasma does not require additional chemical treatment. It is used for purification of technogenic polluted waters. This is developed under a UK Grant;

- multifunctional laser computer complex with 8 channels system was developed for treatment of wounds and trophic disorders of participant of Antiteroristic Operation and Operation of Joint Forces, as well as their rehabilitation;

- new mathematical tools for optimizing the air monitoring system of man-made areas was developed. This unlike existing ones takes into account technogenic, environmental, socio-economic factors, level and consequences of air pollution. Its application allows to determine coordinates of stationary and mobile posts depending on current monitoring tasks for a specific network/territory. Mathematical tools are implemented in the form of a specialized software package.

Scientific results and innovative developments created by employees of the Department of Nuclear Physics Technologies and the Department of Environmental Protection and Radiation Safety of IEG NAS of Ukraine are of great practical importance for environmental safety, as
evidenced by the acts of implementation in various enterprises and organizations. Also number of patents for copyright certificates for the above developments is received.

3. International cooperation and implementation of scientific results

Another important achievement of IEG NAS of Ukraine is successful integration into the international scientific system. It contributed to the promotion of Ukrainian inventions abroad and increased importance of the contribution of our scientists to the achievement of world science. Employees of IEG NAS of Ukraine are experts of: Pure Earth International Organization (USA); Pegasus Environmental and Nuclear Services, Inc. (USA); Ministry of Ecology and Natural Resources of Ukraine and others, etc. [5]. The Institute also cooperates with various international organizations and universities: PLEJADES Independent Experts (Germany), Clemson University (USA), Indra Scientific SA (Belgium), Blacksmith Institute (USA), etc.

Employees of IEG NAS of Ukraine fruitfully cooperate with domestic and foreign research centers and production associations. Priority areas of such cooperation are within the framework of international scientific cooperation under EU programs “Horizon 2020”, NATO “Science for Peace and Development”. These are creation of new functional materials and nanocomposites for elements and devices used in telecommunications and engineering; research of new coordination compounds for the needs of medicine and agriculture; development of resource-saving technologies for efficient processing of metal-containing natural and man-made substances. They will certainly help to reduce technogenic load on the environment.

The Department of Nuclear Physical Technologies and the Department of Environmental Protection and Radiation Safety Technologies employ qualified scientific personnel with many years of positive experience in conducting scientific research. The Institute gained authority and respect not only through the work of scientists, but also through tireless work of large number of engineers, graduate students, talented youth, support departments and services. They all love their profession, are proud of their Institute and develop domestic science.

Process of creating innovative developments is accompanied by discussion, testing and description of their benefits by presenting scientific results and innovative developments at various scientific and exhibition events and publishing scientific articles, monographs and more. Also, employees of these departments initiated, annually organize and conduct international workshop “Innovative Approaches for Solving Environmental Issues (IASEI)” in the framework of the International Conference on Sustainable Futures: Environmental, Technological, Social and Economic Matters (ICSF) [33]. Figure 8 presents photo of international workshop, which was held in 2021 in online format, more details on the materials of workshops and conferences can be found in [33,34].

As a result of analysis and systematization of the work of scientists of the Department of Nuclear Physics Technologies and the Department of Environmental Protection and Radiation Safety of IEG NAS of Ukraine in recent years it is determined:

1. The Institute has reputation of leading scientific institution of Ukraine on the development of nuclear and physical technologies and radwaste management. This promotes interest of foreign investors in cooperation and financing of various projects.
2. The results of scientific research are unique (carried out at the intersection of different branches of science). Therefore, innovative projects are attractive for investment and competitive for world science.
3. The Institute is a leading research institution in the development of plasma-chemical technologies, in particular, developed innovative plasma-chemical reactors for the purification of liquid radwaste from radionuclides of objects.
4. Scientists of the Institute for the first time carried out radiation mapping of territories, including the Chornobyl Exclusion Zone, using the developed technology on the basis of
unmanned aerial vehicles.

5. Reviews and responses of scientific papers from leading scientists at Clemson University, Khazar University, Vilnius University and other organizations indicate a high level of technical and software-analytical tools for solving problems of radiation and technogenic-ecological safety.

4. Conclusions
Importance of conducting research on the issue of technogenic environmental safety was exacerbated by the pandemic caused by coronavirus disease (COVID-19) and the military situation in eastern Ukraine. Our country has large number of potentially dangerous facilities. Nuclear power plants occupy the first positions among such facilities.

Thus, the Institute is one of the recognized research institutions, whose employees are able to solve pressing problems environmental and radiation safety. The Department of Nuclear Physics Technologies and the Department of Environmental Protection and Radiation Safety provides solutions to pressing problems of national security of Ukraine in the following areas: comprehensive environmental monitoring of technogenic areas; radiation and technogenic-ecological security; civil protection of territories, population and environment.

For the needs of the nuclear energy complex of Ukraine, scientists of IEG NAS of Ukraine performed a number of studies on scientific and technical support of nuclear energy development and application of radiation technologies. Their main task is scientific and technical support of safe and reliable operation and development of nuclear energy, broadening of resource base, development of new generation nuclear physics facilities and applied research in promising areas of nuclear physics, plasma physics, radiation materials science and instrumentation, development of mathematical and software tools for modeling and forecasting the impact of radiation-hazardous objects on the environment.
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