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PROBLEMS OF RISK MANAGEMENT IN THE RADIATION SAFETY IN THE REPUBLIC OF BELARUS IN DIFFERENT SITUATIONS

M. G. Germenchuk

Candidate of Technical Sciences, Associate Professor, Deputy Director for Research, International Sakharov Environmental Institute of Belarusian State University, Minsk, Belarus, e-mail: germenchuk@iseu.by

Abstract

The article presents an analysis of the main sources of radioecological risks and disasters in the world and the Republic of Belarus. It is shown that the consequences of radioecological disasters are aggravated by natural phenomena and disasters (hydrometeorological, seismological, etc.). For the Republic of Belarus, the most significant sources are nuclear heritage sites, potential nuclear and radiation disasters, transportation of nuclear materials and transboundary transfer. The main problems of radioecological risk management in Belarus before 1986 are identified and methods for solving them are proposed, taking into account the implementation of a preventive approach. The need for control and management of organizational risks in the radiation safety is shown. The importance of improving the efficiency of the radiation monitoring and radiation situation forecast system, as well as early warning systems and threat and risk mapping, was noted, taking into account known current and potential threats.

Keywords: radioecological disasters and radiation safety, radioecological risk management mechanisms, risk rank, monitoring and forecasting of the radiation situation, exposure situations, radiation safety management (RSM), ionizing radiation (IR), Sendai Framework for Disaster Risk Reduction 2015–2030.

ПРОБЛЕМЫ УПРАВЛЕНИЯ РИСКАМИ В СФЕРЕ РАДИАЦИОННОЙ БЕЗОПАСНОСТИ В РЕСПУБЛИКЕ БЕЛАРУСЬ В РАЗЛИЧНЫХ СИТУАЦИЯХ

М. Г. Герменчук

Реферат

В статье представлен анализ основных источников радиоэкологических рисков и бедствий в мире и Республике Беларусь. Показано, что последствия радиоэкологических бедствий усугубляются явлениями и бедствиями природного характера (гидрометеорологическими, сейсмологическими и др.). Для Республики Беларусь наиболее значимыми источниками являются объекты ядерного наследия, потенциальные ядерные и радиационные катастрофы, транспортирование ядерных материалов и трансграничный перенос. Выделены основные проблемы управления радиоэкологическими рисками в Беларуси до 1986 и предложены методы их решения с учетом реализации превентивного подхода. Показана необходимость контроля и управления организационными рисками в сфере ОРБ. Отмечена важность повышения эффективности системы радиационного мониторинга и прогноза радиационной обстановки, а также систем раннего оповещения и картирования угроз и рисков, учитывая известные действующие и потенциальные угрозы.

Ключевые слова: радиоэкологические бедствия и радиационная безопасность, механизмы управления радиоэкологическими рисками, степень риска, мониторинг и прогноз радиационной обстановки, ситуации облучения, обеспечение радиационной безопасности (ОРБ), ионизирующее излучение (ИИ), Сендайская рамочная программа по снижению риска бедствий на 2015–2030 гг.

Introduction

The results of the analysis of disaster management activities, including in the field of radiation safety, lead to the conclusion that the most effective method is the systematic implementation of a preventive approach. This means increasing the role of disaster risk prediction for planning protective measures and subsequent resilience building in terms of establishing and maintaining risk management mechanisms, as envisioned by the Sendai Framework for Disaster Risk Reduction 2015–2030 (hereinafter referred to as the SDRR).

It is important to note that the SDRR provides middle-income countries that face specific challenges with additional support through international cooperation to provide them with means of implementation in line with their national priorities.

The Republic of Belarus, which faces specific difficulties in the form of radiological and radioecological consequences of the Chernobyl catastrophe, has had scientific, technical and humanitarian support for a long period of time in the framework of international conventions and bi- and multilateral treaties.

The SDRR currently consists of seven global targets, two of which directly affect radiation protection and safety:

Strengthening critical infrastructure and disaster resilience;

implementation of multi-hazard early warning systems, and improving access to information and assessments of disaster risk for information stakeholders, primarily the public.

Materials and methods of research

The object of the study is radiation safety and sources of radioecological risks and disasters. The subject of the study is the methods of radioecological risk management. As a general scientific, methodological and practical base the current strategies of disaster risk reduction of natural and anthropogenic character, proposed by the PSA, adapted to radioecological risks important for the Republic of Belarus are used [1]. Based on this approach, a critical analysis of the main problems of radiation safety in the Republic of Belarus before and after the Chernobyl NPP disaster is presented [2, 3, 4, 5].

The logical-historical approach and system analysis, risk theory, expert and other methods were used in the analysis.

Sources of radioecological risks and disasters in the world in the Republic of Belarus

The worldwide practice of disaster management in the field of radiation safety identifies six main categories that cover a wide range of man-made events and that generate different types of exposure situations:

I. Nuclear and radiation accidents and disasters, including nuclear and reactor accidents, industrial accidents, accidents with orphaned IR source, accidents with spacecraft and satellites, accidental discharges into the world's oceans, and others.

II. Nuclear explosions for peaceful purposes.

III. Mining of naturally occurring radioactive materials.

IV. Dumping of radioactive materials into the world's oceans for disposal.
V. Transportation of radioactive materials.
VI. Nuclear Legacy.

It should be noted that analysis of the data presented in available sources shows that all categories, except III and V, consider only those events that are a fait accompli of an accident or disaster. Potential sources of disasters are not identified, e.g. planned for construction nuclear power facilities (hereinafter – NPF) are not systematically analyzed and categorized, which does not allow assessing the whole range of radiation safety threats and risks.

Note that global radioactive contamination due to the testing and use of nuclear weapons as a source of radioecological disasters is also not singled out as a separate category, but can be considered in Category I as the event itself, and in Category VI "Nuclear Legacy" as radioecological consequences for the environment. It should be noted that as of January 1, 1990, no less than 1806 nuclear explosions had been carried out in the world in natural mediums: in space, in the atmosphere, under water and underground. Of these, 922 (51 %) were carried out by the USA and 644 (36 %) by the former USSR, while the remaining countries accounted for 240 (13 %) [6].

In general, it can be stated that six known Category I events caused radioecological disasters of different levels and scales: from 5 to 7 on the INES scale, including the Chernobyl and Fukushima NPP catastrophes (Table).

Table – The most significant nuclear and radiation accidents and disasters at nuclear and reactor facilities

№	Name of the object/location of the source radioecological risk, contaminated environmental objects	Causes of accident, catastrophe / INES level	Time	Main radionuclides in the release / discharge, other parameters of the radiation situation
1.	Mayak Production Enterprise / former USSR, Russia, Southern Urals / Techa River, East Ural trace / atmosphere, soil / hydrosphere, flora, fauna	Violations of radiation safety requirements / Level 6	1949–1956	Strontium-89,90, cesium-137, ruthenium-103,106, zirconium-95, niobium-95, cerium-141,144, yttrium-91, barium-140
2.	Sellafield nuclear complex, Windscale site / United Kingdom, Cumbria, / atmosphere, soil	Violations of nuclear and radiation safety requirements / Level 5	1957	Iodine-131, cesium-137, ruthenium-106, xenon-133, polonium-210
3	Mayak Production Enterprise / former USSR, Russia, South Urals, Kyshtym / Lake Karachay, Karachay trace / soil, bottom sediments	Violations of radiation safety requirements in combination with natural hazards / Level 6	1967	Strontium-89, 90, cesium-137, cerium-144
4	Three Mile Island Nuclear Power Plant / USA, Pennsylvania / Atmosphere	Violations of nuclear and radiation safety requirements / Level 5	1979	Iodine-131, cesium-137, xenon-133
5	Chernobyl NPP / former USSR, Ukraine, Chernobyl, atmosphere, soil, hydrosphere, flora and fauna	Violations of nuclear and radiation safety requirements, the consequences of which were multiplied by the transfer of radioactive materials in the biosphere and the negative impact of IR on biota and humans / Level 7	1986	Radioisotopes of iodine and tellurium, including iodine-131, tellurium-132, cesium-134,136,137, ruthenium-103,106, IRBs, including xenon-133, strontium-89,90, zirconium-95, niobium-95, cerium-141,144, barium-140, plutonium-238,239,240 and others
6	Fukushima NPP / Japan, Fukushima Prefecture / atmosphere, soil, hydrosphere, flora and fauna	Natural processes (tsunamis) that resulted in nuclear and radiation safety violations, the consequences of which were multiplied by the transport of radioactive materials in the biosphere and the consequences of the negative impact of IR on biota and humans / Level 7	2011	Radioisotopes of iodine and tellurium, including iodine-131, tellurium-132, cesium-134,137

At present radiological and radioecological consequences of these accidents and disasters are studied quite well and are used in the scientific process as a reliable base of empirical and theoretical knowledge, but attention should be paid to an important identified property of such events – aggravation of negative consequences for humans and the biosphere in the interaction of man-made disasters, in our case - radioecological, with natural conditions/disasters of hydrometeorological, seismic and other nature.

Thus, as an example of such a negative interaction effect, we can consider the events (radioecological disasters) associated with Mayak Production Enterprise (Lake Karachay and Karachay trace, 1967), as well as the disasters at the Chernobyl NPP (1986) and Fukushima NPP (2011).

Radioactive contamination of Lake Karachay (water and bottom sediments) was caused by the fact that, starting from 1951, liquid radioactive waste of Mayak Production Enterprise through the hydrographic network was redirected into Lake Karachay [7].

As a result of natural sedimentation processes in the bottom sediments of the lake, significant amounts of radioactive substances were accumulated from the suspended sediment and, partially, from the soluble fraction, which were artificially removed into the hydrographic network.

In 1967, due to dangerous hydrometeorological phenomena (drought and lowering of the lake level), radioactive contamination of the territories adjacent to Lake Karachay occurred, when about 5 hectares of the lake bed dried up, exposing radioactive bottom sediments. Then, under the action of meteorological phenomena (dust wind uplift and strong wind), radioactive material from the lake bottom got into the surface layer of the atmosphere and in the form of finely dispersed particles and aerosols atmospheric transport was activated, as a result, radioactive contamination with a total activity of about 22 TBq (strontium-90, cesium-137, cerium-144) was formed in the area of more than 2700 square kilometers adjacent to the lake [8].

Thus, we can say that for Lake Karachay and Karachay trace the process of radioactive contamination consisted of three parts: artificial release of radioactive substances into the environment (discharges of liquid RAW by the enterprise “Mayak” into the river Techa and Lake Karachay) → natural processes of redistribution of radioactive substances in the lake ecosystems → natural processes in the environment (drought, wind uplift, strong wind), which led to further redistribution of radioactive substances in the surface layer of the atmosphere, in soil, biotic and abiotic objects and formed the “Karachay trace”.

The process of radioactive contamination of the biosphere as a result of the Chernobyl NPP catastrophe consisted of two parts: artificial release of radioactive substances into the environment as a result of the release from the accident reactor → natural processes of redistribution of accidental radioactive substances in the environment (near and far atmospheric transport, wind uplift, surface and underground watercourses, washing off from catchments, biogeochemical processes in soils, subsoils and biotic objects) → radioactive contamination of the atmosphere, soils and hydrosphere.

As a result, radioactive substances of “Chernobyl” origin were recorded on the territory of the Northern Hemisphere of the Earth, which were further included in the global processes of substance transfer in nature [9].

Let us analyze the process of radioactive contamination of the environment as a result of the Fukushima NPP catastrophe in 2011, which looks as follows: natural processes (tsunami) led to the disruption of safe operation of the NPP (including disruption of emergency power supply) → artificial release of radioactive substances into the environment as a result of releases from 3 emergency reactors → natural processes of redistribution of emergency radioactive substances in the environment (near and far atmospheric transport, wind uplift, surface and airborne radioactive contamination of the environment) [10, 11]. As is known, the scale of radioactive contamination of the Fukushima catastrophe is so significant for the Northern Hemisphere of the Earth that traces of iodine-131, cesium-134,137 of “Fukushima” origin were detected on the radiation monitoring network even in Belarus at a distance of more than 11 thousand kilometers [12].

Analysis of the sources of disasters in the field of radiation safety listed above, as applied to the Republic of Belarus, shows that out of the six categories identified, the following are relevant for Belarus:

nuclear and radiation accidents and disasters, in terms of accidents at nuclear and reactor facilities, industrial accidents, accidents with orphaned IR sources;

extraction of natural radioactive materials – mining of potash ores and production of potash fertilizers on the territory of Minsk and Gomel oblasts of Belarus, as well as the presence of natural radionuclides in the waste of phosphate fertilizers production (Gomel oblast);

nuclear legacy – consequences of global nuclear weapons tests and the Chernobyl NPP catastrophe, storage and disposal sites for nuclear materials and RW, as well as disposal sites for decontamination waste;

transportation of nuclear and radioactive materials, including transboundary transportation;

use of nuclear materials for medical, energy and other purposes.

It should be noted that accidents with spacecraft and satellites, accidental discharges into the world ocean, nuclear explosions for peaceful purposes are of no practical importance for ensuring radiation protection and safety of the population and the environment in the Republic of Belarus.

An important task of radiation safety in Belarus is to study the threats and risks of Category V related to the management of RW received from previous activities and, which is a specific country feature, with decontamination wastes, which were formed in the process of ensuring radiation protection of facilities in settlements and other territories and (or) industries (forestry, agriculture, municipal, etc.) after the Chernobyl NPP catastrophe.

In the Republic of Belarus, by decision of the Department of Nuclear and Radiation Safety of the Ministry of Emergency Situations, the “Register of radioactive waste and nuclear heritage storage (disposal) facilities” (hereinafter – the Register), which includes 101 objects, has been created [13].

As of 2024, the most numerous group of objects included in the Register is 86 objects of decontamination waste disposal, 10 objects of RAW storage and disposal at UE “Ecores”. Belarusian NPP is responsible for 2 RAW storage facilities (solid RAW storage facilities at Units 1 and 2). The Scientific Institution of NAS of Belarus “United Institute of Nuclear Research – Sosny” ensures nuclear and radiation safety of the complex of buildings and structures decommissioned after years of scientific research using nuclear energy. The Gomel-30 radioactive waste disposal facility is included in the Register as a separate facility.

In addition, the Polessky State Radioecological Reserve is included in the Register as a nuclear legacy site. The PGRES includes the Belarusian sector of the Chernobyl NPP Exclusion Zone and adjacent territories, where the highest levels of radioactive contamination of atmospheric air, soil, surface water, flora and fauna have been recorded, with the forecast indicating that the radiation situation will not change significantly over the next centuries due to transuranic elements [14, 15].

In the Republic of Belarus, according to the annual Reviews of the state of nuclear and radiation safety in the Republic of Belarus submitted by the Department of Nuclear and Radiation Safety of the Ministry of Emergency Situations of the Republic of Belarus, 4 cases related to the discovery of lost radioactive sources and other radiation incidents were registered in 2022, in 2021 – 2, in 2020 – 5, in 2019 – 10, in 2018 – 5 [4, 5].

There are industries (Category III) in the world, which include thousands of facilities related to the extraction of natural radioactive materials (uranium mining) or in which radioactive materials are a by-product of production (metallurgical, phosphate, coal and other fuel, oil and gas industries, etc.). In the case of the Republic of Belarus, attention should be paid to the phosphate, potash and fuel industries.

In Belarus, over the decades of operation of the Gomel Chemical Plant, which is engaged in the production of complex phosphorus-containing fertilizers, powerful dumps have formed, which consist mainly of phosphogypsum, their mass to date exceeding 20 million tons, the highest dumps reaching 95 m [16]. At present, phosphogypsum dumps of the Gomel Chemical Plant as a monitoring object in the NSMOS of the Republic of Belarus are not included in the radiation monitoring programs, which is associated with low activities of natural radionuclides of the uranium-thorium series in the production waste; however, the existing dumps can be considered as a potential source of negative impact of IR on the environment and humans.

It should be noted that it is also necessary to refer to assessments of radioecological risks in potash fertilizer production, which can potentially be the subject of management in the field of radiation protection and radiation safety for the Republic of Belarus, which, along with Canada, Russia, Germany, Brazil, USA, Israel and Jordan, is the leader in potassium salt reserves with total reserves of more than 7.6 billion tons. The content of potassium chloride in sylvinite of the second horizon at the deposits of the Republic of Belarus is 25–33 %, at the same time, the content of radioactive potassium-40 in the natural mixture of potassium-39,40,41 is known to be 0.012 %.

Analysis of the world practice shows that the activity on transportation of radioactive materials, including transboundary transportation, is the most active. Every year many thousands of cargo/packages with radioactive materials are transported by road, rail, sea and air. Many thousands of radioactive material packages are routinely transported annually both within and between countries by road, rail, sea and air. In Europe alone there are over 1 million shipments a year [17]. It should be noted that in 2023, the Department of Nuclear and Radiation Safety issued 213 permits for the import/export of radioactive materials to the Republic of Belarus.

In conditions of “Chernobyl” radioactive contamination of the territory of the Republic of Belarus the use of local fuel resources, mainly wood and peat, has formed local problems due to increase of caesium-137 radionuclide concentration in ash waste, and it is possible to obtain ash with activity corresponding to the category of radioactive waste (more than 10 000 Bq/kg). According to the radiation safety requirements established in the Republic of Belarus, specific activity of cesium-137 in wood fuel should not exceed 740 Bq/kg (“Republican permissible levels of cesium-137 content in wood, wood and wood products and other non-food forestry products (RPL-2001)”.

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Main problems of radioecological risks management on the example of the Republic of Belarus and methods of their resolution

At the present stage, a general algorithm of radiation safety risk management, which includes eight blocks/subsystems, has been created and is used for analysis [18].

Retrospective analysis of the practice of radiation safety management in the Republic of Belarus in the period from 1960 to April 1986 and in the first period of the Chernobyl NPP catastrophe from the point of view of the modern system of radioecological risk management shows that the lack of long-term system planning in case of an accident has led to the following consequences: scientific, methodological, organizational, technical and informational problems were formed in each subsystem.

Subsystem I "Radiation Safety Threat Assessment" (scientific, methodological and information problem)

In practice, sources of threats in the sphere of radiation safety have not been identified, quantified and ranked, with the exception of a "nuclear" strike during military operations, while global radioactive contamination, existing and potential scientific and industrial nuclear facilities, including power plants (Chernobyl, Ignalina, Rovno, Smolensk NPPs), other sources of radiation impact on the population and territories as a threat to radiation safety have not been considered [18, 19].

Subsystem II "Vulnerability Assessment" (problem (scientific, methodological and informational)

Only "present and future generations" in the context of radiological risks were considered as the main object of radiation protection, which is the most vulnerable from the point of view of negative impact of IR; due to the lack of assessments of threats in the sphere of radiation safety, the vulnerability of other objects, including natural ones, was not assessed, which should have been differentiated: at the territorial level (settlement, district, city, region), at the level of ecosystems, at the social level (economy, health care, etc.).

Subsystem III "Assessment of existing and planned activities" (scientific, methodological and information problem)

Before the Chernobyl disaster, large nuclear facilities, such as the four nuclear power plants around the country's borders, as well as planned activities, such as the design of the Belarusian nuclear thermal power plant, were not considered as sources of radioecological risks and threats due to the lack of scientifically based requirements for assessing radiation safety threats and vulnerability.

Subsystem IV "Analysis and Identification of Radiation Safety Risks" (scientific, methodological and information problem)

Due to the erroneous statement about "absolute safety of NPPs" for the population and the environment, risks from nuclear power facilities in the energy sector were not analyzed, and the radiation control system included, as a rule, only the 30-km zone around the nuclear power plant. Nevertheless, the rank of risk, for example, from radioactive contamination of the environment with radioactive iodine on the territory of Belarus in April-August 1986 was characterized as "high" and "extremely high". At the same time, the scientific community, the public and the mass media did not have access to reliable information important for radiation protection and safety until 1987 [21].

Subsystem V "Analysis of possible options for risk reduction" (scientific, methodological, organizational, technical and information problem)

Based on the documents on civil defense of the population for "wartime" in force in 1986, it was assumed that the following options for limiting exposure in the short term were possible: special protective suits, sheltering in a specialized protective facility, limitation of food consumption, limitation of stay in the open air, taking iodine preparations and, finally, evacuation.

Decisions to ensure the radiation safety of the public and the environment based on a choice among these options in the first phase of the accident in 1986 were ineffective because they should have been based on a preliminary vulnerability and risk assessment, which were not performed. At the same time, in 1986, decisions were made in an extremely short time frame in the absence of necessary information in a situation of uncertainty. Protective measures of medium- and long-term nature were not planned, as well as measures aimed at minimizing environmental pollution and its consequences.

Subsystem VI "Complex of operational and long-term measures to prevent and neutralize radiation safety threats and risks" (scientific, methodological, organizational, technical and information problem)

Lack of forces and means maintained in constant readiness on the basis of organizational, personnel, financial, material, technical, informational and other resource support did not allow taking all necessary measures to ensure radiation safety of the population and territories. Combined with the policy of "closedness" of information about the Chernobyl NPP radiation catastrophe and its consequences, and in the absence of an effective system of radiation monitoring of the environment, the situation only worsened.

As is well known, the so-called "iodine prophylaxis" of the population was not carried out in time to block radioactive iodine intake into the body "spontaneous" amateur iodine prophylaxis of the population was late and, of course, ineffective. It was not possible to promptly assess the scale of radioactive contamination of the territory of Belarus, for example, samples of atmospheric air and soil were not taken in time for determination of short-lived iodine-131 on the whole territory of Belarus, and systematic study of radioactive contamination of soil in the Mogilev region was started only in June 1986.

Subsystem VII "Implementation of the complex of measures" (scientific, methodological, organizational and informational problem)

The absence in the first years after the Chernobyl NPP catastrophe of a normative legal framework for the implementation of a set of measures in the form of laws of the Republic of Belarus, resolutions of the Council of Ministers, other normative and normative technical acts, as well as state and regional programs to eliminate and minimize the consequences of the Chernobyl catastrophe, including radiation monitoring, had a negative impact on the level of radiation safety.

Subsystem VIII "Evaluation of results and adjustment of the set of measures, including on the basis of program monitoring" (scientific, methodological, organizational and information problem)

Fulfillment of the requirements of this subsystem is currently implemented through improvement of the regulatory legal framework in the field of radiation safety, in the form of state programs to eliminate and minimize the consequences of the Chernobyl catastrophe, including in terms of radiation monitoring, including using the "feedback method".

Based on the results of logical-historical analysis, we note that Belarus had sufficient material, human and financial resources for the purposes of radiation safety in the conditions of global bomb contamination.

However, in the conditions of the Chernobyl NPP catastrophe, the problems of lack of resources for protection from the known, but not previously assessed threat immediately arose, including the lack of specialized laboratories equipped with the appropriate equipment (except for some institutes of the Academy of Sciences, BSU, regional design and survey stations of agricultural chemicalization of the Ministry of Agriculture and Food), the lack of a sufficient number of qualified specialists, as well as the lack of planned allocations for the purchase of equipment, consumables and other materials.

It should be noted that in 1986 the equipment in common use had an insufficient sensitivity threshold because it was designed to detect very high levels of contamination due to a possible nuclear strike. For example, the DP-5 dosimeter, which were mostly used at civil defense posts, had a lower range of dose rate measurement (hereinafter referred to as DPM) of 0 – 50 μR/h, while the DPM from natural background radiation in the Republic of Belarus was estimated as 4 – 20 μR/h, and the widely used at that time field scintillation radiometer (type SRP-6801), originally designed for geological exploration works, due to its design features had a significant overestimation error in the lower range of measurements. As a rule, the equipment was not calibrated and certified, calibration sources and batteries were often missing, and there was no system of test quality control.

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Unfortunately, it should be recognized that by this time there was also no real assessment of the needs of different information groups, so the information that could be obtained could not fully satisfy the state administration bodies, radioecologists, radiobiologists and radiation hygienists, as well as the public [18].

Let us analyze the problems of radioecological risk management when decisions in the field of radiation safety are made in situations of risk and uncertainty, assuming that these situations need to be reduced to a situation of certainty.

The situation of risk is applicable to the situation of existing exposure, for example, in the conditions of known radioactive contamination of the environment after the Chernobyl catastrophe in the long term, when risks are identified, ranked, for example, by RR, and programs for their minimization are in place.

On the one hand, assessments of the radiation situation, based on data from environmental radiation monitoring and radiation monitoring of foodstuffs, make it possible to control radioecological and radiological risks and to maintain radiation safety at a socially acceptable level.

On the other hand, the existence of a number of variants (scenarios) of radiation situation development and the presence of organizational risks in the course of implementation of activities in the field of radiation protection do not always allow to turn the situation of risk into a situation of certainty. It should be noted that in this case such function of the system of radiation monitoring of the environment as "assessment and forecast of changes in the environment under the influence of natural and anthropogenic factors" becomes decisive for assessment of consequences of realization of this or that variant (scenario) of changes in the radiation situation.

Besides the problems related to forecasting, in the situation of risk in the system of ensuring radiation safety there arises a methodical problem of "radioactive contamination control". At present, the regulatory documents of the Republic of Belarus determine that radioactive contamination control is subject to objects for which permissible levels of controlled parameters are established [22].

For example, in accordance with the Law of the Republic of Belarus "On the legal regime of the territories affected after the Chernobyl NPP catastrophe" the territories, settlements are referred to the zones of radioactive contamination when the control value of excess of radiation dose over natural 1 mSv per year or "density of soil contamination with cesium-137, strontium-90, plutonium - 238, 239, 240 is more than 1, 0.15 and 0.01 Ci/sq.km, respectively" [23], and rationing of radiation doses was carried out through radioactive contamination of foodstuffs in accordance with the current hygienic standards or other standards of maximum permissible exposure to ionizing radiation [23].

Norming of radiation doses was carried out through rationing of radioactive contamination of foodstuffs in accordance with the current hygienic standards or other standards of maximum permissible exposure to ionizing radiation.

At the same time, it should be realized that the problem of "control of radioactive contamination" carries hidden additional risks. These risks may be related, for example, to changes in the rationing systems. It should be noted that food products in the post-Chernobyl period were consistently rationed by a number of normative technical acts: from temporarily permissible levels (TPL) during the accident, republican permissible levels – 1992, 2000, 2012 to the regulations of the Customs Union.

This state of affairs causes another type of risks - organizational risks, and can lead to a significant loss of information quality, since radiation monitoring is carried out at the input and output of the technological process of production of certain types of products at the enterprise to assess its compliance with hygienic standards and does not meet the quality requirements for spatial and temporal parameters mandatory for the monitoring network [18].

At the same time, the equipment massively used for product monitoring, which is relatively inexpensive and, as a rule, has a low threshold of ispulse measurement, does not allow obtaining representative results in a range much smaller than the specified control levels. However, it is this range that is of interest in terms of the timely detection of trends in radiation parameters, e. g. radioactive contamination of local foodstuffs of plant and animal origin. On the contrary, the monitoring system uses expensive measuring equipment with high sensitivity thresholds designed to measure very low activities in samples, allowing to detect additional contamination above the background contamination.

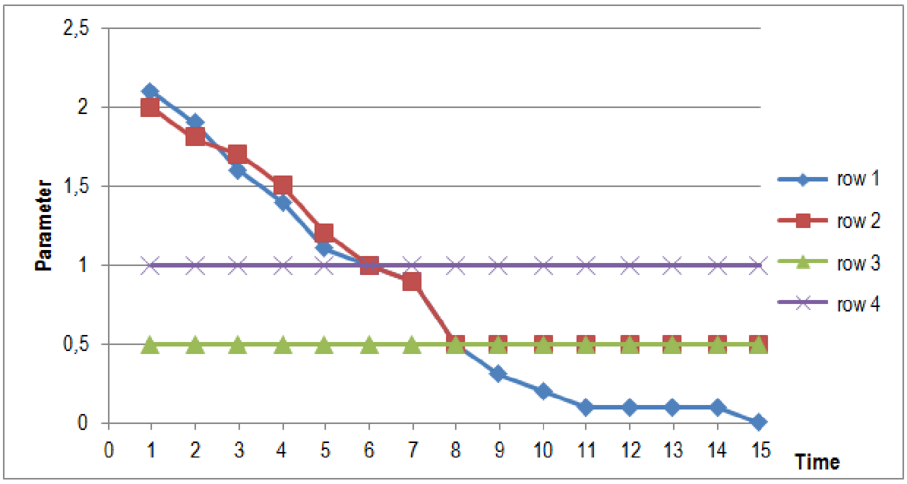

Figure 1 – Positive scenario (row 1 – monitoring results, row 2 – control results, row 3 – lower detection limit of massively used equipment, row 4 – norm)

The diagrams shown in Figure 1 and Figure 2 illustrate the above. Let's analyze the results of measurements of some environmental object in the "control" mode and in the "monitoring" mode for some specified time.

So, if we take the conditional standard equal to 1 (row 4), and the lower limit of detection of massively used equipment is conditionally taken equal to 0.5 (row 3), it is obvious that the results in the "control" mode (row 2), presented in Figure 1 indicate that the situation in the entire time period 1 – 15 is positive: in the first period 1 – 8 there was a sharp decrease in contamination of the object under study, then in the time period 8 – 15 results "reached the plateau" of the lower detection limit and the curve of results actually merged with it (rows 2 and 3). At the same time it should be noted that the main task of control in terms of radiation safety – detection and withdrawal from circulation of environmental objects that do not meet the requirements of safety standards, for example, foodstuffs, is completely fulfilled.

However, the results of the "control" mode do not give an idea of how the situation develops in the range below the detection limit [0 – 0.5]. Nevertheless, from the point of view of radiation safety, two scenarios are possible here: positive and negative, and it is clear that organizational risks are present in both cases.

Let us consider the positive scenario further, when in the time period 8 – 15 the real measured contamination levels continue to decrease and finally gradually tend to trace amounts, which is clearly demonstrated by the results of monitoring using highly sensitive equipment (row 1).

It is obvious that mass radiation monitoring, which requires a significant amount of financial, material and labor resources, is irrational at this stage, i. e. there are organizational risks. To resolve this situation, it is sufficient to organize random inspections and ensure monitoring at production nodal points, which, in the end, allows optimizing the functioning of the control system and reducing the risks associated with a negative outcome, as will be shown below, as well as eliminating the inefficient use of available resources.

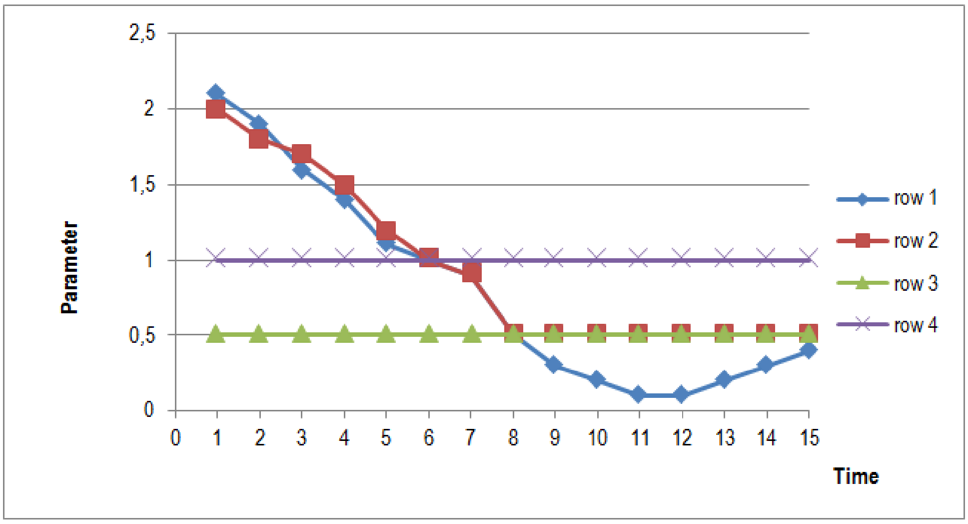

Figure 2 – Negative scenario (row 1 – monitoring results, row 2 – control results, row 3 – lower detection limit of massively used equipment, row 4 – norm)

Let us consider a negative scenario (Figure 2), when in the time period 8 – 11 real contamination levels continue to decrease, but in the period 12 – 15 a negative trend appears – radioactive contamination of the object increases (row 1), but radiation control data do not show this (row 2). This is due to the fact that the "control" system, unlike the "monitoring" system, does not react to changes in the trend from positive to negative, if these changes are in the range significantly below the control level and the lower measurement threshold.

Thus prerequisites are created for occurrence of organizational risks on timely detection and reduction of risks of achievement and exceeding of normative values of radioactive contamination of controlled objects. It is likely that already in the period 12 – 13, when the negative trend has formed and become stable, there is an opportunity to take timely measures to identify and eliminate its causes.

As a result, it is shown that the range of parameter values closed in the "control" mode contains important information about the trends of their changes in both positive and negative contexts.

The situation of uncertainty is the most difficult from the point of view of radiation safety, since it is associated with a large number of possible outcomes, and their probabilities are unknown.

From the point of view of radiation safety, a situation of uncertainty arises in the case of emergency exposure and/or emergency planning. In this case it is very important that the source of uncertainty can be incomplete and (or) unreliable information from the system of radiation monitoring of the environment or from other systems, e.g. monitoring of emergency situations, for example, about the facts of threat realization. In general, the requirements to information quality can be formulated as five basic requirements to information quality: timeliness, reliability, completeness, accessibility, sources of uncertainty and their assessment [18].

Of course, the ideal risk management strategy is to eliminate risks and threats, i. e. to directly affect their source, which is practically impossible due to the objective nature of risks and threats in the field of radiation safety. In this case, the most effective way to minimize risks in the situation of uncertainty is the method of modeling and forecasting of radiation situation and characteristics of the radiation monitoring system of the environment. An obligatory condition for modeling is the ranking of current or potential risks and threats for subsequent emergency planning. It should be noted that this is the approach proposed by the SDRR.

In order to improve early warning systems in the field of radiation safety, automatic systems for early detection and warning of radioactive contamination of the environment in 100 km zones of Chernobyl, Ignalina, Rovno and Smolensk NPPs, as well as in the surveillance zone of Belarusian NPPs, are currently established and successfully functioning in the Republic of Belarus; information is generally available on-line using modern communicative IT-technologies [24, 25].

The SDRR proposes four main priority areas of risk management activities.

Priority 1. Understanding disaster risk: to effectively counteract disasters, it is necessary to ensure that radiation safety hazards and risks are assessed on a continuous basis, assessing the vulnerability of protection facilities before events occur and preventing disasters or mitigating their consequences through the development and implementation of appropriate measures.

The development and implementation of such an approach in the Republic of Belarus will ensure a socially acceptable level of DRR in different conditions/types of exposure situations in the medium and long term.

Priority 2. Improving the organizational and legal framework for disaster risk management: The organizational and legal framework for disaster risk reduction at the national, regional and global levels is of great importance for effective and efficient risk management in the sphere of radiation safety [26].

In the Republic of Belarus, the necessary strategies for counteracting risks at the national level have been developed and are in place, including specific plans and activities, for example, the External Emergency for the Belarusian NPP or the "Strategy for Radioactive Waste Management in the Republic of Belarus" [27], defining the competencies of individual state administration bodies in the field of ORB and their coordination at the level of individual sectors of the economy and between sectors, as well as the participation of relevant stakeholders – subjects of the economy.

Priority 3: Investments in disaster risk reduction measures to strengthen resilience: public investments in prevention and risk reduction in the form of:

scientific activities in the field of nuclear energy utilization and counteracting the risks accompanying these activities;

formation of necessary emergency response forces and means.

It is important that investing in the introduction of modern IT and AI-technologies allows improving early warning systems within the framework of radiation monitoring and radioactive contamination mapping, which, along with a preventive approach, is one of the most important priorities in countering radioecological disasters.

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Priority 4: Enhancing disaster preparedness for effective response and implementing the principle of "doing better than before" in recovery, rehabilitation and reconstruction activities: practical activities on the example of the Republic of Belarus on minimizing the consequences of the radioecological disaster – the Chernobyl NPP catastrophe – demonstrate that the recovery, rehabilitation and reconstruction stage is crucial for implementing the principle of "doing better than before", including by combining measures Such an example is the State programs that envisage advanced socio-economic development of the territories affected by the Chernobyl disaster, construction of centralized water supply systems and gasification of rural settlements, expansion of the network of qualified medical services, measures to increase productivity in agriculture, which are designed to ensure an acceptable level of radiation protection and safety and, on the other hand, solve social and domestic problems.

Wide use of nuclear energy for scientific and economic progress, improvement of human life quality, solution of other social or military tasks, creates new sources of risks, threats and disasters of anthropogenic nature (radioecological disasters), the consequences of which may be aggravated by natural phenomena and disasters (hydrometeorological, seismological, other).

In addition to radioecological risks for radiation safety purposes it is important to identify and assess for subsequent management other risks – organizational risks.

Analysis of available information on the sources of radiological and radioecological risks allows us to conclude that the number of realized events important for radiation safety can be estimated in the range from six most significant nuclear and radiation disasters to 1,806 (categories I and II – nuclear and radiation accidents, testing and use of nuclear weapons). The number of potentially dangerous events from other sources of radioecological risks, e. g. transportation of radioactive materials (category V), can reach several millions.

For the Republic of Belarus, the most significant sources of radioecological risks and disasters are nuclear legacy sites, potential nuclear and radiation accidents, transportation of nuclear materials and transboundary transfer.

In the period before 1986, information on current and potential sources of radiation safety threats and risks was clearly insufficient and, due to underestimation of its importance, was not a valid factor of radiation safety.

Belarus had sufficient material, human and financial resources for radiation safety in the conditions of global bomb contamination before 1986, but the Chernobyl NPP catastrophe showed that the system of radiation monitoring of the environment was ineffective in the conditions of emergency exposure.

Retrospective analysis of the practice of the Republic of Belarus in the period from 1960 to April 1986 and in the first period of the Chernobyl NPP catastrophe shows that the lack of long-term systematic planning in case of an accident led to the emergence of scientific, methodological, organizational, technical and informational problems that required resolution at a high scientific level.

In order to successfully solve these problems with respect to the Republic of Belarus, a critical analysis of the sources of disasters and methods of risk management in the field of radiation safety for effective counteraction to radioecological disasters is necessary to act in the long and medium term.

In the long term, radiological/radioecological risk management mechanisms should be maintained on an ongoing basis:

(A) monitor radiological and radioecological risks with subsequent risk assessment and ranking;

(B) ensure effective functioning of the radiation monitoring system (observations, assessment and forecast of radiation situation, mapping), including the use of IT and IA technologies;

(C) ensure the functioning of the early warning system on radioecological threats, risks and disasters, including with the use of IT- and IA-technologies;

(D) provide scientific and information support for risk management and radiation safety activities.

In the medium term:

(A) assess radioecological and radiological risks in the potash industry and phosphate fertilizer production in the situation of planned irradiation (for the Republic of Belarus) in order to make a subsequent decision on the inclusion of additional observation points in the National Environmental Monitoring Program;

(B) to pay special attention to specific difficulties of the Republic of Belarus: long-term radioactive contamination of the environment due to the Chernobyl NPP catastrophe, presence of a large object of "nuclear legacy" – the territory of Polessky State Radioecological Reserve.

To achieve these goals it is necessary to further improve and increase the efficiency of the system of radiation monitoring and forecasting of radiation situation, as well as early warning systems, taking into account all known current and potential threats.

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