ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Radiation In The City: Natural And Artificial Radiation, Reality And Myths.

Vladimir Alexandrovich Grachev[1]*, Rafael Varnazovich Arutyunyan[2], and Olga Vladimirovna Plyamina[3].

[1]President of the V.I. Vernadsky Nongovernmental Ecological Foundation, Honorary Member of the Parliamentary Assembly of the European Council, Corresponding Member of the Russian Academy of Sciences, Member of the Commission of the Russian Federation for UNESCO. The V.I. Vernadsky Nongovernmental Ecological Foundation, 29/1 Bolshaya Ordynka Street, Suite 104, Moscow, 119017, Russia.
[2]Professor, DSc in Phys. & Math., Deputy Director on Science and Coordination of Advanced Development of the Nuclear Safety Institute, Russian Academy of Sciences (IBRAE RAN), Russia. The Nuclear Safety Institute, Russian Academy of Sciences (IBRAE RAN), Bolshaya Tulskaya Street, 52, Moskva, 115191, Russia.
[3]Scientific Secretary of the Russian Environmental Academy. The Russian Environmental Academy, 29/1 Bolshaya Ordynka Street, Suite 503-A, Moscow, 119017, Russia.

ABSTRACT

The authors of the paper performed a systematic analysis of the world-wide data published on the population irradiated by natural and anthropogenic sources of ionizing radiation. Taking into account that the scientific validity of the USA and Russia's intervention criteria in radiation accidents is being discussed, this issue is of high relevance. The existing super-rigid rating system, which is not based on the actual identified effects of radiation on human health in small doses, becomes a factor of a very high social vulnerability to the radiological terrorism threat. Authors proved the necessity to harmonize international radiation protection criteria with due consideration of acceptable levels of social risks.
Keywords: natural radiation background, annual radiation dose, radiation safety, human health, internal irradiation.

*Corresponding author

INTRODUCTION

Why is it important to study the atom? The study and use of knowledge about the atom has given considerable impetus to scientific and technological progress in almost all fields of knowledge and technology. The result is a range of achievements from space rockets to nuclear battery that is thinner than a human hair, from medical diagnostics and isotope research to the phenomena of superconductivity, from nuclear weapons to nuclear power (Figure 1).

What is radiation? In Latin "*radiatio*" means "shining", "glittering". Radiation is the emission that is generated by radioactive decay, nuclear transformation, and deceleration of charged particles in matter and that produces ions upon interaction with the environment (causes ionization).

Cosmic rays are represented by high-energy flux (99% are the nuclei and about 1% are solitary electrons), of the nuclei about 90% are protons, about 9% are alpha particles, and 1% are the nuclei of heavier elements (NASA, 2016). However, the planet Earth, being a part of the Solar System, has its own mechanisms of protection against radiation, otherwise life on the Earth would be impossible.

Natural radioactivity was formed 15 billion years ago, along with the solid Earth. Three families of radioactive elements – uranium, thorium, and actinium – are mainly responsible for the Earth's natural radiation. Radioactive elements, contained in rocks that were formed as a result of geophysical processes, are the main source of the Earth's radiation. And all the generations of people have lived side by side with the influence of background radiation. In its physical and chemical composition and location in the outer space, the Earth is arranged so that radiation is everywhere. Along with the sunlight, air composition and atmospheric pressure, radiation is a typical living condition. Radiation is one of the adaptation mechanisms. Without radiation a person would not be able to adapt to the changing conditions.

Tens of millions of people are constantly getting exposed by the natural radiation background, including the natural radioactive gas radon (toron), every year getting a dose at the level of 5-10 mSv (millisieverts). Whereas, there have been certain areas with an increased natural radiation background where a dose of radiation could reach annually up to 15-30 mSv, where children and women have also been exposed to this natural radiation for centuries, while the world average annual dose of exposure per person is about 2.4 mSv. This being said, the overall lifetime dose in the areas with the increased radiation background could reach 1000 mSv and more without any negative health outcome diagnosed during special epidemiological exams.

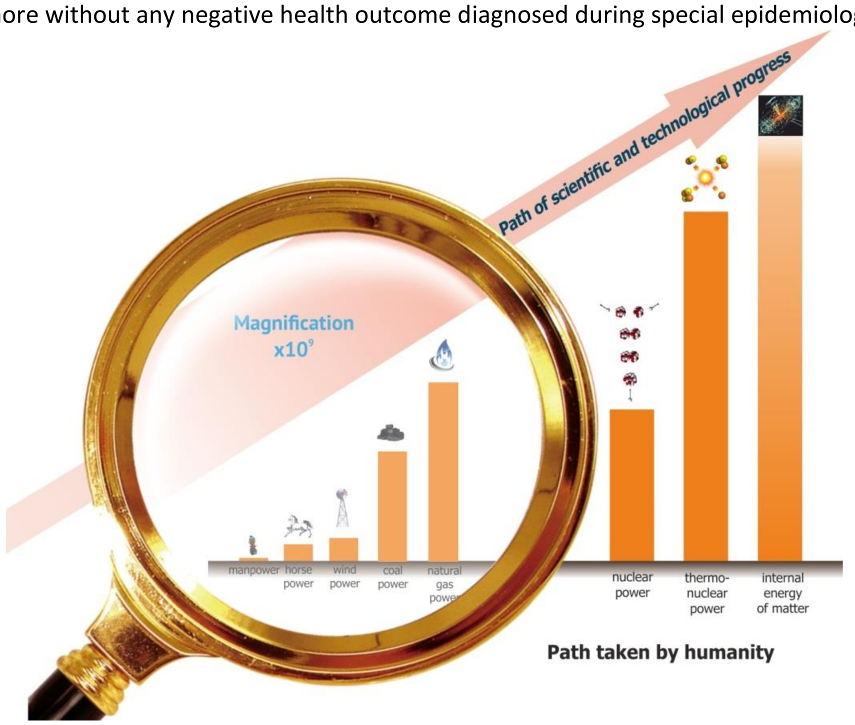

Figure 1. Path taken by humanity ("Environment and emergency management", 2014)

METHODS

We carried out a systematic analysis of the world-wide data on the population irradiated by natural and anthropogenic sources of ionizing radiation. A comparative analysis of radiation doses and intervention criteria set by the US Environmental Protection Agency and the Chernobyl legislation of the Russian Federation included the analysis of unintentional and intentional dispersion of radioactive substances at the level of gram (this corresponds to the activity of about 100-1000 Curie, depending on the isotopic composition) in the metropolis and resulting socio-economic consequences in the case of implementation of the existing in Russia and other countries criteria of rehabilitation or introduction of various protective measures in annual doses of more than 0.15 mSv per year (US EPA's preferred annual dose constraint for individual sources) ("Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials", 1999) and more than 1 curie/km2 for Cs-137 in soil or 1 mSv per year extra dose in accordance with Russian, Ukrainian and Belarusian Chernobyl legislation on which nearly 8 million people were classified as "affected" (Law of the Russian Federation No. 1244-1, 15 May 1991, Law of Ukraine No. 796-XII, 28 February 1991, Law of the Republic of Belarus No. 9-3, 6 January 2009, Law of the Republic of Belarus No. 1227-XII, 12 November 1991).

RESULTS

Typical background radiation in a contemporary city is 8-12 μR/hr (microroentgens per hour). According to the experience of mankind, increased background radiation may positively affect human health. For example, centenarians live in high mountain areas, where increased cosmic ray flux and content of natural radionuclides in rocks are much higher than the natural background radiation. On average, about 2/3 of the radiation dose that a person receives from natural sources of radiation comes from radioactive substances consumed with food, water and air (Figure 2).

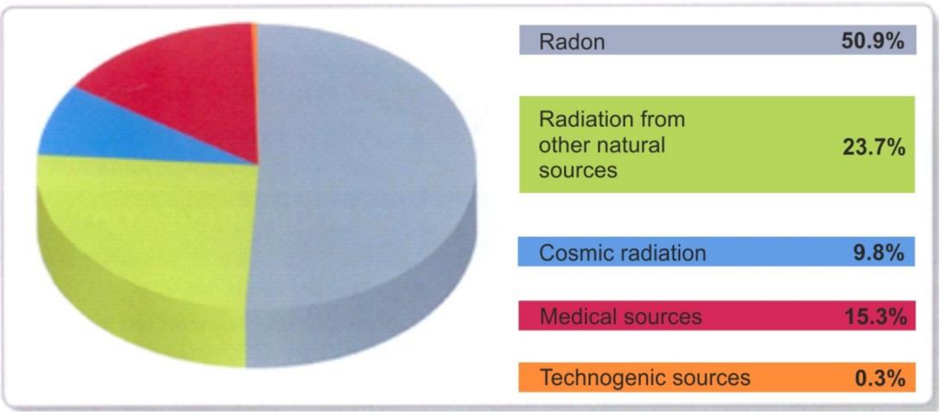

Figure 2. Share of various radiation sources in the total irradiation dose received by human per year ("Environment and emergency management", 2014)

Tens of thousands of people in the Far North eat mostly reindeer meat which contains high levels of lead-210 and polonium-210. These isotopes enter the body of a deer in winter when they feed on lichens which accumulate these isotopes. In these cases internal radiation dose for humans may be 35 times higher than average. People in Western Australia receive doses that are 75 times greater than the average because they eat meat and offal of sheep and kangaroos (E. Kebin, 1996).

Half of the annual dose from terrestrial sources of radiation is received by human from radon, a colourless, tasteless and odorless heavy gas.

Radionuclides are scattered in the environment and are present in any surroundings, no matter organic or inorganic. This radionuclides radiation together with cosmic radiation creates a natural radiation background. We are not surprised with the radiation level of 10-14 μR/hr (0.10-0.14 μSv/hr (microsieverts per hour), and we know this is a norm for the most areas. We also know that the atmosphere is more permeable to cosmic rays at the height of 10 km (civil airplanes' flight altitude) and therefore, the background therein is 200-250 μR/hr (2,0-2,5 μSv/hr). However, we are unaware of the places on the Earth, where the natural background is increased significantly, not causing any problems for the inhabitants ("Interesting facts about atom and radiation", 2009).

Investigation of the Increased Natural Radiation Phenomenon

Earth's sources of radiation are more than 60 natural radionuclides. The main contribution to the external radiation dose is made by gamma-emitting nuclides of uranium and thorium radioactive series, as well as of potassium-40. There are radiation anomalies in those areas, where thorium and uranium content in the soil is increased. Here are some examples:

France. The average radiation background runs up to 2 μSv/hr (20 times more than "typical" background) in a number of regions. On average, 7 million French people receive an annual natural radiation dose that is 1.5-2 times more than the world average one. There are areas with the same radiation level in **Italy**, **the USA**,

Sweden, **Madagascar**, volcanic islands in the Pacific Ocean. There are regions with the increased natural background in Russia as well – for example, some regions of **Altai and Karelia** ("Interesting facts about atom and radiation", 2009).

India (Kerala State). 7 000 people live in the area with an average background of 0.43 μSv/hr. There are monazite sand seeps along the coastal strip where thorium-232 and decay products content is approx. 10% by weight. More than 100 thousand residents of Kerala and Madras states live under the annual average background of 0.14-3.2 μSv/hr ("Interesting facts about atom and radiation", 2009).

Brazil (Espírito Santo and Rio de Janeiro States). The radiation dose ranges from 1 to 10 μSv/hr along the Atlantic coast, running up to 20 μSv/hr at the sea beaches ("Interesting facts about atom and radiation", 2009).

Iran (Ramsar). There are areas where the dose rate ranges from 0.7 to 50 μSv/hr due to high uranium content in the water (Figure 3) ("Interesting facts about atom and radiation", 2009). Residents receive an average radiation dose of 10 mSv/yr, ten times more than the ICRP recommended limit for exposure to the public from artificial sources and four times more than worldwide average natural dose to humans; in some areas of Ramsar annual radiation absorbed dose from background radiation is up to 260 mSv/yr, higher than the 20 mSv/yr permitted for radiation workers (Mortazavi S.M.J. & Karamb P.A., 2005; Ghiassi-nejad M. et al., 2002).

Figure 3. Ramsar, Iran. The most radioactive inhabited area on the Earth.

In other words, the radiation background can be 500 times higher than typical one. However, at the same time, "according to the scientists of the Pan American Health Organization: "...the influence of the relatively increased background on the mortality because of oncopathology, frequency of congenital anomalies, physical development disorders, fertility rate, frequency of congenital pathology, child mortality rate, sex ratio and spontaneous abortion frequency is not ascertained" in these cities (Reichmuth B. et al, 2005).

Natural radioactive background accompanies the biosphere through all its evolution. The radiation sources are: *external radiation* (cosmic radiation and radiation from the radioactive elements, present in the Earth's interior, atmosphere, water, and living things) and *internal irradiation* (from natural radionuclides, penetrating into organism with air, food and water). The internal radiation accounts for 60%, the external one – 40% of the natural radiation.

Average irradiation per capita is 3 800 μSv/yr. The medical examination accounts for 600 μSv/yr, nuclear weapons tests in the atmosphere and past accidents – approx. 10 μSv/yr, nuclear power – approx. 2 μSv/yr ("Environment and emergency management", 2014).

Radon – a colorless, odorless and tasteless dense gas (7.5 times denser than air) – accounts for a half of the annual natural radiation dose from the natural sources of radiation. Radon is a decay product of thorium radioactive series. Person gets a significant part of doses from radon while being in enclosed, unventilated spaces where radon seeps through the foundation and floor from the ground, via inhaled air. A man receives the highest radiation dose in bathrooms when taking a shower, where the radon content is 40 times higher than in other rooms.

The natural radiation background is one of the conditions for biota normal functioning. It is believed that it is necessary for the evolution of life on the Earth, for maintaining active self-regulation of the living. That is probably why people live much longer in the mountains, at the sites of granite abruption where the background is of 0.3-0.5 μSv/hr. There are resorts in Brazil and India where irradiation exceeds several times the annual permissible levels ("Environment and emergency management", 2014).

Hard cosmic radiation, gamma-radiation from potassium-40 of the Earth's crust and alpha-radiation from radon-220 and radon-222, which is a product of all three series decay, make the greatest contribution to the irradiation. A radioactive background dose depends on such factors as altitude, quantity and type of radionuclides, present rocks and soil. For example, people living at the sea level, receive an average equivalent dose from cosmic radiation of approx. 300 μSv/yr. External irradiation is several times more for people living 2 km above the sea level. Notably, 5 km are the maximum height where human constructions are present (Peru and Bolivia). Crews and passengers of airplanes are exposed to quite intensive irradiation. At the height of 12 km (maximum flight altitude of transcontinental airplanes) the cosmic radiation dose is 25 times higher ("Environment and emergency management", 2014).

Besides radon there other sources of internal irradiation – potassium-40, which is absorbed by organism along with nonradioactive isotopes of potassium, vital to the organism functioning. Person receives significantly larger dose of internal irradiation from the nuclides, which are the products of uranium-238 and thorium-232 series radioactive decay. Some of them, e.g. lead-210 and polonium-210 nuclides, are absorbed along with food. They are accumulated in fish and shellfish. There is quite high concentration of isotopes in the reindeer meat, of polonium-210 in particular. Deer absorb these isotopes during winter, when they eat lichen where both isotopes are accumulated. People living in Western Australia, in places with increased concentration of uranium, receive higher irradiation doses when eating sheep and kangaroo meat ("Environment and emergency management", 2014).

Radiation Explication and Health Conditions

Tens of millions of people are constantly getting exposed by the natural radiation background, including the natural radioactive gas radon (toron), every year getting a dose at the level of 5-10 mSv. Whereas, there have been certain areas with an increased natural radiation background where a dose of radiation could reach annually up to 15-30 mSv, where children and women have also been exposed to this natural radiation for centuries, while the world average annual dose of exposure per person is about 2.4 mSv ("Sources and effects of ionizing radiation", 2008). This being said, the overall lifetime dose in the areas with the increased radiation background could reach 1000 mSv and more without any negative health outcome diagnosed during special epidemiological exams ("Radiation: general information, metrics, impacts on human", 2012).

The experience of the past radiation accidents and incidents shows, however, that a high perception of radiation risks by society causes serious socio-economic consequences, even in the case of expected extra irradiation lifetime doses at the level of 100-300 mSv. Such doses are expected for 100 thousand residents of contaminated areas in the Bryansk Region of Russia ("Chernobyl Accident: Ten Years on. Problems and Results of Elimination of the Consequences of the Accident in Russia", 1996). The same doses are expected across the most part of the so-called Chernobyl areas, legally referred to as "affected" in Russia, Ukraine and Belarus. Legislative and statutory regulation of radiation influence of nuclear power facilities and when using ionizing radiation sources in industry, medicine and other spheres of human activity on human beings at the level of doses several and 10 times lower than natural background irradiation doses is a factor of socio-economic risk, especially in the case of megalopolis.

Extensive use of radioisotope technologies, the threat of radiological terrorism are inevitably accompanied by the potential risks of radiation pollution in the metropolitan areas and infrastructure facilities, supporting life activities. The current radiation protection system of reference for the intervention, at the expected annual doses lower than the variability of exposure from natural background, despite the absence of any proven health risks, can and does lead to large-scale socio-economic consequences; even in the case of small and insignificant doses of the additional exposure. The most recent striking example of such a situation is the introduction in Japan, as a criterion for the planned evacuation after the accident at the NPP Fukushima-1, the radiation dose for the first year at the level of 20 mSv. The expected life dose in such areas does not exceed 150-300 mSv without any interference and cannot be a significant factor of negative impact on the health conditions ("Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation", 2013).

We carried out the analysis of unintentional and intentional dispersion of radioactive substances at the level of gram (this corresponds to the activity of about 100-1000 Curie, depending on the isotopic composition) in the metropolis and resulting socio-economic consequences in the case of implementation of the existing in Russia and other countries criteria of rehabilitation or introduction of various protective measures in annual doses of more than 0.15 mSv per year (US EPA's preferred annual dose constraint for individual sources) ("Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials", 1999) and more than 1 curie/km^2 for Cs-137 in soil or 1 mSv per year extra dose in accordance with Russian, Ukrainian and Belarusian Chernobyl legislation on which nearly 8 million people were classified as "affected" (Law of the Russian Federation No. 1244-1, 1991, Law of Ukraine No. 796-XII, 1991, Law of the Republic of Belarus No. 9-3, 2009, Law of the Republic of Belarus No. 1227-XII, 1991). In such a situation, the application of such intervention criteria in the case of dispersion of radioactivity in the metropolis over dozens of square kilometers with a population of hundreds of thousands of people and a huge economic potential, restrictions will be imposed that would lead to a large-scale socio-psychological and economic damage and could destabilize the economy of the metropolis in general, in the absence of any significant health risks. Findings of the similar analysis conducted by experts of the U.S. Pacific Northwest National Laboratory were demonstrated as an example of deliberate dispersion with a radioisotope source of Cs-137 in New York (Reichmuth B. et al., 2005).

The results of this analysis are presented in Figure 4; they also demonstrate the dependence of the economic impact of the application of different territory radiation rehabilitation criteria. Such terrorist act could lead to a small number of overexposed people, however, the cost of rehabilitation, and restoration of buildings is quite substantial (up to half of the U.S. GDP), the most conservative standard for the rehabilitation of contaminated areas to the level of residual annual dose of 0.15 mSv (Figure 4).

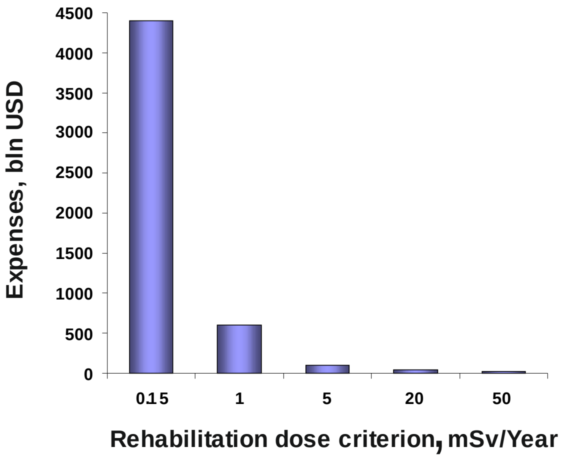

Figure 4. Dependence of the economic impact of the application of different territory radiation rehabilitation criteria (Reichmuth B. et al., 2005)

CONCLUSIONS

Thus, the existing super-rigid rating system, which is not based on the actual identified effects of radiation on human health in small doses, becomes a factor of a very high social vulnerability. Given the exacerbated perception of radiation by people and society as a whole, the obvious relation by mass-media – and any radiation accident, any incident with the release of radioactivity, especially in areas with a high population density and economic potential, regardless of the scale of emission, and even in the cases with negligible radiological consequences, are fraught with a large-scale social and economic damage.

Without any doubts, in the public interest the radiation protection standards must be harmonized with the socio-acceptable risk and should be based on the real scientific values of the impact of the radiation on human health and the environment, but not on the unsubstantiated extensive research hypotheses.

REFERENCES

[1] Cosmic Rays. NASA, Goddard Space Flight Center. Retrieved January 12, 2016, from http://imagine.gsfc.nasa.gov/science/objects/cosmic_rays1.html.

[2] Kebin, E. Radiation. (1996). Fears, real and false [in Russian]. Retrieved 25 December 2015, from http://nuclphys.sinp.msu.ru/ecology/public/.

[3] Mortazavi, S.M.J., Karamb, P.A. (2005). Apparent lack of radiation susceptibility among residents of the high background radiation area in Ramsar, Iran: can we relax our standards? *Radioactivity in the Environment*, 7, 1141-1147. doi:10.1016/S1569-4860(04)07140-2. ISSN 1569-4860.

[4] Ghiassi-nejad, M., Mortazavi, S.M., Cameron, J.R., Niroomand-rad, A., Karam, P.A. (January 2002). Very high background radiation areas of Ramsar, Iran: preliminary biological studies. *Health physics,* 82 (1), 87-93. doi:10.1097/00004032-200201000-00011. PMID 11769138.

[5] Akatov, A.A., Koryakovsky, Yu.S. (2009). Interesting facts about atom and radiation. Moscow: Rosatom Public Council. Retrieved April 15, 2011, from http://www.myatom.ru/mediafiles/u/files/Biblioteca/Interesnye_fakty.pdf.

[6] Reichmuth, B.A., Short, S.M., Wood, T.W., Rutz, F.C., Schwartz D.S. (2005). Economic Consequences of a Rad/Nuc Attack: Cleanup Standards Significantly Affect Cost. In *Working Together: R&D Partnerships in Homeland Security.* Richland, WA: Pacific Northwest National Laboratory. PNNL-SA-45256. Retrieved from https://fas.org/man/eprint/econcon.pdf.

[7] Grachev, V.A., Zakhlebny, A.N. (Eds.). (2014). *Environment and emergency management. Education guidance for general education institutions* [in Russian]. Moscow: Education and Environment Center. ISBN 978-5-94078-012-0.

[8] United Nations Scientific Committee on the Effects of Atomic Radiation. (2010). *Sources and effects of ionizing radiation*. New York: United Nations. ISBN 978-92-1-142274-0.

[9] Aleksakhin, R.M., Anissimova, L.I., Belyaev, S.T., Bolshov, L.A., Izrael, Yu.A., Il'in, L.A., et al. (Eds.). (1996). *Chernobyl Accident: Ten Years on. Problems and Results of Elimination of the Consequences of the Accident in Russia.* Moscow: IBRAE RAS.

[10] Radiation: general information, metrics, impacts on human [in Russian]. Healthcare and Science. Retrieved February 27, 2012, from http://zdorovie.akipress.org/news:13511.

[11] World Health Organization. (2013). *Health risk assessment from the nuclear accident after the 2011 Great East Japan earthquake and tsunami, based on a preliminary dose estimation*. ISBN: 978-92-4-150513-0. Retrieved from http://www.who.int/ionizing_radiation/pub_meet/fukushima_risk_assessment_2013/en/.

[12] Committee on Evaluation of EPA Guidelines for Exposure to Naturally Occurring Radioactive Materials, Commission on Life Sciences, Division on Earth and Life Studies, National Research Council. (1999). Evaluation of Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials. Washington, DC: National Academy Press. Retrieved from http://www.nap.edu/catalog/6360/evaluation-of-guidelines-for-exposures-to-technologically-enhanced-naturally-occurring-radioactive-materials.

[13] Law of the Russian Federation No. 1244-1, 15 May 1991. On Social Protection of Citizens Exposed to Radiation as a Result of the Chernobyl Accident [in Russian]. Retrieved from http://www.mchs.gov.ru/document/3485793.

[14] Law of Ukraine No. 796-XII, 28 February 1991. On the Status and Social Protection of Citizens Affected by the Chernobyl Disaster [in Russian]. Retrieved from http://base.spinform.ru/show_doc.fwx?rgn=15896.

[15] Law of the Republic of Belarus No. 9-3, 6 January 2009. On Social Protection of Citizens Affected by the Chernobyl Power Plant Catastrophe as well as Other Radioactive Accidents [in Russian]. Retrieved from http://base.spinform.ru/show_doc.fwx?rgn=25929.

[16] Law of the Republic of Belarus No. 1227-XII, 12 November 1991. On Legal Status of Territories Contaminated as a Result of the Chernobyl Accident [in Russian]. Retrieved from http://base.spinform.ru/show_doc.fwx?rgn=3112.