N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN
SERIES OF BIOLOGICAL AND MEDICAL
ISSN 2224-5308
Volume 3, Number 333 (2019), 5 – 10 **https://doi.org/10.32014/2019.2519-1629.24**

UDC 614.2:613.1:551.577.7

S. T. Turuspekova, R. T. Tsoy

JSC «NMU», Almaty, Kazakhstan.
E-mail: doctorsaule@mail.ru davletovkairat@gmail.com

THE IMPACT OF THE BACKGROUND RADIATION ON THE HEALTH

Background: Background ionizing radiation is present in all environments on Earth. There is no consensus on the effects of radiation at different levels on the human body. There is a huge gap in the information concerning the impact of radiation on health.

Objective: To determine the impact of natural background radiation on health.

Methods and materials: We conducted a literature review. A search for English-language literature published between 2013 and 2018 related to background radiation and its effect on human health was conducted using PubMed and Medline.

Results: 1934 papers were found and abstracts screened. 1898 papers were excluded, and the full text assessed for 36 papers. 28 papers met our inclusion criteria for this writing this paper. Radiation levels varied from ≤100 mSv to ≥6 mSv. Five papers found that radiation at ≤100 mSv level was beneficial to health in high background-radiation areas, and conversely four papers found it was detrimental. The other 19 papers recommended conducting long-term research. Only in one paper was found neurological disorder. Ionizing radiation is a risk factor for Alzheimer's disease.

Conclusion: However, there are still unknown areas with abnormal radiation. The opinion of scientist differs in this issue. Thereby, there is a need for more investigation into the effects of radiation effects.

Key words: natural background radiation, health, cognition, mild cognitive impairment, Alzheimer disease.

Introduction. For the last two decades, the international scientific community has expressed concern about the interaction between the environment and human health. One unknown and disputable theme is the impact of the natural background radiation on human health. In our previous paper, we summarized all essential data about the natural background radiation [1]. The aim of this paper is to add information about the main effects of natural ionizing radiation on the human brain.

The question of the radiation exposure is still under study. The impact of radiation on the organism depends on the radiation dose. Ionizing radiation can be categorized into low (≤1 Gy) and high (≥1 Gy) doses. There are several areas with High natural Background Radiation, and different populations are exposure to different doses. As for instance in China (Yangjiang province) it corresponds to 5.06mSvy^{-1} to6.86mSvy^{-1}, in Brazil (Poços de Caldas, Araxà) 7 mSv, Iran (Ramsar) ranges between 0.7 and 131 mSv with a mean of 6 mSv and India (Kerala) considerable range of 1 to about 45 mSv y−1 has also been reported [2]. In terms of the effects induced by the low doses of ionizing radiation, the annual dose varies from 100 Gy to 1 Gy [3].

Naturally occurring radionuclides such as ^{226}Ra, ^{232}Th and ^{40}K, cosmic rays, mountains and rivers are formed the Natural Background Radiation of any area [4].

The molecular epidemiological study Shibiao Su et.al., revealed that low dose of ionizing radiation induced adaptive response (Hormesis effect) on the cell at the High Background Radiation Area (HBRA) [5]. It is quite interesting result presented in Vinay Jain and Birajalaxmi Das paper. The authors formed four different background dose groups based on the individual dose received annually by them and made transcriptome analysis to 36 respondents. The result showed that individuals exposed to background doses

of >5mGy/year have shown alteration in expression of many genes involved in important functions or pathways. The results have also shown that, Group II (<5.0mGy/year) has very few significantly differentially expressed genes as compared to Group III and Group IV of high level natural radiation areas (>5.0mGy/ year).The plausible explanation could be that individuals belonging to higher background dose groups (> 5.0mGy/year) have accumulated larger doses and thus stimulating many genes from different cellular and molecular pathways to maintain genome integrity. Overall analysis has revealed that biological processes such as regulation of transcription, apoptosis, regulation of cell cycle, response to DNA damage, metabolic processes, RNA processing, Immune response, signal transduction, DNA repair, protein transport, histone/chromatin modification, response to oxidative stress, protein ubiquitination are over-represented in higher dose groups (Group III and Group IV) as compared to Group I [6].

Ionizing radiation generates plenty of reactive oxygen species (ROS) which interact with the biomolecules such as DNA, protein, lipids thus producing a variety of oxidative lesions. Majority of oxidative damages include oxidative clustered DNA lesions (OCDLs) [7].Understanding the risk from the natural background radiation, Vinay Jain et al., the authors studied the repair of DNA double strand breaks (DSBs)in high background radiation area and determined the low dose as 1.51–5.0 mGy/year and high dose as >5.0 mGy/year. The results demonstrated that faster repair of DSBs and involvement of non-homologous end joining repair pathway in High level natural radiation area group of individuals was assessed as adaptive response [8]. However, further studies on DNA damage induction and repair kinetics are required for the strong evidence [9, 10].

One of the common opinion is ionizing radiation induced effect, which can increase the risk of cancer incidence. Despite the low value of the effective dose rate, which ranged from 0.06 to 0.38mSv/y, with mean of 0.20mSv/y; the area was characterized by low background radiation. Therefore, this made clear to the authors that natural radioactivity is probably not directly influencing the increase in cancer incidence in the region. Therefore, the future research is needed to conduct, as doses from internal radiation exposure and analyses of environment such as rocks, soils, as well as food and water for human consumption may contribute to the impact on the human health by ionizing radiation [11, 12]. However, the research, conducted in France from 1990 to 2009 did not reveal any correlation between risk factors for childhood acute leukemia and low doses due to natural background radiation[13]. In Swiss Cohort Study with children under 16 years old, Ben D. Spycher et al., 2015, suggested that background radiation may contribute to the risk of cancer in children, including leukemia and CNS tumors. Furthermore, the authors found the correlation between the cumulative dose and age [14].

There are few papers dedicated to the assessment of ionizing radiation in food. Nasrin Fathabadi et.al., identified the radioactivity levels in Iran, Ramsar local foodstuff consumed by residents of the high level natural radiation areas. The results showed the high doses in some products (milk and eggs). Additionally, the radionuclides in the uranium and thorium decay series may also considerably influence on the Ramsar food [15, 16]. Additional sources of natural background radiation exposure might be due to the natural radionuclides. In the paper done by Iwaoka, K. et al., 2017, the ranges of ^{222}Rn mass exhalation rates were almost identical to the natural rocks in Japan. Authors recommended that the risk of inhalation of ^{220}Rn decay products should be considered (as the radiological performance of the products depends on raw material) and the methodology should be further studied[17]. Another sources of exposure due to radionuclides is the contamination of water by ionizing radiation. Terrestrial radionuclides are one of the most important sources of human exposure to radiation due to the emission of radioactive particles (UNSCEAR2008) [18, 19]. Furthermore, chronic exposure to ionizing radiation might be the potential health risk for the population[20]. In terms of terrestrial radionuclides, one of the main contributor to radiation exposure is monazite – rich black sands in Miami Bay, Malaysia. Miami Bay can be listed as a High Background Radiation Areas (HBRA) and considered as a potential risk area for its inhabitants [21]. Also, it is quite interesting research, dedicated to the impact of the natural radioactivity and technical radiation on the soil and as a consequences on the human health. In this term, paper was written by Amira Kasumović et. al., 2015 revealed no significant difference in the samples taken from the industrial and from non-industrial areas [22]. Also, in Qureshi A. A. et al. paper, there was no any significant confirmation in supporting hazards due to the usage Mansehra granite as a building materials [23], as well as there was not found the potential risk for health due to the raw ceramics as a material for bulding dwelling houses [24]. Also, Luevano-Gurrola, S.et. al.,2015, revealed low annual effective dose of outdoor

radiation that might play non-significant role for producing some health effect, compare with radiation after nuclear accidents [25]. In paper by Krishnamoorthy, N., et al.,2013, the radiological hazard parameters such as indoor gamma dose rate (DIN), is higher than the recommended level whereas the other calculated hazard parameters are within the criterion limit suggested by UNSCEAR. That can be a potential risk for the human health [26].

In Sajad Borzoueisileha et al., 2013, retrospective study of health status of former students in High Natural Background Radiation area (HNBRA). There was no significant difference between students from HNBRA compared with control group. However, the authors recommend continuing the health supervision of this population (from HBRA) in the future [27, 28]. Lehrer, S. et al., 2017 found the strong correlation between natural background radiation and risk of developing Alzheimer Disease [29]. Still, this question is under discussion, as there are might be ecological fallacy.

Thereby, the opinions in terms of natural background radiation impact on the health is debatable. However, we cannot deny possible influence of the chronic low doses of radiation on the human health. Hereby, this theme requires detailed study.

Objective: to search the data about the natural ionizing radiation impact on human health.

Materials and Methods. We searched the PubMed and the Medline databases for English language peer-reviewed articles between 2013 and 2018. Keywords were the following: "Natural background radiation AND health", "Background ionizing radiation AND health", "Natural background radiation AND brain", "Natural background radiation AND mild cognitive impairment", "Background radiation AND Alzheimer disease", "Radiation Background AND dementia". Papers for uranium mining sites, man-made radiation (due to CT scan, X-ray, radiation the rapyetc.) and atomic bombing victims were excluded. We excluded papers available only in the form of abstract, duplicate papers and animal studies.

Results: 6923titles and abstracts identified through database search. We identified 1934 citations from searches and reviews of reference lists after removal of duplicates and assessed full-text reviews for eligibility. Overall, 28 articles met the inclusion criteria. Radiation levels varied from ≤100 mSv/y to ≥6 mSv/y. Five papers found that radiation at 0.06 mSv/y level was beneficial to health in high background-radiation areas, and conversely four papers found it was detrimental. The other 19 papers recommended conducting long-term research. Only in one paper was found neurological disorder, such as Alzheimer's disease (AD) [29].According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), there are four main sources, which form the Natural Background Radiation: cosmic rays, terrestrial radiation, intakes of naturally occurring radionuclides through inhalation and ingestion.

We identified 13 papers that fulfilled the criteria of natural background radiation impact on the health over the terrestrial radiation, intakes of naturally occurring radionuclides through inhalation and ingestion [5-7, 12, 13, 16, 17, 19, 21-23, 27, 28]. There are several molecular epidemiological studies that revealed low dose of natural background radiation beneficial for health, as it induce the adaptive response in the DNA damage repair capacity and antioxidant capacity of inhabitants in the high background-radiation area [1-3, 9-11, 15, 18, 25].There were just four papers, which suspected the adverse effect from natural background radiation on the human health [4, 8, 11, 14, 18, 20]. However, the authors still recommended studying this question, as to be sure that radiation is a dominant risk factor for the health. Additionally, there was no any significant danger to the population health in two papers by Muneer Aziz Salehab et al. and Krishnamoorthy, N. et al. [24, 26].

Discussion. Environmental issues increase interest in all scientific spheres. A huge number of papers published with hazard effect of air pollution, ozone layer depletion, climate changing and natural ionizing radiation.

To our knowledge, this is the first systematic review that evaluated the influence of natural background radiation on human health. There are numerous systemic review in terms of man-made (due to the technic radiation), atomic bomb disaster impact on the human's health [30-32]. However, there was few studies with strong evidence of hazard effect on human health. One of the reason is difficulties in identifying the true natural ionizing radiation risk, as comorbidities such as diabetes mellitus, cardiovascular disease, metabolic syndrome contribute negative effect to the whole organism as well [33]. Our findings seems to suggest that the first step in identifying clear effect on health due to natural radiation is conducting a good epidemiological study in order to detect an annual effective dose of radiation. The second step should be longitudinal study for identifying the main health issues and possible risk factors.

At the experimental works on the animals, the adverse effect on the animal health was proved. However, the limitation of such kind studies is the artificial radiation exposure [34, 35].

The strengths of our review is that we investigated the association between natural background radiation as source of exposure on human health. We searched two scientific databases. Nevertheless, some potential limitations of the review process exist. Despite intensive searches, relevant publications may have been missed. The strength of our conclusion is limited by the very low quality of evidence available for our research question of interest.

Conclusion: However, there are still unknown areas with abnormal radiation. The opinion of scientist differs in this issue. The specific effects due to radiation (stochastic and deterministic effects) are controversial as there are a huge restriction in terms of study diseases, immune and gene respond to the natural background radiation. Definitely, there is impact on health due to radon gas (one of the source of background radiation) and radionuclides, but there is no approved methodology in order to measure the effects on human health. Furthermore, there is no studies about the radio-resistance and radio-tolerance in human, what can be taken into consideration and become the first step for the future research project idea.

С. Т. Туруспекова, Р. Т. Цой

«ҰМУ» АҚ, Алматы, Қазақстан

ТАБИҒИ РАДИАЦИЯЛЫҚ ФОННЫҢ АДАМ ДЕНСАУЛЫҒЫНА ӘСЕРІ

Аннотация. Табиғи радиациялық фон жаппай, бүкіл Жерде кездеседі. Қазіргі уақытта табиғи радиациялық фонның адам ағзасына әсері салдарынан пайда болатын нәтижелер туралы әртүрлі гипотезалар бар. «Радиацияның адам денсаулығына әсері» атты әдеби деректерде білімнің үлкен олқылықтар орын алған.

Мақсаты. Табиғи радиациялық фонның адам денсаулығына әсер ететін-етпейтіндігін анықтау.

Материалдар мен әдістер. Біз әдеби шолу жасадық. Іздеу 2013 жылдан бастап 2018 жылға дейін PubMed және Medline деректер базасында ағылшын тілінде жүргізілді.

Нәтижелері. 1934 абстракт табылды. 1898 жарияланым шығарылып тасталды. Біз 36 толық мәтінді құжатты зерделедік. Осы әдеби шолуды жазу үшін 28 құжат біздің критерийлерімізге сәйкес келді. Табиғи радиациялық фон ≤100 мЗВ-дан ≥6 мЗВ-ға дейінгі диапазонда орналасқан. Бес жарияланымда ≤100 мЗВ дозадағы табиғи радиациялық әсердің оң әсері анықталды, ал төрт жұмыста авторлар табиғи радиациялық фонның адам денсаулығына зиянды әсері туралы көрсеткен. Он тоғыз жарияланымның авторлары ұзақ уақыт бойы мұқият зерттеу жүргізуді ұсынды. Тек бір жұмыста ғана табиғи радиациялық фонның әсері салдарынан когнитивтік тапшылық туралы, атап айтқанда Альцгеймер ауруының дамуы туралы нәтижелер айтылған.

Қорытынды. Ғалымдардың пікірі табиғи радиациялық фонның адамға әсері мәселесінде әр түрлі. Табиғи радиациялық фонның әсері салдарынан туындайтын әсерлерді анықтау бойынша қосымша зерттеулер жүргізу қажеттілігі бар.

Түйін сөздер: табиғи радиациялық фон, денсаулық, когнитивті функциялар, орташа когнитивті бұзылулар, Альцгеймер ауруы.

С. Т. Туруспекова, Р. Т. Цой

АО «НМУ», Алматы, Казахстан

ВЛИЯНИЕ ПРИРОДНОГО РАДИАЦИОННОГО ФОНА НА ЗДОРОВЬЕ ЧЕЛОВЕКА

Аннотация. Природный радиационный фон встречается повсеместно, по всей Земле. На данный момент существуют различные гипотезы об эффектах, возникающих вследствие воздействия природного радиационного фона на организм человека. В литературных данных на тему «Воздействие радиации на здоровье человека» существует огромный пробел в знаниях.

Цель. Выявить влияет ли природный радиационный фон на здоровье человека

Материалы и методы. Нами был проведен литературный обзор. Поиск осуществлялся на английском языке с 2013 по 2018 года в базах данных PubMed и Medline.

Результаты. Было найдено 1934 абстракта. 1898 публикаций были исключены. Мы изучили 36 полнотекстовых документа. 28 документов соответствовали нашим критериям включения для написания данного литературного обзора. Природный радиационный фон находится в диапазоне от ≤100 мЗВ до ≥6 мЗВ. В пяти публикациях было выявлено положительное влияние природного радиационного в дозе ≤100 мЗВ, в то время как в четырех работах авторы указали о пагубном влиянии природного радиационного фона на здоровье человека. Авторы девятнадцати публикаций рекомендовали провести более тщательное исследование с длительным временным промежутком. Только в одной работе были упомянуты результаты о возможном когнитивном дефиците вследствие воздействия природного радиационного фона, а именно, о развитии болезни Альцгеймер.

Вывод. Мнение ученых расходится в вопросе влияния природного радиационного фона на человека. Существует необходимость в проведении дополнительных исследований по выявлению эффектов, возникающих вследствие действия природного радиационного фона.

Ключевые слова: природный радиационный фон, здоровье, когнитивные функции, умеренные когнитивные нарушения, болезнь Альцгеймер.

Information about authors:

Turuspekova S. T., Head of the the Department of the Nervous Diseases with a course of neurosurgery of the JSC «NMU»; https://orcid.org/0000-0002-4593-3053

Tsoy R. T., PhD student of the Department of the Nervous Diseases with a course of neurosurgery of the JSC «NMU»; https://orcid.org/0000-0002-1450-9604

REFERENCES

[1] Tsoy R.T., Turuspekova S.T., Tsoy O.V. Sovremenniy vzglyad na vopros o vliyanii prirodnogo radiacionnogo phona na cognitivnie funkcii cheloveka // Izdatelstvo «Zdravoohranenie Kazakhstana». Journal «Medicine». 2019. N 2/188. P. 39-45. Almaty, Kazakhstan. ISSN-1728-452X.

[2] Hendry J.H., et al. Human exposure to high natural background radiation: what can it teach us about radiation risks? // Journal of Radiological Protection. 2009. Vol. 29, N 2A. P. A29. doi:10.1088/0952-4746/29/2A/S03

[3] Tang F.R., Loke W.K., Khoo B.C. Low-dose or low-dose-rate ionizing radiation–induced bioeffects in animal models // Journal of radiation research. 2016. Vol. 58, N 2. P. 165-182. doi:10.1093/jrr/rrw120

[4] Sohrabi M., Roositalab J., Mohammadi J. Public effective doses from environmental natural gamma exposures indoors and outdoors in Iran // Radiation protection dosimetry. 2015. Vol. 167, N 4. P. 633-641. doi:10.1093/rpd/ncv018

[5] Su S., et al. Evidence for Adaptive Response in a Molecular Epidemiological Study of the Inhabitants of a High Background-radiation Area of Yangjiang, China // Health physics. 2018. Vol. 115, N 2. P. 227-234. doi:10.1097/HP.0000000000000860

[6] Jain V., Das B. Global transcriptome profile reveals abundance of DNA damage response and repair genes in individuals from high level natural radiation areas of Kerala coast // PloS one. 2017. Vol. 12, N 11. P. e0187274. doi:10.1371/journal.pone.0187274

[7] Sedelnikova O.A., Redon C.E., Dickey J.S., Nakamura A.J., Georgakilas A.G., Bonner W.M. Role of oxidatively induced DNA lesion in human pathogenesis // Mutat. Res. 704 (2010) 152-159. doi:10.1016/j.mrrev.2009.12.005

[8] Jain V., et al. Efficient repair of DNA double strand breaks in individuals from high level natural radiation areas of Kerala coast, south-west India // Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis. 2017. Vol. 806. P. 39-50. doi:10.1016/j.mrfmmm.2017.09.003

[9] Jain V., et al. Lack of increased DNA double-strand breaks in peripheral blood mononuclear cells of individuals from high level natural radiation areas of Kerala coast in India // Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis. 2016. Vol. 788. P. 50-57. doi:10.1016/j.mrfmmm.2016.03.002

[10] Kumar P.R.V., et al. Effect of chronic low dose natural radiation in human peripheral blood mononuclear cells: Evaluation of DNA damage and repair using the alkaline comet assay // Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis. 2015. Vol. 775. P. 59-65. doi:10.1016/j.mrfmmm.2015.03.011

[11] Santos J.M.N., et al. Investigation of natural radioactivity as a possible driver of cancer incidence in Paraiba, northeastern Brazil // Radiation protection dosimetry. 2017. Vol. 178, N 1. P. 112-115. doi:10.1093/rpd/ncx082

[12] Aliyu A.S., et al. Health and ecological hazards due to natural radioactivity in soil from mining areas of Nasarawa State, Nigeria // Isotopes in environmental and health studies. 2015. Vol. 51, N 3. P. 448-468. doi.org/10.1080/10256016.2015.1026339

[13] Demoury C., et al. Residential exposure to natural background radiation and risk of childhood acute leukemia in France, 1990–2009 // Environmental health perspectives. 2016. Vol. 125, N 4. P. 714-720. doi:10.1289/EHP296

[14] Spycher B.D., et al. Background ionizing radiation and the risk of childhood cancer: a census-based nationwide cohort study // Environmental health perspectives. 2015. Vol. 123, N 6. P. 622. doi:10.1289/ehp.1408548

[15] Fathabadi N., et al. Radioactivity levels in the mostly local foodstuff consumed by residents of the high level natural radiation areas of Ramsar, Iran // Journal of environmental radioactivity. 2017. Vol. 169. P. 209-213. doi:10.1016/j.jenvrad.2016.12.011

[16] Heidari M.H., et al. The effect of high level natural ionizing radiation on expression of PSA, CA19-9 and CEA tumor markers in blood serum of inhabitants of Ramsar, Iran // Journal of environmental radioactivity. 2014. Vol. 128. P. 64-67. doi:10.1016/j.jenvrad.2013.11.001

[17] Iwaoka K., et al. Measurements of radon exhalation rate in NORM used as consumer products in Japan // Applied Radiation and Isotopes. 2017. Vol. 126. P. 304-306. doi:10.1016/j.apradiso.2017.01.024

[18] Abdellah W.M., et al. Natural radioactivity levels and associated health hazards from the terrestrial ecosystem in Rosetta branch of the River Nile, Egypt // Isotopes in environmental and health studies. 2017. Vol. 53, N 4. P. 427-439. doi:10.1080/10256016.2017.1293668

[19] Tollefsen T., et al. From the European indoor radon map towards an atlas of natural radiation // Radiation protection dosimetry. 2014. Vol. 162, N 1-2. P. 129-134. doi:10.1093/rpd/ncu244

[20] Chaves L.C.C., et al. Water mutagenic potential assessment on a semiarid aquatic ecosystem under influence of heavy metals and natural radioactivity using micronuclei test // Environmental Science and Pollution Research. 2016. Vol. 23, N 8. P. 7572-7581. doi:10.1007/s11356-015-5993-2

[21] Shuaibu H.K., et al. Assessment of natural radioactivity and gamma-ray dose in monazite rich black Sand Beach of Penang Island, Malaysia // Marine pollution bulletin. 2017. Vol. 119, N 1. P. 423-428. doi:10.1016/j.marpolbul.2017.03.026

[22] Kasumović A., et al. Natural radioactivity and radiation hazards assessment of soil samples from the area of Tuzla and Lukavac, Bosnia and Herzegovina // Isotopes in environmental and health studies. 2015. Vol. 51, N 3. P. 469-477. doi:10.1080/10256016.2015.1023798

[23] Qureshi A.A., et al. Study of natural radioactivity in Mansehra granite, Pakistan: environmental concerns // Radiation protection dosimetry. 2013. Vol. 158, N 4. P. 466-478. doi:10.1093/rpd/nct271

[24] Viruthagiri G., Rajamannan B., Suresh Jawahar K. Radioactivity and associated radiation hazards in ceramic raw materials and end products // Radiation protection dosimetry. 2013. Vol. 157, N 3. P. 383-391. doi.org/10.1093/rpd/nct149

[25] Luevano-Gurrola S., et al. Lifetime effective dose assessment based on background outdoor gamma exposure in Chihuahua City, Mexico // International journal of environmental research and public health. 2015. Vol. 12, N 10. P. 12324-12339. doi:10.3390/ijerph121012324

[26] Krishnamoorthy N., et al. Evaluation of natural radioactivity and its associated health hazard indices of a south Indian river // Radiation protection dosimetry. 2013. Vol. 162, N 3. P. 364-374. doi.org/10.1093/rpd/nct288

[27] Borzoueisileh S., et al. The highest background radiation school in the world and the health status of its students and their offspring // Isotopes in environmental and health studies. 2014. Vol. 50, N 1. P. 114-119. doi.org/10.1080/10256016.2013.821986

[28] Aziz Saleh M., et al. Assessment of health hazard due to natural radioactivity in Kluang District, Johor, Malaysia // Isotopes in environmental and health studies. 2014. Vol. 50, N 1. P. 103-113. doi:10.1080/10256016.2013.821469

[29] Lehrer S., Rheinstein P.H., Rosenzweig K.E. Association of radon background and total background ionizing radiation with Alzheimer's disease deaths in US states // Journal of Alzheimer's Disease. 2017. Vol. 59, N 2. P. 737-741. doi:10.3233/JAD-170308

[30] Tharmalingam S., et al. Low-dose ionizing radiation exposure, oxidative stress and epigenetic programing of health and disease // Radiation research. 2017. Vol. 188, N 4.2. P. 525-538. doi:10.1667/RR14587.1

[31] Hardell L. World Health Organization, radiofrequency radiation and health-a hard nut to crack //International journal of oncology. – 2017. – Т. 51. – №. 2. – С. 405-413. DOI:10.3892/ijo.2017.4046

[32] Shimura T., et al. Radiation occupational health interventions offered to radiation workers in response to the complex catastrophic disaster at the Fukushima Daiichi Nuclear Power Plant // Journal of radiation research. 2014. Vol. 56, N 3. P. 413-42. doi:10.1093/jrr/rru110

[33] Kitahara C.M., et al. A new era of low-dose radiation epidemiology // Current environmental health reports. 2015. Vol. 2, N 3. P. 236-249. doi:10.1007/s40572-015-0055-y

[34] Chen J., et al. A study on the levels of radioactivity in fish samples from the experimental lakes area in Ontario, Canada // Journal of environmental radioactivity. 2016. Vol. 153. P. 222-230. doi:10.1016/j.jenvrad.2016.01.005

[35] Zhou H., et al. Fractionated radiation-induced acute encephalopathy in a young rat model: cognitive dysfunction and histologic findings // American Journal of Neuroradiology. 2011. Vol. 32, N 10. P. 1795-1800. doi:10.3174/ajnr.A2643