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Overestimation of Cardiovascular and Ophthalmological Consequences of Low-Dose Radiation

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Abstract

This review is focused on the radioactive contamination in the Urals, where the consequences have been more serious in the long run than those after the Chernobyl accident. Mayak Production Association, constructed in 1948, has been the first plutonium manufacturing site in the Soviet Union. The difference between contaminations in the Urals and Chernobyl is that the latter was an accident, but the former - a radioactive contamination tolerated since 70 years with several accidents in between. The tendency to overestimate health-related risks from low-dose low-rate exposures has been noticed in Chernobyl-related studies since approximately 1990 and in the research from the Urals since 2005. Cancer-related research has been commented previously. Selected cardio-, cerebro-vascular and ophthalmological conditions are discussed here. The rate of self-reporting correlates with dose estimates and awareness about radiation-related risks, the latter being associated with the work experience at the nuclear industry or residence in contaminated areas, and hence with the accumulated dose. Individuals informed of their higher doses would more often seek medical advice and on average more thoroughly examined. As a result, lens opacities and other pathological conditions are diagnosed in exposed people earlier than in the general population. This explains the dose-effect correlations reported for the incidence of cataracts but not for the frequency of cataract surgeries. Analogously, different pathological conditions are more often detected in exposed people. Results of bioassays are generally not supportive of harmful effects of low doses with possible exception of genetically modified animals. Mechanisms of damage at low doses remain speculative and the evidence inconclusive. The harm caused by anthropogenic radiation would tend to zero with a dose rate decreasing down to the level of natural background. Admittedly, irradiation may act synergistically with other noxious factors. Therefore, the optimal approach to the radiation protection is "as low as reasonably practicable". Excessively strict regulations would cause some industries and modern technologies relocating to countries with less legalistic traditions. The environmental movement was founded on economic prosperity and complacency. When the global peace is threatened, the attitude should change.

Introduction

Since many years we have tried to demonstrate that certain scientific writers and environmental campaigners act in accordance with the interests of governments selling petroleum and natural gas [1,2]. Most evident is this tendency in regard to ionizing radiation; while the overestimation of medical and environmental side effects of nuclear energy contributes to its strangulation [3], supporting appeals to dismantle nuclear power plants (NPPs). The dismantling of nuclear facilities is a complex affair; the work may span decades exceeding the building time [4]. The cost of dismantling each NPP may reach into billions of dollars [5]. The use of atomic energy for the electricity production is on the agenda today due to increasing needs of the growing humankind. The environmental damage is maximal for coal and oil, lower for gas and much lower for atomic energy - the cleanest and practically inexhaustible energy resource [3,6].

This review is focused on the radioactive contamination in the Urals, where the consequences have been more severe in the long run than those after the Chernobyl accident [1,2]. Mayak Production Association (MPA), constructed in 1948, has been the first plutonium manufacturing site in the former Soviet Union (SU). The dumping of radioactive materials into the Techa river, 1957 Kyshtym accident and dispersion by winds from the open repository lake Karachai (1967) led to exposures of the local population and some personnel. The East Urals Radioactive Trace (EURT) cohort includes people exposed after the Kyshtym accident. The difference between contaminations in the Urals and Chernobyl is that the latter was an accident, but the former - a radioactive contamination tolerated since 70 years with several accidents in between.

The Chernobyl catastrophe contributed to the dissolution of SU with subsequent privatization of the state property. At least, disregard for written instructions and safety rules were among the causes of the Chernobyl accident [7-10]. The number of control rods in the reactor was only half the minimum required for safe operation [11]. An emergency power system had been shut off, which is forbidden during on-line operation [4]. Purportedly, this was done to carry out an experiment [10,11], which might have been a pretext used to cover sabotage. It is known that sabotage and stupidity often go hand in hand. When some wreckers are caught, they pretend not realizing possible consequences. The crew kept violating regulations until they had run the reactor into unstable state that caused loss of control [4].

The weightiest argument against NPPs is that they are potential war targets. Therefore, military threats are reasons against the use of nuclear power for electricity production. Escalation of military conflicts contributes to the maintenance of high fossil fuel prices. This might have been one of the motives of unleashing the Ukraine war. The Chernobyl accident was exploited for the same purpose [3], followed by antinuclear protests in many countries [12,13]. In the aftermath of Chernobyl, some citizens decided that it was time for nuclear moratorium [4,14].

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The tendency to overestimate health-related risks from low-dose exposures has been noticed in Chernobyl-related studies since approximately 1990 [15-17] and in the research from the Urals since 2005; commented previously [1,2,18,19]. In earlier Russian publications no cancer incidence elevation was reported in populations with mean total exposures ≤0.5 Sv or among MPA employees in general [20-25]. The absolute risk of leukemia per 1 Gy and 10000 man-years was found to be 3.5-fold smaller in the Techa river cohort compared to the Life Span Study (LSS) of atomic bomb survivors in Hiroshima and Nagasaki. This was reasonably explained by a higher impact of the acute exposure compared to protracted or fractionated ones. Later on, the same scientists started claiming similar risks for cancer and other diseases in the exposed cohorts of the Urals and the LSS [26-28]. Along the same lines, an earlier study found a reduction of cancer mortality in the EURT cohort compared with the general population [23]. A review dated 2004 found the same level of both cancer-related and all-cause mortality in the EURT cohort and the control [21].

In a later report about the same population, the authors avoided direct comparisons but fitted the data into a linear model. Configurations of dose-response curves shown in this paper are inconclusive but the authors claimed an elevated cancer risk in the EURT population [29]. An unofficial directive was apparently behind this ideological shift noticed around the year 2005. Manipulations with statistics have been not unusual in the former SU [30]. Exaggeration of risks from low-dose low-rate exposures contributed to anti-nuclear resentments in other countries and strangulation of nuclear energy for the boosting of fossil fuel prices [1,2,18].

Cardio- and cerebro-vascular conditions

In earlier reports, an incidence elevation of cardio- and cerebro-vascular conditions, if even found in MPA, Techa river and EURT populations, was not accompanied by a mortality increase [31-33]. This can be explained by a greater diagnostic effectiveness in people with higher doses, leading to a recording of mild and questionable cases. However, in a recent paper based on the MPA cohort, an increased excess relative risk (ERR) of death from ischemic heart disease was claimed for the dose range 5-50 mGy/year [34]. It seems that our preceding comments [1,2], though not cited, have been taken into account by some writers. The recent review by Koterov et al. [35] has apparently been influenced by our comments cited in [36] and commented [37]; trying, however, to shift the responsibility for biased information onto foreign experts. This can be illustrated by the following citation from the abstract: "In most sources, 2005-2021 (publications by M.P. Little with co-workers, and others) reveals an ideological bias towards the effects of low doses of radiation … In selected M.P. Little and co-authors sources for reviews and meta-analyses observed both absurd ERR values per 1 Gy and incorrect recalculations of the risk estimated in the originals at 0.1 Gy" [35]. Of note, Koterov [36] used mistranslations with a change of meaning in his Russian-language writings, commented in [37]. It must be stressed that relevant research with participation of Dr. Little [38-40] processed the data originating from Russian co-authors. In this connection, it should be agreed that the "Russian national mortality data is likely to be particularly unreliable, with major variations in disease coding practices across the country [41,42], and should therefore probably not be used for epidemiologic analysis, in particular for the Russian worker studies considered here [43-46]" [47].

Enhanced risks of cardiovascular diseases were claimed for Chernobyl, MPA, Techa river and EURT populations, where mean dose rates have been comparable with those from the natural radiation background. There are many populated areas in the world where dose rates from the natural background are ≥10-fold higher than the global average (2.4 mSv/year) with no health risks reliably proven [48]. The mean individual annual dose to residents of the Russian Federation (RF) in 2020 ranged from 2.47 mSv (Kamchatka) to 9.06 (Altai) with an average of 4.18 mSv [49]. In the above-mentioned cohorts from the Urals the doses have been protracted over decades: the MPA workers were first employed in the years 1948-1982. For example, the mean dose of gamma-radiation was 0.54 Gy in men and 0.44 Gy among women in an MPA cohort study, where the incidence of arteriosclerosis in lower limbs correlated with the radiation dose [50]. The average doses in the Techa river cohort were 34-35 mGy while the follow-up was since the 1950s [51], so that the dose rates were compatible with those from the natural background. Apparently, the data from the Techa river cohort have not enough statistical power for a precise evaluation of dose-effect relationships. The authors themselves acknowledged that the risks for the doses ≤0.1 Gy may be lower than those calculated on the basis of a linear model [52].

In particular, the risk estimates by Azizova et al. [53] were significantly higher than those by other researchers [54]. Among members of the MPA cohort who received gamma-ray doses ≥0.1 Gy, the incidence of circulatory diseases was found to be higher than in people exposed to lower doses [55,56]. Cause-effect relationships are improbable at this level of exposure, considering the dose comparisons provided here. The UNSCEAR could not reach a final conclusion in regard to causality between exposures ≥1-2 Gy and cardiovascular diseases [57]. Apparently, the level 1-2 Gy is an underestimation as a result of the screening effect, selection, self-selection, other bias and confounding factors in the epidemiological research [1,2].

Dose levels associated with cardiac derangements in animal experiments and in humans after radiotherapy are much higher than averages in the cohorts discussed above [58-62]. Results of bioassays are generally not supportive of harmful effects of low doses, with possible exception of genetically modified animals [62,63]. In certain experimental and epidemiological studies, low doses were protective against cardiovascular and other adverse effects [61,64-69]. In humans after radiotherapy, myocardial fibrosis developed after exposures ≥30 Gy. An increased risk of coronary disease has been noticed after radiotherapy with doses 7.6-18.4 Gy [59], which is higher than averages in the cohorts discussed above.

It has been noted in the recent review that a "diagnosis (by a physician knowing the patient's history) could vary with dose" [39]. The same has been noticed in [1,2,18]. Mild and borderline abnormalities are more often diagnosed in individuals with higher doses due to more thorough examinations and the people's attention to their own health. The high incidence and mortality of cardiovascular diseases in studied populations [38] can be explained by the screening effect with recording of mild cases and unsubstantiated diagnoses post mortem. At least in the former SU, there is a tendency to use cardiovascular diseases as post mortem diagnoses in unclear cases [70].

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The unreliability of data on mild conditions can be confirmed by the greater risks of cerebro-vascular diseases at higher radiation doses in females than in males [71]. This agrees with the known tendency that women in RF care more than men about their health. Middle-aged and elderly men are visibly underrepresented among visitors of healthcare institutions; hence the worldwide greatest sex gaps in the life expectancy: countries of the former SU are at the top of the list [72]. Accordingly, the diagnostics in women is on average more efficient. Therefore, the screening effect must be more pronounced in females than in males.

Cataracts

Similar tendencies have been noticed in regard to cataracts. Results of the studies reporting correlations between the cumulative radiation dose and cataract incidence among MPA workers [73-75] have been questioned [76,77]. The risk in higher dose groups starting from 0.25-0.50 Sv was found to be significantly higher than that in the control group having ≤0.25 Sv. The average doses were 0.54±0.061 Gy in males and 0.46±0.01 Gy in females [74]. Dose-effect relationships were claimed for cataracts; but the well-known association of the latter with diabetes mellitus was not confirmed [74-76]. This called into question the biological relevance of other results by the same researchers. Presumably after the critical comments [76], the data on diabetes did not reappear in a subsequent article by the same researchers [78]. Of note, there were no significant associations of the radiation dose with cataract surgeries [79]. The cataracts including mild cases not requiring surgery must have been diagnosed more frequently in individuals with higher doses due to an increased attention to their own health and/or attention on the part of medics. Earlier publications with participation of the same researchers reported that radiation-induced cataracts developed among MPA workers only after exposures ≥4 Gy [80]. A review of data from RF indicated that chronic exposures ≤ 2 Gy were not associated with cataracts [81].

In animal experiments, the doses were higher than the averages in Chernobyl, MPA and Techa river populations. Some experiments in rodents investigated low doses and suggested that genetic factors have an influence on the susceptibility to radiation-induced lens opacities [61,82,83]. According to the UNSCEAR, a minimum of 3-5 Gy is needed to produce significant opacities in animals which are, similar to humans, not prone to the cataract development. Higher doses are required if protracted or fractionated. The threshold for chronic exposures was supposed to be in the range 6-14 Gy [84]. Later on, lower thresholds and the no-threshold model have been suggested. Based predominantly on epidemiological studies, ICRP revised preceding recommendations and proposed a threshold of 0.5 Gy for low linear energy transfer radiation. However, some epidemiological studies have not supported this lower threshold for cataracts [61]. “A threshold for highly fractionated or protracted exposure was judged as <0.5 Gy mainly from one paper [85] on cataracts at 12-14 years after exposure in Chernobyl clean-up workers” [86], whereas a possibility of “underestimation of uncertainties” in dosimetry was acknowledged [85]. A threshold for chronic exposures is uncertain for lack of reliable evidence [86].

In a study of radiologic technologists, the cumulative occupational exposure was associated with self-reported cataracts, but not with the cataract surgery. “The population of radiologic technologists… is medically literate” [87]. The self-reporting might have been related to a professional awareness associated with a longer work experience and hence with a cumulative dose. A similar pattern of significant ERR for cataract morbidity but not surgery has been found in MPA workers [78,79]. This agrees with the concept of a dose-dependent diagnostic efficiency with a registration in persons with higher doses of mild cases not requiring surgery. A significantly increased risk of the cataract surgery as a function of radiation dose has been reported only in LSS [88], where the effect of acute exposure could have been indeed significant. Of note, the reports by Azizova [78,79] on “a clear and significant increased ERR/Sv in females compared to males” among MPA workers were designated as “the most striking study observing sex effects relating to radiation-induced cataract incidence” [89]. The sex differences can be attributed to a gender-related attitude in the Russian healthcare. As mentioned above, middle-aged and elderly men visit health care centers (polyclinics) on the average less frequently than women. A higher frequency of cataracts in females than in males was found also in a study of the Techa river cohort [90].

Undoubtedly, ionizing radiation is a proven cataractogen; but doses and dose rates associated with risks, i.e. potential thresholds, should be further investigated. The number of studies that provide explicit biological and mechanistic evidence at doses ≤2 Gy is small [88,91]. Some recent research used genetically manipulated or mutant animals. Such data cannot be directly extrapolated to humans. Reliable information can be obtained in large-scale bioassays.

Discussion

Mechanisms of damage at low doses remain speculative and the evidence inconclusive [92,93]. Summarizing the above and previously published arguments [1,2], the harm caused by anthropogenic radiation would tend to zero with a dose rate decreasing down to a wide range level of the natural background. The damage and repair are normally in a dynamic balance. Accordingly, there must be an optimal exposure level, as it is for many environmental agents: visible and ultraviolet light, various chemical elements and compounds including products of water radiolysis [94]. Moreover, the evolutionary adaptation to a changing environmental factor would lag behind its current value. Natural background radiation has been decreasing during the life existence on the Earth [95]; so that there may be some adaptation to a higher background. There are many substances and physical factors in the environment that are toxic at some dose level. The lower anthropogenic radiation, the less would be its share compared to the natural radioactive background and other environmental factors [1,2]. There is considerable evidence in favor of hormesis [61,64-69,96-99]. Admittedly, irradiation may act synergistically with other noxa. Therefore, the petition to remove the phrase “As low as reasonably achievable” (ALARA) from the radiation safety regulations [100] is hardly justified, as exposures are unpredictable during a human life, while their effects may accumulate. However, the principle ALARP (as low as reasonably practicable) is more realistic and workable than the ALARA [101].

Nuclear power has returned to the agenda because of increasing global energy demands and declining fossil fuel reserves. NPPs emit virtually no greenhouse gases compared to fossil fuels [6]. Hopefully, nuclear fission will be replaced in the future by fusion, which is

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intrinsically safer. The fusion offers a potential source of clean power generation with a plentiful supply of raw materials [5,102]. Durable peace and international cooperation are needed for construction of NPPs in optimally suitable places, notwithstanding national borders, considering all sociopolitical, geographic, geologic factors, attitude of workers and engineers to their duties (exemplified by the Chernobyl accident in the Introduction above). Considering potential vulnerability of large NPPs during armed conflicts, attention should be directed to small reactors, which are generally safer and have some economic advantages [103-107]. Small mobile reactors can be used also by the military. Nuclear power is the road to a carbon free future.

The optimal approach to the radiation protection is to determine thresholds and establish regulations to ensure that doses are kept well below the thresholds [108], as low as reasonably practicable considering economical realities. Otherwise, some industries and modern technologies will flee to countries with less legalistic traditions i.e. disregard for laws and regulations [109]. The environmental movement was founded on economic prosperity and complacency. When prosperity and the global peace are threatened, the attitude must change [110].

According to a recent review, epidemiological data provide essentially no evidence of harmful effects at doses <100 mSv [111]. The value 200 mSv has been mentioned in some reviews as a level, below which a cancer risk elevation is unproven [112,113]. In the author's opinion, the current safety regulations are exceedingly restrictive. Elevation of the limits must be accompanied by measures guaranteeing their observance. Strictly observed realistic safety norms would bring more benefit for the public health and economy than excessive restrictions that would be violated by some nations disregarding laws and regulations.

Fossil fuels are used as a political weapon today [114]. Oil and natural gas will become increasingly expensive in the long run, contributing to excessive population growth in the producing regions and poverty elsewhere. Probably not all writers and green activists exaggerating medical and ecological risks from nuclear energy do realize that they serve the interests of fossil fuel producers. Many of them have good intentions; some are ideologically biased, serve certain companies or governments. Citizens should be aware that their best intentions are exploited to disadvantage their own countries. The weightiest consideration against NPPs is that they are potential targets during armed conflicts. By analogy with the Chernobyl accident, the war damage and shutdown of the Zaporozhie NPP (the largest NPP in Europe) enhances demands for oil and gas. Apparently, one of the motives to unleash the war in Ukraine, of the militarist rhetoric and threats to use nuclear weapons [115,116], has been the strangulation of nuclear energy and boosting fossil fuel prises.

Conclusion

Studies of human populations exposed to low-dose low-rate ionizing radiation, though important, will hardly add much reliable information on dose-effect relationships. Some reviews analyzed together papers of different quality and reliability. The inter-study heterogeneity makes assessment of risks problematic [92,117]. Finally, political and economical interests sometimes overweighed scientific objectivity [1,2]. Screening effect, selection and ideological biases will contribute to appearance of new reports on enhanced risks from a moderate anthropogenic increase of the radiation background, which would not prove causality. Reliable results can be obtained in lifelong animal experiments. The life duration is a sensitive endpoint attributable to radiation exposures [118], which can measure net harm, if any, from low-dose exposures.

Certain writers and environmental campaigners, exaggerating medical and ecological consequences of the anthropogenic increase in the radiation background, serve the interests of fossil fuel producers. Some of them may have good intentions; others are ideologically biased or have a conflict of interest. Tendentiousness is recognizable in reports aimed at the strangulation of nuclear energy and boosting fossil fuel prices. A safe implementation of nuclear power should be managed by an authority based in developed countries. The economy must become independent from politically unpredictable nations [119], including those producing fossil fuels.

Conflicts of Interest

The author declares that he has no conflicts of interest.

References

1. Jargin SV (2024) The overestimation of medical consequences of low-dose exposure to ionizing radiation. 2nd edition, paperback. Newcastle upon Tyne: Cambridge Scholars Publishing.
2. Jargin SV (2018) Hormesis and radiation safety norms: Comments for an update. Hum Exp Toxicol 37: 1233-1243.
3. Jaworowski Z (2010) Observations on the Chernobyl Disaster and LNT. Dose Response 8: 148-171.
4. Ludewig B, Eidemüller D (2020) The nuclear dream: the hidden world of atomic energy. Berlin: DOM.
5. Bailey CC (1989) The aftermath of Chernobyl: History's worst nuclear power reactor accident. Dubuque (Iowa): Kendall Hunt.
6. Markandya A, Wilkinson P (2007) Electricity generation and health. Lancet 370: 979-990.
7. Beliaev IA (2006) Chernobyl. Vahta smerti (Chernobyl. Death shift). Moscow: IzdAT.
8. Semenov AN (1995) Chernobyl. Desjat let spustia: Neizbezhnost ili sluchajnost? (Chernobyl. Ten Years Later: Inevitability or Coincidence?) Moscow: Energoatomizdat.
9. Prister BS, Kluchnikov AA, Shestopalov VM, Kuhar VP (2013) Problemy bezopasnosti atomnoi energetiki. Uroki Chernobylia (The safety problems of the nuclear power. The lessons of Chernobyl). Chernobyl: Institute of NPP Safety.
10. Medvedev G (1991) The truth about Chernobyl. New York: Tauris.
11. Smith JT, Beresford NA (2005) Introduction. In: Smith J and Beresford NA, eds. Chernobyl - Catastrophe and Consequences. Chichester: Springer Pp: 1-34.
12. Thompson M (1988) Lines of Latitude: People's Détente, East and West. In: Mackay L, Thompson M, eds. Something in the Wind. Politics after Chernobyl. London: Pluto Press Pp: 103-129.
13. Park CC (1989) Chernobyl: The Long Shadow. New York: Routledge.
14. Sweet W (2006) Kicking the carbon habit: global warming and the case for renewable and nuclear energy. New York: Columbia University Press.
15. Chuchalin AG, Maracheva AV, Grobova OM, et al. (1997) Lungs exposed to nuclear catastrophe: One-year therapeutic programme in Chernobyl liquidators group. Schweizerische Medizinische Wochenschrift 127: 165-169.
16. Kogan EA, Cherniaev AL, Chuchalin AG, et al. (1999) Morphologic and

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molecular-genetic characterization of lung cancer developing in people who have worked at nuclear facilities and who have lived in Russian territories polluted after the accident at the Chernobyl power plant. Arkh Patol 61: 22-26.

17. Lysenko AI, Kirpatovskii ID, Pisarenko SS (2000) Morphological changes in male sexual glands in Kaluga regions contaminated with radionuclides. Arkh Patol 62: 27-31.

18. Jargin SV (2023) Overtreatment of supposedly radiogenic cancer and precancerous lesions. Cancer Screening and Prevention 2: 270-272.

19. Jargin SV (2024) Overestimation of medical consequences of low-dose radiation exposures and overtreatment of cancer. J Health Sci Res 9: 25-36.

20. Akleyev AV, Kossenko MM, Krestinina LYu, et al. (2001) Zdorov'e naselenija, prozhivajushhego na radioaktivno zagrjaznennyh territorijah ural'skogo regiona (Health status of population exposed to environmental contamination in the Southern Urals). Moscow: Radekon.

21. Akleev AV, Preston D, Krestinina LI (2004) Medical and biological consequences of human's chronic exposure to radiation. Med Tr Prom Ekol (3): 30-36.

22. Buldakov LA, Demin SN, Kosenko MM,Kostiuchenko VA,Koshurnikova NA, et al. (1990) The medical sequelae of the radiation accident in the Southern Urals in 1957. Med Radiol (Mosk) 35: 11-15.

23. Kostyuchenko VA, Krestinina LYu (1994) Long-term irradiation effects in the population evacuated from the East-Urals radioactive trace area. Sci Total Environ 142: 119-125.

24. 24. Okladnikova ND, Pesternikova VS, Azizova TV, Sumina MV, La Kabasheva N,et al. (2000) Health status among the staff at the nuclear waste processing plant. Med Tr Prom Ekol (6): 10-14.

25. Tokarskaya ZB, Scott BR, Zhuntova GV, Okladnikova ND, Belyaeva ZD, et al. (2002) Interaction of radiation and smoking in lung cancer induction among workers at the Mayak nuclear enterprise. Health Phys 83: 833-846.

26. Akleev AV, Krestinina LI (2010) Carcinogenic risk in residents of the Techa riverside villages. Vestn Ross Akad Med Nauk (6): 34-39.

27. Krestinina LY, Davis FG, Schonfeld S,preston DL, Degteva M,et al. (2013) Leukaemia incidence in the Techa river cohort: 1953-2007. Br J Cancer 109: 2886-2893.

28. Ostroumova E, Preston DL, Ron E,Kerstinina L,Davis FG, et al. (2008) Breast cancer incidence following low-dose rate environmental exposure: Techa river cohort, 1956-2004. Br J Cancer 99: 1940-1945.

29. Akleyev AV, Krestinina LY, Degteva MO, Tolstykh EI (2017) Consequences of the radiation accident at the Mayak production association in 1957 (the 'Kyshtym Accident') J Radiol Prot 37: R19-R42.

30. Jargin SV (2020) Misconduct in medical research and practice. Ethical Issues in the 21st Century. New York: Nova Science Publishers.

31. Azizova TV, Moseeva MB, Grigor'eva ES, Muirhed CR, Haylock RGE, et al. (2012) Mortality risk of cardiovascular diseases for occupationally exposed workers. Radiats Biol Radioecol 52: 158-166.

32. Azizova TV, Haylock R, Moseeva MB, Bannikova MV,Grigoryeva ES (2015) Cerebrovascular diseases incidence and mortality in an extended Mayak worker cohort 1948-1982. Med Radiol Radiaton Safety (Moscow) 182: 529-544.

33. Soloviev VYu, Krasnyuk VI (2018) On possible mistakes in the estimation of radiation risk non-cancer effects in Mayak plant workers. Med Radiol Radiaton Safety (Moscow) 63: 15-21.

34. Azizova TV, Grigoryeva ES, Hamada N (2023) Dose rate effect on mortality from ischemic heart disease in the cohort of Russian Mayak Production Association workers. Scientific Reports 13: 1926.

35. Koterov AN, Ushenkovaa LN, Wainson AA (2023) Excess relative risk of mortality from diseases of the circulation system after irradiation. Report 1. Overview of reviews and meta-analysis declared effects of low doses. Radiats Biol Radioecol 63: 3-33.

36. Koterov AN (2017) To the letter to the editor of S.V. Jargin "On RET/PTC Rearrangements in Thyroid Carcinoma after the Chernobyl Accident". Med Radiol Radiaton Safety (Moscow) 62: 53-64.

37. Jargin SV (2021) Comment on the article: Koterov AN, Wainson AA. Radiation hormesis and epidemiology of carcinogenesis: 'Never the twain shall meet'. Medical Radiology and Radiation Safety; 66(2):36-52. Molodoi Uchenyi - Young Scientist 28(3: 151-154.

38. Little MP, Azizova TV, Hamada N (2021) Low and moderate-dose non-cancer effects of ionizing radiation in directly exposed individuals, especially circulatory and ocular diseases: a review of the epidemiology. Int J Radiat Biol 97: 782-803.

39. Little MP, Azizova TV, Richardson DB, Tapio S, Bernier MO,et al. (2023) Ionising radiation and cardiovascular disease: systematic review and meta-analysis. BMJ 380: e072924.

40. Cahoon EK, Grimm E, Mabuchi K,Mai JZ,Zhang R,et al. (2024) Prevalence of thyroid nodules in residents of Ukraine exposed as children or adolescents to Iodine-131 from the Chornobyl accident. Thyroid 34: 890-898.

41. Danilova I, Shkolnikov VM, Jdanov DA, Mesle F, Vallin J (2016) Identifying potential differences in cause-of-death coding practices across Russian regions. Popul Health Metr 14: 8.

42. Wasserman D, Varnik A (1998) Reliability of statistics on violent death and suicide in the former USSR, 1970-1990. Acta Psychiatr Scand Suppl 394: 34-41.

43. Azizova TV, Grigoryeva ES, Haylock RG, pikulina MV,Moeeva MB (2015) Ischaemic heart disease incidence and mortality in an extended cohort of Mayak workers first employed in 1948-1982. Br J Radiol 88: 20150169.

44. Moseeva MB, Azizova TV, Grigoryeva ES, Haylock R (2014) Risks of circulatory diseases among Mayak PA workers with radiation doses estimated using the improved Mayak Worker Dosimetry System 2008. Radiat Environ Biophys 53: 469-477.

45. Ivanov VK, Maksioutov MA, Chekin SY, Petrov AV,Kruglova ZG, et al. (2006) The risk of radiation-induced cerebrovascular disease in Chernobyl emergency workers. Health Phys 90: 199-207.

46. Kashcheev VV, Chekin SY, Maksioutov MA,Tumanov KA,Menyaylo AN, et al. (2016) Radiation-epidemiological Study of Cerebrovascular Diseases in the Cohort of Russian Recovery Operation Workers of the Chernobyl Accident. Health Phys 111: 192-197.

47. Little MP (2016) Radiation and circulatory disease. Mutat Res 770: 299-318.

48. Sacks B, Meyerson G, Siegel JA (2016) Epidemiology without biology: false paradigms, unfounded assumptions, and specious statistics in radiation science. Biol Theory 11: 69-101.

49. Barkovsky AN, Akhmatdinov RR, Akhmatdinov RR, Baryshkov NK, Biblin AM, et al. (2021) Radiation doses to the population of the Russian Federation in 2020. Radiatsionnaya Gygiena 14: 103-113.

50. Azizova TV, Bannikova MV, Grigorieva ES, Bagaeva YP, Azizova EV,et al. (2016) Risk of lower extremity arterial disease in a cohort of workers occupationally exposed to ionizing radiation over a prolonged period. Radiat Environ Biophys 55: 147-159.

51. Krestinina LYu, Silkin SS, Degteva MO, Akleyev AV (2019) Risk analysis of the mortality fromthe diseases of the circulatory system in the Ural cohort of emergency-irradiated population for the years1950-2015. Radiatsionnaya Gygiena 12: 52-61.

52. Schonfeld SJ, Krestinina LY, Epifanova S, Degteva MO, Akleyev AV, et al. (2013) Solid cancer mortality in the Techa River cohort (1950-2007) Radiat Res 179: 183-189.

53. Azizova TV, Muirhead CR, Moseeva MB, Grigoryeva ES, Sumina MV, et al. (2011) Cerebrovascular diseases in nuclear workers first employed at the Mayak PA in 1948-1972. Radiat Environ Biophys 50: 539-552.

54. Rühm W, Breckow J, Dietze G, Friedl A, Greinert R, et al. (2020) Dose limits for occupational exposure to ionising radiation and genotoxic carcinogens: a German perspective. Radiat Environ Biophys 59: 9-27.

55. Azizova TV, Haylock RG, Moseeva MB, Bannikova MV, Grigoryeva ES

ISSN: 2334-2838

(2014) Cerebrovascular diseases incidence and mortality in an extended Mayak Worker Cohort 1948-1982. Radiat Res 182: 529-544.

56. Simonetto C, Schöllnberger H, Azizova TV, et al. (2015) Cerebrovascular diseases in workers at Mayak PA: The difference in radiation risk between incidence and mortality. PLoS One 10: e0125904.
57. UNSCEAR (2006) Report. Efects of Ionizing Radiation. Annex B. Epidemiological evaluation of cardiovascular disease and other non-cancer diseases following radiation exposure. New York: United Nations.
58. Boerma M, Sridharan V, Mao XW, Nelson GA, Koturbash I, et al. (2016) Effects of ionizing radiation on the heart. Mutat Res Rev Mutat Res 770: 319-327.
59. Puukila S, Lemon JA, Lees SJ, Tai TC, Boreham DR,et al. (2017) Impact of ionizing radiation on the cardiovascular system: A review. Radiat Res 188: 539-546.
60. Schultz-Hector S (1992) Radiation-induced heart disease: review of experimental data on dose response and pathogenesis. Int J Radiat Biol 61: 149-160.
61. Authors on behalf of ICRP; Stewart FA, Akleyev AV, Hauer-Jensen M,Hendry JH,Kleiman NJ, et al. (2012) ICRP publication 118: ICRP statement on tissue reactions and early and late effects of radiation in normal tissues and organs - threshold doses for tissue reactions in a radiation protection context. Ann ICRP 41: 1-322.
62. Jahng JWS, Little MP, No HJ, Loo Jr BW, Wu JC (2024) Consequences of ionizing radiation exposure to the cardiovascular system. Nat Rev Cardiol.
63. Azimzadeh O, Merl-Pham J, Subramanian V, Oleksenko K, Krumm F, et al. (2023) Late effects of chronic low dose rate total body irradiation on the heart proteome of ApoE-/-mice resemble premature cardiac ageing. Cancers (Basel) 15: 3417.
64. Baldwin J, Grantham V (2015) Radiation hormesis: historical and current perspectives. J Nucl Med Technol 43: 242-246.
65. Calabrese EJ (2022) Linear non-threshold (LNT) fails numerous toxicological stress tests: Implications for continued policy use. Chem Biol Interact 365: 110064.
66. Doss M (2013) Linear no-threshold model vs. radiation hormesis. Dose Response 11: 480-497.
67. Scott BR (2008) It's time for a new low-dose-radiation risk assessment paradigm - one that acknowledges hormesis. Dose Response 6: 333-351.
68. Shibamoto Y, Nakamura H (2018) Overview of biological, epidemiological, and clinical evidence of radiation hormesis. Int J Mol Sci 19: 2387.
69. Xu J, Liu D, Zhao, Zhao D, Jiang X, Meng X, et al. (2022) Role of low-dose radiation in senescence and aging: A beneficial perspective. Life Sci 302: 120644.
70. Jargin SV (2017) Cardiovascular mortality in Russia: a comment. Cardiovasc Diagn Ther 7: E13-E14.
71. Azizova TV, Moseeva MB, Grigoryeva ES, Hamada N (2022) Incidence risks for cerebrovascular diseases and types of stroke in a cohort of Mayak PA workers. Radiat Environ Biophys 61: 5-16.
72. 72. https://en.wikipedia.org/wiki/List_of_countries_by_life_expectancy
73. Azizova TV, Bragin EV, Hamada N (2018) Risk assessment of senile cataract incidence in a cohort of nuclear workers of Mayak Production Association. Medical Radiology and Radiation Safety 63: 15-21.
74. Azizova TV, Bragin EV, Hamada N, Bannikova MV (2016) Risk of cataract incidence in a cohort of Mayak PA workers following chronic occupational radiation exposure. PLoS One 11: e0164357.
75. Bragin EV, Azizova TV, Bannikova MV (2017) Risk of senile cataract among nuclear industry workers. Vestn Oftalmol 133: 57-63.
76. Soloviev VYu, Krasnyuk VI (2018) On possible mistakes in the estimation of radiation risk non-cancer effects in Mayak plant workers. Med Radiol Radiaton Safety (Moscow) 63: 83-84.
77. Tukov AR, Kashirina OG (2018) To the article of T.V. Azizova, E.V. Bragin, N. Hamada, M.V. Bannikova "Risk assessment of senile cataract incidence in a cohort of nuclear workers of Mayak Production Association". Medical Radiology and Radiation Safety 63: 82.
78. Azizova TV, Hamada N, Grigoryeva ES, Bragin EV (2018) Risk of various types of cataracts in a cohort of Mayak workers following chronic occupational exposure to ionizing radiation. Eur J Epidemiol 33: 1193-1204.
79. Azizova TV, Hamada N, Bragin EV, Bannikova MV, Grigoryeva ES (2019) Risk of cataract removal surgery in Mayak PA workers occupationally exposed to ionizing radiation over prolonged periods. Radiat Environ Biophys 58: 139-149.
80. Okladnikova ND, Sumina MV, Pesternikova VS, Azizova TV, Kabasheva N Ia (2007) Long-term consequences of external gamma-radiation according to the results of the observation of the personnel of the first atomic power plant in the country. Klin Med (Mosk) 85: 21-26.
81. Guskova AK (1999) Fifty years of the nuclear industry in Russia - through the eyes of a physician. Atomnaya energiya - Atomic Energy 87: 479-485. (in Russian)
82. McCarron RA, Barnard SGR, Babini G, Dalke C, Graw J, et al. (2022) Radiation-induced lens opacity and cataractogenesis: a lifetime study using mice of varying genetic backgrounds. Radiat Res 197: 57-66.
83. Worgul BV, Smilenov L, Brenner DJ, Vazquez M, Hall EJ, et al. (2005) Mice heterozygous for the ATM gene are more sensitive to both X-ray and heavy ion exposure than are wildtypes. Adv Space Res 35: 254-259.
84. UNSCEAR (1982) Report. Annex J: Non-stochastic effects of irradiation. New York: United Nations.
85. Worgul BV, Kundiyev YI, Sergiyenko NM, Chumak VV, Vitte PM, et al. (2007) Cataracts among Chernobyl clean-up workers: implications regarding permissible eye exposures. Radiat Res 167: 233-243.
86. Hamada N, Azizova TV, Little MP (2020) An update on effects of ionizing radiation exposure on the eye. Br J Radiol 93: 20190829.
87. Little MP, Cahoon EK, Kitahara CM, Simon SL, Hamad N, et al. (2020) Occupational radiation exposure and excess additive risk of cataract incidence in a cohort of US radiologic technologists. Occup Environ Med 77: 1-8.
88. Ainsbury EA, Dalke C, Hamada N, Benadjaoud MA, Chumak V, et al. (2021) Radiation-induced lens opacities: Epidemiological, clinical and experimental evidence, methodological issues, research gaps and strategy. Environ Int 146: 106213.
89. Barnard SGR, Hamada N (2023) Individual response of the ocular lens to ionizing radiation. Int J Radiat Biol 99: 138-154.
90. Mikryukova LD, Akleyev AV (2017) Cataract in the chronically exposed residents of the Techa riverside villages. Radiat Environ Biophys 56: 329-335.
91. Ainsbury EA, Barnard S, Bright S, Dalke C, Jarrin M, et al. (2016) Ionizing radiation induced cataracts: Recent biological and mechanistic developments and perspectives for future research. Mutat Res Rev Mutat Res 770: 238-261.
92. Zablotska LB, Little MP, Hamada N (2024) Revisiting an inverse dose-fractionation effect of ionizing radiation exposure for ischemic heart disease: insights from recent studies. Radiat Res 202: 80-86.
93. Manenti G, Coppeta L, Kirev IV, Verno G, Garaci F, et al. (2024) Low-dose occupational exposure to ionizing radiation and cardiovascular effects: a narrative review. Healthcare (Basel) 12: 238.
94. Kaludercic N, Deshwal S, Di Lisa F (2014) Reactive oxygen species and redox compartmentalization. Front Physiol 5: 285.
95. Karam PA, Leslie SA (1999) Calculations of background beta-gamma radiation dose through geologic time. Health Phys 77: 662-667.
96. Vaiserman A, Cuttler JM, Socol Y (2021) Low-dose ionizing radiation as a hormetin: experimental observations and therapeutic perspective for age-related disorders. Biogerontology 22: 145-164.

ISSN: 2334-2838

97. Calabrese EJ (2015) Model uncertainty via the integration of hormesis and LNT as the default in cancer risk assessment. Dose Response 13: 1559325815621764.

98. Calabrese EJ (2020) The Muller-Neel dispute and the fate of cancer risk assessment. Environ Res 190: 109961.

99. Petin VG, Pronkevich MD (2013) Radiacionnyi gormezis pri deistvii malyh doz ioniziruiushhego izluchenia (Radiation hormesis under the influence of low doses of ionizing radiation). Obninsk: MIFI.

100. Marcus CS (2015) Time to reject the linear-no threshold hypothesis and accept thresholds and hormesis: A petition to the U.S. Nuclear Regulatory Commission. Clin Nucl Med 40: 617-619.

101. Toshinskiy GI (2022) Introduction to nuclear power. Obninsk: Rosatom Technical Academy.

102. Duffy DM (2010) Fusion power: A challenge for materials science. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 368: 3315-3328.

103. Trakimavicius L (2021) Is small really beautiful? The future role of small modular nuclear reactors (SMRs) in the military. Energy Highlights 15: 2-16.

104. Egan JR (1988) Preventing another Chernobyl: codes, practices, and the role of new technology. In: Cameron P, Hancher L, Kuhn W, eds. Nuclear energy law after Chernobyl. London: Graham & Trotman Pp: 159-177.

105. 105. World Nuclear Association (2024) Small Nuclear Power Reactors. Updated 16 Frbruary 2024

106. Sekimoto H (1992) Several features and applications of small reactors. In: Sekimoto H, ed. Potential of small nuclear reactors for future clean and safe energy sources. Specialists' meeting on potential of small nuclear reactors. Tokyo, Japan, 23-25 Oct., 1991. Amsterdam: Elsevier Pp: 23-32.

107. Liou J (2023) What are Small Modular Reactors (SMRs)? IAEA 13 September 2023.

108. Doss M (2016) Future of radiation protection regulations. Health Phys 110: 274-275.

109. Garcia-Johnson R (2000) Exporting environmentalism: U.S. multinational chemical corporations in Brazil and Mexico. Ronie Cambridge, Ma London: MIT Press.

110. Drake BA, Cronon W (2013) Loving nature, fearing the state: environmentalism and antigovernment politics before Reagan. Seattle: University of Washington Press.

111. Roszkowski S (2023) Low doses of radiation - impact on the environment and human. Medical Research Journal 8: 1-7.

112. Heidenreich WF, Paretzke H, Jacob P (1997) No evidence for increased tumour rates below 200 mSv in the atomic bomb survivors data. Radiat Environ Biophys 36: 205-207.

113. Gonzalez AJ (2004) Radiation safety standards and theirapplication: international policies and current issues. Health Phys 87: 258-272.

114. D'Anieri P (2023) Ukraine and Russia: from civilized divorce to uncivil war. Cambridge University Press.

115. Light F (2022) Kadyrov says Russia should use low-yield nuclear weapon. Reuters. October 1, 2022

116. Stewart W (2022) Vladimir Putin's Chechen warlord Ramzan Kadyrov declares Ukraine war a 'Big Jihad'. New York Post, 26 October 2022

117. Little MP, Boerma M, Bernier MO, Azizova TV, Zablotska LB, et al. (2024) Effects of confounding and effect-modifying lifestyle, environmental and medical factors on risk of radiation-associated cardiovascular disease. BMC Public Health 24: 1601.

118. Braga-Tanaka I 3rd, Tanaka S, Kohda A, Takai D, Nakamura S, et al. (2018) Experimental studies on the biological effects of chronic low dose-rate radiation exposure in mice: overview of the studies at the Institute for Environmental Sciences. Int J Radiat Biol 94: 423-433.

119. Paehlke RC (1989) Environmentalism and the future of progressive politics. New Haven: Yale University Press Pp: 325.