

Review

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Review

Overestimation of Cardiovascular Consequences of Low Dose Radiation Exposures

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Abstract: This commentary is focused on radioactive contaminations in the Urals, where the consequences were more severe in the long term than those after the Chernobyl accident. The difference is that the latter was a technogenic catastrophe, but the former - a radioactive contamination tolerated since 70 years with several accidents in between. In earlier publications of Russian researchers no cancer frequency elevation was reported after exposures below 0.5 Sv or generally in the populations exposed to low doses. Later on, the same scientists started to claim similar relative risks for cancer and other diseases among exposed people in the Urals and in atomic bomb survivors from Hiroshima and Nagasaki. Apparently, an unofficial directive has been behind this ideological shift noticed around the year 2005. Trimming of statistics has been not unusual in the former Soviet Union. Potential motives included fostering radiophobia, stirring anti-nuclear protests in other countries and strangulation of nuclear energy aimed at the boosting of fossil fuel prices. Recent publications claiming cardiovascular risks after low-dose low-rate exposures and recommending more stringent standards of radiological protection are discussed here in some detail. Such recommendations for dose rates compatible with the natural radiation background are obviously nonsensical.

Keywords: Techa river; Mayak facility; East Urals Radioactive trace; ionizing radiation; cerebrovascular diseases; cardiovascular diseases

Introduction

It is important in our time of international tensions that scientists preserve objectivity. Potential conflicts of interests should be discussed. Since many years we have tried to demonstrate that certain environmentalists and grassroots act in accordance with the interests of companies and governments selling petroleum and natural gas (Jargin 2018, 2022). Most evident is this tendency in regard to ionizing radiation, whereas the overestimation of medical and environmental side effects of nuclear energy contributes to its strangulation (Jaworowski 2010), supporting appeals to dismantle nuclear power plants (NPP). The use of nuclear power for electricity production is on the agenda today due to increasing energy needs of the growing humankind. Of note, health risks and environmental damage are maximal for coal and oil, lower for gas and much lower for the atomic energy - the cleanest, safest and practically inexhaustible energy resource (Jaworowski 2010; Markandya and Wilkinson 2007).

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. The Chernobyl disaster has been discussed previously (Jargin 2010a, 2018, 2022). Mayak Production Association (MPA) has been the first plutonium production site in the former SU, built in 1948. The dumping of radioactive materials into Techa river, 1957 Kyshtym accident and dispersion by winds from the open repository lake Karachai in 1967, led to exposures of residents. 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 a technogenic catastrophe, but the former - a radioactive contamination tolerated since 70 years with several accidents in between. For inside observers it is obvious in retrospect that the party leadership prepared the end of the communist regime since

mid-1980s at the latest in order to privatize the state property into their own pockets, which was in fact accomplished in the early 1990s. The most efficient tools to destabilize the Soviet society were the following:

1. Shortage of consumer goods (the word “deficit” is used in Russian): empty shelves in shops and long queues everywhere. The situation was somewhat better in Moscow and certain Soviet republics but generally bad everywhere especially in the period 1986-1990. This was also a disguised inflation: salaries and prices in state-owned shops were kept stable but shops were empty while prices at markets were much higher. This is obviously explained by market economics. Shops would never be empty if prices were set by supply and demand. Waiting hours in queues is a cost. Today the prevailing insiders’ opinion is that the shortage was planned and arranged intentionally.

2. Chernobyl accident contributed to the destabilization but it would be a speculation to claim that there was intention. At least, negligence and disregard for written instructions were among the causes of the disaster (Beliaev, 2006; Mould, 2000; Semenov, 1995). One can await everything in view of the rhetoric of Russian officials, their appeals to use nuclear weapons and declarations of jihad (Light 2022; Stewart 2022). The weightiest argument against NPPs is that they are potential targets in an armed conflict with radiation-related environmental consequences. Therefore, military threats are arguments against the use of nuclear power for electricity production thus boosting fossil fuel prices. The Chernobyl accident was exploited for the same purpose (Jaworowski, 2010).

3. The anti-alcohol campaign (1985-1989) that ended with a failure, contributed to crime, the use of alcohol surrogates and narcotic drugs. After the campaign there was an upsurge of drunkenness that anesthetized the populace during the privatization of state property.

In earlier publications by Russian researchers no cancer frequency elevation was reported in cohorts with average exposures below 0.5 Sv or among MPA employees in general (Akleyev et al. 2001, 2004; Buldakov et al. 1990; Kostyuchenko and Krestinina 1994; Okladnikova et al. 2000; Tokarskaya et al. 2002). For example, 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 atomic bomb survivors of Hiroshima and Nagasaki. This was reasonably explained by a higher efficiency of the acute exposure compared to chronic ones. Later on, the same scientists started to claim similar risks for cancer and other diseases in the Techa river, MPA and EURT cohorts, on one hand, and atomic bomb survivors on the other hand (Akleyev and Krestinina 2010; Krestinina et al. 2013; Ostroumova et al. 2008). Analogously, an earlier study found a reduction of cancer mortality in the EURT cohort compared with the general population (Kostyuchenko and Krestinina 1994). A review confirmed the same level of both cancer and all-cause mortality in the EURT cohort vs. control (Akleyev et al. 2004). In a later report on the same cohort, the authors avoided direct comparisons but fitted the data into a linear model. The configuration of dose-response curves shown in this paper is inconclusive but nonetheless the authors claimed an elevated cancer risk in the EURT population (Akleyev et al. 2017). An unofficial directive was apparently behind this ideological shift noticed around the year 2005. Trimming of statistics has been not unusual in the former SU (Jargin 2020). Potential motives have been discussed previously: financing, international help after the Chernobyl accident, publication pressure, writing of dissertations and articles for scientific careers, fostering radiophobia, stirring anti-nuclear protests in other countries and strangulation of nuclear energy aimed at the boosting of fossil fuel prices. Some papers about radioactive contaminations in the former SU have common features: large volume, plentiful details and mathematical computations, but no clear insight into medical consequences. Oncological aspects of the problem have been reviewed previously (Jargin 2018, 2022). Cardiovascular diseases and their supposed associations with low-dose low-rate radiation exposure are discussed below.

In earlier reports, an incidence increase in cardio- and cerebro-vascular diseases, if even found in MPA, Techa river and EURT populations, was not accompanied by a mortality increase (Azizova et al. 2012, 2015a; Soloviev and Krasnyuk 2018). This can be reasonably explained by a greater diagnostic effectiveness in people having higher doses with registration of mild and questionable cases. However, in the recent paper based on the MPA cohort, an increased excess relative risk (ERR/Gy) of mortality from ischemic heart disease was claimed for the range of 5-50 mGy/year (Azizova 2023). It

might be that our preceding comments, though not cited, have been taken into account by the authors. Moreover, the recent review by Koterov et al. (2023) has apparently been influenced by our comments cited by Koterov (2017), commented by Jargin (2021), trying however to shift responsibility for biased information onto foreign experts, which can be illustrated by the following quote from the English 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" (Koterov et al. 2023). Note that relevant papers co-authored by Prof. Little e.g. (2021, 2023) used the data provided by co-workers from the former SU. In this connection, the author agrees that the "Russian national mortality data is likely to be particularly unreliable, with major variations in disease coding practices across the country [references], and should therefore probably not be used for epidemiologic analysis, in particular for the Russian worker studies considered here [references]" (Little 2016). Koterov (2017) used mistranslations of quotes with a change of meaning in his Russian-language writings, commented by Jargin (2021).

Enhanced risks of cardiovascular diseases were claimed for Chernobyl, MPA, Techa and EURT populations, where average doses have been comparable with those from the natural radiation background. There are many densely populated areas in the world where dose rates from the natural background are 10-100-fold higher than the global average (2.4 mSv/year) with no health risks reliably proven (Sacks et al. 2016). The doses have been protracted over decades: studied 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 the MPA cohort study, where the incidence of arteriosclerosis in lower limbs correlated with the radiation dose (Azizova et al. 2016). Average doses in the Techa river cohort were 34-35 mGy whereas the follow-up was since the 1950s (Krestinina et al. 2019), so that the dose rates were compatible with those from the natural background in some populated areas. Apparently, the Techa river cohort data do not possess sufficient statistical power to determine the dose response shape. The authors acknowledged that the risks for doses ≤ 0.1 Gy may be smaller than those calculated on the basis of the linear model (Schonfeld et al. 2013). In particular, the uncertain and biased data are unsuitable for computations of the Dose and Dose Rate Effectiveness Factor (DDREF). Earlier Russian publications stressed the higher biological efficiency of acute exposures compared to chronic and fractionated ones (Akleyev et al. 2001); later on the same scientists reiterated that the International Commission on Radiological Protection (ICRP) underestimates cancer risks from chronic exposures, and recommended the use of DDREF = 1.0 (Akleyev et al. 2022). This recommendation is obviously unreasonable for dose rates compatible with those from the natural radiation background. The topic of DDREF has been commented previously by Jargin (2017).

It has been rightly noted in the recent review that "diagnosis (by a physician knowing the patient's history) could vary with dose"; and the "interstudy variation in unmeasured confounders or effect modifiers" (Little et al. 2023). Mild and borderline conditions are probably more often diagnosed in people with higher doses due to averagely more thorough examinations and patients' attention to their own health. The high frequency of cardiovascular diseases in studied populations from Russia (Little et al. 2021) have been explained by unsubstantiated conclusions in unclear cases both post- and ante-mortem. At least in the former SU, there is a tendency: the lower the diagnostic quality, the higher the fraction of cardiovascular diseases among all causes of death. The same is true also for deceased patients not undergoing autopsy, where cardiovascular diseases are often recorded as causes of death in questionable cases (Jargin 2015).

Another recent study based on the MPA cohort analyzed 9469 cases of cerebrovascular diseases including 2078 strokes. The following statements seem to be contradictory: "Cerebrovascular diseases incidence was found to be significantly associated with cumulative radiation dose" and "No significant associations of either stroke or its types with cumulative gamma-ray dose of external exposure or alpha-particle dose of internal exposure were found" (Azizova et al. 2022). It can be reasonably expected that with more arterial occlusions and stenoses there would be more strokes. An apparent explanation for the discrepancy is the dose-dependent diagnostic quality and a larger screening effect

in subjects with higher doses. At that, mild and borderline conditions would be recorded more frequently. On the contrary, strokes are usually diagnosed based on distinct morphological and/or clinical criteria, false-positivity being thus less probable. Moreover: "The estimates of the cerebrovascular diseases incidence risk significantly decreased with the increasing duration of employment for the entire cohort ($p < 0.001$)" and "In addition, a significant decrease in cerebrovascular diseases incidence risk with increasing attained age was observed in both males and females" (Azizova et al. 2022). The incidence of cerebrovascular diseases increases with age; so that the above citations are compatible with a protective effect of radiation i.e. hormesis. Radiation hormesis is mentioned neither by Azizova et al. (2022) nor in other above-cited papers. In our opinion, the authors should have discussed harmful cerebrovascular diseases (strokes) and concluded that there was no increase of strokes after the low dose low rate exposures. In fact, this is common knowledge. By including relatively harmless and less reliably diagnosed conditions, they were able to generate a sensational headline that low-dose radiation elevates the frequency of cerebrovascular diseases.

The higher risks of cerebrovascular diseases at higher doses in females than in males (Azizova et al. 2022) agrees with the known tendency that women in Russia care more than men about their health and are generally given more attention by medical personnel. Hence the worldwide highest gender gaps in the life expectancy: countries of the former SU crown the list (Wikipedia 2023). Accordingly, the diagnostics in women must be on average more efficient and reliable than in men. This notion doesn't contradict to the higher relative risk in some low-dose male groups: Tables 1 and 1S in (Azizova et al. 2022). Cerebrovascular diseases are more frequent in men, among others, thanks to alcohol and smoking. Some overdiagnosis of mild conditions may occur just because these conditions are expected. For example, the author encountered descriptions of age- and hypertension-related changes of retinal vessels in a medical record of a middle-aged man after a dispensarization (yearly workplace examination) whereas his eyegrounds had not been inspected. As for post mortems, supposedly age-related changes (aortal, coronary, cerebral or basilar atherosclerosis) have been habitually written without sufficient evidence in autopsy reports and death certificates (Jargin 2010b, 2015). In higher-dose groups the diagnostics would be more reliable resulting in a more pronounced screening effect especially in women but less frequent unsubstantiated recordings especially in men.

Among members of the MPA cohort who received gamma-ray doses more than 0.1 Gy, the incidence of circulatory diseases was found to be higher than in people exposed to lower doses (Azizova et al. 2014a; Simonetto et al. 2015). The excess relative risk (ERR/Gy) of cerebrovascular conditions in MPA employees was claimed to be even higher than among atomic bomb survivors in Japan (Azizova et al. 2014a, 2018), where dose-dependent selection could have taken place like in other epidemiological studies. Some data assessments of life span studies (LSS) of atomic bomb survivors are compatible with hormesis (Doss 2016; Luckey 2008; Grant et al. 2021; Little and Muirhead 1996). For cancers, a dose-response association was detected among the survivors who received doses ≤ 0.5 Sv but not below 0.2 Sv (Heidenreich 1997; Little and Muirhead 1996, 1998). For example, the data about renal cancer in men indicated hormesis: U-shaped dose-response with negative ERR estimates at low-to-moderate doses, while those in women did not. The authors noted that these findings could have been observed by chance (Grant et al. 2021). A preceding article by the same researchers also showed different shapes of dose response curves for males and females (Grant et al. 2017). When studies based on the same cohort report different dose responses, reliability should be doubted. Other studies found no significant risks for kidney cancer from low doses (Boice et al. 2022; Haylock et al. 2018; Richardson et al. 2018). Apparently, epidemiological data have too many uncertainties to reliably evaluate hormesis; large-scale animal experiments would be more informative.

This review is about cardiovascular diseases, but one insightful example from the field of oncology should be given in the end. A significantly increased risk of non-melanoma skin cancer was reported in MPA workers exposed to radiation at doses ≥ 2.0 Sv accumulated over prolonged periods (Azizova et al. 2018). For comparison, the Japanese A-bomb survivor non-melanoma skin cancer dataset was consistent with a threshold at about 1.0 Sv of acute exposure (Little and Charles 1997). However, an observation bias seems to be probable in (Azizova et al. 2018). The workers and some medical personnel knew the individual work histories, from which accumulated doses could be

approximately inferred, potentially influencing the diagnostic thoroughness. The skin doses were unknown in (Azizova et al. 2018). The subjects were exposed mainly to gamma-rays having a relatively high penetration distance in tissues, so that the absorbed doses within the skin must have been relatively low. Accordingly, the premalignant skin lesions and actinic keratoses were “very rare” in members of the study cohort (Azizova et al. 2018). It is known that radiation exposure is associated with premalignant epidermal changes; in particular, actinic keratosis may be caused by X-ray and radiotherapy (Gawkrodger 2004; Schmitt and Miot 2012). Therefore, a cause-effect relationship between radiation and skin tumors in the study (Azizova et al. 2018) is improbable.

Considering the above, the following claims by the same scientists, being unfounded and/or excessively generalizing, create biased impression of risks associated with low dose low-rate radiation exposures. The statements cited below, not specifying dose levels, are inapplicable to the cohorts under discussion (EURT, MPA, Techa River) and to low doses in general. Conclusions of this kind reiterated in various papers demonstrate that the risks have been exaggerated intentionally. Apparently, an unofficial directive could have been behind this ideological bias. Trimming of statistics has been not unusual in the former SU (Jargin 2020). Here follow the examples:

“It was shown that ionizing radiation is one of the promoters of the development of atherosclerosis” (Rybkina and Azizova, 2016).

“It is concluded that this study provides evidence for an association of lower extremity arterial disease incidence with dose from external gamma-rays” (Azizova et al. 2016).

“This study provides *strong evidence* [emphasis added] of ischemic heart disease (IHD) incidence and mortality association with external gamma-ray exposure and some evidence of IHD incidence and mortality association with internal alpha-radiation exposure” (Azizova et al. 2015b).

“A significant increasing trend in circulatory diseases mortality with increasing dose from internal alpha-radiation to the liver was observed” (Azizova et al. 2015c).

“Significant associations were observed between doses from external gamma-rays and IHD and CVD incidence and also between internal doses from alpha-radiation and IHD mortality and CVD incidence” (Moseeva et al. 2014).

“Findings are that aortal atherosclerosis prevalence was higher in males and females underwent external gamma-irradiation of total dose over 0.5 Gy, in males and females underwent internal alpha-irradiation from incorporated plutonium of total absorbed radiation dose in liver over 0.025 Gy” (Azizova et al. 2014b).

“There was a significantly increasing trend (ERR/Gy) of the IHD mortality with the total absorbed dose to liver from internal alpha-radiation due to incorporated plutonium” (Azizova et al. 2012).

“The incidence data point to higher risk estimates (in MPA workers) compared to those from the Japanese A-bomb survivors” (Moseeva et al. 2012).

“The categorical analyses showed that CVD incidence was significantly higher among workers with total absorbed external gamma-ray doses *greater than 0.1 Gy* [emphasis added] compared to those exposed to lower doses and that CVD incidence was also significantly higher among workers with total absorbed internal alpha-particle doses to the liver from incorporated plutonium greater than 0.01 Gy compared to those exposed to lower doses” (Azizova et al. 2014a).

The risk estimates by Azizova et al. (2011) were found to be significantly higher than those in other studies (Rühm et al. 2020). Among members of the MPA cohort who received gamma-ray doses of more than 0.1 Gy, the incidence of circulatory diseases was found to be higher than in people exposed to lower doses (Azizova et al. 2014a; Simonetto et al. 2015). Cause-effect relationships are improbable at such a low dose level, considering dose comparisons below. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2006) could not reach a final conclusion concerning causality between exposures below 1-2 Gy and cardiovascular diseases. 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 epidemiological studies. About 10 years ago during the author’s visit at the Medical Radiological Research Center in Obninsk, Russia, Dr. Victor Ivanov said in a conversation about his participation in the UNSCEAR Reports, paraphrasing Louis XIV:

“UNSCEAR, it is me!” Apparently, political and economical interests sometimes outweigh scientific objectivity, which is perceivable from certain documents issued by highly esteemed international organizations. As mentioned above, Chernobyl accident has been exploited to strangulate worldwide development of atomic industry (Jaworowski 2010). Today there are no alternatives to the nuclear power: in the long run, nonrenewable fossil fuels will probably become increasingly expensive, contributing to the uncontrolled population growth in the oil-producing countries and poverty in the rest of the world.

Dose levels associated with cardiac derangements in animal experiments and in humans after radiotherapy have been much higher than average doses in the cohorts discussed above (Authors on behalf of ICRP et al. 2012; Boerma et al. 2016; Puukila et al. 2017; Schultz-Hector 1992). Results of animal experiments are generally compatible with hormesis, i.e. favorable effect within a certain low-dose range, with possible exception of genetically modified cancer-prone animals. In certain experimental and epidemiological studies, low doses turned out to be protective against cardiovascular disease (Authors on behalf of ICRP et al. 2012). Existing evidence in favor of hormesis is considerable (Baldwin and Grantham 2015; Calabrese 2022; Doss 2013; Scott 2008; Shibamoto and Nakamura 2018). In humans after radiotherapy, myocardial fibrosis developed at doses ≥ 30 Gy. An increased risk of coronary disease after radiotherapy has been registered after exposures to 7.6-18.4 Gy (Puukila et al. 2017), which is much higher than mean doses in cohorts discussed above. Unrealistic cardiovascular risks at low-dose exposures call in questions cancer risks reported by the same researchers. Finally, the quality of dose estimation is essential for studies of radiation risks. Recall bias should be mentioned in this connection: cancer patients tend to recollect the circumstances related to radiation better than controls (Jorgensen 2013).

Summarizing the above and previously published arguments (Jargin 2009-2022), the harm caused by anthropogenic radiation would probably tend to zero with a dose rate decreasing down to a wide range level of natural background; the dose-effect relationship may become inverse within a certain range in accordance with hormesis. Obviously, hormesis cannot be used in radiation safety regulations without consistent experimental evidence obtained in large-scale animal experiments using different species. Even thereafter, precautions would be necessary as hormetic stimuli may act without threshold on pre-damaged or atrophic tissues, or synergistically with known or unknown noxious agents. The DNA damage and repair are normally in a dynamic equilibrium. Accordingly, there may be an optimal exposure level, as it is for many other environmental agents: visible and ultraviolet light, various chemical elements and compounds, as well as products of water radiolysis (Kaludercic et al. 2014). Moreover, evolutionary adaptation to a changing environmental factor would lag behind its current value and correspond to some average from the past. Natural background radiation has been decreasing during the time of life existence on the Earth (Karam and Leslie 1999). The character of the dose-response relationship at the dose level close to the natural radiation background can be predicted on the basis of general considerations. There are many carcinogenic factors. The lower would be the level of environmental radioactivity, the less would be the contribution of the radioactive contamination compared to the natural radioactive background and other carcinogens. The dose-effect dependence can become inverse in accordance with hormesis. A corresponding graph, plotted on the basis of experimental data, with a sagging of the dose-effect curve below the background cancer risk within the dose range 0.1-700 mGy, is depicted in the review by Mitchel (2009). Dose-effect relationships after low-dose exposures should be clarified in animal experiments with exactly known doses and dose rates. Animal studies can provide reliable information; whereas dose reconstructions in human populations are often inexact and, as discussed above, partly comparable with those received from the natural radiation background. Further work in this direction, parsing of extensive studies on relative biological effectiveness of radiation in different animal species (Higley et al. 2012), would better quantify radiosensitivity of the species thus enabling more precise extrapolations to humans.

The quality of working is one of the factors determining where to construct nuclear power plants (NPP). In the period 1979-1987, the author repeatedly participated in construction of the Kola Nuclear Power Plant and the nearby town Polyarnye Zori (Polar Dawns). In 1984 he participated in concrete

works on the foundation for the Reactor No. 4, being a team leader for some period. Other workers: Timur Dzhnanashwili, Mikhail Selivanov (deceased 2015); later joined Dmitrii Gotlib. The leader of the larger team, which included the above-named workers, was engineer Andrei Kaloshin. Concrete of special quality with coarse gravel was used for the foundation; it was poured down to the foundation pit with a rocky floor from mixer and other trucks. The workers leveled concrete with manual vibrators. Large amounts of concrete were often poured down at one moment, so that the quality of compaction was uneven. Occasionally the trucks poured into the foundation pit concrete of different quality if there was a leftover they could not dispose of elsewhere. Mikhail Selivanov (1956-2015) had films and photographs of the works. It was supposed that he will print the photos for other workers, but after 1995 he refused to give them out. The only photograph of the foundation pit in possession of the author was submitted for publication in 2004 with a manuscript to the publishing house Meditsina (editor-in-chief - Andrei Stochik); the manuscript was not published and the photographs have not been returned to the author in spite of repeated requests. The case was reported to the authorities and published with some documentary evidence (Jargin and Kaloshin 2015).

Nuclear power has returned to the agenda because of the concerns about increasing global energy demand, declining fossil fuel reserves and climate changes. NPPs emit virtually no greenhouse gases in comparison to coal, oil or gas (Markandya and Wilkinson 2007). Moreover, nuclear research and technology employs many objectively thinking scientists: the laws of physics are not steerable by directives like man-made laws and mores. Militarism is generally known to be associated with suppression of independent public thought (Jargin 2023). More international trust and cooperation would enable construction of NPPs in optimally suitable places, notwithstanding national borders, considering all sociopolitical, geographic, geologic factors, attitude of workers and engineers to their duties, the latter possibly influenced by observance of human rights. Consideration of all these factors would make nuclear accidents improbable.

The optimal approach for setting radiation protection regulations is to determine the threshold dose for the carcinogenic effect and establish regulations to ensure that doses are kept well below the threshold (Doss 2016), as low as reasonably achievable taking into account economical and societal considerations (Rühm et al. 2020). Large-scale animal experiments using different species is the most reliable tool to determine threshold doses. In the author's opinion, the current safety norms are exceedingly restrictive. Elevation of the limits must be accompanied by measures guaranteeing their observance. Strictly observed realistic safety regulations would bring more benefit for the public health than excessive restrictions that would be violated in some countries disregarding international law. Note that excessive restrictions are harmful for the economy.

In 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, hormesis and DDREF. Screening effect, selection, self-selection and ideological biases will contribute to appearance of new reports on enhanced risks associated with a slight increase of the radiation background, which would not prove causality. Finally, manipulations with statistics have been not unusual in the former SU (Jargin 2020) that should be taken into account by authors of systematic reviews and meta-analyses. Reliable results can be obtained in lifelong animal experiments. The life duration is known to be a sensitive endpoint attributable to radiation exposures (Braga-Tanaka et al. 2018), which can measure the net harm or potential benefit (within a certain range according to the concept of hormesis) from low-dose exposures.

Conflicts of Interest: The author declares that he has no conflict of interest.

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