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Point of View

Overestimation of medical consequences of low-dose radiation exposures and overtreatment of cancer

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ABSTRACT

It is crucial in our time of international tensions that scientists preserve objectivity. Certain scientific writers acted in the interests of fossil fuel vendors. Most evident is this tendency regarding ionizing radiation, whereas the overestimation of medical side effects of a slight anthropogenic increase of the radiation background contributes to the strangulation of atomic energy. The use of nuclear energy for electricity production is on the agenda today due to the increasing energy needs of humankind. Health risks and environmental damage are maximal for coal and oil, lower for natural gas, and much lower for atomic energy. Counting dormant cancers and questionable cases found by screening exposed populations, overdiagnosis, and registering people from clean areas as Chernobyl victims jointly contributed to the elevation of registered thyroid cancer incidence after the accident. Many neglected malignancies found by the screening in Chernobyl and Urals areas were misinterpreted as aggressive radiogenic cancers and overtreated. The epidemiological research on radiation-related malignancies is valuable, but conclusions of certain studies should be revised considering that many cases, interpreted as aggressive radiogenic cancers, were neglected. A promising approach to the study of dose-response relationships is lifelong animal experiments.

Keywords: Nuclear energy, Ionizing radiation, Cancer, Cardiovascular diseases, Overtreatment

INTRODUCTION

It is vital in our time of international tensions that scientists preserve objectivity. Potential conflicts of interest should be discussed. For many years, we have tried to demonstrate that certain scientists' act following the interests of companies and governments selling petroleum and natural gas.[1-3] Most evident is this tendency regarding ionizing radiation, whereas the overestimation of medical and environmental side effects of nuclear energy contributes to its strangulation,[4] supporting appeals to dismantle nuclear power plants (NPPs). The use of atomic energy for electricity production is on the agenda today due to the increasing energy needs of humankind. Properly managed NPPs bear fewer risks than those using fossil fuels. Health risks and environmental damage are maximal for coal and oil, lower for natural gas, and much lower for atomic energy - the cleanest, safest, and practically inexhaustible energy resource.[4-6] Admittedly, NPPs are possible targets during armed conflicts. Overestimation of the health-related impact of low-dose exposures contributes to the strangulation of atomic energy.

Many papers appeared during the last decades, where pathological conditions in populations exposed to low ionizing radiation were a priori deemed radiogenic;[7-9] others discussed previously.[1-3,10] Among the motives for overestimating the damage from the Chernobyl accident were foreign aid and participation in international scientific cooperation. Furthermore, economic interests have come to light: the strangulation of atomic energy.[4] Trimming and manipulation of numerical data have been common in post-Soviet science.[11] Other biases have been discussed elsewhere.[12-14] The selection and self-selection bias noticed in exposed populations are particularly significant.[15-17] The formal analysis indicated that there has been some selection bias for many endpoints, particularly solid cancer and leukemia.[18] Persons receiving relatively high doses would care more about their health and frequently ask for medical attention. The diagnostics would be averagely more thorough in such people as medics may be informed about the patients' higher doses.

The following comparisons are of importance in this connection. Individual dose rates from the natural radiation

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background (NRB) are usually within the range of 1.0-10 mSv/year; mean values for some countries are above 10 mSv/year.[19,20] Effective doses among federal subjects of Russia ranged from 2.47 to 9.06 mSv/year, with an average of 4.18 mSv/year.[21] According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the mean cumulative dose for 1986-2005 to six million inhabitants of the areas recognized as contaminated after Chernobyl was ~9 mSv.[22] In the life span study (LSS) of atomic bomb survivors of Hiroshima and Nagasaki, there was a significant dose-effect association for cancer among persons who received ≤500 mSv. However, the statistical significance disappeared if only doses ≤200 mSv were considered.[23-25] The doses below 100 mGy at low rates induced adaptive responses.[26]

RADIOACTIVE CONTAMINATION IN THE URALS

Consequences of the radioactive contamination in the Urals were summarily more significant than those after the Chernobyl disaster. The difference is that the latter was due to an accident, but the former was a contamination lasting over 70 years with several accidents. Apart from professional exposures, the disposal of radioactive substances into the river Techa, the 1957 Kyshtym accident, and dispersion by winds from Lake Karachay in 1967 led to residents' exposure. The East Urals Radioactive Trace (EURT) cohort included people exposed after the Kyshtym accident. The Chernobyl disaster and some cancer-related aspects of EURT have been discussed in more detail.[1-3]

In earlier studies (until 2005-2010), Russian researchers found no cancer increase in populations with average exposures below 0.5 Sv or among general Mayak Production Association (MPA) employees.[27-32] The absolute risk of leukemia per 1 Gy and 10,000 person-years was 3.5-fold smaller in the Techa River cohort (TRC) than in LSS. A higher efficiency of acute exposure reasonably explained this compared to chronic and fractionated ones. Later on, the same experts reported comparable or even higher risks of cancer and other diseases in the cohorts from the Urals compared to LSS.[33-35] Analogously, an earlier study found reduced cancer mortality in the EURT populace.[30] A review confirmed the same cancer-related and all-cause mortality level in the EURT vs. control.[28] In a later report on the same cohort, the authors avoided direct comparisons but fitted the figures into a linear model. The configurations of dose-response curves depicted in this paper seem inconclusive, but an elevated cancer risk in the EURT population was claimed.[36] Along the same lines, earlier Russian publications pointed out a higher biological efficiency of acute exposures compared to chronic ones;[27] later on, the same researchers claimed that the International Commission on Radiological Protection (ICRP) underestimates health risks from chronic exposures, and recommended dose and dose-rate effectiveness factor (DDREF) = 1.0 for the use in safety regulations.[37] This recommendation is unfounded for dose rates comparable with those from NRB.[38,39] Potential motives behind this metamorphosis have been discussed: financing, publication pressure, and, most importantly, exaggeration of health risks from low-dose radiation, strangulation of atomic energy, and boosting fossil fuel prices.[1-3]

In earlier reports, a mortality increase was not accompanied by an incidence elevation of cardio- and cerebrovascular diseases in MPA, TRC, and EURT populations.[40-42] This can be reasonably explained by greater diagnostic effectiveness in exposed people, leading to the detection of mild and questionable cases. A similar tendency for cancer was noticed among Chernobyl emergency workers.[43] commented previously.[44] The mechanism was analogous: Chernobyl cleanup workers underwent repeated medical checkups. As a result, tumors were efficiently detected, including small, dormant cancers and nodules with uncertain malignant potential. The early detection and treatment of diseases contributed to the diminution of mortality. Besides, some differentiated and borderline tumors, statistically filed as cancers, did not lead to death. The overestimation of cardiovascular consequences of low-dose, low-rate ionizing radiation has been reviewed recently.[45]

The excess relative risk (ERR) of cerebrovascular conditions in MPA employees was claimed to be even greater than in LSS.[46] Of note, some LSS data analyses were compatible with hormesis.[47-49] As mentioned above, a dose-response correlation for solid cancers and leukemia was detected in LSS at doses ≤500 mSv but not ≤200 mSv.[23-25] Furthermore, the data on kidney cancer in males indicated hormesis: U-shaped dose-response with negative risk estimates at low doses.[49] A preceding article by the same researchers showed different shapes of dose-response curves for men and women.[50] Other studies found no significant risks for renal cancer from low radiation doses.[51-53] Apparently, epidemiological data have too many uncertainties for a reliable evaluation of hormesis; large-scale animal experiments would be more informative.

Considering the above, the EURT experts' following statements may create a biased impression. The statements cited below, not specifying dose levels, are apparently inapplicable to the cohorts from the Urals and to low radiation doses in general. Here follow the examples:

"It was shown that ionizing radiation is one of the promoters of the development of atherosclerosis"[54]

"It is concluded that this study provides evidence for an association of lower extremity arterial disease incidence with dose from external gamma-rays."[55]

"This study provides strong evidence of ischemic heart disease incidence and mortality association with external gamma-ray exposure and some evidence of ischemic heart disease incidence and mortality association with internal alpha-radiation exposure."[56]

"A significant increasing trend in circulatory diseases mortality with increasing dose from internal alpha-radiation to the liver was observed."[57]

"Significant associations were observed between doses from external gamma-rays and ischemic heart disease and cerebrovascular disease incidence and between internal doses from alpha-radiation and ischemic heart disease mortality and cerebrovascular disease incidence."[58]

"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 the liver over 0.025 Gy".[59]

"There was a significantly increasing trend (ERR/Gy) of ischemic heart disease mortality with the total absorbed dose to the liver from internal alpha-radiation due to incorporated plutonium."[40]

"The incidence data point to higher risk estimates (of cerebrovascular disease in MPA workers) than those from the Japanese A-bomb survivors."[60]

"The categorical analyses showed that cerebrovascular disease incidence was significantly higher among workers with total absorbed external gamma-ray doses greater than 0.1 Gy compared to those exposed to lower doses and that cerebrovascular disease 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".[46]

The risk estimates by Tamara Azizova and co-workers[59] were found to be significantly higher than those in other studies.[61] Among members of the MPA cohort who received gamma-ray doses ≥0.1 Gy, circulatory disease incidence was more significant than in people exposed to lower doses.[46,62] Cause-effect relationships are improbable at such a low dose level, considering dose comparisons quoted in this review. The UNSCEAR could not reach a conclusion concerning causality between exposures ≤1-2 Gy and cardiovascular diseases.[63] The level 1-2 Gy is an underestimation due to the screening effect, selection, and other biases in epidemiological research.

Dose levels associated with cardiac derangements in experimental animals and humans after radiotherapy have been much more significant than average in Chernobyl and Urals populations.[64-67] Results of animal experiments (apart from genetically modified animals) are generally compatible with hormesis. In some experimental and epidemiological studies, low doses were protective against cardiovascular diseases.[64] The evidence in favor of hormesis is considerable.[13,68-72] In humans, myocardial fibrosis developed after radiotherapy at doses above 30 Gy. An increased risk of coronary heart disease after radiotherapy was noticed after exposures to 7.6-18.4 Gy.[66] which is much higher than the mean doses in Chernobyl and the Urals cohorts. It should be stressed that unrealistic cardiovascular risks at low-dose exposures call into question cancer risks reported by the same and other researchers. Finally, the recall bias should be mentioned: cancer patients remember radiation-related facts more often than healthy controls,[73] which may lead to overestimation of doses and dose-effect correlations.

The author agrees that "certain studies[56,58,74,75] should probably not be used for epidemiologic analysis, particularly…the Russian worker studies".[76] Russian national mortality data is likely to be unsound.[77] The contrast between the medical surveillance of nuclear workers and the rest of the population has caused bias in data analyses from MPA. About 41% of the MPA cohort migrated away by the end of 2005, and information on causes of death was derived from various regions. The largest number of deaths in 1998-2010 happened not in Ozyorsk (where the Mayak facility is located) but elsewhere in Russia[77] whereas the reliability of data and interpretations are questionable.[3]

Here follows an example of a questionable attribution of lesions to radiation: a significantly increased risk of epidermal carcinoma was found in workers of MPA after exposures to 2.0 Sv or more.[78] This formally agrees with the LSS data indicating a threshold of ~1.0 Sv.[79] However, an observation bias seems to be probable in this study.[78] The workers and some medical personnel knew the employment duration that correlated with radiation doses. The latter could have influenced the diagnostic quality. Doses absorbed within the epidermis were not specified in the paper.[78] The workers were exposed predominantly to gamma, i.e., low-linear energy transfer (LET) radiation, so the doses within the epidermis were probably not high. Accordingly, the premalignant (actinic) epidermal lesions were "very rare."[78] It is known that radiation exposures may cause premalignant epidermal changes, including actinic keratosis[80,81] that was not observed in the studied cohort.[78]

Another citation to be commented on: "…important issue in the field of radiation protection is the hypothesis of a reduction of radiation-associated cancer risk per unit dose at low dose-rates.[82-84] Such a hypothesis was derived from observations of biological results and has been implemented

in the system of radiation protection by the introduction of a dose and dose-rate effectiveness factor (DDREF)… For solid cancer mortality, summary estimates of ERR/Gy derived from the LSS and The International Nuclear Workers Study (INWORKS) were similar in magnitude, a finding that does not support the conclusion of a reduction of ERR/Gy at low dose-rates".[85] The conclusions regarding DDREF based on the studies of nuclear workers receiving doses largely compatible with broad-range NRB are unfounded,[38,39] as well as the statements that the linear no-threshold theory (LNT) for low radiation doses is unrejectable:[86] to reject the LNT, it suffices to prove hormesis. Some mathematical models suggested DDREF values from two up to infinity;[87] the latter agrees with the hormesis concept.

One more comment: the risks of leukemia in MPA employees, excluding chronic lymphocytic leukemia (CLL), calculated using incidence figures, were significantly greater than those calculated based on mortality.[88] A more efficient screening in people with higher doses is a probable mechanism. CLL is a special matter, often diagnosed early because of enlarged lymph nodes.[89]

THYROID CANCER

It is widely agreed that the frequency of thyroid cancer (TC) in people exposed at a young age after the Chernobyl accident (hereafter accident) increased significantly. The cause-effect relationship between Chernobyl exposures and other cancers has not been convincingly demonstrated.[22,90] The dramatic elevation of TC 4-5 years after the accident coincided with the start of mass screening;[9] it could be predicted neither from LSS nor from experience with radiotherapy.[91-100] The evidence of correlations between radiation doses and cancer risks comes predominantly from the epidemiological research associated with bias discussed in this article and elsewhere.[3]

Before the Chernobyl accident, the registered incidence of childhood TC in the Soviet Union was lower than in other industrialized countries.[101-105] The predominant increase among children and adolescents can be explained by the fact that the youth, contrary to older people, was actively screened at schools and kindergartens after the accident. Despite the normalized radiation background, awareness about thyroid tumors among medics and the population contributed to the enhanced TC incidence decades after the accident.[106,107] The detection rate of TC is known to depend on the screening intensity due to the pool of undiagnosed, dormant, and borderline tumors.[4,108]

The considerations delineated above have been camouflaged. The period 1986-1990 (when the TC frequency started to grow after the accident) was chosen for comparison with post-accident figures[109] "Since 1986, and not earlier, specific data on thyroid cancer incidence have been specifically collected by local oncologists" (UNSCEAR Secretariat, e-mail communication, 2013). It was stated that the TC incidence in Belarus in the period 1971-1985 did not significantly differ from global statistics,[110] referring to the paper,[95] where no such information was found. The pre-accident TC incidence in children <10 years old in Belarus and Ukraine was claimed without references to be 2-4 per million per year,[111] which is much higher than statistics published earlier (0.3 in Belarus, 0.1 in the North of Ukraine).[102] Extensive screening after the Chernobyl disaster found small tumors and neglected malignancies misinterpreted as radiogenic cancers arising after a short latency. Besides, residents were preoccupied with their recognition as victims of the accident to gain access to compensation and other provisions.[112] Cases brought from non-contaminated territories tended to be more advanced because there had been no mass screening outside the Chernobyl area. Accordingly, TCs found ten years after the accident were, on average, more advanced than those detected later.[113,114] Many early patients had advanced TC with distant metastases.[115]

Counting dormant cancers and questionable cases among malignancies, false-positivity, and registering people from clean areas as Chernobyl victims jointly contributed to the elevation of the recorded TC incidence after the Chernobyl disaster.[1-3,116] The frequency of papillary microcarcinoma in the general population was estimated at 1/200 people ≥ 30 years old;[117] its finding by the screening would elevate the detection rate considerably. In this connection, the following statement is potentially misleading: "77% of primary tumors were larger than 1 cm, suggesting that these were not incidental TCs detected by screening".[118] It should be noted that the screening can find small nodules and advanced tumors, especially if targeted medical examinations have not covered the populace.

A recent study reported, "dose-related increases in DNA double-strand breaks in human TCs developing after the Chernobyl accident".[119] This is not surprising considering that people with higher doses were generally better examined, and advanced malignancies were misinterpreted as rapidly growing radiogenic cancers: mutations tend to accumulate along with the neoplastic progression.[120,121] As for the lower TC incidence among people born after the accident, there were no motives to inflate the statistics, while the screening exhausted the pool of latent and neglected cases. The understanding of these facts finds its way to the literature: a recent study negated phenotypic differences between sporadic and supposedly radiogenic TCs[122] in contrast with preceding papers by the same research group, e.g.,[8] Analogous suggestions published more than a decade before[123] are, however, not cited.

OVERTREATMENT OF SUPPOSEDLY RADIOGENIC CANCER AND PRECANCEROUS LESIONS

The misinterpretation of neglected cancers, found by the screening, as rapidly growing radiogenic malignancies gave rise to the concept that radiogenic cancers are generally more aggressive. This contributed to the excessive radicalism of thyroid cancer (TC) treatment. The following was recommended for post-Chernobyl TC in children: "Radical thyroid surgery including total thyroidectomy combined with neck dissection followed by radioiodine ablation"[101] and radiotherapy with 40 Gy.[124] Side effects of the radioiodine therapy included salivary gland dysfunction (44.8% of cases), xerostomia (36%), and depressive states (38%).[125] Certain experts deemed subtotal thyroidectomy "oncologically not justified" and recommended total thyroidectomy with prophylactic neck dissection.[126-129] Less radical surgery was "only acceptable in exceptional cases of very small solitary intrathyroidal carcinomas without evidence of neck lymph node involvement on surgical revision."[130] It was claimed that bilateral neck dissection is indicated for all TCs irrespective of size (including microcarcinoma), histological type, and lymph node involvement.[131] A similar approach was applied to radiation-exposed TC patients in the Urals.[132]

According to a recent report from Belarus, 69% of post-Chernobyl pediatric patients underwent total thyroidectomy; among them, radioiodine therapy was carried out in 69% of cases. For comparison, in patients diagnosed with TC after the Fukushima Daiichi accident, hemithyroidectomy was performed in 92% and total thyroidectomy in 8% of cases only.[125] In a study from Ukraine, "given the presence of radiation exposure in the patients' histories," total thyroidectomy was performed in 405 out of 465 papillary thyroid microcarcinomas (87.1%) with postoperative radioiodine therapy in 76.1% of the cases. The neck dissection was performed in ~50% of the cases.[133] Of note, recurrences to lymph nodes were detected only in 1.3% of the patients (median follow-up of 5.2 years). At the same time, the authors noted that microcarcinomas in their series were "rather indolent" and advised "more frequent organ-preserving surgeries vs. total thyroidectomy even for potentially radiogenic papillary thyroid microcarcinomas."[133] In another paper, the same authors rightly concluded that "internal irradiation does not affect tumor phenotype… and does not worsen prognosis in pediatric or young adult patients with papillary thyroid microcarcinoma, implying that radiation history may not be a pivotal factor for determining treatment strategy".[122] The long-term overall survival of post-Chernobyl TC patients was designated as excellent: during the 1990-2014 period, 21 (1.9%) pediatric TC patients died, among them only 2 from advanced cancer, 3 from secondary malignancies, 3 from other internal diseases, 6 due to trauma; 7 TC patients committed suicide.[125] These figures indicate the overdiagnosis and overuse of total thyroidectomy, associated with complications: hypoparathyroidism and recurrent laryngeal nerve palsy. The neck dissection is also associated with adverse effects.

Epidemiologists issued warnings against false-positive diagnoses of malignancy in thyroid nodules.[117,134] Many experts argued that the worldwide increase in TC incidence (not only in children) is caused by screening, medical surveillance improvements, and technological diagnostics advancements.[125,135] The author agrees with the following conclusions: "After the Chernobyl and Fukushima nuclear accidents, thyroid cancer screening was implemented mainly for children, leading to case over-diagnosis;" "The existence of a natural reservoir of latent thyroid carcinomas, together with advancements in diagnostic practices leading to case overdiagnosis, explain, at least partially, the rise in TC incidence in many countries;" "Total thyroidectomy, as performed after the Chernobyl accident, implies that patients must live the rest of their lives with thyroid hormone supplementation. Additional treatment using radioactive iodine-131 therapy in some cases may result in potentially short- or long-term adverse effects";[136] "The extent to which opportunistic thyroid cancer screening is converting thousands of asymptomatic persons to cancer patients without any known benefit to them needs to be examined carefully."[135] Similar concerns were expressed by other experts. American Thyroid Association (ATA) guidelines indicate that thyroid nodules less than 1 cm should not be biopsied, nodules 1 cm to 1.5 cm should be biopsied only when features concerning a malignant tumor exist, and papillary thyroid cancer (PTC) nodules 1 cm or less should be managed with active surveillance or lobectomy.[137]

The sources[138-140] were quoted to corroborate the recommendation: "The most prevailing opinion calls for total thyroidectomy regardless of tumor size and histopathology."[130] This is a misquoting: the talk is about subtotal resection in the cited sources, which is not the same.[139-140] Analogously, the sources[140-142] were misquoted in the paper.[127] Potential health-related, cosmetic, and social (stigmatization as a cancer patient) adverse effects of surgical hyper-radicalism are known.[117,143-145] Histological images from Russian textbooks, potentially conducive to false-positivity, were reproduced and discussed previously.[3,116,146] Chernobyl-associated radiophobia contributed to the false positivity and overtreatment: "Practically all thyroid nodules, independently of their size, were regarded at that time in children as potentially malignant tumors, requiring an urgent surgery."[147]

Mechanisms of false-positivity have been discussed previously;[3,116,146] among others, the misinterpretation of nuclear pleomorphism as a malignancy criterion of thyroid nodules occurred in the former Soviet Union (SU) of the 1990s. If the screening finds a thyroid nodule, a fine-needle aspiration is usually performed. The thyroid cytology is accompanied by some percentage of inconclusive results when histological examination is indicated. This percentage was relatively high in the former SU due to insufficient experience with pediatric material, suboptimal quality of specimens, and insufficient use of modern literature. The surgical specimen is sent to a pathologist, who may be sometimes prone, after in toto resection of the nodule to confirm malignancy even in case of uncertainty. The fine-needle aspiration cytology was introduced into practice later than ultrasonography, contributing to the overdiagnosis of malignancy, especially during the 1990s.

Analogous overtreatment tendencies have been noticed regarding renal and bladder lesions.[148-158] Surgeons might overuse nephrectomy if they learn that renal-cell carcinoma from contaminated territories is, on average, more aggressive, while surrounding parenchyma contains "proliferative atypical nephropathy with tubular epithelial nuclear atypia and carcinoma in situ."[148] The same Chernobyl experts found in patients with the benign prostatic disease and cystitis from contaminated territories and the city of Kyiv (not recognized as contaminated), severe dysplasia or carcinoma in situ in urinary bladders of 56%-73% randomly selected cases.[153-158] These percentages are unrealistic for overdiagnosis and hypertherapy. Histological images from the papers[153,154] were reprinted and commented previously;[159] neither malignancy nor severe dysplasia is recognizable. The clinical and morphological findings designated as "Chernobyl cystitis" or "irradiation cystitis" with "reactive epithelial proliferation associated with hemorrhage, fibrin deposits, fibrinoid vascular changes, and multinuclear stromal cells"[158] were contributed by repeated cystoscopy, "mapping" punch biopsies and electrocoagulation of vesical mucosa. The "marked activation of angiogenesis," described in supposedly radiation-related cystitis,[154] could have resulted from iatrogenic injury. The microphotographs from the papers[160,161] (reproduced[159]) indicate that overdiagnosis and overtreatment also occurred back in the 1980s.

In conclusion, the following unreasonable claim should be commented on: "When considering the effects of irradiation on human health, it is necessary to clearly distinguish between the effects of increased background radiation to which adaptation can occur over many generations at the population level and the effects of irradiation as a result of accidents or medical procedures."[162] Note that an equivalent dose is essential, no matter where it was received: from natural or anthropogenic sources.

DISCUSSION

Mutations and DNA repair are in a permanent balance. There must be an optimal exposure level, as it is for many physical factors, chemical elements, and compounds, including water radiolysis products.[163] NRB has probably been decreasing on the Earth's surface.[164] Therefore, an optimal exposure level may be even higher than today's NRB. It can be reasonably assumed that the evolutionary adaptation would be operative at all ages, including embryogenesis. There are suggestions that, in utero, relative risks in LSS may be lower than those in some other groups.[18] although acute exposures are generally more effective than chronic and fractionated ones, overviewed previously.[38,39] This adds doubts about conclusions based solely on epidemiological research. The available literature does not provide direct evidence that low-dose prenatal exposures increase stochastic effects (excess cancer risk) or deterministic impact on the offspring.[165]

The optimal approach for radiation protection regulations is determining the threshold dose for the carcinogenic effect and establishing rules to ensure that professional exposures are kept well below.[47,61] According to a recent review, epidemiological data provide no convincing evidence of harm at doses ≤100 mSv, whereas some studies suggested hormesis.[166] The dose level of 200 mSv was mentioned in some reviews as a threshold below which radiation-related cancer risks are unproven.[23,167,168] Dose reconstructions in humans are often imprecise. Screening effect, selection, and ideological bias in epidemiological research may contribute to the appearance of new reports on enhanced cancer risks associated with a moderate increase in the radiation background. This would not prove causality. Large-scale animal experiments using different species are the most reliable tool to determine threshold doses. In utero, damage, and corresponding thresholds can also be studied in animals.

CONCLUSION

Certain scientific writers act following the interests of companies and governments selling petroleum and natural gas. Most evident is this tendency regarding ionizing radiation, whereas the overestimation of medical and environmental side effects of nuclear energy contributes to its strangulation, supporting appeals to dismantle nuclear power plants and boosting fossil fuel prices. The use of atomic energy for electricity production is on the agenda today due to the increasing energy needs of humankind. Health risks and environmental damage are maximal for coal and oil, lower for natural gas, and much lower for atomic energy - the cleanest, safest, and practically inexhaustible energy resource. The weightiest argument against NPPs is that they are potential targets in armed conflicts. Escalation of conflicts and nuclear threats contribute to the boosting of fossil fuel prices. This

is probably one of the motives of the Ukraine war, nuclear threats, and other militaristic rhetoric. Finally, speculations about the extraordinary aggressiveness of radiogenic cancers have contributed to the overtreatment. Nuclear energy production should be developed under the guidance centered in developed countries.

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