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Hormesis and radiation safety norms

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Abstract

Today's radiation safety norms are based on the linear no-threshold theory (LNT): extrapolation of the dose-response relationships down to the minimal doses, where such relationships are unproven and can be inverse due to hormesis. The most promising way to obtaining reliable data on the dose-effect relationships for low radiation doses would be large-scale animal experiments. Outstanding published data on carcinogenic effects of the doses e.g. below 100 mSv should be verified by experiments. Arguments against applicability of the LNT to the doses comparable to those from the natural radiation background are discussed. Furthermore it is stressed that medical consequences of the Chernobyl accident have been overestimated; and this theme has been exploited to strangle development of atomic energy and to elevate prices for fossil fuels. Worldwide introduction of nuclear energy will be possible only after a concentration of authority within a powerful international executive. It would enable the construction of nuclear reactors in optimally suitable places, considering all sociopolitical, geographical, and geological conditions, which would contribute to the prevention of accidents like in Japan in 2011. A concluding point is that radiation safety norms are exceedingly restrictive and should be revised to become more realistic and workable. Elevation of the limits must be accompanied by measures guaranteeing their strict observance. It is also concluded that there are no evidence-based contraindications to five-fold elevation of the total equivalent effective doses to individual members of the public (up to 5 mSv/year), and doubling of the limits for professional exposures.

Keywords

Radiation safety norms, ionizing radiation, hormesis, Chernobyl accident

Unrealistic laws and regulations are often violated, which contributes to disrespect for law in general. Today's radiation safety norms are based on the linear no-threshold theory (LNT): extrapolation of the dose–response relationships down to the minimal doses, where such relationships are unproven and can be inverse due to the hormesis, i.e. beneficial effect of low-level exposure.[1–4] According to the existing norms, an equivalent effective dose to individual members of the public should not exceed 1 mSv/year.[5] The limits of effective dose for exposed workers are 100 mSv in a consecutive 5-year period, with a maximum effective dose of 50 mSv in any single year.[6] For comparison, worldwide annual exposures to natural radiation sources are generally expected to be in the range of 1–10 mSv, 2.4 mSv being a current estimate of the global average.[7] In some densely populated regions, the background radiation is considerably elevated without any detected increase in health risks.[8–13] Previously, we discussed some publications on the Chernobyl accident because of the inadequate use of the term 'long-term low-dose exposure to ionizing radiation,' which is sometimes, in fact, just a slight elevation of the radiation background.[14] For example, in a series of studies, commented in references 14,15, patients with cancer or precancerous lesions from radiocontaminated areas around Chernobyl were combined in one cohort with patients from Kiev, thus creating a ground for discussion of radiation-induced malignancy in the big city. Average annual effective doses to the residents of Kiev during the first year after the Chernobyl accident (external irradiation about 3 mSv and internal irradiation 1.1 mSv, decreasing in the following years),[16] were comparable with average annual doses from the natural radiation background. In residents of

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contaminated areas around Chernobyl (living in the strictly controlled zones, surrounding the 30-km exclusion zone, from where initial evacuation took place), annual average effective doses received by the inhabitants were around 40 mSv in the first year after the accident but decreased to less than 10 mSv in the following years.[17] These figures approximately correspond to the upper limits of doses from a single examination by computed tomography.[18] For comparison, 3414 uranium miners with lung cancer, who worked in Germany in the period 1946–1990, underwent mean individual cumulative exposure over 800 Working Level Month (WLM), which is equivalent to more than 4 Sv.[19]

Radiation-induced cancer is the most important stochastic effect of ionizing radiation.[20] The nonstochastic (deterministic) complications develop generally after higher doses of radiation.[21] In different countries, there was classified research on biological effects of radiation. Publications that are open to the public sometimes contain poorly substantiated information,[22] further complicating the matter. It is difficult to determine with certainty a level of exposure below which there is no appreciable risk for humans;[23] it appears to be around 200 mSv.[5,24] For solid cancers, a significant dose–response relationship was found for survivors of atomic explosions receiving doses less than 500 mSv but not for doses less than 200 mSv; analogous data were also reported for leukemia.[25–27] According to the UNSCEAR 2010 Report, statistically significant elevations of cancer risk are observed in epidemiological studies at the doses 100–200 mGy and above.[13] There were also reports on dose–response relationships for lower doses,[28,29] but validity of the results was questioned.[25,30] The 'practical thresholds'[12,31] can be in fact higher because of the biases in epidemiological research on stochastic effects of low doses.[32,33] It was also stated that epidemiological data fail to demonstrate detrimental effects of ionizing radiation at absorbed doses below 100–200 mSv;[34] and at single doses of less than 100 mGy, the detrimental action of radiation disappears and is replaced by protective effects.[3,30] Benefit from a moderate exposure was demonstrated epidemiologically among survivors of atomic explosions,[35] although these data might be not free from confounding factors such as better medical surveillance of the survivors. Occupational exposures were repeatedly shown to be associated with better health statistics,[2,4] which, however, can at least in part be explained by the 'healthy worker effect.'[4] Furthermore, cancer mortality was found to be lower in the high-elevation areas, where the natural radiation background is increased due to the higher intensity of the cosmic rays.[2,36] In small animals, minimal doses associated with tumorigenesis are comparable with and sometimes higher than those determined in humans by epidemiological studies, being in the range of hundreds or thousands of mSv or mGy.[20,25,30,37,38] The following, for example, witnesses in favor of hormesis: in mice irradiated with the dose rate of 70–140 mGy/year, a significant increase in life expectancy was observed.[39] Doses up to 100 mGy reduce the incidence of some malignancies in cancer-prone mice, while the dose of 100 mGy increased osteosarcoma risk.[40] It was concluded that higher doses correspond to a transition zone between reduced and increased risk, while the level of transition varies with the tumor type.[40]

Hormesis is assumed to work on molecular (stimulating DNA repair) and cellular levels; corresponding studies were reviewed in references 2, 4. Eukaryotic cells display an adaptive response that enhances their radioresistance after a low-dose priming irradiation.[41] So, the repair of DNA damage is enhanced in cells irradiated with a priming dose of 0.25 Gy followed by 2 Gy compared with those irradiated only with 2 Gy.[42] Doses 50–75 mGy significantly enhanced the proliferation of cultured cells via activation of a signaling pathway.[43] Furthermore, the bystander effect (a biological response of a cell resulting from an event in a nearby cell) may play a role in radiobiological responses to low-dose irradiation. A review[44] concluded that below 100 mGy, the bystander effect reduces rather than increases the risk of radiation-induced damage and hence of genetic instability. Certainly, knowledge on hormesis is incomplete. There have been, for example, no clinical reports demonstrating that exposure to low doses has a beneficial effect on human health during a long period of time. However, the most promising way to obtaining reliable data on the dose–effect relationships for low radiation doses would be large-scale animal experiments, which would require a high level of responsibility from researchers. Outstanding data, e.g. that 'above doses of 50–100 mSv (protracted exposure) or 10–50 mSv (acute exposure), direct epidemiological evidence from human populations demonstrates that exposure to ionizing radiation increases the risk of some cancers,[45] or a fourfold increase in the incidence of thyroid cancer in children linked to an estimated thyroid dose of

90 mGy[46] should be verified by experiments. It might be useful to find an international research center for the purpose of independent evaluation of low-dose actions on large animal populations to ensure reliable and statistically significant results.

The LNT provides theoretical basis for the radiation safety standards. LNT is supported by the following arguments: effects of ionizing radiation are of stochastic nature; the more high-energy particles or photons hit a cell nucleus, the more DNA damage will result and the higher the risk of malignant transformations. This concept does not take into account that DNA damage and repair are permanent processes, normally being in dynamic equilibrium. Background radiation has always existed, and there must be adaptation to it.[5,12] So it is with other environmental factors such as light and ultraviolet radiation, temperature, atmospheric pressure, etc., where deviation from the optimum can be harmful. The natural selection is a slow process; therefore, current adaptation must correspond to some average level from the past. Background radiation has probably been decreasing during last millions of years, due to the decay of radionuclides on the surface and oxygen accumulation in the atmosphere, resulting in the formation of ozone layer; declining volcanic activity bringing less radionuclides to the surface; changing direction of the Earth's magnetic aisle with magnetic poles and, correspondingly, maximum levels of cosmic radiation located in the past farther from the geographical poles thus affecting more living organisms, etc. It means that ancient intracellular mechanisms such as DNA repair had developed under the conditions of higher radiation,[4] so that living organisms must have been adapted to a higher background radiation level than that existing today.[14]

Discussing the exclusion of hormesis from the current risk assessment, Zbigniew Jaworowski writes, 'It seems to me that the driving force was (and still is) . . . the antinuclear power lobby, concerned that demonstration of the beneficial effects of small radiation doses, and thus of the existence of a threshold for harmful effects occurring near this dose region, will destroy their raison d'etre.'[1] The 'raison d'etre' should probably be replaced by 'cui prodest': strangulation of nuclear energy production due to the Chernobyl accident[47] contributed to higher prices for fossil fuel. The motives for overestimation of Chernobyl consequences in the former Soviet Union were discussed in reference 48. In many countries, among the motives were antinuclear sentiments supported by the Green movement, well in accordance with the interests of oil producers. For example, in reference 22 it was noticed that in the volume,[49] dedicated to the Chernobyl accident, references to nonprofessional publications (mass media, Web sites of unclear affiliation, commercial editions, etc.) were used to corroborate scientific views. The following statement was made without references: 'The calculations suggest that the Chernobyl catastrophe has already killed several hundred thousand human beings in a population of several hundred million that was unfortunate enough to live in territories affected by the fallout. The number of Chernobyl victims will continue to grow over many future generations.'[50] Then follows an inexact citation, 'Twenty years after the catastrophe, the official position of the Chernobyl Forum (2006) is that about 9000 related deaths have occurred and some 200,000 people have illnesses caused by the catastrophe.'[50] There are no such statements in the Chernobyl Forum publication referred to.[51] In pages 15–16 it is written 'The international expert group predicts that among the 600,000 persons receiving more significant exposures (liquidators working in 1986–1987, evacuees, and residents of the most 'contaminated' areas), the possible increase in cancer mortality due to this radiation exposure might be up to a few per cent. This might eventually represent up to four thousand fatal cancers in addition to the approximately 100,000 fatal cancers to be expected due to all other causes in this population.'[51] Another example, 'Very conservative estimate of cancer fatalities in Europe attributable to Chernobyl—889,336 to 1,778,672.'[52] As discussed above, doses comparable with those received from the natural radiation background are most probably not carcinogenic; and the LNT-based extrapolations of this kind are misleading.

A concluding point is that radiation safety norms are exceedingly restrictive and should be revised to become more realistic and workable. Elevation of the limits must be accompanied by measures guaranteeing their strict observance, including openness of dosimetric data. Currently there are no evidence-based contraindications to e.g. fivefold elevation of the total equivalent effective doses to individual members of the public (up to 5 mSv/year), which would correspond approximately to 1 CT scan in 2 years.[18] Note that a radiation dose delivered at a low-dose rate produces fewer late effects than the same dose delivered at a high-dose rate.[30] Considering unavoidable global spread of nuclear energy production, elevation of the limits for professional exposures (e.g. doubling) should be considered as well, bearing in mind the main goal of the radiation safety regulations: maximizing the ratio of benefits to risks for the population. As discussed above, the Chernobyl accident has been exploited to strangle worldwide development of atomic energy,[47] but it was necessary so: nuclear industry should have been prevented from spreading to the densely populated areas, where conflicts or terrorism are not excluded. The accident in Goiânia, Brazil (1987) demonstrated what can happen as a result of mere negligence, let alone nuclear terrorism or international conflicts. Worldwide introduction of nuclear energy will be possible only after a concentration of authority within a powerful international executive, leaving aside policy disputes and competition. It will enable the construction of nuclear reactors in optimally suitable places, considering all sociopolitical, geographical, and geological conditions, which would contribute to the prevention of accidents like in Japan in 2011.

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