Low doses of radiation: scientific controversy and public choice for nuclear hazards

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Abstract

While the Linear No-Threshold (LNT) model of low-dose radiation damage is widely accepted by public and regulatory bodies at present, it is still ill-founded. The accumulated and still emerging scientific evidence points that there is probably rather high practical threshold for such a damage. Moreover, it is even probable that low levels of nuclear radiation are beneficial for human health.

LNT-caused policy is costly – both for the state budget and for the general public. Compulsory and coercive relocation, such as in Chernobyl or Fukushima, bear an additional heavy human price tag of depressions, excessive alcohol consumption and even suicides. These definite human costs should be compared with the hypothetic LNT-predicted health benefits of evacuations, and forced evacuation should be considered only in case of explicitly life-endangering situation.

Certain groups are objectively interested in being "on the safe side" regarding the nuclear hazards, nevertheless the high price. While these interests cannot be eliminated in the framework of democratic society, they should be properly acknowledged and mitigated.

In the modern society, education to nuclear issues becomes more and more important, and is especially true for politicians and decision-makers. It is very important that the society develops incentives for them to be properly informed themselves and to inform the general public.

1. Scientific Controversy on Biomedical Issues

1.1 History: tolerance level vs. Linear No-Threshold (LNT)

Adverse effects of high doses of ionizing radiation were discovered nearly immediately after the discovery of X-rays and radioactivity back in the XIX century. However, it took about two decades before early medical practitioners began to control their exposures to ionizing radiation. For example, the British X-ray and Radium Protection Committee was formed in 1921. In 1924, at a meeting of the American Roentgen Ray Society, Arthur Mutscheller recommended "tolerance" (permissible) dose rate for radiation workers, a dose rate that could be tolerated indefinitely. This rate was 0.2 roentgen per day (R/day), based on applying a factor of 1/100 to the commonly accepted average erythema dose of 600 R (not accidentally – lethal dose in case of acute whole-body irradiation), spread over 30 days [1]. The International Commission on Radiological Protection (ICRP), established in 1928, accepted in 1931 this tolerance

dose rate as a universal recommendation that was in effect for more than quarter of a century. This level corresponds to 70 R/year or about 700 mSv/year, which is 35 times higher than the present-day occupational (professional) exposure limit and 700 times higher than the present-day public one. It was assumed that no harm will be caused by radiation below this tolerance level. To illustrate the extent of public confidence in the usefulness and safety of ionizing radiation we will remind that until after the Second World War X-ray machines were typical equipment of shoe shops (this fact was mentioned in passing in Rudolf Peierls' book from 1956 [2]).

It should be stressed that until now nobody succeeded to disprove the assumption of tolerance level (while it is clear that high dose is harmful: acute dose of 100 R leads to radiation sickness and 200 R may be already lethal). For example, a study of British radiological society members [3] reveals that while the pre-1921 radiologists (who had not controlled their exposure and therefore received high doses of ionizing radiation) had a 75% (4σ of the expected value) higher cancer mortality than other medical practitioners, the post-1920 radiologists had an insignificant 5% (0.4σ) excess. Furthermore, the studies of radium dial-painters, exposed to huge cumulative doses (mostly at low rates), revealed that no cancer excess was observed below the life-time dose of about 1000 rad [4]. For α-particles, emitted by radium, the radiation weighting factor w_R=20, i.e. 1000 rad = 10 Gray and correspond to 200,000 mSv!

However, geneticists were convinced in the theory that the number of genetic mutations is linearly proportional to the radiation dose, just like the number of ionized atoms, and that mutagenic damage was cumulative. According to this point of view, no tolerant (safe) dose for radiation could ever be set, as there is no absolute radiation safety, and the safety level should only be weighed against the cost to achieve it [1].

After the bombing of Hiroshima and the start of the nuclear arms race, geneticists greatly amplified their concerns that exposure to radiation of atomic bomb fall-out would likely have devastating consequences on the gene pool of the human population. Hermann Muller was awarded the Nobel Prize in 1946 for his discovery of radiation-induced mutations. In his Nobel Prize Lecture, he argued that the dose-response for radiation-induced germ cell mutations was linear and that there was "no escape from the conclusion that there is no threshold" [5].

There was great controversy and extensive arguments during the following decade. Probably, both super-powers became interested in exaggerating the nuclear fall-out hazard. Ultimately, all kinds of ionizing radiation became connected in public perception with nuclear apocalypse. As a result of (or at least in the wake of) this change in public perception, the ICRP and the national regulators changed their radiation protection policies in the mid-1950s. They rejected the tolerance dose concept and adopted the ALARA (as low as reasonably achievable) policy, i.e., to keep the radiation exposure ALARA. The accepted model for low-dose radiation-induced health damage became the so-called Linear No-Threshold (LNT) model. In LNT, the acute exposure, high-dose cancer mortality data from the study on Hiroshima-Nagasaki survivors [6] was taken as the basis for extrapolation to low doses of radiation. The ICRP has been progressively tightening its recommendations for occupational and public exposures, from 50 and 5 mSv/year in 1958 [7] to 20 and 1 mSv/year in 1990 [8], and national regulators usually followed. And probably even more importantly, these stringent norms were (and, unfortunately, to a large extent are still being) considered unsafe by the general public.

1.2 Problems with LNT

While the Linear No-Threshold (LNT) view is commonplace for the present regulation and for the public perception, it has never been a subject to scientific consensus. The absence of consensus has been always officially acknowledged. As the US National Council on Radiation Protection and Measurements put it [9],

"*…essentially no human data can be said to prove or even to provide direct support for the concept of collective dose with its implicit uncertainties of nonthreshold, linearity and dose-rate independence with respect to risk. The best that can be said is that most studies do not provide quantitative data that, with statistical significance, contradict the concept of collective dose.*

Ultimately, confidence in the linear no threshold dose-response relationship at low doses is based on our understanding of the basic mechanisms involved…"

From the scientific point of view, the concept of cumulative no-threshold damage to living organism by *any* possible factor contradicts most of the existing scientific evidence. E.g., for paracetamol – a widely used non-prescription medicine – the lethal dose LD_{50} is about 2 g/kg, i.e. below 200 g for a normal person (few weigh above 100 kg). Following the LNT logic, each caplet of paracetamol (0.5 g) has lethal probability of 50%×0.5/200=0.125% – i.e. a caplet should kill on average 1 out of 800 patients! Clearly, the LNT logic is completely inapplicable here, which is typical for biology.

1.3 New trends

An enormous amount of research has been underway on genetics and on the effects of radiation on DNA throughout the XX century. Towards the end of the Cold War, the LNT model becomes more and more challenged. A very important review of this subject, as pointed by Jerry Cuttler [1], was published in 1990 by Daniel Billen in the Radiation Research Journal [10].

The above review points out that

"*DNA is not as structurally stable as once thought. On the contrary, there appears to be a natural background of chemical and physical lesions introduced into cellular DNA by thermal as well as oxidative insult. In addition, in the course of evolution, many cells have evolved biochemical mechanisms for repair or bypass of these lesions*."

Billen points that spontaneous DNA damage occurs at a rate of about 10,000 natural events (lesions) per cell per hour. Let us compare this with the damage caused by ionizing radiation. The number of DNA damaged sites per cell per roentgen (R) is estimated to be below 100 [10]. A radiation level of 0.2 R (or 2 mSv) per day (ICRP 1931 recommendation) would cause on average less than 20 events per cell per day, or below 1 event/cell per hour. This is 10,000 times lower (!) than the natural rate of DNA damage that occurs in every person. The above numbers have been known for more than 20 years, verified by numerous investigations and are considered to be a solid scientific evidence.

Moreover, one can even suggest that low doses of X-rays and nuclear radiation are beneficial to human health ("hormesis" hypothesis) – just as the ultraviolet radiation (also a form of ionizing radiation) is clearly beneficial in low doses (sun tanning) while high doses are certainly harmful (sunburns and skin cancer). In that context it is worth mentioning that the healing properties of radon spas have been utilized for centuries before people heard the word "radiation", and that radon treatment is definitely not considered to be an "alternative therapy" by the mainstream medicine in Europe (as opposed to the US) [11]. Another fact worth mentioning is that in most of the nuclear

industry workers studies, the rate of cancer mortality (as well as overall mortality) among the radiation workers is substantially lower than in the reference population [12]. These little-spoken facts and many others [11,13] comprise emerging (though not yet conclusive) scientific support for the hormesis hypothesis. The very idea of radiation hormesis and the term itself appeared back in 1920-s, but since 1950-s were missing in the scientific literature for decades till re-appearance in 1982. Since then, the scientific interest to hormesis steadily grows, as shown in Fig. 1.

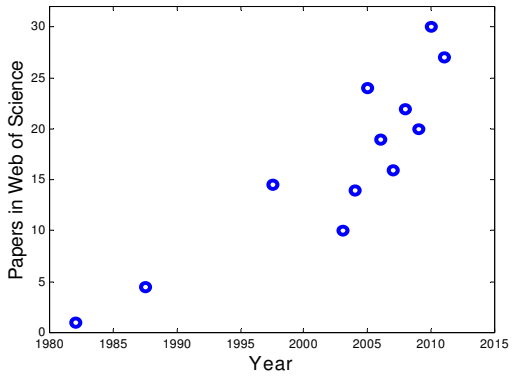

Fig. 1: Growing number of scientific papers dealing with *radiation hormesis* (beneficial effects of low-dose ionizing radiation). The term "hormesis" appeared in 1920-s, but since 1950-s was missing in the scientific literature for decades till re-appearance in 1982. Source: Science Citation Index Expanded [14].

While this scientific debate has not yet given fruit in terms of changes in radiation regulation policy, we may expect this to happen in the near to middle term. For example, after the Fukushima accident it was publicly announced – probably for the first time after 1950-s – that no positive scientific evidence (besides extrapolation from high acute dose) supports carcinogenic or other harmful effect of radiation dose below 10 R (100 mSv). While the above understanding did not prevent the Japanese authorities from performing large-scale (and in our opinion unjustified) evacuation [1], it was still essential in *ad hoc* setting higher radiation limits for the radiation workers, which led to ultimate solving of the damaged reactors' issues.

Instead of the ALARA (as low as reasonably achievable) demand, "as high as reasonably safe" AHARS approach was suggested [15]. This reasonably safe tolerance level is anticipated to be very high according to the present standards, probably orders of magnitude higher than the present limits, as discussed in sec. 1.1 above.

2. Moral Aspects and Public Choice

2.1 The cost of nuclear protection

From the economic point of view, LNT-caused policy advice realization is costly – both for the state budget and for the general public. E.g., the cost of each human life hypothetically saved in the Western society by implementation of present radiation protection regulations is estimated to be about $2.5 billion (!) [16]. As mentioned by Zbigniew Jaworowski, such a cost is not only absurd but also immoral, since it cause the reduction of other life-saving programs which are by far more efficient. E.g., heart transplant costs less than 1/10,000 of the above sum, not to speak about immunization in developing countries which may cost as low as $50-100 per saved life!

In the context of nuclear or radiological accident it should be born in mind that the evacuation itself bears extremely high human price in additional to the monetary one. For example, after Fukushima several tens of people died as a direct consequence of the evacuation – mainly patients of evacuated hospitals [17], due to logistical flaws, unavoidable in such situations.

Next, large-scale compulsory relocations (like Chernobyl and Fukushima) cause businesses destruction, job losses, disruption of family routine etc. These in turn lead to increased number of depressions, excessive alcohol consumption and even suicides in the displaced populations. Displaced populations are known to develop psychological and psycho-somatic problems. It is more than reasonable to suggest that the above factors shorten their lives in addition to causing direct (temporary?) suffering.

E.g., as pointed by Du et al. [18], social disruption and economic hardships, caused by unexpected compulsory evacuation, lead to decreased basic hygiene. According to the World Health Organization, after Chernobyl "*evacuation and relocation proved a deeply traumatic experience to many people because of the disruption to social networks and having no possibility to return to their homes. For many there was a social stigma associated with being an 'exposed' person*" [19]. By the way, "green" activists tend to accent evacuation harms in the context of supporting their claim to ban atomic energy [20].

Self-esteem crash and psychological consequences were studied by Stuckler et al. [21]. The study, published in "The Lancet", one of the most respectable medical journal, stresses grave consequences of social disruption and failure to support self-respect, caused by long-term occupation loss. These consequences include statistically significant life shortening.

This certain human price should be compared with the hypothetic LNT-predicted health benefit of evacuation, but the authors are not aware of any such comparison in scientific literature. E.g., the Fukushima evacuees would have been exposed to probably up to 30 mSv during the first year [22]. Even assuming LNT is valid, this would lead to life expectancy shortening by less than 1 week! It is hardly arguable that the human price of the forced evacuation was higher.

Not to speak about the simple fact, that in every country the life expectancy can vary a lot for different locations. However, this difference of typically several years (as in the extreme case of Calton in the UK – 25 years below the country average!) does not urge any government to order forced evacuation of the underprivileged locations.

2.2 State officials and their incentives: Public Choice basic approach

From the Public Choice point of view, LNT excellently fits the known trend of coercive salvation ideas and compulsory consumption of "public goods". It tends to call for centralized state-run rescue operation instead of decentralized (commercial, NGO-non-government organizations, families & individuals), while the latter proved their efficiency. Emergency assistance is often well provided by private entities (NGO's usually), so claiming this sort of problems to be exclusively in the governmental domain serves the interests of state officials to extend their power and budget.

Following W. Niskanen [23], we describe here an "ideal" state official (in economic theory it is usually referred to as "bureaucrat"), free of any kind of corruption and sincerely interested in public welfare – according to his understanding. However we assume him to be neither a superman nor an angel, but a human being. As such, he is interested in career opportunities, stability of occupation, public recognition and prestige of his occupation (services). Therefore, he must be interested in maximizing the

resources redistributed under his control and in bigger amount and complexity of regulations.

The state officials represent therefore a hard-core highly motivated interest group. Such small groups are able to extort the rent (or to reach other goals like power strengthening), imposing costs on the rest of the society (until the opponents' organizational costs would be exceeded by imposed costs of regulation or redistribution – see [24] and [25]).

Pure public goods (defense, security and justice) are historically restricted to 1-5% of GDP (Gross Domestic Product) and poorly defendable under universal suffrage – i.e. it is hard to impress the prototypic voter by supplying more. In a sharp contrast, *mixed public goods* (education, health care, social benefits) are known to comprise as high as 50% of GDP. More important, providing mixed public goods gives reasoning for countless regulations to "protect" citizen [26].

Trend to be "on the safe side" regarding nuclear hazards objectively serves the above aims. In reality, since the probability of a nuclear disaster seems pretty low, general public is reluctant to seek for in-depth considerations. People are rationally ignorant, so they are ready to rely on the "expert opinion" provided for free (by state-run or state-dependent media), if the issue does not seem to them important enough [27]. The LNT model, no matter whether valid or not, optimally meets officials' demand for simple and defendable decision-making procedure. The model itself is extremely simple and rather famous, being taught as a scientific fact for half a century (though, as we showed in Sec. 1, it has never been a such). As LNT-driven policy is costly, the model leads to increasing public spending.

2.3 Politicians' incentives

The term “left-wing politician” will be used here to denote a certain “ideal” (non-corrupted) politician in a democratic state. Such politician argues for expanding the functions of the state beyond supplying the *pure public goods*. A “left-wing politician” considers these historically new functions – supplying *mixed public goods* (including education, health care and social benefits), controlling the behavior of citizens and markets – as the main functions of a modern state.

Oppositely, a “right-wing (or conservative) politician” assumes that the only function of the state is to supply *pure public goods* – that is, the state provides defense, security and justice only, i.e. performs the functions of a “night watchman” (a famous comparison coined by Ferdinand Lassalle in mid-19th century).

Naturally, as the assessment of probable damage of certain hazard (e.g. nuclear accident) gets higher – so are the chances to gain support for the pro-spending, pro-regulative coalition. Moreover, being "on the safe side" real or hypothetical nuclear hazards – unfamiliar to most voters and demanding considerable intellectual effort to comprehend it properly – is highly efficient for “left-wing politician” (as well as for the bureaucrats) in view of the long-run strategy to increase number of voters heavily relying on the governmental aid [26], [28].

Politicians are also human beings. As such, many of them "*act solely in order to attain the income, prestige, and power which come from being in office . . . . their only goal is to reap the rewards of being in office per se*." (Ref. [27] p. 23). These goals (prestige and power) are applicable for state officials also, as discussed above. We see therefore very strong correlation between the interests of left-wing politicians and those of bureaucrats.

Both politician and bureaucrat compare the pay-off in terms of gained power versus the costs of electoral ("informational") campaigns. If public media could be captured by

certain parties, the cost to provide the voter by biased information could be almost eliminated for theses parties, being actually imposed on the taxpayer [29]. If nuclear damage assessment is increased as a result of intensively media-covered disaster, the idea to protect the voter from nuclear danger can turn to be successful, as illustrated by the recent Baden-Württemberg elections in Germany.

Baden-Württemberg elections were held on March 27, 2011, just couple of weeks after the Tōhoku devastating earthquake, tsunami and Fukushima nuclear accident in Japan. The Green party achieved more than two-fold increase in electoral support. This was probably caused by switching the public attention to nuclear danger. See, for instance, the coverage of the pre-election situation in Germany by the newspaper "Bild" [30]. The "danger" perception was shaped by long-lasted public TV media-bias [29]. Objectively, public perception of the tsunami disaster (which claimed to be about 30,000 lives) as predominantly Fukushima nuclear accident (which did not cause any loose of life whatsoever) does not look well-reasoned. The voters rationality failure could be, however, easily explained by the described above (sec. 2.2) "rational ignorance" model. Surely, foreign Japanese scene fits for the voters' opinion management much better than the domestic one.

Conclusions

While the Linear No-Threshold (LNT) model of radiation damages is presently widely accepted by public and regulatory bodies, it is ill-founded. LNT emerged after the atomic bombings of Japan and is connected in public perception with the nuclear apocalypses. However even according to its proponents, this model is neither proven nor disproven. The accumulated and still emerging scientific evidence points that there is probably rather high practical threshold for radiation damage. Moreover, it is even probable that low levels of nuclear radiation are beneficial for human health.

Compulsory and coercive relocation in Chernobyl or Fukushima led to businesses destruction, job losses, disruption of family routine etc. Those in turn led to excessive alcohol consumption, mental health problems and even suicides in the displaced populations. This definite grave cost should be compared with hypothetic LNT-predicted health benefits of the evacuation. Therefore, forced evacuation should be considered only in case of explicitly life-endangering situation.

From the Public Choice point of view, LNT excellently fits the known trend of coercive salvation ideas and compulsory consumption. Certain groups are objectively interested in being "on the safe side" regarding the nuclear hazards, nevertheless the high price (including the human price). While these interests cannot be eliminated in the framework of democratic society, they should be properly acknowledged and mitigated. The official bodies should stress that LNT is an overcautious hypothesis, bearing high price tag in both human and economic terms.

In the modern society, education to nuclear issues becomes more and more important, and is especially true for politicians and decision-makers. It is very important that the society develops incentives for them to be properly informed themselves and to inform the general public.

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