The flawed logic of LNT – a short analysis

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Introduction

The U.S. Nuclear Regulatory Commission (NRC) has received three petitions for rulemaking (PRM) requesting that the NRC amend its "Standards for Protection Against Radiation" regulations and change the basis of those regulations from the Linear No-Threshold (LNT) model of radiation protection to the radiation hormesis model. The radiation hormesis model provides that exposure of the human body to low levels of ionizing radiation is harmless and might even be beneficial by protecting the human body against deleterious effects of high levels of radiation. Whereas, the LNT-model provides that radiation is always considered harmful, there is no safety threshold, and biological damage caused by ionizing radiation (essentially the cancer risk) is directly proportional to the amount of radiation exposure to the human body (response linearity).

In this contribution we will focus on the legitimacy of the LNT-model of radiation protection. We will do that by examining the *validity* and *soundness* of the premises that characterise the LNT-model. Please remember the bare essence of deductive reasoning. An argument is said to be *valid* if and only if it takes a form that makes it impossible for the premises to be true and the conclusion nevertheless to be false. Otherwise, a deductive argument is said to be invalid. A deductive argument is *sound* if and only if it is both valid, and all of its premises are *actually true*. Otherwise, a deductive argument is unsound.

If the premises that lead to the validity and soundness of the core tenet of the LNT-model are shown to be defective in some way, then the LNT-model needs to be abandoned unequivocally. We are aware of the fact that that will have far-reaching consequences. Not only the discipline of radiology needs to incorporate that change, however defined, but also the 'downstream users' in multiple policy fields. With what the LNT-model needs to be replaced is another matter. However, what is clear is that any replacement needs to be empirically founded first and foremost, next to a valid and sound structure of the whole. Hormesis in our opinion seems to fit that bill. That we will however not investigate further here.

Our conclusion is that the LNT-model is unsound, and should therefore be abandoned both as a scientific as well as a regulatory construct.

Analysis

The classical stance on risk of radiation is: 'Complexities notwithstanding, the genetic damage done, however felt and however measured, is roughly proportional to the total mutation rate.' … 'Any radiation is genetically undesirable, since any radiation induces harmful mutations. Further, all presently available scientific information leads to the conclusion that the genetic harm is proportional to the total dose …. This tells us that a radiation dose of 2X must be presumed to be twice as harmful as a radiation dose of X.' **[*1*]**

Since the publication of 'Genetic Effects of Atomic Radiation' in 1956, any ionising radiation is regarded as 'genetically undesirable' (quite a partisan terminology we observe). Therefrom, the developed regulatory Linear No-Threshold (LNT)-model holds that for ionising radiation (*and* genotoxic carcinogenic chemical substances), *any level* of exposure –except for zero- implies a health risk. **[*2*]** Thus, only zero exposure is ultimately deemed to be 'genetically' safe.

This line of reasoning has been broadened to toxicology. Again, one ionising photon (or one molecule of a genetoxic carcinogen) may give rise to irreversible health damage: 'Even at the lowest possible exposure (which, in theory, could involve just a single molecule), genotoxic carcinogens can still initiate the cancer process, although the risk is very small. This line of reasoning clearly indicates that when two molecules of carcinogen are present the risk involved is twice as great. In this way, a linear relationship could be created be tween exposure and the risk of a hit. This is also referred to as one-hit kinetics. It is based on the assumption that the probability of effective hits is directly proportional to the level of exposure'. **[*3*]**

Here, we want to raise an argument that fundamentally undermines the LNT-model as described above. This requires first, for sake of clarity, that the precepts of the LNT-model be rephrased into a logically valid argument of the following structure, *which simultaneously is regarded as sound*, considering the almost global acceptance of the LNT-model in research and policy:

(1) Ionising radiation causes genetic harm (mutations).
(2) Genetic harm is by default detrimental to living organisms (including humans).
(3) Genetic harm is proportional to the total dose of ionising radiation.
(4) Thus, a radiation dose of 2X is twice as harmful as a radiation dose of X.
(5) The corollary of (4) (and (3)) is (assumed to be) that 2 photons of ionising radiation induce twice the amount of genetic harm compared to one photon of ionising radiation.
(6) Consequently, even one photon of ionising radiation could create genetic harm, ultimately detrimental to the exposed organism.

Premises (1) and (2) *prima facia seem* unproblematic; most accept both. However, premise (2) requires closer inspection. Our knowledge on the molecular mechanisms involved in the radiation induced DNA damage has increased tremendously during the last decades. Free radicals play an important role. At the start of this field of research (1970-1990), free radicals were regarded as the culprit. The reasoning was rather simplistic. Radiation splits the water molecule in which a very reactive hydroxyl radical is formed. These hydroxyl radicals damage DNA by oxidation.

Consequently, antioxidants, which prevent oxidation, should protect the DNA. Increasingly, it is realized that the mechanism is more complex. Some oxidation results in the activation of endogenous protecting

systems. Oxidation sensitive transcription factors (like Nrf2) have been discovered that activate the endogenous antioxidants. Thus: damage induces protection. DNA repair systems are strongly regulated by mild damage. **[*4*]** So, premise (2) seems untenable, as damage, genetic harm, is not just a straightforward route towards disease but, conversely, initiates protection mechanisms bolstering genetic integrity. **[*5*]**

Furthermore, the soundness of premises (3) and (4) are by default limited to a range of dosages of ionising radiation that have actually been investigated either experimentally or epidemiologically. So, linearity of the dose-response curve is only known for a finite part of the whole of possible exposures levels, which is essential with respect to the lowest possible exposures up to the single photon or molecule.

The epistemological question therefore is whether premises (3) and (4) entail premise (5). Instead of the assumptive character implied in (5), one would need to *know* the empirical quality of premise (5) in order to conclude (6) and thereby implement LNT in radiation protection policy with all that that entails for society as a whole.

Premise (5) thus is the crucial assertion on which the entire LNT-model is built and does *not* seem to be acceptable. Proportionality of damage to dose, necessarily up to the single ionising photon, requires extraordinary empirical evidence in order to justify the soundness of this premise, and thereby the soundness of the whole argument.

So, the question is: In terms of research, what is required in order to show convincingly that premise (5) is sound? What kind of scientific experiment(s) would suffice to show that premise (5) is indeed tenable? Empirically, this seems impossible to do. No experiment would actually be possible to casually connect the perturbation of some part of the DNA by *one* ionising photon that subsequently would develop, over the organism's lifetime, into some disorder such as cancer. Worse, in view of the fact that damage induces protection, premise (5) seems even less tenable. In conclusion, premise (5) is question begging. Premises (3) and (4) *do not* entail premise (5) whereby (6) altogether becomes moot.

Already in 1996, Goldman noted this palpable absurdity of the LNT-model when he linearly calculated the increased risk of cancer, due to increased cosmic radiation, if the entire world population would add a one-inch lift to their shoes (*sic*):

> 'As an extreme extrapolation, consider that everyone on Earth adds a 1-inch lift to their shoes for just 1 year. The resultant very small increase in cosmic ray dose (it doubles for every 2000 m in altitude), multiplied by the very large population of the Earth, would yield a collective dose large enough to kill about 1500 people with cancer over the next 50 years. Of course no epidemiological confirmation of this increment could ever be made, and although the math is approximately correct, the underlying assumptions should be questioned.' **[*6*]**

Goldman, despite his flippant exemplar, does describe the basic scientific and regulatory assumptions of the LNT-model correctly.

All in all, it seems clear that premise (5) is untenable, whereby the soundness of the entire argument for LNT is undercut, despite the fact that premises (3) and (4) might be correct within a limited exposure-range of ionising radiation. *That*, however, is irrelevant with respect to the extrapolative character of LNT towards diminishing levels of radiation exposures to which the public might be exposed.

Based on this concise analysis of the logic of LNT that has survived since the 1950s, it seems clear that LNT cannot be maintained empirically. Uncovering empirical evidence for premise (5) seems a hopeless cause. It is interesting to see that within the sciences a valid argument is implicitly and erroneously taken to be sound. That is a gross oversight that needs to be corrected.

References

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