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The linear no-threshold theory: Readers weigh in FREE

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500-page *BEIR VII* report by 17 experts and 16 reviewers assembled by the US National Academies.[1] That review concluded "that the risk would continue in a linear fashion at lower doses without a threshold and that the smallest dose has the potential to cause a small increase in risk to humans" (page 7).

In the decade since the French academies review, a wave of studies of protracted human exposure, as discussed in a 2009 meta-analysis,[5] has suggested that protracted exposures have dose responses similar to or greater than single exposures. It is hard to justify a threshold if a dose accumulated from a large number of small exposures has an impact the same as or larger than the same dose delivered in a single exposure.

The public-health and risk-assessment communities should ignore partisan views and assume the linear no-threshold (LNT) dose-response relationship at low doses, with uncertainty bands above and below the LNT that cover alternative hypotheses. Disputes over radiation dose-response models distract attention from the fact that the individual risks at the low-dose levels that are being debated are small, whether assessed using a linear, supralinear, or threshold model. However, for situations in which hundreds of thousands of people are irradiated, risk is spread over a huge population in a kind of reverse lottery. To estimate such social risks is considered inappropriate by some, but it is necessary for cost–benefit calculations in retrofit analysis of nuclear power plants or for seeing whether medical diagnostic procedures carry a net population benefit. Accounting for uncertainty should make such calculations more palatable. The concern that the public can't handle bad news about risk is misplaced. What destroys public trust is the idea of a cover-up, which is implied by an unwillingness to calculate possible risks.

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One of us is a radiologic educator, and the other a scientist. We do not support the linear-threshold (LT) radiation dose–response relationship that Jeffry Siegel and his coauthors do. The linear no-threshold (LNT) model has been extensively studied in numerous works that have established appropriate imaging with acceptably reduced patient radiation dose. Siegel and company correctly recognize that we do not know what the response is to medical radiation exposure below perhaps 100 mSv. However, many continue to subscribe to LNT, and we agree that it is the correct position.

To abandon LNT for LT would be another example of "normalization of deviance," a term coined by Diane Vaughan following the 1986 *Challenger* disaster and first applied to medicine in anesthesiology[1] in 2010. Normalization of deviance is the gradual shift in belief or behavior that strays from accepted safety standards because the belief or behavior has no adverse consequences—until it does. Andrew Woodward and Melissa Jackowski, in a presentation they gave at the Radiological Society of North America 2014 Scientific Assembly and Annual Meeting, explored normalization of deviance as the reason for radiologic technologists taking shortcuts that violate the concept of ALARA (as low as reasonably achievable).

Although the true dose–response relationship may well be nonlinear at low doses, assuming a threshold would be irresponsible. In medical imaging, low doses of radiation are viewed as acceptable given the diagnostic benefits. But radiologists must always strive to minimize radiation exposure to their patients and to themselves.

Abandoning LNT, in medical imaging at least, will result in another example of normalization of deviance and in an unknown but large number of unnecessary deaths. Consider, for example, the 80 million CT imaging studies performed annually in the US.[2] Estimates of lethality from radiation-induced cancer from such medical exposures approach 30 000 per year.[3]

Of course, the difficulty with such predictions is that radiation-induced cancer has no tag of any kind to identify it as such. Furthermore, whatever the true rate of radiation-induced fatalities is, it is hidden by the 20% normal cancer lethality in our total population.

At least for medical imaging, we recommend continuing to use LNT while accepting that a patient radiation dose less than approximately 100 mSv is well worth the benefit of the imaging and should be accepted as safe.

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A letter in the January 2016 issue of PHYSICS TODAY questioned the validity of the linear no-threshold (LNT) model of radiation damage. We would like to share the results of a study that shows a threshold effect in fruit flies.[1]

In our experiment, we gave fruit flies one dose of radiation shortly after they hatched. The incident radiation exposures ranged from 0.1 J/kg to 1000 J/kg (10–100 000 roentgen). We tracked life spans and gene expression at 2 days, 10 days, and 20 days after irradiation.

We found that there was no measurable effect on lifetimes below a radiation threshold of 50 J/kg. Above that threshold, lifetimes decreased. Below it, whatever gene expression changes occur at 2 days and 10 days are corrected at

20 days. Above the threshold, the changes are not corrected.

Obviously, many questions remain, but our results clearly indicate that the LNT model is not applicable in our experiment.

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Petitions filed in 2015 with the US Nuclear Regulatory Commission seek the rejection of the linear no-threshold (LNT) hypothesis of the dose-response function for low-level ionizing radiation. We have filed documents in support of those petitions. Jeffry Siegel, Charles Pennington, and Bill Sacks, in their letter on the linear no-threshold hypothesis, included a nullifying reanalysis of data originally used to establish the LNT hypothesis. Our comments here are based on our case-control study of the risk of lung cancer from residential exposure to radon and its decay products in Worcester County, Massachusetts, between 1990 and 1999.

In our study[1] 200 cases with primary lung cancer were each matched in sex and age to two controls from the same health maintenance organization; that methodology gave a better socioeconomic, geographical, and health-care match than population-based controls. Other important methodology improvements were also made compared with earlier American studies. Analysis of the data produced unexpected support for a protective, or hormetic, effect at the low doses typical of residential radon exposures.

The average control exposure in our study was 66.3 Bq/m^3 but the average cancer-case exposure was lower, 60.2 Bq/m^3 (with one outlier removed)—the opposite of an LNT perspective. But that was not an unusual result. The pooling of seven previous North American studies found[2] mean values of 71.1 Bq/m^3 for controls and 69.8 Bq/m^3 for cases, yet that result went unmentioned: Daniel Krewski and his coauthors concentrated on presenting only evidence that supported the LNT hypothesis. If those mean values had been the first results known, would LNT ever have been invented?

The hormetic benefit we found persisted when we adjusted for smoking history, years of home residency, job exposure to carcinogens, education level, and household income. Indeed, those adjustments yielded a nearly threefold *reduction* in the risk of cancer from increased radon concentrations (compared with a twofold reduction before adjustment). And statistical significance (95% confidence interval) was reached for a hormetic effect.

Krewski and coauthors presented a detailed sensitivity analysis whereby their statistical LNT models were recalculated when the individual studies were removed one by one. Interestingly, the results were no longer statistically significant when the Iowa data were