The Boice Report #40

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LNT 101

The linear no-threshold (LNT) model has been used in radiation protection for over 40 years and has been hotly debated that whole time! This column might be titled "LNT According to Boice, Reflections" and should not be taken as an official position of the National Council on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Disclosure: I've been involved with these committees for nearly four decades.

What is the LNT hypothesis? It is the assumption used in radiation protection that radiation doses greater than zero will increase the risk (probability) of excess cancer or heritable disease in a simple proportionate (straight-line) manner in the low-dose range. The LNT model assumes that the probability (i.e., risk) of cancer or heritable effects attributable to radiation is vanishingly small as the dose approaches zero, but is not zero.

How is the LNT model used? Both the NCRP and ICRP recommend that the LNT model be used as a prudent basis for the practical purposes of radiological protection, that is, the management of risks from low-dose radiation exposure. The LNT model is remarkably suited to handling practical challenges in radiation protection, such as summing partial-body exposures, including intakes of radionuclides, and adding doses over time for incorporation into the radiation protection measure of effective dose based on the linearity assumption.

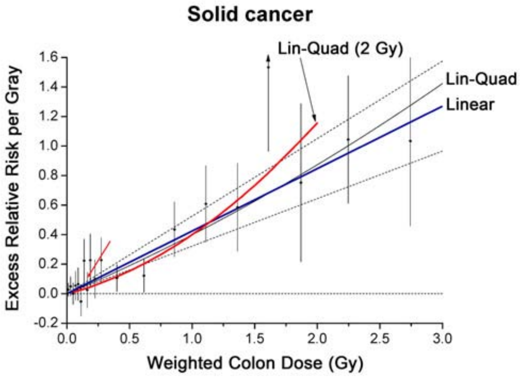
Is there a scientific basis for the LNT assumption? The most informative "must read" is NCRP Report No. 136, "Evaluation of the Linear-Nonthreshold Dose-Response Model for Ionizing Radiation." This 309-page report provides the scientific rationale for the LNT model as used in radiation protection. Another excellent scientific report is the UNSCEAR 2000 Report (Annex G and Annex I). Other informative summaries of epidemiology, fundamental biology, experimental radiation mutagenesis and carcinogenesis, and uncertainty analysis can be found in ICRP Publication 99 (2004) and the National Academies BEIR VII Report (2006).

Are there other views? Definitely, and the debate remains heated if not contentious. LNT is not TNT, but differences in opinions sometimes appear explosive! Contrarian views come from the French Academies (2005), who argue in support of a practical threshold for radiation cancer risk, and from other scientists and concerned citizens. The U.S. Nuclear Regulatory Commission is seeking public comment on several petitions that argue against the LNT model for use in radiation protection and for considering alternative threshold and hormesis (beneficial) models.

Is the LNT assumption correct? All models are wrong but some are useful. The LNT model is an assumption and has not been and cannot be scientifically validated in the low-dose range. Other dose-response relationships for the mutagenic and carcinogenic effects of low-level radiation cannot be excluded, and there are notable exceptions to the LNT relationship seen in experimental and epidemiologic studies. ***Nonetheless***, it is the current judgment by national and international scientific committees that no alternative dose-response relationship appears more plausible than the LNT model on the basis of present scientific knowledge.

Does the LNT assumption matter? Certainly it does. Exaggerated risks at low doses could result in spending limited societal resources to reduce exposures unnecessarily—resources that might be spent more effectively in other areas of protection. Exaggeration of risks also fans the flames of the growing public aversion to medical exposures and other man-made sources of radiation. Underestimating risks, however, might allow population exposures that unduly increase the risk of cancer and heritable effects.

Is the LNT assumption based on past or present understanding? It's based on current epidemiologic and experimental data, not the past. For example, if you glance at the dose-response curve (next page) on solid cancer mortality among atomic bomb survivors (Ozasa 2012), you might be



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struck with two observations. First, a straight line adequately fits the data in the low-dose range. Second, the statistical uncertainty in the data for <100 mGy (weighted colon dose) is large as seen by the wide confidence intervals. In fact, the best fit in the range of <2 Gy is "linear quadratic" and not linear, but I'm challenged to see any practical difference. For the complete skinny, check out NCRP Report No. 136, ICRP Publication 99, BEIR VII, and UNSCEAR 2000!

Is the LNT model abused? Definitely, and most notably is the misuse of collective dose. NCRP, ICRP, and UNSCEAR have argued that it is inappropriate to calculate the hypothetical number of cancers or heritable diseases that "might" be associated with very tiny radiation doses received by large numbers of people over very long periods of time, especially since such predictions are not observable. For example, multiplying a 1-µSv average dose to a population times millions of persons to compute a theoretical number of cancer deaths based on the ICRP nominal risk coefficient is inappropriate, misleading, and unnecessarily alarming.

Will the LNT hypothesis ever be validated? No. Epidemiology is an observational (i.e., non-experimental) science. It is not possible to provide convincing and consistent evidence of risks in the low-dose domain because of the inability to control for confounding factors and biases as well as the statistical inability to detect a tiny signal against a huge background noise (i.e., cancer is not an uncommon disease); the inherent uncertainties are just too great.

What about adaptive response? There are remarkable biological realities such as adaptive response, genetic instability, bystander effect, epigenetic and telomere changes, and other cellular processes demonstrated in experimental settings that have not been incorporated into protection schemes. No one really knows how these processes work, but perhaps insights will come in the future. Since epidemiology (i.e., human studies, imperfect as they are) remains the basis for radiation risk modeling, the assumption is that whatever these marvelous processes might be, they are all integrated into the human data where the final outcome is a diagnosed cancer. It doesn't really matter, it is argued, what the cellular processes are that result in the outcome.

What to do? Although imperfect, the scientific consensus process seems to have worked, although not without contention, for the past four decades and has fostered both a safety culture and a reduction in unnecessary radiation exposures to workers and the public. Practical and prudent guidance has been provided on ways to protect workers and the public from any harmful effects of radiation without curtailing, hopefully, the beneficial uses of radiation in our society. So pragmatic judgment will likely continue, noting the science is in a constant state of renewal and understanding and evidence will be changing and taken into account.

Sure, but what's on the horizon? The march of science requires a constant assessment of emerging evidence to provide an optimum, though not necessarily perfect, approach to radiation protection. Alternatives to LNT may be forthcoming. If I were to offer an opinion (why not, it's my column), I'd like to see an approach that couples the best epidemiology with biologically based models of carcinogenesis, focusing on chronic (not acute) exposure circumstances for the epidemiology.

Philosophy? Stepping back for a moment from the scientific debate, consensus agreements, and regulatory responsibilities, the philosophical issue and a reason for the great debate might revolve around the uncertainty in how to make decisions based on imperfect, incomplete, inconsistent, and conflicting knowledge. Today for the practical purposes of radiation protection, the LNT hypothesis reigns supreme as the best of the rest, but all should be open to what tomorrow may bring.

CHANGE OF DATE: The 2016 NCRP Annual Meeting has been rescheduled to 11–12 April 2016. Save the new date!

Post Script: It was with great sadness that I learned that Bill Beckner died 12 August 2015 at the age of 82 years. After a career in the U.S. Navy, Bill served NCRP with distinction for 22 years and retired in 2004 as our second executive director. In 2014 the Military Health Physics Section of the Health Physics Society recognized Bill with the John C. Taschner Leadership Award. He was a colleague, advisor, and personal friend to me and many others over many years.