excluded, suggesting that the evidence supporting LNT is based not on multiple North American studies but only on the Iowa study. Moreover, as we have pointed out,[1] the Iowa study relied on an unusually broad reference exposure range, which, based on the hormetic effect we found, raises the apparent effect of higher exposure levels.

Based on the results of our study, we feel there is compelling evidence both to reject the LNT hypothesis for low-level radon exposure and to support a hormetic, beneficial range in the dose–response function.

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In their letter, Jeffry Siegel and coauthors discussed the linear no-threshold (LNT) model of radiation-induced cancer. Vital to any such discussion is the relationship of high-dose and low-dose radiation to cancer and radiological standards. The LNT model was primarily based on gamma radiation. The other types of radiation producers are alpha emitters and beta emitters. All three produce cancer, and that is important since cancer may soon surpass heart problems as the leading cause of death.

Radiation exposure standards are based on studies of survivors of the Hiroshima and Nagasaki bombings. The resultant standards are thus inherently biased in favor of survivors.

Data were collected five years after the bombing. Therefore, those studies—carried out by US investigators and not by Japanese medical personnel—and the standards based on them depend primarily on the memory of survivor interviewees rather than on actual exposure data. Much guesswork went into determining the dose that survivors actually received.

After World War II, national and international organizations were established to study radiation health effects and recommend standards for acceptable radiation exposure for workers in the industry and for the general public. The principal organizations were the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection (ICRP). Exposure standards that emerged are based on analysis of radiation from external sources and do not include sources lodged in the body. The *BEIR VII* study,[1] which is the most comprehensive study of low-dose exposure to date and reinforces the LNT approach, concludes that any exposure to ionizing radiation is potentially harmful.

Some alpha and beta emitters do lodge in the body and cause cancer and other illnesses. The European Committee on Radiation Risk started looking at populations exposed to internal radioactive isotopes from anthropogenic sources. Radioactive sources can enter the body through several means; ingestion, inhalation, and absorption through skin cuts are the main pathways. Most of the ingested or inhaled radioactive substances pass through the digestive system or are expectorated.

Compared with gamma sources, alpha and beta emitters produce much smaller doses of electromagnetic radiation but do emit particles. Beta emitters—strontium-90 is an example—tend to migrate to bones and cause bone cancer.

The manmade alpha emitter plutonium-239 can be found worldwide as a consequence of fallout from nuclear weapons testing and use.

Many nuclear sites in the US have some ^{239}Pu. At the Rocky Flats Plant just a few miles northwest of Denver, large quantities of ^{239}Pu were used for construction of components for nuclear warheads. Residential housing sits on both the east and south sides of the facility, and there are nearby cities to the north. Residents living near the plant showed increased cancer rates, and many plant workers are receiving medical attention because of their exposure to ^{239}Pu. The major pathway into the body for ^{239}Pu is inhalation, because the particles are small. A Columbia University study found that a single plutonium alpha particle induces mutations in mammal cells.[2] Once in the body, the ^{239}Pu lodges in a specific location—primarily lung, bone, liver, brain, and gonads—and stays there. With a half-life of 24 110 years, it continuously emits alpha particles over the person's lifetime.

The Colorado Health Department stated that airborne emissions of ^{239}Pu were the most dangerous emissions from the Rocky Flats facility. However, most airborne ^{239}Pu particles are too small to be detected by the Environmental Protection Agency's high-volume monitoring devices. But even if they could be detected, the EPA has no standards regulating airborne particles of ^{239}Pu.

Thus there are many questions remaining related to radiological standards and cancer.

The discussion about radiation standards is based in part on work by LeRoy Moore, Rocky Mountain Peace and Justice Center, Boulder, Colorado.

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▶ Siegel, Pennington, and Sacks reply: We are grateful to all the letter writers for their comments.

The figures mentioned in J. S. Levinger's first two references, contrary to his claim, do not indicate linear responses down to 0.1 Gy or 0.05 Gy; rather, when properly interpreted, they suggest thresholds. Even the authors of Levinger's reference 1 admit that the existence of risk below 0.5 Gy is "unclear." Levinger asserts without evidence that the linear-no-threshold (LNT) hypothesis is "probably true"—a statement about the writer's prejudice, not about reality.

Bemnet Alemayehu and Thomas Cochran mistakenly claim that we attribute the LNT model solely to 70-year-old work and that we neglect more recent studies ostensibly validating it. They endorse the conclusion of the 2006 *BEIR VII* report that the atomic bomb survivor data (the life-span study, LSS) tend to favor LNT. However, a critical review of the LSS data demonstrates that *BEIR VII* was wrong, as has been confirmed by more recent analyses in reference 1, and as we noted in our letter, "No epidemiological studies have ever demonstrated a causal relationship between low-dose radiation exposure and carcinogenesis" or, for that matter, increased all-cause mortality.

The superposition of a straight line on the revised LSS data is not the only possible, or even the best-fitting, graphical approximation. The baseline zero-dose rate had been falsely lowered, which artificially elevated relative risk (RR) at higher doses to make RR > 1 and eliminate the possibility of RR < 1 by definition, not by empirical fact. That is a hidden circular argument that assumes what must be demonstrated through evidence, which does not exist.

In their conclusion, apparently unaware of voluminous evidence to the contrary, Alemayehu and Cochran simply point—correctly—to the existence of authoritative bodies and scientific studies that support the LNT model. But such a statement relies on the logically fallacious "argument from authority." Those authoritative bodies and investigators have failed science and broader humanity; no valid studies support LNT, whereas many valid studies support hormesis.

An upcoming paper[2] by two of us (Sacks and Siegel) and Gregory Meyerson shows the ways in which many relevant epidemiological studies putatively supporting LNT make hidden errors of circular reasoning, cherry picking, and invalid mathematical and statistical manipulations; we also indicate how *BEIR VII* mischaracterized even its own sources.

We do not contend, as Jan Beyea states, that modern-day concepts of LNT are based on Hermann Muller's fruit-fly data. We point to the likely origin of LNT only to show that even then—70 years ago—an incorrect conclusion was drawn from the data. We emphasize more contemporary studies as evidence that LNT is false.

Beyea points to a "widespread consensus . . . that linearity holds at least down to 100 millisieverts," and he says there is a "broad but not unanimous view that it is likely to continue to apply at lower doses." Again, contrary evidence is abundant.

Once Beyea dismisses arguments about "repair and evolutionary protection," he has no way to explain, among other things, greater longevity in the face of increasing medical exposure to radiation. His claim that repair or removal of radiation-damaged cells "on occasion . . . can fail" may be true. However, it overlooks the fact that the repair or removal can not only correct the radiation-caused damage but also reduce the damage from reactive oxygen species (ROS) resulting from normal metabolism. The damage from ROS is several orders of magnitude greater than that caused by low-dose radiation exposure. The net result of such repair or removal is a healthier outcome than would be obtained without low-dose, low-dose-rate radiation.

Beyea mentions the publication (his reference 2) by one of us (Siegel) of a graph of LSS data for cancer incidence that suggests a threshold, an idea corroborated by others. He says we did not show the comparable mortality graph that suggests a supralinear response. But the two graphs illustrate almost identical behavior, and both suggest the existence of a threshold.

Beyea promulgates an illegitimate statistical ploy: that it is the LNT model, not the "no effect" model, that is the null hypothesis, the starting presumption that must be rejected in order to establish the truth of any alternative hypothesis. A null can never be *accepted*—it can only fail to be *rejected*, if either the putative alternative is false or there is insufficient statistical power to reject the null. A favored hypothesis cannot be legitimately pronounced the null merely to challenge opponents to reject it.

Further, Beyea says that our view is "partisan," implying both that his predilection for LNT is not partisan and that we have no evidence for our contentions. Let the readers judge just who deserves the "partisan" label.

Beyea ends by stating that our "concern that the public can't handle bad

news about risk is misplaced." In references 1 and 2 we cite refusals to get needed x rays and CTs, radiophobia leading to mass evacuations that have caused illnesses and deaths, and widespread fear of potential low-dose radiation exposure to show that the concern is *not* misplaced. What destroys public trust is not "the idea of a cover-up," as Beyea suggests, but rather false science.

Elizabeth Shields and Stewart Bushong reject the existence of a dose or dose-rate threshold and declare their support for LNT, apparently because many others also do. They admit, however, that they "do not know what the response is to medical radiation exposure below perhaps 100 mSv."

The writers say, "Although the true dose–response relationship may well be nonlinear at low doses, assuming a threshold would be irresponsible," and they warn against the harmful effects of the "normalization of deviance." That is, they warn that if our contention were to prevail within radiation science, it would risk generating a consensus that low-dose/low-dose-rate radiation is harmless—until scientists in the field learn, hypothetically, that it is really harmful. That is equivalent to the better-known "precautionary principle"—better to err on the side of caution when a controversy over policy or approach remains unsettled.

We do not simply assume a threshold. There is abundant biological experimental and observational evidence of a threshold. And as we mentioned in our letter and in greater depth in reference 1 below, erring on the side of LNT in the name of caution has far deadlier consequences than even LNT falsely predicts.

Shields and Bushong assert that "abandoning LNT, in medical imaging at least, will result in . . . an unknown but large number of unnecessary deaths." They then give the magnitude of this unknown number as "30 000 per year." If LNT is false, the irresponsibility lies in such erroneous projections of deaths and in their uncritical acceptance and repetition. Such irresponsibility encourages radiophobia, resulting in actual, unnecessary deaths due, for example, to patient and parent refusals of medically indicated x rays, life-saving tests and procedures.

Shields and Bushong conclude with the conventional radiological risk-to-benefit mantra: "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." That is, the increased cancer risk, according to LNT, is outweighed by the benefit of diagnostic accuracy. In contrast, the bulk of the evidence shows that the imaging radiation dose confers not a risk but a double benefit: greater diagnostic accuracy and hormetic reduction of mortality due to reduced ROS damage and slowing of age-related immune system decline.

We thank Leon Cooper and Michael Antosh, and Donald Nelson, Richard Thompson, Joel Popkin, and Zenaida Popkin, who agree with our view that LNT is invalid and should be rejected.

The letter by W. Gale Biggs is about internal radiation emitters, whereas our letter was predominantly about external exposure from low linear-energy-transfer radiation. Biggs says that internally deposited radionuclides lodged in the body cause cancer and other illnesses. However, the overwhelming evidence of radon studies contradicts his contention.[3]

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