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.

References

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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.

References

1. National Research Council, Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation, *Health Risks from Exposure to Low Levels of Ionizing Radiation: BEIR VII Phase 2*, National Academies Press (2006).
2. T. K. Hei et al., *Proc. Natl. Acad. Sci. USA* **94**, 3765 (1997).

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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.