RESIDENTIAL RADON AND ALPHA EMITTERS

Jerome Puskin, Chair

The Risk of Cancer from Exposure to Plutonium

E. S. Gilbert

Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, 6120 Executive Boulevard, Room 7050, Rockville, Maryland 20852-7238

The risk of cancer from exposure to plutonium has been evaluated in experimental animal studies and in epidemiological studies of workers involved in the production of nuclear weapons. The BEIR IV Committee (*1*) and, more recently, NCRP 131 (*2*) have reviewed these data.

Experimental studies in dogs and rats, supplemented by autopsy studies in humans, have contributed greatly to our understanding of health risks from plutonium. Findings from these studies indicate that inhalation is the route of exposure of greatest concern, and that exposures to intact skin or to the gastrointestinal tract are of considerably less concern. These studies have demonstrated that doses to the lung, skeleton and liver (the most highly exposed organs of the body) depend not only on the amount of deposited plutonium and time since intake but also on the size of the inhaled particles, solubility and other physicochemical characteristics of the plutonium. Life-span studies in dogs and rats exposed to various forms of plutonium have clearly demonstrated excess risks of cancers of the lung, liver and bone with little evidence of excess risks of other cancers. Animal experiments have also informed us regarding comparative risks of different types of radiation exposure such as plutonium compared to radon or high-LET compared to low-LET radiation.

In contrast to the experimental studies, epidemiological studies of plutonium-exposed workers at Rocky Flats, Los Alamos, and Hanford in the United States (*2*) and the Sellafield plant in the United Kingdom (*3*) have provided little evidence of excess cancer risk, probably because the numbers of exposed workers and the doses were too low to yield adequate statistical power. Because of limitations in direct epidemiological data, quantitative estimates of risks from exposure to plutonium have been obtained either from studies of persons exposed to other α-particle-emitting radionuclides or by applying a radiation weighting factor to estimates obtained from Japanese A-bomb survivors exposed to low-LET radiation. For example, the BEIR IV Committee (*1*) based its lung cancer risk estimate on studies of underground miners exposed to radon and radon progeny, its liver cancer risk estimate for Thorotrast from human data, and its bone cancer risk estimate on a Bayesian analysis data for exposure of human to radium and of animals to transuranics and radium. NCRP (*2*), in a more recent evaluation, continued to support the BEIR IV recommendations.

With the opening up of the former Soviet Union, data from an epidemiological study of about 20,000 workers at the Mayak nuclear facility in Ozyorsk, Russian Federation have become available. The Mayak worker cohort was initially established by Dr. Nina Koshurnikova of the Southern Urals Biophysics Institute (SUBI) and is now the focus of collaborative research between Russian scientists and scientists at several organizations in the United States, Europe and Japan. Doses from both external sources and plutonium are much larger for Mayak workers than for plutonium workers in other countries, especially for workers who began employment in the period 1948–1958. Among about 5700 workers in the radiochemical and plutonium plants who were monitored for plutonium, the average body burden was 1.9 kBq (52 nCi). Over 1000 workers had body burdens that exceeded 1.5 kBq (40 nCi), a level that has served as a guideline for the maximum permissible burden in many countries, and about 260 workers had burdens that exceeded 7.4 kBq (200 nCi). Average doses to the lung, liver and bone surfaces among the 5700 monitored workers were 0.26, 0.29 and 1.8 Gy, respectively. By contrast, the highest body burden reported in U.S. workers was 3.2 kBq (*4*), and the average lung dose among 4600 Sellafield workers monitored for plutonium was about 0.01 Gy (*3*).

Risks of lung, bone and liver cancers have been clearly linked with plutonium exposure in Mayak workers. Lung cancer risks have been studied by several investigators, most recently by Kreisheimer *et al.* (*5*), who evaluated the risk of lung cancer as a function of external dose and internal dose from plutonium among males who either were monitored for plutonium or worked only in the reactor plant, where there was little potential for plutonium exposure. A statistically significant association was demonstrated for internal dose and suggested for external dose, and both associations were consistent with linear dose dependencies. For dose from plutonium, the excess relative risk (ERR) per Sv at age 60 (with a radiation weighting factor of 20 for particles) was estimated to be 0.6 (95% CI: 0.4–1.0). For external dose, the ERR per Sv at age 60 was estimated to be 0.2 (95% CI: 0.04–0.7). Bone and liver cancers have also been studied. In analyses by Koshurnikova *et al.* (*6*) and Gilbert *et al.* (*7*), relative risks in the highest plutonium exposure category (estimated body burden 7.4+ kBq) were estimated to be 7.9 (95% CI: 1.6–32) for bone cancer and 17 (95%CI: 8.0–36) for liver cancer. Further analyses evaluating the dose–response relationship for lung, liver and bone cancers are under way, and they incorporate recent improvements in plutonium dosimetry. Results of these analyses will be presented.

A limitation of the Mayak worker study is that a systematic bioassay program based on measurements of plutonium in large urine samples did not begin until about 1970. As a result, only about 40% of workers with potential for plutonium exposure have the data needed to estimate body burdens and doses. In addition, estimated doses from plutonium are subject to many sources of uncertainty, including imprecision in urine measurements, uncertainties in the time and form of plutonium exposure that in most cases occurred many years before measurements were taken, uncertainties in the biokinetic models and parameter values that are used to estimate deposition and clearance of plutonium in the human body, and the fact that these models can only approximate the behavior of plutonium in any given individual. Nevertheless, the Mayak worker cohort is a unique resource for future estimation of cancer risks from exposure to plutonium, and it is important to continue to follow these workers and also to continue efforts that are now under way to improve both external and internal dose estimates. However, it is also important to consider other approaches for evaluating risks from plutonium exposure and to check the consistency of estimates derived from different types of data.

Acknowledgments. I would like to acknowledge the contribution of several collaborators in the Mayak worker studies, including N. A. Koshurnikova, N. S. Shilnikova and M. Sokolnikov of the Southern Urals Biophysics Institute; D. L. Preston of the Radiation Effects Research Foundation; and E. Ron of the National Cancer Institute.

References

1. National Research Council, Committee on the Biological Effects of Ionizing Radiation, *Health Effects of Radon and Other Internally Deposited Alpha Emitters* (*BEIR IV*). National Academy Press, Washington, DC, 1988.
2. NCRP, *Scientific Basis for Evaluating the Risks to Populations From Space Applications of Plutonium.* Report No. 131, National Council of Radiation Protection and Measurements, Bethesda, MD, 2001.
3. R. Z. Omar, J. A. Barber and P. J. Smith, Cancer mortality and morbidity among plutonium workers at the Sellafield plant of British Nuclear Fuels. *Br. J. Cancer* **79**, 1288–1301 (1998).
4. G. L. Voelz, J. N. P. Lawrence and E. R. Johnson, Fifty years of plutonium exposure to the Manhattan Project plutonium workers: An update. *Health Phys.* **73**, 611–619 (1997).
5. M. Kreisheimer, N. A. Koshurnikova, E. Nekolla, V. F. Khokhryakov, S. A. Romanov, M. E. Sokolnikov and A. M. Kellerer, Lung cancer mortality among nuclear workers of the Mayak facilities in the former Soviet Union. *Radiat. Res.* **154**, 3–11 (2000).
6. N. A. Koshurnikova, E. S. Gilbert, M. Sokolnikov, V. F. Khokhryakov, S. Miller, D. L. Preston, S. A. Romanov, N. S. Shilnikova,

K. G. Suslova and V. V. Vostrotin, Bone cancers in Mayak workers. *Radiat. Res.* **154**, 237–245 (2000).

7. E. S. Gilbert, N. A. Koshurnikova, M. Sokolnikov, V. F. Khokhryakov, S. Miller, D. L. Preston, S. A. Romanov, N. S. Shilnikova, K. G. Suslova and V. V. Vostrotin, Liver cancers in Mayak workers, *Radiat. Res.* **154**, 246–252 (2000).