Ionizing Radiation and Cancer Prevention

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Ionizing radiation long has been recognized as a cause of cancer. Among environmental cancer risks, radiation is unique in the variety of organs and tissues that it can affect. Numerous epidemiological studies with good dosimetry provide the basis for cancer risk estimation, including quantitative information derived from observed dose–response relationships. The amount of cancer attributable to ionizing radiation is difficult to estimate, but numbers such as 1 to 3% have been suggested. Some radiation-induced cancers attributable to naturally occurring exposures, such as cosmic and terrestrial radiation, are not preventable. The major natural radiation exposure, radon, can often be reduced, especially in the home, but not entirely eliminated. Medical use of radiation constitutes the other main category of exposure; because of the importance of its benefits to one’s health, the appropriate prevention strategy is to simply work to minimize exposures. — Environ Health Perspect 103(Suppl 8):241–243 (1995)

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Introduction

It is well recognized that exposure to ionizing radiation is unavoidable. Most human exposure is from natural sources, with radon accounting for more than half the total. Figure 1 illustrates the distribution of exposure sources for the general public as determined by the National Academy of Science’s Committee on the Biological Effects of Ionizing Radiation (BEIR V). The total comes to the equivalent of about 3.5 mSv per year per individual. With environmental radon and man-made radiation sources collectively accounting for about three-quarters of the total, there is an opportunity to reduce exposures to man. Methods are well known for both the assessment and the reduction of radon exposures in the home and workplace. The broad categories of man-made radiation sources are provided in Figure 2. The public’s concern is focused primarily on the smallest exposure category, occupational and other sources, which amounts to or represents less than 1% of total human exposure. Although much remains to be done in estimating health effects of indoor radon exposure, there has been little public concern over this most prominent source of exposure. This may not appear to be rational at first appearance. It makes sense, however, if one considers that exposures received occupationally, from toxic waste, or through accidents, are likely to be higher than those from natural background radiation.

The estimate of 3% of total radiation exposures from consumer products is somewhat misleading, since the main sources are building materials, water supplies, and agricultural products, which are not generally thought of as consumer products. The best-known consumer product involving radiation exposure is cigarette smoking. Polonium 210 found in tobacco is a result of airborne radon decay that is deposited on tobacco plants’ leaves. Wide differences in estimates of radiation doses resulting from cigarette smoking leave the contribution of cigarette smoke to radiation carcinogenesis somewhat uncertain (1,2).

Figure 1. Average annual radiation exposure; effective dose equivalent in mSv.

Figure 2. Average annual radiation exposure, man-made exposures in mSv.

The issue of exposures from nuclear power and nuclear waste receives the greatest public attention, yet these types of exposures are only a minor source of total radiation exposure. For those close to these sources, however, the issue is a real one. The concern here is the risk of unforeseen accidents as well as the public’s lack of understanding about the exposures and their associated risks. The greatest changes expected in the years ahead involve the establishment of central radioactive storage facilities and the massive cleanup faced by the Department of Energy at their many waste sites. Risks to populations in the vicinity of these activities, including interstate transportation, need careful assessment. Even more dangerous is the potential health risk to the workers engaged in the cleanup process. The amounts and types of radioactive materials that will be disturbed during any such cleanup is not completely understood. Further, there are gaps in the knowledge of biological effects of certain of the various radionuclides present in waste. Unfortunately, there is little interest in studying the biological effects of the various types of

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Abbreviations used: BEIR V, Committee on the Biological Effects of Ionizing Radiation; DREF, dose rate effectiveness factor; kV, kilovolt; LET, linear energy transfer; mSv, milliSieverts; RBE, relative biological effectiveness; UKAEA, United Kingdom Atomic Energy Authority.
The complexity of radiation spontaneously radioisotopes to which man would be exposed in any cleanup process.

**Radiation Health Issues**

The complexity of radiation types is generally not well appreciated. Natural radioactivity is the property of some nuclides to spontaneously emit particles or gamma radiation. There are about 50 naturally occurring radionuclides. Radiation typically is classified by the amount of energy lost per unit of track length (i.e., linear energy transfer [LET]). Low-LET radiation is characteristic of electrons, X-rays, and γ-rays, in which the distance between ionizing events is large on the cellular nucleus scale. High-LET radiation has ionization events whose distances are small on the nucleus scale; protons, neutrons, and alpha (i.e., helium nucleus) are of this type.

Equal doses of different types of radiation can produce different biological effects. The term relative biological effectiveness (RBE) is used to attempt to quantify these potential differences. RBE is simply defined as the ratio of the reference dose to the test dose, where the doses produce the same degree of biological effect. If, for example, the RBE value is greater than 1 for a particular radiation type, then this test radiation is more effective or potent than the reference or standard radiation, which is generally 200-kV X-ray. RBE data for high-LET radiation are often obtained for experimental systems. Neutron cancer effects are estimated to have RBE values around 20. Because radioactive waste is a mixture of various radionuclides, that emit various types of radiation at various energy levels, it is necessary to arrive at a better understanding of the biological effects of these exposures. Further, pharmacokinetic effects differ for the various radionuclides essential to understanding the health risks of these mixed exposures. Therefore, much more research is needed to produce more accurate risk assessments associated with toxic waste and its cleanup.

A second quantity of considerable importance is the dose rate effectiveness factor (DREF). This factor measures the difference between acute and chronic or fractionated exposures of the same type of radiation at the same total dose. Again, the DREF is the ratio of doses that produce the same effect. It has been observed in some experimental cancer studies that for a low-LET radiation (i.e., gamma), the DREF ranges between 2 and 10. That is, the continuous exposure is less effective than the acute exposure by a factor of between 2 and 10. This, if correct, is good news, since most occupational and environmental exposures are chronic exposures. For high LET, on the other hand, the DREF value seems to be less than 1. Therefore, environmental radon may be a greater cancer risk than estimated from the mining studies. Again this is an important public health issue that should be studied, both epidemiologically and experimentally.

### Table 1. Major epidemiologic studies conducted to obtain estimates of radiation-induced cancer risk.

| High-dose radiation studies, number of cancer cases | Low-dose radiation studies | Nuclear worker studies, number of deaths |
|---------------------------------------------------|---------------------------|----------------------------------------|
| - Atomic bomb survivors, 6000                     | - Diagnostic radiography  | - British Nuclear Fuels, 2300          |
| - Ankylosing spondylitis patients, 600            | - Fallout downwind, weapons tests | - U.K. Atomic Energy Authority, 3400 |
| - Cervical cancer patients, 4200                  | - (U.S., U.K., Canada), global | - U.S. DOE, Hanford, Oak Ridge, Rocky Flats, 7000, 1800, 400 |
| - Canadian Fluoroscopy Study, 500 breast         | - Near nuclear installations | - Atomic Energy of Canada, 900        |
| - Postpartum Mastitis Study, 115 breast           | - Nuclear workers         | - Ontario Hydro, 2900                  |
| - Tinea Capitis, 55 thyroid                        | - High natural background |                                        |

The best information on cancer incidence from acute external radiation is found in the new A-bomb results published this year (6,7). Table 2 presents the excess absolute risk for specific types of solid tumors, which were significantly increased compared with controls. The tumor sites have been ranked according to the amount of excess risk. We see from the table that the breast is the most sensitive site. Also, melanoma skin cancer has been added to the list of radiation-induced cancers. Table 3 gives hematopoietic cancer risk.
risk values. For the first time, the risk values for the various leukemia subtypes have been made available. Of particular importance is the fact that multiple myeloma was found not to be related to radiation exposure. Previous mortality studies have reported that it is induced by radiation, but in the incidence study the larger number of cases and the correction of misclassifications have resulted in the conclusion that multiple myeloma is not induced by radiation.

Conclusions

The estimated average exposure of 1.5 mSv per year for nonradon sources contributes about 4 to 5% of all cancer mortality (Table 4). The estimate does not incorporate a dose-rate effect (DREF), for which BEIR VI suggests a value of 2 which reduces the percentage to 2 or 3% of all cancer mortality. Occasional worker studies suggest a much greater risk. For example, Wing et al. (9), based on a follow-up of Oak Ridge workers, suggest that the radiation—cancer dose response is 10 times higher than estimates from A-bomb survivor studies which were the basis of the BEIR V estimates. The Wing estimate then translates to roughly 40 to 50% of all cancer mortality being attributable to radiation, which clearly is doubtful. The estimated lung cancer risk from the 2 mSv radon exposure presently depends on mining data and awaits results of environmental studies. Table 5 provides estimates of cancer risk for the various categories of man-made radiation sources that are theoretically preventable or at least reducible. Also, there is the possibility of future increases in exposures for older women from such things as yearly mammography exams, which would add about 0.2 mSv to their radiation burden. However, because postmenopausal women are at much less risk of radiation-induced breast cancer than premenopausal women, this exposure, coupled with the potential benefit of early detection, is not of major concern at this time.

Of greatest concern is protection of the public and workers exposed to radiation sources from the nuclear industry and nuclear waste sites. This protection would not measurably reduce national figures on radiation-induced cancers, but is, however, essential to reduce the risk to those individuals being so exposed.

Much is known about the cancer effects of acute exposures of low-LET radiation. The more relevant issue of chronic exposures, however, requires additional studies and research. For high-LET radiation—in particular, alpha—the available data are much more limited. We especially need data on chronic radon exposures in the low-dose region not only to better estimate lung cancer risks but also to assess other possible effects such as leukemia. Finally, research is especially needed for a better understanding of the potential cancer effects of those radionuclides associated with toxic waste.

| Table 4. Percentage of total cancer mortality, 1 mSv exposure per year.
| Male, % | Female, % |
|-------|--------|
| Leukemia | 8.9 | 8.6 |
| Nonleukemia | 2.3 | 3.2 |
| Total | 2.5 | 3.4 |

* mSv, milliSievert. Data from the Committee on the Biological Effects of Ionizing Radiation (8).

| Table 5. Radiation cancer mortality risk, man-made exposures.
| Exposure, mSv per year | Cancer deaths, % |
|----------------------|----------------|
| Medical X-ray | 0.39 | 1.2 * |
| Nuclear medicine | 0.14 | 0.4 |
| Consumer products | 0.10 | 0.3 |
| Occupational | 0.01 | 0.03 |
| Other | 0.01 | 0.03 |

mSv, milliSievert. * Considering age, this value may be two times too high from BEIR V (8).

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