# NATURAL RADIATION IN THE ENVIRONMENT

D. W. Moeller

Office of Continuing Education, Harvard School of Public Health, Boston, Massachusetts

## PRELIMINARY COMMENTS

It is an honor to take part in this, the Twenty-Eighth Hanford Symposium on Health and the Environment and, especially, to have been invited to present the 1989 Herbert M. Parker Lecture. I had the privilege of interacting with Herb in a variety of professional activities and serving with him on several subcommittees of the Advisory Committee on Reactor Safeguards. I have many fond memories of his intellect, his ability to get immediately to the heart of a matter, his uncanny ability to provide a clear and concise way in which to word a complicated statement and, above all, his humor, for example, his Lauriston S. Taylor lecture, which he titled "The Squares of the Natural Numbers in Radiation Protection."

I was also impressed by his love of his wife and family, having enjoyed visits to his home here in Richland and dinners with him and his daughter in Washington, DC, and with his clever ways of resolving issues among his children. Some were definitely biblical in origin. A good example is how he would have one of his twins divide a piece of candy into two portions and give the other the opportunity to make the first selection. You can rest assured that the one doing the dividing was careful not to show partiality to either side.

I was also impressed with Herb's total commitment to nuclear safety, and the absolute honesty, accuracy, and integrity with which he approached every issue. He was a "giant among giants," and we miss him!

## INTRODUCTION

My topic is "Natural Radiation in the Environment." If you do not already know it, you will soon realize that we live in a "sea of radiation." Understanding the components of this "sea" is important for a variety of reasons. First, radiation has been with us since the beginning of the universe. Scientists tell us that the warmth provided by relatively large concentrations of naturally occurring radioactive materials, during the first few billions of years, helped life evolve. Second, the fact that we live in the presence of the dose rates associated with these original sources provides us with knowledge relative to what can be considered acceptable levels of exposure.

However, it is important to note that the dose rates received by each person from natural sources are not the same. Rather, they are heavily dependent on our living habits. Discussed below are the various components of natural background radiation and the key factors that influence the dose rates that such sources contribute to the public.

## COMPONENTS OF NATURAL RADIATION

There are two basic types of natural radiation; namely, sources that contribute exposure from outside the body and those that contribute exposure from inside. For each type, there are two other contributing sources.

### External Sources

The two primary sources of external exposure are cosmic radiation (from outer space) and terrestrial (from naturally occurring radioactive materials in soil).

***Cosmic Radiation.*** Dose rates from cosmic radiation vary with altitude (Figure 1) (NCRP, 1987a) because the atmosphere serves as a shield from radiations coming from outer space. The higher we go, the thinner the protective atmosphere and the greater the dose rate received. The dose rate from cosmic radiation at sea level (as in Boston) is about 30 mrem (0.3 mSv)/year; at an altitude of 1 mile (as in Denver), the dose rate is about 50 mrem (0.5 mSv)/year; in Mexico City (at an altitude of over 8,000 ft), the dose rate is 80 mrem (0.8 mSv)/year; and in La Paz, Bolivia (at an altitude of almost 12,000 ft), the dose rate is 150 mrem (1.5 mSv)/year (Mark, 1988).

Those of us who do not live at high altitudes may still experience increased doses from cosmic radiation. In a cross-country flight on a jet, passengers receive 2 to 3 mrem extra from cosmic radiation. People going on long flights over the polar regions may receive up to 10 mrem (0.1 mSv) per trip. For approximately 100,000 people who serve as commercial airline pilots and flight crews, annual dose rates in excess of 500 mrem (5 mSv) are common. Dose estimates for astronauts who travel in outer space range from 160 to 1100 mrem (1.6 to 11 mSv) for those involved in lunar flights, 1600 to 7700 mrem

(16 to 77 mSv) for those taking part in experiments in Skylab, and 20 to 500 mrem (0.2 to 5 mSv) for those flying on the shuttle (Benton, 1984).

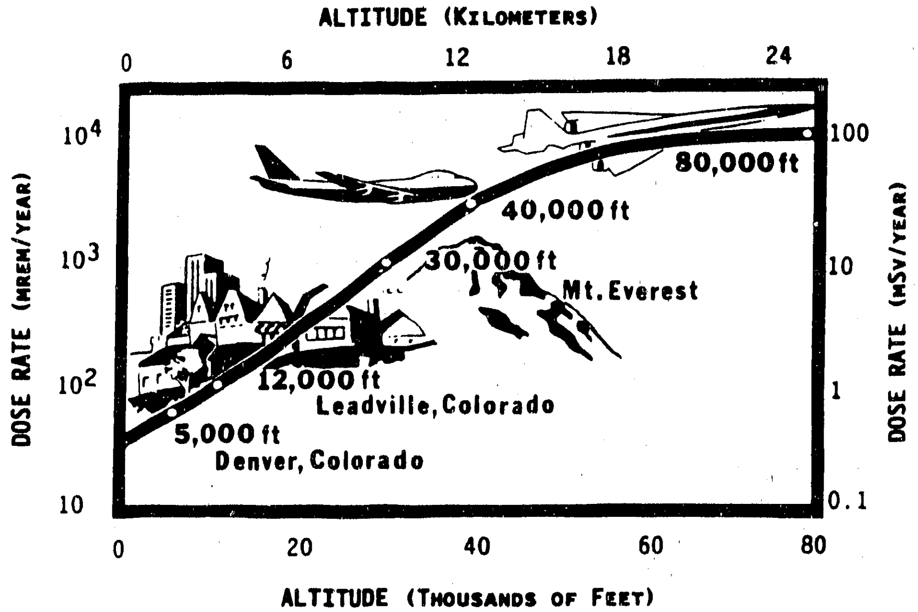


**Figure 1.** Increase in cosmic radiation dose rate with altitude.

***Terrestrial Radiation.*** Location plays a significant role in the dose rates from terrestrial radiation. Dose rates over freshwater lakes with a minimum of dissolved and suspended minerals are essentially zero because water serves as an excellent shield. Dose rates over the open ocean are about 20 mrem (0.2 mSv)/year because salt water contains a multitude of naturally occurring radioactive materials. Dose rates above sandy soils such as those in Florida and on Long Island may be as low as 5 to 15 mrem (0.05 to 0.15 mSv)/year. Above sedimentary rock they may range from 30 to 55 mrem (0.3 to 0.55 mSv)/year, while over granitic rock such as that in Vermont and New Hampshire, and over soils containing high concentrations of uranium, like that in the Colorado Plateau, they may reach 160 mrem (1.6 mSv)/year. Thus, dose rates to members of the population from terrestrial sources vary widely with location. However, dose rates for the contiguous 48 states can generally be divided into the three principal regions shown in Figure 2 (Oakley, 1972).

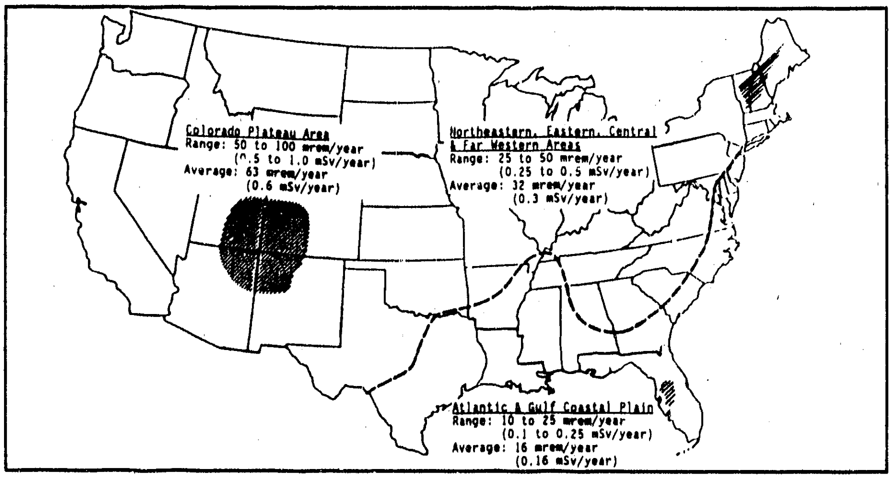


**Figure 2.** Dose rates from natural terrestrial sources in the United States.

Because people spend a major portion of their time indoors, the dose rates they receive from naturally occurring radionuclides can be heavily influenced by the nature of the materials used in constructing the building they are in. For example, dose rates inside houses built of concrete and/or brick, which frequently contain relatively large quantities of naturally occurring radioactive materials, generally exceed terrestrial dose rates outdoors. In contrast, dose rates inside houses constructed of wood are generally lower than terrestrial dose rates outdoors (Figure 3). Wood contains essentially no naturally occurring radioactive materials that lead to external doses and, furthermore, wood serves as a good shield against radiation from the ground beneath or outside a house.

Because dose rates from cosmic and terrestrial sources vary widely, there are major differences in those received by various segments of the U.S. population. Figure 4 shows estimates of the distribution of dose rates to the U.S. population from terrestrial and cosmic sources. This graph is based on data originally published by Oakley (1972) and has been modified to take into account newer information.

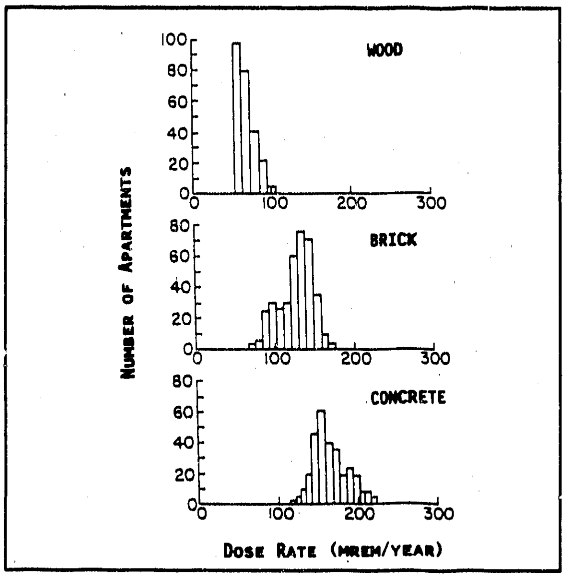


**Figure 3.** Influence of construction materials on dose rates inside apartments.

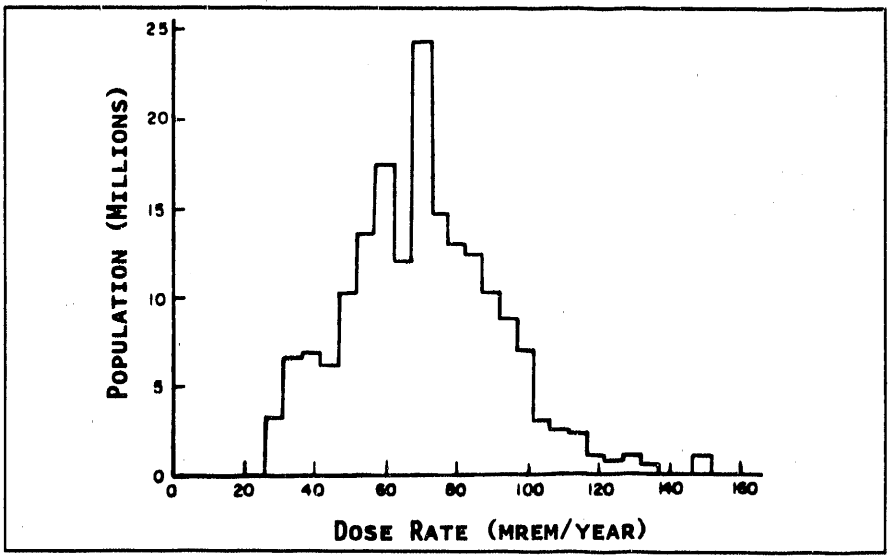


**Figure 4.** U.S. population distribution versus dose rate from terrestrial and cosmic radiation.

### Internal Sources

Internal sources of natural radiation can also be divided into two categories: those that arise through ingestion and those that arise through inhalation of radioactive materials.

***Ingestion.*** The principal naturally occurring radioactive materials that contribute to internal exposure through ingestion are potassium and radium. A common source of potassium is the banana. This radionuclide, common to muscular tissue, contributes an annual dose of about 15 mrem (0.15 mSv) to women and about 19 mrem (0.19 mSv) to men. Because some radiations emitted by potassium are highly penetrating, the potassium in our bodies also exposes people nearby; associated dose rates are estimated to range from 1 to 2 mrem (0.01 to 0.02 mSv)/year. Although we might be inclined to avoid foods containing potassium to reduce these doses, it is important to recognize that potassium in the body is under homeostatic control in the body. Any dietary intake above a minimum will maintain the normal balance. Maintaining such a balance is essential to health. Commercial products, such as Gatorade,® which contains relatively large quantities of potassium, are specifically designed to restore the potassium balance for athletes who have exercised and perspired heavily.

In contrast, radium is not essential to the body, and the amounts ingested can be significantly affected by what, and how much, we eat and drink. For the average adult, dose rates from this source to bone are about 17 mrem (0.17 mSv)/year (NCRP, 1987a). For selected populations, dose rates can be much higher. Well waters in certain areas of the country such as Illinois contain relatively high concentrations of radium. People drinking these waters receive higher dose rates.

One of the most significant sources of radium is the Brazil nut, which is produced exclusively in the Amazon Valley. One of the chemical elements that is essential to the vitality of the Brazil nut tree is barium. In meeting its demand for this element, the tree "mistakenly" takes up radium as a substitute. The entire tree, its bark, trunk, and roots, as well as the nuts it produces, all contain high concentrations of radium. Average concentrations of radium in Brazil nuts range from 1 to 2 pCi/g, with some samples containing up to 4 pCi/g (Penna-Franca et al., 1968). A person eating one-quarter to half a pound of Brazil nuts, not a large amount, in a single day will exceed the radium intake limit for radiation workers.

***Inhalation.*** The major source of radiation exposure from inhalation of naturally occurring radioactive materials is radon and its airborne decay products. Because radon is produced through decay of radium and uranium, it is commonly found in areas where these two radionuclides are present. All decay products of uranium, prior to radon, are solid elements and remain in soil. However, radon is a gas and, once formed, tends to emerge from the soil and enter the air. If radon is released outdoors, it is highly diluted in the atmosphere and does not represent a problem. If radon is released in a house, where dilution is limited, relatively high concentrations can accumulate.

Although there are potential sources of radon inside buildings other than soil, in general the only one that is significant is the water supply. Sources such as building materials, and natural gas used in unvented kitchen stoves, generally do not represent a problem. Thus, the potential for high radon concentrations inside a home is primarily a function of the geology of the area (Figure 5).

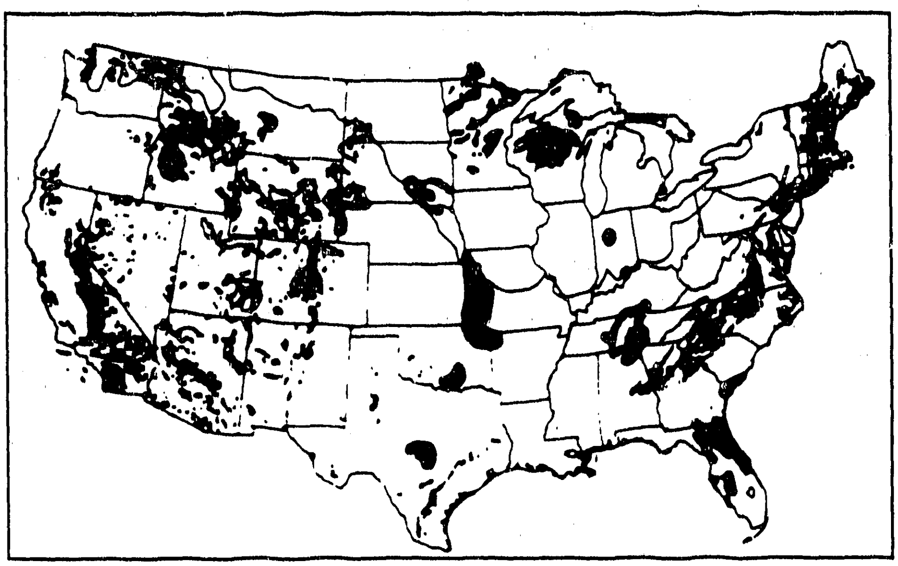

**Figure 5.** Areas with potential for high radon concentrations; selections based on geology.

Several factors influence the concentrations of radon in homes and in a particular place in the home; for example, where you are within the home and how well it is sealed, that is, the degree to which indoor air is diluted with air from outside. A poorly maintained, drafty house will have radon concentrations 70% to 80% of those for a "normal" house. In contrast, a tightly sealed house will have radon concentrations ranging from 1.1 to 1.3 times those for the "normal" house. For houses in which the ground beneath the basement is the primary source of radon, concentrations in the basement are generally almost twice those on the first floor; those on the second floor may be 90% of those on the first floor; and those on the third floor may be 50% of those on the first floor (Cohen, 1989).

For homes in which the water supply contains high radon concentrations, the concentrations in the air can be significantly affected by the ways the water is used. Simply flushing the toilet can lead to releases. Operation of dishwashers and clothes washers and, most especially, use of a shower, can cause significant short-term increases in the airborne radon concentrations in a home (Figure 6) (Hess, personal communication*). Overall, an estimated 50% of the radon in water used in a home becomes airborne and is available for breathing. A concentration of 10,000 pCi/L of radon in water will generally produce an airborne radon concentration of about 1 pCi/L in a home.

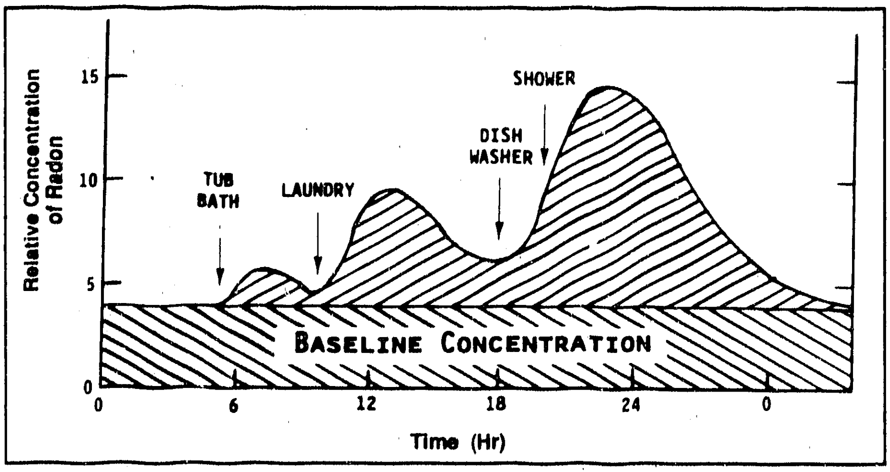


**Figure 6.** Influence of water use on indoor radon concentrations.

* Hess, C. T., University of Maine, Orono, Maine. Personal communication, 1987.

The U.S. Environmental Protection Agency (EPA) and state and local public health departments are currently encouraging people to monitor their homes for radon. Estimates by the National Council on Radiation Protection and Measurements (NCRP, 1987b) indicate that this source contributes an average dose rate of about 2400 mrem (24 mSv)/year to the lungs of the U.S. public. This is an effective dose equivalent rate of about 200 mrem (2 mSv)/year and represents the single most important source of general radiation exposure to the U.S. public today. The estimated distribution of radon concentrations in U.S. houses is shown in Figure 7 (Nero et al., 1986).

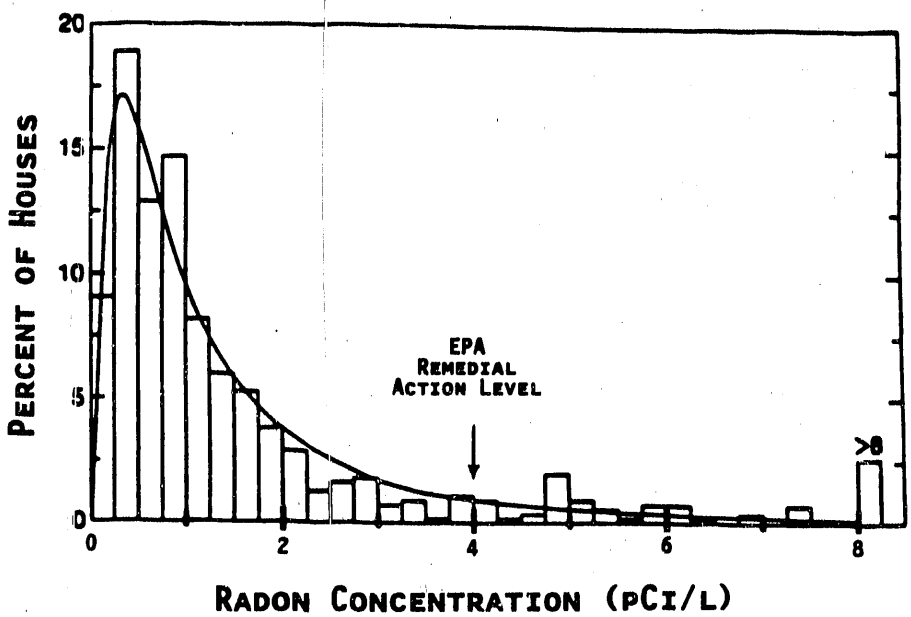


Figure 7. Frequency distribution of radon concentrations in U.S. homes.

## OTHER EXPOSURES FROM NATURAL SOURCES

The naturally occurring radiation sources summarized above are those to which members of the public, in general, are exposed. Many additional exposures occur as a result of using various consumer products. Examples are given below.

### Luminous Compounds and Glazes

Although radium is no longer routinely incorporated into luminous dial clocks and watches, millions of these items are still in use in the

United States. Associated dose rates to the whole body range from about 0.5 to 3 mrem (5 to 30 mSv)/year (Moeller et al., 1988). Localized dose rates to portions of the body in contact with such items can range up to 300 mrem (3 mSv)/year. Today, artificially produced tritium has largely replaced the use of radium in such products. However, it will be some time before the radium sources cease to be in use.

Other related products that can be sources of exposure include eyeglasses tinted with uranium or thorium, which can produce dose rates of 4,000 mrem (40 mSv)/year to the cornea; bathroom tile; false teeth glazed with uranium, leading to dose rates of ~700 mrem (7 mSv)/year to the basal mucosa of the gums of some 45 million denture wearers; and "Fiesta-ware" china, which produces dose rates of 10 to 20 mrem (0.1 to 0.2 mSv)/*hour* to diners (Moeller et al., 1988).

### Cigarette Smokers

Two naturally occurring radioactive materials, lead and polonium, are commonly present in tobacco. Their presence results primarily from deposition on tobacco leaves of airborne radioactive materials resulting from the radon decay. These are longer-lived decay products of the radon gas that is currently a problem inside houses.

Because tobacco leaves are large and sticky, they readily retain these materials once deposited. When tobacco is incorporated into cigarettes, and the smoker lights up, radon decay products are volatilized and enter the lungs. The resulting dose to small segments of the bronchial epithelium of approximately 55 million U.S. smokers is about 16,000 mrem (160 mSv)/year (NCRP, 1987c). This is the greatest dose received by the population from any consumer product and probably represents the single greatest source of radiation exposure to this segment of the U.S. population. The whole-body dose equivalent of this dose to the lungs of a two-pack-a-day smoker is about 1,300 mrem (13 mSv)/year. This is more than 10 times the long-term dose rate limit for members of the public.

## SUMMARY AND COMMENTARY

Table 1 shows typical dose rates from selected artificial radiation sources in our everyday lives. In spite of these sources, natural radiation remains the major source of exposure to the U.S. population. Radon and its airborne decay products account for over half (55%) of the total dose received by the average member of the public (Figure 8).

When dose rates from cosmic and terrestrial sources, and other radionuclides in the body, are considered, natural sources contribute 82% of the total dose to the average nonsmoking member of the U.S. public (NCRP, 1987b). Thus, it would be sound public health practice to direct more attention both to the control of natural radiation sources and to evaluations of their potential health effects.

**Table 1.** Dose rates from artificial rad' ..ion sources.

| Source | Dose Rate |
|---|---|
| Chest X-Ray Examination | 10 to 15 mrem |
| Television Set | < 0.5 mrem/year |
| Smoke Detector | 0.01 mrem/year |
| Nuc!ear Power Plant | < 5 mrem/year |

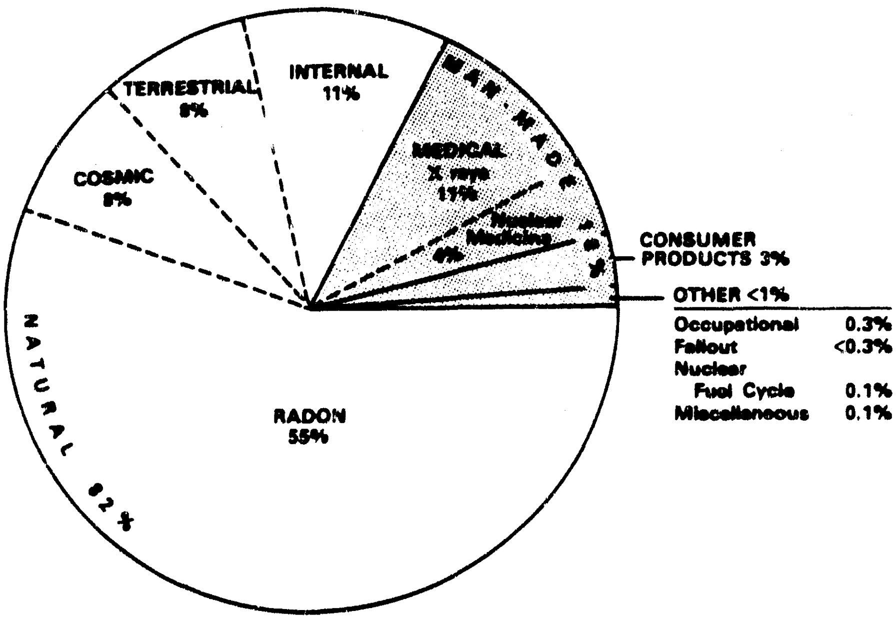


**Figure 8.** Contributions of various radiation sources to U.S. population dose (nonsmokers).

Studies of the behavior of naturally occurring radioactive materials in our environment are proving useful for other reasons. Scientists seeking to develop methods for the disposal of high-level radioactive wastes in a deep underground geologic repository have found it beneficial to study the long-term behavior of naturally occurring radionuclides. Naturally occurring radioactive materials may provide analogs for predicting the behavior of artificial wastes that have been placed in a repository. Underground behavior of other naturally occurring radionuclides, such as radon, are also being evaluated as a possible means to predict natural events such as earthquakes.

In terms of the control of radiation exposures, experience has shown that in many cases reductions in population doses from natural sources can be accomplished far more effectively and at lower cost than for artificial sources. Thus, control of natural sources should be given more attention. However, there are limitations on what can be done with certain natural sources. For example, it is almost impossible to reduce the dose rates from cosmic radiation. In contrast, buildings can be constructed to minimize dose rates from terrestrial sources and building materials, and low-cost techniques are readily available to control radon in houses.

There are limits on how much data can be obtained for assessing health effects of radiation exposures through studies of natural sources. Although comparisons have been made of the health of populations living in areas such as Denver, with high cosmic and terrestrial dose rates, and in Boston or New York, where dose rates are lower, many factors make it difficult to draw definitive conclusions. One factor is air pollution and, most particularly, any differences in the percentages of cigarette smokers in each place. Another is the ethnic background of the populations in the two areas. Other factors include their social and economic statuses. Finally, at the low dose rates involved, the number of people who must be studied (even where all factors are known and carefully controlled) to provide data that are statistically significant is extremely large. Assuming that the difference in dose rates between two populations was 150 mrem (1.5 mSv)/year, the population size required to produce useful data relative to detecting an increase in the incidence of leukemia, even if the two groups were carefully followed for a lengthy period of time, would be over half a million (Table 2) (Eisenbud, 1973).

**Table 2.** Population sizes required to detect increase in leukemia (10 years observation).

| Dose from Birth To Age 34 (mrem) | Annual Dose (mrem) | Required Population |
|---|---|---|
| 5,000 | 150 | 600,000 |
| 10,000 | 300 | 160,000 |
| 20,000 | 600 | 50,000 |
| 100,000 | 3,000 | 1,000 |

It is interesting to examine overall trends with time in the doses received by peoples of the world from naturally occurring radiation sources. Although biased, the data in Figure 9 indicate that people, through changes in living habits, have in many cases added to their dose rates. In the early days, people lived in caves that were undoubtedly of natural origin. In all probability, these caves were located in limestone areas carved out of the ground by flowing underground streams. Because limestone is almost devoid of naturally occurring radioactive materials, dose rates to cave-dwellers were minimal. Because such caves were often located in the side or at the foot of a mountain, this provided considerable shielding against cosmic radiation.

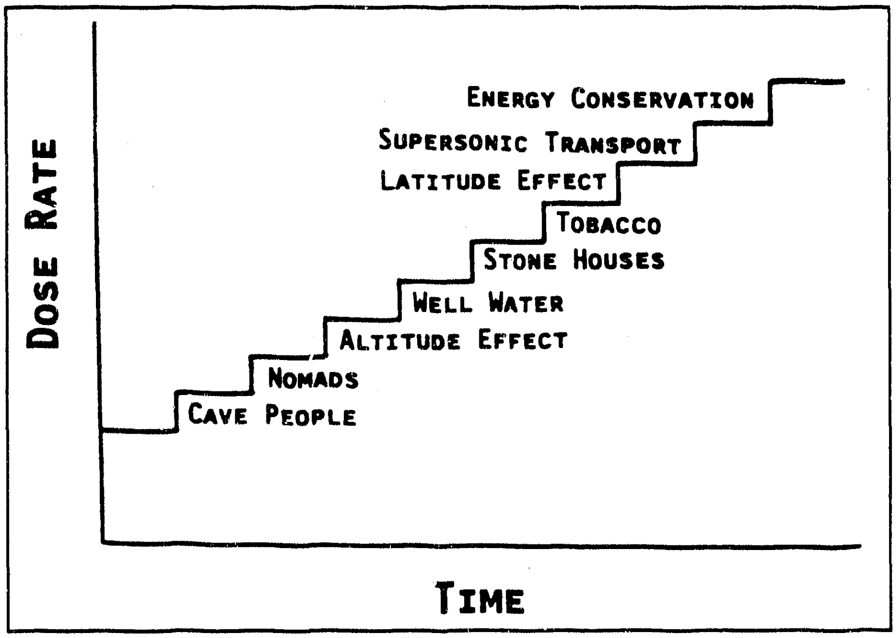


**Figure 9.** Changes over time in dose rates from natural background.

Later, people moved outdoors and became nomads and hunters. They slept on the ground, where they breathed concentrated radon and its decay products as they emanated from soil. Initially, such peoples lived along the shore of a lake or the bank of a stream and used the water for drinking. Later, they moved into the hills, thus increasing their dose rates from cosmic radiation and, becoming tired of the daily journey down to the lake or stream for water, they dug wells and began to consume radium. After leaving the caves, these people first lived in thatched-roof huts; later, they learned to build log cabins; both represented minimal sources of radiation exposure. Still later, they learned to make concrete and brick and to build houses of stone, all of which increased their dose rates. In the latter part of the 15th century, explorers traveled to the New World, where the Indians introduced them to tobacco and exposed their lungs to large doses of radiation. With subsequent population increases, people moved from the tropics toward the North and South Poles. This, coupled with the advent of jet airplanes, which carried people to higher altitudes, increased dose rates from cosmic radiation. More recently, energy shortages have caused many people to insulate and "tighten" their homes, thus increasing their dose rates from radon. Although the accompanying increases in dose rates from natural sources due to these changes cannot be quantified, they are undoubtedly larger than the contributions from many artificial sources that are subject to strict regulatory controls.

## REFERENCES

Benton, E. V. 1984. Summary of current radiation dosimetry results on manned spacecraft. *Adv. Space Res.* 4:153-160.

Cohen, B. L. 1989. Measured radon levels in U.S. homes, pp. 170-180. In: Proceedings of the Twenty-Fourth Annual Meeting of the National Council on Radiation Protection and Measurements. National Council on Radiation Protection and Measurements, Bethesda, MD.

Eisenbud, M. 1973. *Environmental Radioactivity*, 2nd ed. Academic Press, New York.

Mark, C. 1988. Variability of Natural Background Radiation, Special Report. U.S. Nuclear Regulatory Commission, Washington, DC.

Moeller, D. W., J. W. Hickey, and G. D. Schmidt. 1988. Radiation from consumer products. *Consumers' Res.* 71:25-29.

NCRP. 1987a. Exposure of the Population in the United States and Canada from Natural Background Radiation, Report No. 94. National Council on Radiation Protection and Measurements, Bethesda, MD.

NCRP. 1987b. Ionizing Radiation Exposure of the Population of the United States, Report No. 93. National Council on Radiation Protection and Measurements, Bethesda, MD.

NCRP. 1987c. Radiation Exposure of the U.S. Population from Consumer Products and Miscellaneous Sources, Report No. 95. National Council on Radiation Protection and Measurements, Bethesda, MD.

Nero, A. V., M. B. Schwehr, W. W. Nazaroff, and K. L. Revzan. 1986. Distribution of airborne radon-222 concentrations in U.S. homes. *Science 234*:992-997.

Oakley, D. T. 1972. Natural Radiation Exposure in the United States, Report ORP/SID 72-1. U.S. Environmental Protection Agency, Washington, DC.

Penna-Franca, E., M. Fiszman, N. Lobao, C. Costa-Ribeiro, H. Trindade, P. L. Dos Santos, and D. Batista. 1968. Radioactivity in Brazil nuts. *Health Phys. 14*:95-99.