HORMESIS AND HIGH FLIERS: RADIATION RISKS REVISITED

Arthur C. Upton's article (August 1991, page 34) contributes to the radiation phobia so prevalent in the United States by giving an unduly pessimistic view of radiation risks at low levels of ionizing radiation exposure. This letter gives a more optimistic and realistic view of the risks. My comments in no way contradict the well-known fact that large amounts of ionizing radiation may cause cancer.

Upton's article summarizes the BEIR V report[1] of the National Academy of Sciences–National Research Council Committee on the Biological Effects of Ionizing Radiation. It is ironic that the official title of the BEIR V report is "Health Effects of Exposure to Low Levels of Ionizing Radiation" when the conclusions are based on extrapolation from radiation doses above 0.5 sievert (50 rem). This amount of radiation is about equal to the radiation the typical person receives from background radiation in about 160 years. (I call this way of quantifying radiation exposure the background equivalent radiation time, or BERT.[2])

BEIR V supports a linear no-threshold view of the Japanese A-Bomb Lifetime Survival Study data. Another interpretation of the LSS data appeared in an article in the winter 1990–91 issue of *RERF Update*, a newsletter published by the Radiation Effects Research Foundation in Hiroshima. J. W. Thiessen, associate director of RERF, wrote that "of course, it is doubtful whether our epidemiologic data will ever be able to demonstrate, with any adequate degree of confidence, the existence (or absence) of a real threshold at low doses, *notwithstanding the apparent threshold in the LSS data somewhere between 0.2 and 0.5 Gy* (Shimizu *et al.*, RERF TR 5-88)" (emphasis added). The lower value, 0.2 gray, corresponds to the amount of natural radiation typical residents in the United States receive in their lifetimes.

The LSS data indicate that Japanese A-bomb survivors with moderate radiation exposures had a reduced cancer death rate compared with the "controls." Two-thirds of the approximately 100 000 atomic bomb survivors received small or moderate amounts of radiation.[3] From 1950 to 1982 there were 2438 cancer deaths among the 37 173 survivors who received very little radiation—less than 5 millisieverts (500 mrem), the equivalent of about 1.5 years of natural radiation. In the same period there were 1815 cancer deaths among the 28 855 survivors with moderate amounts of radiation—5 mSv to 50 mSv (0.5–5 rem), about equivalent to 1.5–15 years of natural radiation. This is 108 fewer cancer deaths than would be expected if these survivors had received no radiation from the bomb. BEIR V, of course, predicts an increase in cancer deaths. The statistical chances of a decrease of 108 cancer deaths are about one in ten if the group had received very little radiation. This certainly does not support the BEIR V conclusion that *any* amount of radiation may carry some risk of harm.

Table 4 of Upton's article indicates a 3% increase in cancer for a continuous lifetime exposure of 1 mSv/yr based on the BEIR V report. In a footnote Upton indicates that this is "likely to be an overestimate because it includes no allowance for reduced carcinogenicity of radiation at low dose rates." Natural radiation varies considerably over the Earth. In the United States seven Western states (Wyoming, Colorado, Montana, New Mexico, Utah, Idaho and South Dakota) have background radiation levels about 1 mSv/yr higher than those in the other states.[3] You might expect that this would lead to an increase in deaths from cancer. People in these states have about 15% fewer cancer deaths per thousand individuals than the average for the United States.[3] A detailed study was made in 1972–75 of two stable populations in China of about 70 000 persons each whose background radiations differed by about 2 mSv (200 mrem) per year. The cancer rate in the higher-background population was about half that of the other group.[3] Maybe people who sit in uranium caves are onto something!

There are no definitive data to indicate a risk to humans at doses below about 0.25 Sv (25 rem). Many animal experiments indicate that dose equivalents of about this magnitude are beneficial.[4] The possibility of such "radiation hormesis" is rarely mentioned by official radiation bodies such as the NAS–NRC BEIR committee, the National Council on Radiation Protection and Measurements and the International Council of Radiation Units. Their attitude seems to be, if you can't explain it, don't even mention that it is a possibility.

An example of this attitude is found in a recent NCRP report[5] that presents data that would be most easily explained by radiation hormesis, yet does not even mention this possibility. Researchers exposed mice to varying amounts of cesium-137 gamma radiation to study the increase of lung adenomas with dose. The incidence of this benign tumor in the control mice was about 30%. A gamma-ray dose of 0.25 Gy (the equivalent of about 80 years of background radiation) *decreased* the incidence of tumors to about 20%. At greater exposures the tumor incidence gradually climbed back up, becoming the same as that of the controls at a dose of about 2.5 Gy—the equivalent of over eight centuries of background radiation!

The results of a long-term study of nuclear shipyard workers were recently released, over three years late.[6] In this ten-year study 28 542 nuclear workers were compared with 33 352 non-nuclear workers. To make between-group comparisons appropriate, the study groups were balanced in the initial sample to provide comparability on basic demographic characteristics. The study included exposures received from the beginning of nuclear ship overhauls in the 1960s until the end of 1981. It is probably the best epidemiological study ever done of cancer and mortality associated with low-level occupational radiation. A technical advisory panel headed by Upton reviewed results and advised on the research. I was a member of that panel and of the radiation dosimetry advisory committee for the study. Deaths in each of the groups were classified as due to all causes, leukemia, lymphatic and hematopoietic cancers, mesothelioma and lung cancer. The nuclear worker group had lower death rates from leukemia and from lymphatic and hematopoietic cancers than the non-nuclear group. The most significant and surprising finding was that the death rate from all causes of the nuclear workers was only 0.76 that of the non-nuclear workers. If the study had shown an *increase* of mortality of 24% for the nuclear workers, it is likely that the results of the study would have made the national TV news four years ago, when the study was completed.

It is reasonable to expect that during 2 billion years of evolution mutations would have occurred that resulted in a benefit from ionizing radiation. Animals possessing those mutations would have had an advantage over their competitors and would have become more numerous. Humans only appeared on Earth about 2–4 million years ago. Since humans evolved from lower animals resembling those that today demonstrate radiation hormesis, it seems reasonable to assume that we should also benefit from the effect. The fact that we cannot conclusively demonstrate it in humans should be no more of a handicap than our inability to demonstrate in humans the radiation mutagenesis that has only been seen in animal studies. Even long-term studies of the offspring of the A-bomb survivors showed no evidence of radiation mutagenesis.

Some studies of irradiated mice show a significant increase in their age at death. If the same increase in longevity could be produced in humans by radiation, our average lifetime would be about 120 years.[3] In Kerala State, India, 5000 people receive an annual background dose of greater than 20 mSv (2 rem), about 45 000 receive more than 10 mSv and 125 000 receive more than 5 mSv, compared with an average of 3 mSv in the United States. The average life expectancy in Kerala State is 10–15 years longer than the Indian national average.[7] It may be significant that the Japanese bomb survivors now have a longer average life than other Japanese despite their 340 additional cancer deaths. (This information comes to me by way of Kelly H. Clifton of the University of Wisconsin, Madison, a former scientific director of RERF.) This difference may be due to better health care.

The current BEIR policy of predicting risk from even the smallest amount of radiation exposure creates an undue fear of radiation in the public and some scientists. An example of this fear was the public outcry against the recent Below Regulatory Concern policy proposed by the Nuclear Regulatory Commission.[8] This BRC policy would have allowed dumping of low-level radioactive waste in

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our landfills such that the general public would receive no more than an additional 10 μSv (1 mrem) a year. This is roughly the amount of background radiation the typical individual receives in one day and about equal to the additional radiation you receive in a 90-minute jet flight. Unlike chemical pollution, radiation levels in landfills are easily measured. Failure to adopt this sensible BRC policy will cost the taxpayers money that would be better spent in other health care areas.

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In a photo caption in his interesting article on health effects of low-level radiation, Arthur C. Upton points out that flight crew members receive annual exposures on the order of 1 millisievert per year, compared with the dose of 0.1 mSv from a diagnostic chest x ray. Recent evaluations by the Federal Aviation Administration and measurements performed under a contract from Vereinigung Cockpit, the German airline pilots' association, suggest that considerably higher exposures may commonly be received.[1] This is due in part to the fact that airplanes on long-distance routes now often fly at altitudes between 10 000 and 12 800 m, where the dose equivalent rate is about 12 microsieverts per hour in northern latitudes. The new evaluations also reflect the revised biological threat from neutrons, an important component of the in-flight radiation environment. As a result of these analyses, both the FAA and the German researchers conclude that exposures in the range of 4–9 millisieverts per year are quite common for pilots and flight attendants working normal schedules.

The FAA has recently published dose data derived for common routes. These indicate that personnel flying regularly between New York and Chicago could expect exposures of about 5 mSv per year, and those flying coast to coast between New York and Seattle might receive exposures of 6.5 mSv annually, while crew members flying a transatlantic route such as New York–Athens might receive annual exposures of 9.1 mSv. For a comparison, the Environmental Protection Agency estimates[2] that those "radiation workers" in the United States who are actually exposed (as opposed to those who are monitored but might not get an exposure) receive an average annual dose of 3.4 mSv per year, while the group with the highest exposures, those individuals working around power reactors, receive an average 6.5 mSv per year.

These analyses do not include the additional dose that is received during a period of solar "storm" activity accompanied by proton events. As an example, in September 1989 a major solar storm caused the dose rate at transcontinental airliner altitudes to rise to an estimated 80 microsieverts per hour. Crew members and passengers aloft during the period of most intense solar activity received a significantly greater dose during that trip than they would have on a day when solar activity was "normal."[3]

Coupled with the risks of radiation-induced cancer stated in Upton's article, the conclusion that pilots and flight attendants are among the most highly exposed workers has prompted epidemiologists to initiate an examination of medical records to see if, in fact, an excess of cancers can be demonstrated among this group. The exposed population is sufficiently large that meaningful data might be evoked by such studies.

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UPTON REPLIES: I am grateful to Robert J. Barish for the additional data that he has provided on levels of exposure to ionizing radiation received by today's high-flying jet transport crews. The data confirm the fact that the exposure of such crews compares with that experienced by contemporary "radiation workers."

In response to John R. Cameron, I should like to point out that the BEIR V committee is not alone in its use of nonthreshold dose–response models for estimating the carcinogenic and mutagenic risks of low-level ionizing radiation. Such models have been used for the same purpose by all national and international expert groups within the past couple of decades.[1] The committee's decision to use such models was based on careful review of the relevant scientific data, including the literature on "hormetic effects" of radiation, as discussed in the BEIR V report. In presenting the estimates derived with the models, the committee emphasized their uncertainties and pointed out that the existing data do not exclude the existence of a threshold in the low-dose domain.

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Underground Nuclear Testing, Continued?

Your Washington Reports story on the Strategic Arms Reduction Treaty (August 1991, page 49) reported briefly on an exchange between Sidney Drell and myself on whether the safety problems of the nuclear warheads in the US nuclear stockpile require continued underground nuclear testing. Unfortunately, the description of this exchange was too brief to characterize adequately either Drell's position or my own. Drell has written to clarify his position (November, page 9), and I would like to take this opportunity to do the same.

My position is that the US should stop testing by 1995 unless there are very strong reasons not to do so. The Nonproliferation Treaty must be renewed in that year, and a significant fraction of the non-nuclear-weapon signatory states made it clear at the 1990 NPT review conference that they would support the strengthening of the nonproliferation regime only if the nuclear-weapon states commit themselves to a comprehensive test ban treaty. The Bush Administration has refused to make this commitment and has put special emphasis on the need to test in order to increase the safety of US nuclear warheads.

There have been two independent reviews of the safety issue—both commissioned by Congressional groups. The first was carried out by a committee headed by Drell.[1] The second was carried out by a retired Livermore physicist, Ray Kidder.[2]

Kidder noted that with the scheduled retirement of older US nuclear warheads, only three warheads in the US nuclear arsenal will not be equipped with the principal safety design features in modern US nuclear warheads: enhanced electrical isolation and insensitive high explosives. He also concluded that the three warheads could be replaced or rebuilt to modern safety standards and tested well before 1995 and that this would require less than 20 tests. He believes that the stockpile would then be adequately safe.

The Drell panel was not sure whether this measure would provide enough safety and urged that the weapons labs be encouraged to explore "inherently safe" designs—a program that would prolong testing well beyond 1995. The example of an inherently safe design the panel gave was one in which the plutonium core of the fission trigger would only be emplaced inside the chemical implosion system when the warhead was armed. If the plutonium were well shielded before this, an accidental explosion of the chemical implosion system could neither cause a nuclear explosion nor disperse a dangerous aerosol of plutonium oxide.

However, there are much simpler ways to "mechanically safe" a nuclear warhead, that is, to assure that there won't be a nuclear explosion even if the implosion system is detonated. For example, a neutron-absorbing material could be introduced into the center of the hollow plutonium sphere and only be withdrawn when the warhead was armed. This type of mechanical safing is well understood and requires no nuclear testing at all.

The remaining risk is the possibility that a chemical explosion or fire might result in the release of a plutonium oxide aerosol. The former case would be much more serious, since an explosion could create a more widely dispersed aerosol with smaller, more inhalable particles.

Steve Fetter and I therefore estimated the consequences of a worst-case accident of this type in which 10 kilograms of plutonium was converted into an inhalable plutonium oxide aerosol by the detonation of the chemical explosives in several nuclear warheads.[3] We assumed that this happened at the Bangor Trident submarine base, just 30 kilometers from downtown Seattle. Depending upon atmospheric conditions and the value of the cancer exposure risk coefficient used, we found that from 1 to 1200 extra cancer deaths could result over the remaining lifetime of the exposed population. Individual risks of cancer death in this exposed population would typically be increased by a few tenths of a percent or less.

Historically there have been only two such accidents, and they took