21st Century Science & Technology Magazine

It's Time to Tell the Truth About the Health Benefits of Low-Dose Radiation

by James Muckerheide muckerheide@comcast.net

(Full text of article from Summer 2000 21st Century*)*

Metropolitan Edison

The myth that radiation is dangerous no matter how low the dose, has scared people about all things nuclear. Here, a tour of the Three Mile Island nuclear plant.

Low-dose radiation is documented to be beneficial for human health but, for political reasons, radiation is assumed to be harmful at any dose. Radiation-protection scientists, and others, who cover up the data that contradict present policy should be investigated for misconduct.

Low-dose radiation has been shown to enhance biological responses for immune systems, enzymatic repair, physiological functions, and the removal of cellular damage, including prevention and removal of cancers and other diseases. Research on low-level radiation has also shown it to have no adverse effects. Yet, current radiation protection policy and practice fail to consider these valid data, instead relying on data that are poor, ambiguous, misrepresented, and manipulated.

With no regard for the cost to scientific truth, and to taxpayers, radiation policy is based on the linear no-threshold (LNT) concept, that holds that radiation at any levels above zero is deleterious. In the LNT view, the known damaging effects of high-dose radiation are linearly extrapolated down the dose scale. LNT contradicts the scientific evidence, which shows that there is a radiation threshold, below which there is no harm and, in fact, there is benefit for human health, a process known as hormesis. In defiance of this evidence, radiation-protection policy relies on falsification of the actual science research and reporting. Such malfeasance warrants scientific misconduct investigations for the results promulgated by some radiation protection-funded scientists.

If we are to contribute to the health of the world's population, we need to apply the data on the benefits of low-dose radiation in clinical settings. Unfortunately, the research funded by the U.S. Department of Energy (DOE), and other research in the area of radiation-protection fail to address these essential biology and medicine objectives. Therefore, research and data assessments must be conducted by independent researchers and organizations that are not dependent on radiation-protection-controlled funding, directed to address the health and medical science.

In particular, the U.S. National Institutes of Health Study Section on Radiation Research reviews, and therefore controls, most of the Federal radiation-related research, instead of relevant research being controlled by the specific disciplines, for example, immunology, genetics, and so on. Since this Study Section is made up of current radiation protection-oriented researchers, it has substantially rejected research that pursues the relevant topics on the role of radiation in medicine, biology, and health. It must be disbanded. Biological and health research on radiation should be considered in the relevant biology and medicine research areas. It is necessary to have organizations doing radiation research whose primary interest is in the health and successful treatment of real patients. Further, independent assessment of the data must incorporate the scientists and analysts who have documented *for decades* that radiation health effects data cannot be linear. Rule-makings by government agencies must be conducted where conclusions on radiation health effects can be accountable, instead of hidden in unaccountable proceedings that fail even to respond to critical science and scientists; such rule-making must also be subject to formal appeals for "arbitrary and capricious" agency decisions.

The beneficial results of low-level radiation can be readily confirmed by researchers committed to understanding the underlying role of radiation in health and medicine. But radiation research journals and

their peer-reviewers, dominated by radiation-protection-funded scientists, constrain publication of results that contradict radiation protection objectives.

Scientific Data Biased by Early Health Physics Goals

The bias against recognition of the benefits of low-dose radiation is not new. In a March 1996 meeting at the U.S. Nuclear Regulatory Commission (NRC), Charles Willis of the NRC stated, as reported in the transcript:[1]

> . . . [I]t's clear to many of us that we are not seeing the predicted ill effects at low doses, as has been pointed out to you. I personally came to this hormesis observation fairly late in the game. It wasn't until 1958 that I was working with the laboratory [Oak Ridge National Laboratory] situation where we were doing experiments with below background levels of radiation, taking the potassium-40 out and seeing what the effects would be on the cellular level when we saw that the cells looked good but they didn't function. So we couldn't publish the results, another ill effect of the paradigm about the linear hypothesis.

Potassium is an element that is essential to life. However, about 0.012 percent of natural potassium is a radioactive isotope, potassium-40. Potassium was processed to separate the potassium-40 from natural potassium at Oak Ridge to conduct radiobiology experiments in the 1950s. Dr. Willis confirms that radiation research, funded for radiation-protection objectives, supported the linear no-threshold concept by suppressing contrary scientific data, and that this activity dates back more than 40 years, to the 1950s. At that time, animal studies using separated potassium were also conducted. The animals were stated to have "done poorly," but they recovered when the extracted potassium-40 or natural potassium was added.

Such potential bias in radiation protection-based research and results should be confirmed or refuted, if we are serious about putting to use the benefits of low-dose radiation for human health. The organisms placed in the potassium without potassium-40 were biologically deficient. This finding is consistent with those of a numerous and wide variety of experiments with organisms that have been shielded from background radiation. For example, organisms grown on glass slides were repeatedly found to grow differently. It was eventually found that those grown on slides that had lower thorium content, and hence lower radiation, were deficient. The LNT precludes this "accident" from being known. But, it will be known. And those who suppressed the knowledge will also be known.

It has been extensively and consistently confirmed that supplemental radiation, above the natural background level, stimulates organisms, enhancing their growth and increasing their mean lifespans. These experiments confirm that any data that contradict the LNT have not been adequately considered by radiation protection agencies and scientists. In addition, many scientists who have been interested in conducting such research, and in publishing such results, were constrained in their efforts. Such experience was reported by Dr. Jake Spalding of Los Alamos National Laboratory to Senator Pete Domenici in 1999.[2] Such experience was also reported by Prof. Dr. Gunnar Walinder, the pre-eminent Swedish radiation scientist, about the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in his 1995 book.[3] Walinder stated bluntly: "I do not hesitate to say that the LNT is the greatest scientific scandal of the 20th Century."[4]

Among the many experiments showing the benefits of low-dose irradiation were those with laboratory animals that had whole immune systems; it was found that at doses below tens of rads, to doses of thousands of rads, the animals had increased average lifespan and no adverse effects. For example, Dr. Egon Lorenz of the National Cancer Institute reported in Manhattan Project records that mice

> were irradiated with 4.4, 1.1, 0.11, and 0.044 [rads] per 24-hr day. ... Male mice conceived and living continuously under exposure to 4.4 r/24-hr day up to total doses of over 2,000 r are comparable with non-irradiated mice as far as weight, coat, and activity are concerned. Mammary tumor incidence is not significantly changed in mice exposed for 10-15 months to doses ranging from 4.4 to 0.44 r per 24-hr day. ...

Subsequent generations, Lorenz said, living "under exposure of 1.1 and 0.11 r per 24-hr day show no damage to chromosomes as evidenced by the raising of 5 to 6 generations with normal litter size and an apparently normal life span."[5]

Notwithstanding this reality, by 1950, Dr. Lorenz states: "It is well-known that absorption of ionizing radiation by tissues is connected with damage, no matter how small the dose," in a study that showed that whole mice had *longer* lifespans than controls in research that exposed the mice to chronic radiation at 0. 11 r/day, or about 40 r/year.[6]

Marshall Brucer, M.D., states with respect to the Manhattan Project:[7]

> Their first experiment, raising mice in an atmosphere of uranium dust, showed exposed mice lived longer than controls. They set up an arbitrary Maximum Permissible Dose (MPD) after proving that mice in radiation fields 10 times the MPD lived longer than controls.

After World War II, Brucer writes, about 20 articles per year mentioned hormetic effects but:

> Health Physicists soon learned that their livelihood depended on scaring the pants off Congress. Every Genetics budget meeting opened its request for funds with an anti-nuclear litany. During the 1960s and 1970s about 40 articles/year described hormesis. In 1963, the AEC [Atomic Energy Commission] repeatedly confirmed lower mortality in guinea pigs, rats, and mice irradiated at low dose. In 1964, the cows exposed to about 150 rads after the Trinity A-bomb in 1946 were quietly euthanized because of extreme old age. In 1981, T.D. Luckey revived a very obvious radiation hormesis. No experimental evidence of damage at low doses existed; self-serving extrapolations from high dose-data dominated health physics.[7]

In the May 1961 *Journal of the American Medical Association* (JAMA), Dr. Hugh Henry, then at Oak Ridge, reported on all low-dose studies (defined as "to about 1 rad per day"!), saying that the results show consistent life-lengthening vs. neither life-shortening, nor genetic effects.[8] He reports on early animal studies that had hormetic effects from internal doses, for example, for uranium and plutonium injections, and feeding of uranium compounds, and for external (gamma and X-radiation). Life-lengthening was regularly found, and radiologists and others with relatively high doses had no adverse health effects. Henry concludes:

> The preponderance of data better supports the hypothesis that low chronic exposures result in an increased longevity than it supports the opposite hypothesis of decreased longevity. ... Increased vitality at low exposures to materials that are toxic at high exposures is a well-recognized phenomenon.

Voluminous, credible peer-reviewed scientific literature data exist. Dr. T.D. Luckey, Professor Emeritus of the University of Missouri School of Medicine, presents a great deal of that literature, with more than 2,000 references.[9, 10] Yet, the regulatory agencies ignore this evidence.

How the LNT Myth Was Supported

In 1996, the Department of Energy investigated allegations about the now-accepted fact that the Oak Ridge National Laboratory mega-mouse studies presented false data on genetic effects, starting in 1951. The lab under-reported the numbers of mutations in the control animals. International programs have now abandoned the mouse data, and are assessing the potential effects of radiation for genetic diseases—something that was never before indicated.

An Oak Ridge geneticist and statistician, who is a member of UNSCEAR, and who had access to the original data and the expertise to analyze them, identified these deficiencies. This geneticist also alleged that the misrepresentations of the data seemed to have been intentional. This allegation was rejected by Oak Ridge. However, the other instances of failing to report scientific data indicate possible confirmation of practices of misrepresenting research in the 1950s. The U.S. Nuclear Regulatory Commission, the Department of Energy, and the Congress, should formally inquire about these allegations, and whether contrary data were adequately considered in reviews, research results, and support for research.

In 1971, after the Federal Appeals Court “Calvert Cliffs decision,” that found the Atomic Energy Commission (AEC) Environmental Impact Statement to be inadequate, the AEC contracted for the “Argonne Radiological Impact Program,” to improve the basis for assessing low-level radiation health effects. Dr. Norman Frigerio analyzed U.S. cancer rates by average background radiation doses for each state, applying the linear no-threshold models. His results were found to contradict the LNT: There were consistently lower cancer rates in high-background-radiation states. This finding has since been consistently confirmed.[11]

In 1973, although Dr. Frigerio had been contracted by the AEC itself to address the regulatory issues of low-level radiation effects—in response to a court action—AEC and radiation science policy interests terminated the study, and the results were not published. This study was presented at a 1976 conference on natural radioactivity, sponsored by the International Atomic Energy Agency (IAEA).[12] But, Dr. Walinder reports, these results were suppressed in the 1977 UNSCEAR report. The same results were similarly arbitrarily dismissed in the report of the Biological Effects of Ionizing Radiations Committee (BEIR III) in 1980, with no scientific inquiry.

The AEC termination of the Argonne National Laboratory’s radiation program should be investigated. The program plan was to continue, to obtain more accurate radiation dose data, to apply the analysis at the more definitive correlation at the county level. The result was expected to confirm the preliminary inverse correlation results. Dr. Frigerio and others stated that it was because of the nature of the results, contradicting the LNT, that the study was terminated. Total populations with significant dose differences are the ideal test of the LNT, but here, again, we see that analysis is suppressed.

The results of the Argonne study, however, have been confirmed in analysis of EPA radiation data of high versus low background radiation states. Conferences on natural background radiation consistently report the lack of health effects, and even the existence of beneficial effects, in high-background exposed populations. The high-background whole-body radiation doses show no adverse health effects, to take just one example, in a stable Chinese peasant population of more than 70,000, living for generations in high radiation areas. The natural radioactivity source in high background areas is *millions of times greater,* it should be noted, than the radioactivity allowed to be released from nuclear facilities or nuclear waste sites. The cost to the public for this “overprotection,” is massive.

How Radiation Is Measured

Radiation “dose,” or “exposure,” is a measure of energy absorbed per unit of mass. There are two sets of units used, the older units having been renamed.

For equivalent tissue damage from different types of radiation, the rem was defined as ”rad equivalent man”—or rad times a quality factor. For gamma and beta radiation, the quality factor for most significant energies is 1, so “rad” and “rem“ are taken as equal in these cases. For alpha rays and neutrons, the quality factor is greater, indicating that there is more damage from the same absorbed energy.

New unit	**Old unit**	**Equivalent used here**
1 gray (Gy) 1 sievert (Sv)	= 100 rad = 100 rem	=100 cGy (centi-gray) =100 cSv (centi-sievert)

Radon: Misrepresenting the Data

In the 1980s, Dr. Bernard Cohen, at the University of Pittsburgh, personally undertook natural background radiation studies similar to those terminated by the Atomic Energy Commission in 1973 (and by AEC's successors, ERDA and later DOE, and the NRC). He tested the LNT using the significant lung cancer data compared with variations in residential radon. Initially, he found that lung cancer incidence in the high-radon area of Cumberland County, Pennsylvania, was lower than the Pennsylvania average.[13] Many other studies found similar results.

Because radon data did not exist at the county level, Dr. Cohen obtained at least 100 radon measurements in the 16 large counties with the lowest lung-cancer rates, and the 25 counties with the highest rates.[14] He also found identical results in the various random counties in which 450 university physics professors at 101 universities supported his effort to obtain residential radon measurements.

Dr. Cohen then succeeded in a private effort to do, for radon and lung cancer, what the U.S. government had terminated with the Frigerio study—measuring radon in 272,000 homes in the most populated U.S. counties. These data also consistently found inverse results, in dozens of independent studies of, for example, "all-rural" counties, "all urban" counties, and so on.[15] Dr. Graham Colditz of Harvard University, a world renowned epidemiologist, contributed to an interim analysis of the data by counties. He confirmed the validity of the epidemiological analysis of these data.[16]

Dr. Cohen also acquired all Environmental Protection Agency and state radon data. These data showed an inverse relationship: the higher the radon levels, the lower the incidence of lung cancer. In the full data set, the inverse correlation exceeds 20 standard deviations, compared with the predictions of BEIR IV. The chance of error is equivalent to one in all the electrons in the universe! Any confounding factor must be: (1) much greater than smoking, (2) inversely correlated with radon, and (3) unrecognized. This is inconceivable—except for one postulate: Radon doses at the range of normal background levels stimulate lung tissue functions to protect against lung cancer.

Radiation-protection interests ignore the confirmed results of Cohen et al. by alleging simply that "they are ecological studies"; these critics provide no scientific basis to refute the data. In fact, there is no documented scientific criticism of Dr. Cohen's results, just general rationalizations of highly unlikely reasons why one study might not be valid. In fact, Dr. Cohen as produced dozens of separate studies that are consistent. Nevertheless, radiation protection interests use unfounded statements to misrepresent to the public that Dr. Cohen's data have been refuted.

Dr. Kenneth Bogen at Lawrence Livermore National Laboratory independently compared 1950-1954 lung cancer mortality for women of ages 40 to 80 and 60 to 80 (who had smoked little), by county, with EPA county environmental (not residential) radon data. He also confirmed the inverse correlation between lung cancer and radon. Dr. Bogen's biological model applies cellular response data to show that the inverse relationship is consistent with known biological responses.[17]

Prof. Dr. Werner Schuttmann, of the former East Germany, and Prof. Dr. Klaus Becker of Berlin, Germany, both documented research results that show that women in the very high radon uranium mining areas of Saxony, Germany, who have negligible smoking, have significantly *lower* lung cancer rates than women in lower radon areas.[18] The *Health Physics Journal* denied publication of the Schuttmann and Becker article, however, as a result of comments by reviewers that contained such non-scientific statements as, "this is just another ecological study," and "everyone knows that Dr. Cohen's studies are erroneous."[19]

LNT supporters erroneously claim that "case-control" studies are "better." However, the accuracy of such studies is completely dependent on the ability to know individual doses. This is true in most case-control studies where doses/exposures are measured and controlled. However, in most radon case-control studies, individual doses are poorly known. Residential radon measurements are used. Therefore, "dose groups" are only statistical estimates, without knowing individual doses. Further, with the small numbers in the sample, combined with the uncertainty of the correlation, there are wide errors. Unlike large population studies, case-control cannot produce accurate or replicable dose-response results. In fact, in contrast, the nature of statistics provides statistical power in large ecological studies, because these apply rigorous statistics that more accurately represent mean doses compared with lung cancer rates.

In addition, the uncertain doses in most radon case-control studies produce much greater bias in the higher-dose region. The high-dose group is likely to include persons who have low-doses, while it is unlikely that the low-dose group will have persons with high-doses. Therefore, the high-dose group will have a bias toward excess cancers that will seem to be shown to result from low radon exposures. In addition, case-control studies do not adequately address cases in the very low-radon regions, where the well-documented effects in Dr. Cohen's data (as well as those in other, more definitive population studies), demonstrate that increased lung cancer is expressed. However, despite all the problems with case-control studies, it has been shown that they do not contradict the results reported by Dr. Cohen and others.

When using a small representative population to produce a substantive basis to apply it to a large population, there can be a reason, or reasons, why the small population does not accurately represent the whole population. This is a "confounding factor." For example, the age distribution of the small population might be different from that of the whole population. If the difference can be quantified, such as in producing an "age-adjusted" analysis, the "confounding factor" can be taken into account. Drs. Fritz Seiler and Joe Alvarez have shown that a "dose-response model" specifying "confounding factors" is necessary to determine a risk (for example, the lung cancer risk from radon). In that case, a "model" with any "confounding factors" must correct for systemic errors in applying the specific small-population data to the whole population. However, Seiler and Alvarez demonstrate that Cohen's results, as confirmed by others, show the actual relationship for the whole U.S. population. Therefore, a precise "model" and any "confounding factors" are irrelevant to "predict" the relationship to the whole population.

EPA, and BEIR IV and VI, substantially misrepresent the data on the risk of residential radon for lung cancer in the United States and the world.

The Case of the Radium Dial Painters

In 1974, the pre-eminent radium health effects researcher, Dr. Robley Evans of the Massachusetts Institute of Technology, rigorously demonstrated in an article in the *Health Physics Journal,* that BEIR in 1972[20] had misrepresented the data on the health effects of radium in order to produce a linear no-threshold result from extremely non-linear data.[21] On Evans's retirement in 1970, the Center for Human Radiobiology (CHR) was established at the Argonne National Laboratory.

In 1981, Dr. Evans gave the "Invited Summary" at an international conference in which it was reported that in thousands of cases of radium dial painters worldwide, there were still no occurrences of bone cancer or nasal carcinoma in individuals who had ingested less than 250 microcuries of radium-226, which produced an estimated dose of 1,000 rad to the bone. A report on these data was published in 1983.

Dr. Evans told the conference:[22]

> The studies of the radium cases during the past dozen years . . . have continued to show no radiogenic tumors, or other effects, in hundreds of persons whose effective initial body burden was less than about 50 microcuries of Ra-226, and whose cumulative skeletal average dose is less than about 1,000 rad.

In 1983, DOE initiated termination of this program, which had been established for the life of the dial painters, while more than 1,000 individuals were still alive. It may be that this message was received by the Radiation Effects Research Foundation (RERF), which was established to follow the Japanese A-bomb survivors for life. The reports of the RERF produce consistently biased data.

It is significant that systemic intake of 50 microcuries of radium-226 is about 125,000 times the annual ingestion of 5 picocuries/liter allowed by the EPA in its drinking water limits. The EPA is even proposing reductions in these limits, which will require even greater public water supply expenditures under EPA program control. If, instead, the EPA were to mandate a moderate revision in its limit by a factor of 4, this would essentially eliminate the need for monitoring for radium in drinking water, and eliminate significant unnecessary costs, while still providing a safety margin of 30,000 (times 50 picocuries) to a person who drinks 1.1 liters per day of that water.

In the 1990s, follow-up after "another decade" confirmed the original radium dial-painter health effects results. Dr. Robert Thomas, a long-time radiobiology researcher at Los Alamos National Laboratory, a program manager at DOE, and the last Program Director of the Center for Human Radiobiology at the Argonne National Laboratory, showed that the log-normal distribution of cancers projected a threshold of 400 rad without even considering the total absence of cancers in the large population with doses below 1,000 rad.[23] Work by Dr. Evans, and Dr. Constantine Maletskos and others, similarly established that such a threshold was valid.[24] Further analysis by Dr. Robert Rowland, former Director of the Center for Human Radiobiology, has more conclusively determined that a threshold exists. Rowland states:[25]

> Today we have a population of 2,383 cases for whom we have reliable body content measurements.
> . . . All 64 bone sarcoma cases occurred in the 264 cases with more than 10 Gy, while no sarcomas appeared in the 2,119 radium cases with less than 10 Gy.

To contradict these objective results, in an analysis used in BEIR IV to misrepresent the actual data, Drs. Charles Mays and Raymond Lloyd selected, first, a wide low-dose group range that included no cancers, and, second, a wide dose-group range that included the lowest dose with cancer; from this, they manufactured a "linear" result.

In the *Federal Register* in 1991, the EPA explicitly favored duplicity in the matter, by responding to a recommendation by its Science Advisory Board (SAB) that the radium dial painter data be used to establish the radium limits in water, as follows:[26]

> EPA policy is to assess cancer risks from ionizing radiation as a linear response. Therefore, use of the dial painter data requires either deriving a linear risk coefficient from significantly non-linear exposure-response data, or abandoning EPA policy.

Simply put, science is irrelevant in this campaign to mislead the public about the hazards of radium, and radiation generally.

It was after a notorious radium poisoning case in 1932, that the Food and Drug Administration (FDA) achieved control of radiation from Congress. Well-known Philadelphia industrialist and socialite Eben Byers, died from a massive overdose of radium ingested in large quantities over three years. The Byers case had great publicity and created great public fear of radiation. The truth is that Byers did not die of cancer. Bone necrosis led to removal of his jaw and other interventions that put a gruesome image on the radiation effects. The FDA did not then assess the dose effects to the thousands of persons who had also used radium and other radiation sources in more moderate amounts; or acknowledge that Byers had been the victim of the equivalent of a drug overdose.

The amount of radium that Eben Byers ingested daily is about 2,000,000 times the current EPA limits, based on drinking 1 liter/day at 5 picocuries per liter (pCi/l). The threshold for latent bone cancers from ingesting radium by the dial painters is more than 125,000 times the annual limits from drinking water at 5 pCi/l.

After the Byers case, Dr. Edna Johnson, and others, suppressed well-known data on the stimulatory effects of low doses of ionizing radiation, especially, a 1936 report for the National Research Council, to claim that "radiation is harmful at low doses."

Occupational Studies Show No Adverse Effects

One of the largest and most thorough studies of the effects of low-level radiation on nuclear industry workers is the Nuclear Shipyard Workers Study, funded by DOE but never published. This 10-year, $10-million study of 39,004 nuclear workers, carefully matched with 33,352 non-nuclear workers, from a population of 108,000 nuclear workers in a total population of about 700,000 workers, was completed in 1987.[27] After pressure on the DOE, which had chosen not to publish the data and conclusions, the Department finally, in 1991, issued a contractor's report on the study, with a two-page press release.

The radiation workers in the study were exposed to external cobalt-60. They had good radiation dosimetry and records in the Nuclear Navy program controlled by Admiral Hyman Rickover. They had limited confounding work experience. Nevertheless, these data were kept out of BEIR V, even though the Technical Advisory Panel Chairman for the Nuclear Shipyard Workers Study and the Chairman of BEIR V were the same person, Dr. Arthur Upton. Instead, BEIR V used other non-published sources, just as such sources have been used in the 1998 draft National Committee on Radiation Protection and Measurements (NCRP) SC1-6 report, also chaired by Dr. Upton.[28]

In the summary, the Nuclear Shipyard Workers Study reports that the high-dose mortality rate of the nuclear workers was 0.76 that of the non-nuclear workers in the control group. Of special significance is the fact that the summary report did not include "all cancer," mortality, which is a most common factor, and of most interest in any such study. However, Myron Pollycove, M.D., of the Nuclear Regulatory Commission, documented that the "all cancer" mortality in the detailed tables is also statistically significantly lower among nuclear workers than among the non-nuclear workers.

After long negotiations, Dr. Genevieve Matanoski, Principal Investigator for the shipyard worker study, received another substantial contract from DOE in 1994, and retired as Head of Epidemiology at Johns Hopkins University. Now, more than 5 years later (and about 12 years since the completion of the study), no papers have been published. There is no report to Congress, the shipyard workers, radiation protection agencies, or to the public. There is substantial concern about the integrity of the data, which have been kept under wraps. Further, this most definitive nuclear workers study was not included in a study of "all" U.S., U.K., and Canadian nuclear workers, contracted by DOE with the International Association for Research on Cancer (IARC).[29]

The IARC study included only 95,000 U.S., U.K., and Canadian nuclear workers, and suppressed the more definitive nuclear shipyard workers study. IARC even misrepresents its own data to claim that its results support the LNT. This IARC study, using only the weaker, early nuclear worker data, was then proclaimed as a "definitive study," and a public relations campaign was launched, before the data were published, to claim that the IARC study is the "best evidence of the linear dose-response to low doses." (Ironically, this may be true, to the extent that the study shows, yet again, that no evidence exists for a low-dose linear dose-response!)

The IARC claim rests on data for one cancer, leukemia (absent chronic lymphocytic leukemia) with 119 deaths in a total of 15,825 deaths in the study. One data point in the small highest-dose group at "more than 40 cSv" (centi-sieverts) shows 6 observed deaths vs. 2.3 expected deaths. The 116 leukemia deaths in the six dose groups below 40 cSv show no excess leukemia. The IARC "analysis" discounts data points in the four data groups that are below the controls. This enables the IARC analysts to produce a "trend analysis" in which the 6 vs. 2.3 deaths data point alone causes a positive slope.[30]

These data are then made to seem statistically valid by applying Monte Carlo modelling of 5,000 trials. The manipulated data are then used to support the LNT. This is highly questionable as science, as policy-making, or as ethics. The IARC, along with the international (IRCP) and national (NRCP) committees on radiation protection, and other radiation protection organizations, then mounted a public relations campaign to widely disseminate these conclusions, before the actual data were published. Once the report was published, reviewers found that the data do not support the claims. The NCRP and others know this fact. Actually, as Dr. Don Luckey has shown, the full data of the workers in this study demonstrate a *hormetic* effect, consistent with many other nuclear worker vs. non-nuclear worker dose-response studies.[31]

With small numbers of cases in dozens of specific cancers, it is more surprising that no other cancers reflect the 1 in 20 possibility of exceeding the normal range of statistical significance. Dr. Warren Sinclair, President Emeritus of the NCRP and a controlling influence in NCRP, ICRP, UNSCEAR, and the National Research Council/Board of Radiation Effects Research (BRER), however, misrepresents the IARC report as "vindicating" the LNT hypothesis. Not only does this misrepresent the data, but such a conclusion is contradicted by the lack of health effects in millions of people (1) exposed to moderate radiation doses, which are often much more well defined, especially from medical workers and patients, and (2) to high-dose natural background radiation sources. However, the NCRP and radiation protection interests claim that this is "the best study" to confirm that the LNT is valid. The ICRP/NCRP/BRER group would not use it

so consistently if there were any obviously better studies to support the LNT hypothesis. On that basis alone, the LNT can be seen as refuted.

Dr. Luckey summarized the major nuclear worker vs. non-nuclear-worker studies. He shows that the nuclear workers have 52 percent of the cancer rate in comparable non-exposed workers, in 7 million person-years of exposure![32]

Dr. Luckey notes that, as with other natural nutrients (for example, vitamins and minerals), supplementation is warranted to provide for deficiencies that affect human health. In this case, supplementation of a "radiation deficiency" is warranted.[31] These data further indicate the need to confirm the beneficial effects of low-dose radiation. Unfortunately, such research objectives are not supported, and in fact, are constrained, by the radiation-protection interests.

The Case of BEIR V, 1990

It is important to consider that BEIR V primarily relies on the Radiation Effects Research Foundation Japanese survivor studies.[33] Six other primary studies are identified as "used for model fitting" (pp. 162-3), and these studies are claimed to support the LNT. However, even these few studies have substantial contradictory evidence that BEIR V does not address. Some have internal contrary data. Some are criticized in the literature. For some, other equivalent populations show contradictory results, and stronger studies of other populations produce contrary results. In some cases, arbitrary non-scientific statements dismiss contradictory data without justification. Some populations, especially medically exposed persons, have greater doses than those that BEIR V identifies as "data sets used for model fitting," but they are not included in the BEIR analysis, as they are now not included in the draft NCRP SC1-6 report. Many do not have high-dose effects to project a straight line to zero dose.

Finally, some significantly exposed populations, especially medically exposed populations, of potential significance to assessing radiation health effects, are not studied by the radiation-protection interests; for example, populations who live in areas of high natural background radiation, and persons who use and work at radium and radon spas.

Japanese Survivors Study

The Radiation Effects Research Foundation (RERF) studies of Japanese atomic bomb survivor data at low doses have been substantially questioned, without resolution. This is especially true since the Department of Energy's arbitrary reassignment of the RERF from the National Academy of Sciences to a DOE-recruited and selected investigator at Columbia University. Many independent studies of the RERF data contradict the RERF analyses, even when limited to using the RERF's own processed data in the absence of the ability to access the raw data. Even BEIR V consultants were unable to obtain the data to undertake an independent analysis.

Some of the RERF data show more evidence of hormetic effects than adverse effects at low doses. However, critical analyses are not considered by radiation protection interests in BEIR V or NCRP SC1-6. Certainly however, in the first instance, the conditions of doses to persons exposed directly to an atomic bomb, and confounding factors of survivors, both before and after the bombing, are of no significance to the assessment of the health effects of chronic low-dose exposures to environmental contamination. Use of the RERF results for the assessment of health effects is well known to be inappropriate, because the exposure does not apply to radiation protection for workers or for the public exposed to chronic and highly fractionated and low dose-rate radiation, especially for extreme costly cleanup and decommissioning standards.

Virtually all analysts, including the RERF researchers (as expressed at the November 1997 International Atomic Energy Agency conference in Seville, Spain), have stated that the instantaneous gamma and neutron atomic-bomb-exposed population is not relevant to the assessment of effects for low-dose rate and low-dose exposures. In his book mentioned above, Dr. Gunnar Walinder also reports on the "expectation" of UNSCEAR members that the RERF data would be manipulated to produce "expected" results that support the LNT.[3]

It is also common knowledge that BEIR V states that there are no adverse effects below a high dose, but then presumes a straight line from the high dose to zero. For example, for colon cancer, BEIR states that: In the atomic-bomb survivors there is no excess cancer "evident in doses below about 1.0 Gy." Nevertheless, BEIR applies the linear model down to zero. This presumes effects of radiation to doses of less than 0.0001 Gy, with a radiation protection policy specifying that even 0.00001 Gy should not be ignored in assessing collective dose and regulatory controls (for example, as in the NCRP Report 121).

Relative to significant populations with good dosimetry and relatively unconfounded results—for example, among medical patients and practitioners—the Japanese survivor results are both highly questionable and largely meaningless to the assessment of low-dose, low-dose-rate radiation health effects for radiation-protection policies. They do indicate some agreement with high-dose rate exposure results in animals and humans, which have demonstrated beneficial effects at low to moderate doses.

More Misrepresentation: Fluoroscopy of Women with TB

The individuals in the Canadian fluoroscopy study of breast cancer in women with tuberculosis, by Miller et al., [34] is the second largest exposed group listed in the BEIR V data sets as the set "used for fitting the data." As noted, this study explicitly misrepresents its own data to report a linear dose-response in the literature and BEIR V. A plot of this data was presented to the NCRP annual meeting by Dr. E.W. Webster in April 1992. It has been published elsewhere in the literature, and is contained in the Radiation, Science, & Health "Data Document,"[34] and in the 1995 *Nuclear News* article,[35] both of which are referenced in the draft NCRP report. Below about 30 cGy (centi-grays) there is a highly statistically significant reduction in breast cancer. This reduction is by one-third in the largest group with a mean dose of 15 cGy, which is 2.7 standard deviations below zero risk. This equates to 10,000 fewer cancers in 1 million women at 15 cGy, instead of the false statement that 900 excess cancers are expected. (This is consistent with other evidence of reduced breast cancer from low-dose radiation exposure, for example, in the studies by Makinodan.[36])

In the Canadian study, a straight line is projected from the high-dose data through zero. This forces a linear relationship, despite the data—a consistent way data have been misrepresented in many studies. (See figure) Nevertheless, BEIR V also applies this false straight line in its report, which is presumably the reason to use the Canadian study at all. BEIR does not include more substantial studies that fail to show any adverse effects that can be claimed to support the LNT.

NCRP members continued to claim that this study supports the LNT in 1995 and 1996, using this widely known false straight line to zero. An inquiry is needed to establish whether the authors intended to report the data inaccurately.

In 1996, an "update" of the study was published by Dr. Geoffrey Howe, the second author of the original Canadian study.[37] (DOE recruited Dr. Howe to Columbia University, and reassigned the Radiation Effects Research Foundation study to him from the National Academy of Sciences.) Howe then claimed that the data now fail to show the hormetic effect. However, in Howe's analysis, the large low-dose groups are collapsed to one low-dose group of 1 to 49 cGy. This effectively obfuscates the data from the largest groups at 15 cGy (10 to 19 cGy) and 25 cGy (20 to 29 cGy) and 0-9 cGy, and from the 30-39 cGy, and 40-59 cGy groups. When challenged on this conclusion at a meeting at the National Academy of Sciences in 1997, Dr. Howe stated only that the low-dose groups were "not informative." He responded similarly at a meeting at Chalk River, Canada. However, the low-dose groups in the Canadian study had the largest number of cases, with the smallest errors. The draft NCRP SC 1-6 report states that the later paper by Howe "refutes" the 1989 study. It also states that this is confirmed by a yet later paper by Howe (cited as "1998, in press"), but the report does not provide an explanation or scientific basis for this statement. It was later determined that the paper was never published and was never "in press."

The NCRP report makes this uninformative, dismissive comment to this most significant study (judged so even by BEIR V, which has the same person as chairman as the NCRP SC 1-6), which has been extensively assessed and referenced by scientists who question the LNT, and who introduced it explicitly to the NCRP Committee.

The 1989 Miller study is even actively suppressed in the 1994 UNSCEAR Report, Appendix B, as described by Dr. Pollycove in an NRC transcript. However, the NCRP report is filled with voluminous data of limited, or no applicability to assess adverse health effects, or even biological effects in whole organisms—all data, of course, to support the LNT.

Note also that Dr. Howe published an analysis of lung cancer in these women.[38] They have significantly lower lung cancer at doses below about 2 Gy (200 rad) than the low-dose group, consistent with many other studies, as presented by Drs. Harald Rossi, a member of the BEIR III committees and ICRP, and Marco Zaider, who reviewed all relevant data, finding that lung cancer is lower with exposure to low to moderate doses, from X-rays and other sources.[39]

Evidence of Beneficial Effects Ignored or Suppressed

The data on the beneficial effects of low-dose radiation, including uses of radiation in the first half of the century, have not been studied or considered by the regulatory bodies charged with radiation policy making. The health and medical benefits to patients who receive significant low and moderate diagnostic exposures are not considered, as with the Canadian fluoroscopy breast cancer study. In order to properly assess low-dose effects, all studies should analyze the dose range *below* the level at which adverse effects are demonstrated.

The biological evidence that organisms in below-normal radiation background have demonstrated adverse health effects has also not been considered, or even confirmed and evaluated. But more important, the data on many organisms that have demonstrated beneficial effects from supplemental radiation, including the prevention and elimination of cancer and other diseases, are not considered.

The extensive evidence that low-dose radiation stimulates immune responses is not considered, including the many documented sources in the UNSCEAR 1994 report.[40] Such research has indicated the mechanisms of successful treatment of some cancers by stimulating the immune system using low-dose radiation (both alone and in combination with traditional high-dose cancer therapy). Such results have been reported by Dr. Sadao Hattori[41] from the work of Drs. Sakamoto and Miyamoto[42] and Dr. Takai[43] in Japan, and others. As noted by Dr. Hattori, funding for this research is constrained by radiation-protection interests that prevent such government support of medical research.[44] Private investment in research is constrained by the lack of potential profits in medical applications that would potentially provide health care, and even cancer cures, by low-cost low-dose radiation treatments vs. pharmaceuticals, for example, for chemotherapy, “genetic research,” and so on. These research opportunities can also produce highly successful research careers, whether or not there are successful and cost-effective treatments of real patients.

Low-dose total body irradiation and half-body irradiation has successfully treated and prevented some cancers, as documented in Japan and elsewhere. That breast cancer and other cancers have been prevented or treated should be data to be investigated, not suppressed. It is costing the public hundreds of billions of dollars in environmental cleanup alone, to control radioactivity sources that are far below natural background radioactivity. But this “radiation protection” policy may have even greater costs to women with breast cancer, and to millions of others with cancers and other diseases that may be readily preventable or treatable at low cost, with inconsequential “side effects,” by low-dose radiation treatment. There is also substantial reason to believe that low dose radiation treatments will be effective against HIV/AIDS.

In addition, research is constrained on the millions of persons who have used radium and radon balneology (http://www.radonmine.com) for health and medical applications throughout the world. Such research that has been performed is not considered in establishing radiation-protection policy, as with the radium dial-painters and others with high radium burdens. The positive medical results of such practices are also not considered—at great cost and to the detriment of the public in resolving the role of radiation and health.

Stimulating Health Benefits on the Cellular Level

The biological justification claimed for the LNT model is that a single ionizing photon or particle can damage DNA in a cell, and that this damage can lead to cancer. But an adult body is impacted by about

15,000 nuclear rays or particles every second—there are more than a billion such events every day—from natural sources. And each day, the DNA in each cell loses approximately 5,000 purine bases, because the body's normal heat breaks their linkages to deoxyribose. More damage is caused by normal cell division and DNA replication. But the most damage—a million DNA nucleotides in each cell damaged each day—is caused by free radicals created in the normal process of metabolism, resulting from routine eating and breathing and the stress of heat and exercise.[46]

Radiation causes more double breaks per event in the DNA than normal metabolism does, and these are harder to repair than single breaks. But even given this difference, the mutations (unrepaired or misrepaired damage) from metabolism outnumber those caused by natural radiation by 10-million-fold.[47] There are a large variety of anti-oxidants that prevent damage, enzymes that continually repair damaged nucleotides in DNA, and removal processes to eliminate those it cannot repair.[48] Even high-level radiation adds only a few more mutations to the millions that are occurring from metabolism.

Corbis

The mice that lied? Whether deliberate or not, the control group data on radiation and mice were tampered with. Here, mice from the experimental colony at Oak Ridge National Laboratory in the 1950s, used for examining the long-term hereditary effects of radiation.

"Hundreds of billions of dollars are now being uselessly expended, solely on the basis of LNT-justified radiation protection policies, while the public is misled to believe that these expenditures are protecting public health."

The effect of low-level radiation, which is not strong enough to degrade the body's tissue repair capacity, is suggested by how the body reacts to low levels of other potential toxins. When small quantities of disease bacteria or toxic metals are taken into the body, the result is to stimulate the immune system. One effect is that subsequent attacks by this toxin, in larger amounts, are more effectively countered. Radiation works in an equivalent way. Numerous studies have shown that low-dose radiation enhances immune functions, enzymatic repair capabilities, and cell removal functions, and stimulates cellular and DNA repair mechanisms. This improved immune response affects the entire spectrum of metabolic damage. Therefore, if and when the body's defenses are degraded, low-dose radiation improves the general protection, repair, and removal of damaged DNA and cells.

As discussed above, organisms and animals at low-level natural background radiation or sub-ambient radiation levels, consistently show higher cancer rates and other physiological deficiencies. They recover when returned to normal background radiation levels or when they are provided supplemental radiation from external sources.

Therapeutically, the work in Japan, and in the United States, has shown that 10 to 15 cGy full-body or half-body X-ray doses, delivered in 1 to 2 minutes, several days apart, stimulate the body's defense mechanisms. Specific immune responses were sufficiently definitive in animal studies to justify clinical trials for cancer suppression in human beings, by Dr. Sakamoto and associates. The patients were generally far-advanced cases, therefore not ideal candidates for immune function stimulation. However, individual cases were successful, and a long-term clinical trial on non-Hodgkin's lymphoma patients has confirmed that the group that received low-dose radiation substantially outlived the control group at 5 years and 10 years.[49] (See figure)

New initiatives are under way to establish the role of radiation in health, rather than to maintain the constraints of committees and research committed solely to radiation protection. More is needed. However, existing voluminous radiobiology and epidemiology data provide sufficient bases to refute the LNT, and to find that low-dose radiation does not constitute a public health hazard, and to determine that it is beneficial. Directed research is necessary to better understand the precise mechanisms, to quantify the various levels and conditions at which these benefits exist, and to more precisely establish the levels

and conditions at which human exposure can be considered safe. But those levels are at least many multiples of average natural background radiation for chronic exposure.

Research Needed on Low-dose Radiation As a Treatment for AIDS

There is every indication that low-dose radiation could be successfully used to treat HIV/AIDS. Because AIDS is an immune deficiency disease, and because strong and enhanced immune response has succeeded in preventing full-blown AIDS in persons with HIV, it can be expected that the stimulating effect of low-dose radiation will suppress the development of AIDS in persons whose immune systems are degrading.

It is known that low-dose radiation, in conjunction with small amounts of inactivated tumor cell antigen, have dramatic successes in preventing and retarding tumor development. Such an effect can be reasonably anticipated, and should be researched, for use with HIV vaccines.

Another indication of success with immune system stimulation comes from a case in California, where a transplant patient received a low radiation dose to help prevent rejection of a transplanted organ from a baboon. Although the transplant failed, the patient was in remission for an extended period of time, which was hypothesized to be in response to the low-dose irradiation stimulation.

...

Time for Extreme Corrective Action

Hundreds of credible scientific studies, reported in the peer-reviewed literature, during the 50 years since the Manhattan Project studies, demonstrate beneficial responses to low-level radiation. With more than 2,000 studies going back more than 100 years, research has consistently demonstrated beneficial health effects and biological responses.[50] The LNT has been substantially contradicted. However, these data are shown to be systematically ignored and actively suppressed, and their research terminated, by the radiation-protection interests that control radiation science policy and scientific reviews. To the contrary, no evidence of adverse effects for human beings exists in hundreds of studies in low-, moderate, and even high-radiation-dose populations that in any way confirm the LNT premise.

The LNT hypothesis is a fiction, maintained by a closed, biased, interest group at massive cost to the taxpayers, electric ratepayers, and medically insured public. Its cost will be even higher for future generations, because of the resultant constraints on the human benefits of nuclear technologies. Hundreds of billions of dollars are now being uselessly expended, solely on the basis of LNT-justified radiation protection policies, while the public is misled to believe that these expenditures are protecting public health.

Appropriate extreme corrective actions are needed:

(1) There must be an immediate deferral of the massive expenditures of the site “cleanup” programs, pending an urgent preliminary scientific review, which must be led by persons who are not committed to, or who do not have conflicts of interest in, the funds that support the LNT.

(2) The numerous cases of “scientific misconduct” must be documented, and formal allegations made for adjudication.

(3) BEIR VII must be terminated, along with the NCRP SC 1-6 biased radiation protection policy reviews, and the NIH Radiation Research Study Section, and the Board of Radiation Effects Research of the National Research Council. Reviews and research must be conducted by experts within applicable specialized disciplines, in accordance with current epidemiological, medical, and biological knowledge and applications.

(4) The evidence exists to justify the conduct of low-dose radiation clinical trials, which should include HIV/AIDS applications; and research must be conducted to optimize medical treatment modalities and radiation doses.

(5) For radiation protection purposes, radiation "risks" must be objectively quantified, considering the fact that, like vitamins and minerals, ionizing radiation is essential to life, and that we live in radiation-deficiency conditions.

(6) Engineering design and operations must be revised to produce cost-effective and, therefore, highly economically competitive nuclear technologies, for energy (with heat, desalination, and other applications), and for medicine, industry, agriculture, space, and other applications, with special consideration for expedited applications for China and Second- and Third-World countries.

The indirect costs of constraints on nuclear energy, food irradiation, nuclear medicine, and other nuclear technologies essential to development of a sustainable world economy, including the suppression of health and medical benefits, are greater than the direct costs—that are estimated at greater than $2 trillion worldwide. The benefits of radiation technologies can substantially alleviate pending conflicts over oil, food, water, and other resources. Such benefits can also reduce environmental degradation in a world population that is growing at the rate of the total U.S. population every three years, and can help fulfill the growing expectations for individuals in the developing world.

Knowledgeable scientists and analysts are providing the extensive evidence on the data and questioning the process of controlling research and results, and scientific reviews. Radiation health effects and radiobiology expertise and technologies must be reoriented to develop the enormous opportunities to provide the cost-effective health benefits and environmental and energy capabilities, and to reduce potential world conflicts, for the world our grandchildren will inherit.

Jim Muckerheide, the State Nuclear Engineer for the state of Massachusetts, is a founder and President of Radiation, Science, & Health, which is committed to establishing a radiation policy based on science. He is also Co-director of the Center for Nuclear Technology and Society at Worcester Polytechnic Institute in Massachusetts, which is working to establish a "level playing field" for decisions on the costs and benefits of nuclear technologies that are essential to human prosperity in the 21st century.

This article is adapted from a paper he presented at the 8th International Conference on Nuclear Engineering, held in Baltimore, April 2-6, 2000.

Notes

1. ACRS/ACNW, 1996. U.S. Nuclear Regulatory Commission, Advisory Committee on Reactor Safeguards and Advisory Committee on Nuclear Waste Joint Subcommittee: First Meeting, Rockville, Maryland, March 26, 1996.

2. J. Spalding, 1999. personal communication.

3. Gunnar Walinder, 1995. *Has Radiation Protection Become a Health Hazard?* (Nykoping, Sweden: Karnkraftsakerhet & Utbildning AB, Swedish Nuclear Training and Safety Center).

4. _____, 1996. personal correspondence.

5. E. Lorenz, 1954. *Biological Effects of External Gamma Radiation, Part I,* Ed. R.E. Zirkle (New York: McGraw-Hill), p. 24.

6. _____, 1950. "Some Biologic Effects of Long-Continued Irradiation," *Am. J. Roentgenol.,* Vol. 63, p. 176.

7. M. Brucer, 1990. *A Chronology of Nuclear Medicine* (St. Louis: Heritage Publications).

8. H.F. Henry, 1961. "Is All Nuclear Radiation Harmful?," *J. Am. Med. Assoc.,* Vol. 176, p. 671.

9. T.D. Luckey, 1990. *Hormesis with Ionizing Radiation* (Boca Raton, Fla.: CRC Press). Also in Japanese (Tokyo: Soft Science, Inc., 1980).

10. _____, 1991. *Radiation Hormesis* (Boca Raton, Fla.: CRC Press).

11. N. Frigerio, K. Eckerman, and R. Stowe, 1973. “Carcinogenic Hazard from Low-Level, Low-Rate Radiation, Part I,” Rep. ANL/ES-26. Argonne National Laboratory.

12. N. Frigerio, and R. Stowe, 1976. “Carcinogenic and Genetic Hazard from Background Radiation,” IAEA Symposium, Biological and Environmental Effects of Low Level Radiation, Vol. 2, pp. 285-289, (Vienna).

13. B.L. Cohen, 1987. “Tests of the Linear, No-Threshold Dose-Response Relationship for High-Let Radiation,” *Health Phys.,* Vol. 52, p. 629.

14. _____, 1989. “Expected Indoor 222Rn Levels in Counties with Very High and Very Low Lung Cancer Rates,” *Health Phys.,* Vol. 57, p. 897.

15. _____, 1995. “Test of the Linear-No Threshold Theory of Radiation Carcinogenesis for Inhaled Radon Decay Products,” *Health Phys.,* Vol. 68, pp. 157-174.

16. B.L. Cohen, and G.A. Colditz, 1994. “Tests of the Linear-No Threshold Theory for Lung Cancer Induced by Exposure to Radon,” *Environmental Res.,* Vol. 64, p. 65.

17. K. Bogen, 1996. “A Cytodynamic Two-Stage Model That Predicts Radon Hormesis (Decreased, then Increased Lung-Cancer Risk vs. Exposure)” (Livermore, Calif.: Lawrence Livermore National Laboratory), Preprint UCRL-JC-123219, (40 pp. with 150 references).

18. W. Schuttmann and K. Becker, 1997. “Another Test for the LNT Hypothesis: Residential Radon in Saxony,” to be published.

19. K. Becker, 1998. Personal communication.

20. R. D. Evans, 1974. “Radium in Man,” *Health Physics,* Vol. 27, pp 497-510.

21. BEIR, 1972. “The Effects on Populations of Exposure to Low Levels of Ionizing Radiation.” Report of the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR Committee). Washington, D.C.: National Academy of Sciences-National Research Council.

22. R.D. Evans, 1983. “Highlights of the Meeting—Invited Summary,” In *Radiobiology of Radium and the Actinides In Man,* Proc. of an Int’l Conf., *Health Phys.,* Vol. 44 (Supp 1), pp. 571-573.

23. R. Thomas, 1994. “The U. S. Radium Luminisers: A Case for a Policy of ‘Below Regulatory Concern,’&” *J. Radiol. Prot.,* Vol. 14, No. 2, pp. 141-153.

24. C.J. Maletskos, 1994. “Radium in Man—20 Years Later,” *ANS Transactions,* Vol. 71, p. 33.

25. R. Rowland, 1997. “Bone Sarcoma in Humans Induced by Radium: A Threshold Response?” in *Proc. of the 27th Ann. Meeting,* European Society for Radiation Biology, Radioprotection colloquies, Vol. 32CI, pp. 331-338.

26. U.S. Environmental Protection Agency, 1991. *Federal Register,* Vol. 56, No. 138, pp. 33050-127.

27. J.R. Cameron, 1992. “The Good News about Low Level Radiation Exposure: Health Effects of Low Level Radiation in Shipyard Workers,” *Health Phys. Soc. Newsletter,* Vol. 20, p. 9.

28. BEIR V, 1990. “Health Effects of Exposure to Low Levels of Ionizing Radiation,” Report of the Advisory Committee on the Biological Effects of Ionizing Radiations (BEIR Committee) (Washington, D. C.: National Academy of Sciences-National Research Council).

29. E. Cardis, et al., 1996. “Effects of Low Doses and Low Dose Rates of External Ionizing Radiation: Cancer Mortality Among Nuclear Industry Workers in Three Countries,” *Radiat. Res.,* Vol. 145, p. 647.

30. M. Pollycove, 1997. “The Rise and Fall of the Linear No-Threshold (LNT) Theory of Radiation Carcinogenesis,” American Physical Society Meeting, Physics and Society Forum (April).

31. T.D. Luckey, 1997a, “Ionizing Radiation Decreases Human Cancer Mortality Rates,” in *Low Doses of Ionizing Radiation, Biological Effects and Regulatory Control,* IAEA-TECDOC-976, IAEA-CN-67/64, pp. 227-230.

32. _____, 1997b. “Estimation of a Minimum Yearly Radiation Allowance (MYRA),” *J. Clean Technol., Environ. Toxicol. and Occup. Med.,* Vol. 6, No. 3, pp. 239-252.

33. M. Pollycove, 1994. “Positive Health Effects of Low Level Radiation in Human Populations,” in *Biological Effects of Low-Level Exposures (BELLE)* Ed. E. Calabrese (Boca Raton, Fla.: Lewis Publishers).