RADIATION POLLUTION AND CANCER: COMPARATIVE RISKS AND PROOF

Bernard L. Cohen

Radiation

One of the most important physical phenomena in our universe is the existence of electromagnetic waves. They consist of electric and magnetic fields rapidly reversing in direction and propagating through space ("radiating") at a speed of 186,000 miles per second. The number of times per second the direction of the fields go through a cycle (i.e., reverse and then reverse again back to their original direction) is called the frequency, and it determines their behavior and the uses that can be made of them. Frequencies around 1 million cycles/sec are used for radio broadcasting; television uses about 100 million cycles/sec; radar and microwave ovens use about 10 billion cycles/sec; frequencies around 10 trillion cycles/sec are called "infrared"; our eyes sense frequencies of 400-750 trillion cycles/sec, so we call electromagnetic radiation in this range "light"; frequencies of a few quadrillion cycles/sec are called "ultraviolet"; frequencies above a quintillion cycles/sec are called "X-rays," and still higher frequencies are known as "gamma rays." A remarkable property of these radiations is that they occur in bursts, with each burst containing a definite amount of energy, which is proportional to the frequency. In many ways these bursts of radiation may be thought of as particles.

When one of these particles passes close to an atom, the electrons orbiting the atom feel the force of its rapidly oscillating electric field and are shaken back and forth by it. If there is enough energy in the particle of radiation, this shaking is strong enough to knock the electron loose from the atom. Only the highest frequency particles, X-rays and gamma rays, have enough energy to completely

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The author is Professor of Physics, University of Pittsburgh 15260.

separate an electron from an atom.

Since the orbiting electrons are responsible for binding atoms together to form molecules, knocking an electron loose can destroy a molecule. For example, the water molecule is composed of atoms of hydrogen and oxygen, so an X-ray or gamma ray passing near it can break the molecule up into separate hydrogen and oxygen atoms. The very complex molecules that control biological activity of cells can similarly be broken up or otherwise altered when struck by radiation, and it is because of this property that radiation can cause cancer, which is an uncontrolled growth of cells.

In addition to X-rays and gamma rays, "nuclear radiation" includes other particles emitted from nuclei, like electrons, protons, neutrons, and alpha particles. When an atomic nucleus undergoes a transformation, these particles (as well as X-rays and gamma rays) often come shooting out with velocities in the neighborhood of 100,000 miles per second. Since they have an electric charge (or can transfer their energy to other particles that have an electric charge), they will exert electrical forces on the orbiting electrons of the neighboring molecules they pass. Consequently, the electrons of some of these molecules *may* be jarred loose and destroy, or alter, the molecule. This paper will examine the importance of nuclear radiation as a cause of cancer.

How Dangerous Is Radiation?

Although radiation appears very dangerous, we should remember that individuals are struck by about a million particles of radiation every minute from natural sources. One third of this radiation comes from outer space, another third comes from radioactive materials like uranium, thorium, and potassium, which are found in the ground and in materials we derive from the ground; the remainder comes from radioactive materials in our bodies, especially potassium, a substantial quantity of which is vital to life. In addition to these sources of radiation, which affect all our organs, radon gas (a derivative of uranium) exposes our bronchial regions to radiation from the very air we breathe.

Natural radiation is not insignificant. It is hundreds of times larger than the well-publicized radiation exposure from the nuclear industry. However, natural radiation exposure varies considerably with geography and other factors. In Colorado, where the high altitude reduces the thickness of air that shields us from radiation coming from outer space and where the amount of uranium and thorium in the ground is abnormally large, the average exposure from natural sources is more than 50 percent larger than the national average; in Florida, it is 20 percent below average. Choice of building materials can have a substantial effect on radiation exposure. Living in a brick or stone house typically results in 20 percent higher exposure than living in a wood house, and some particular building materials, like the granite used in New York's Grand Central Station and in the congressional office buildings, can more than double a resident's exposure. Finally, in some houses radon levels are 10 or even 100 times higher than outdoor levels, because air leakage has been reduced.

Besides natural radiation, to which mankind has always been exposed, there is an important new source of radiation introduced this century: medical X-rays. A typical X-ray exposes us to 100 billion particles of radiation, or about one fourth as much radiation exposure as the average American receives annually from natural sources. This is hundreds of times more radiation than we can ever expect to receive from the nuclear industry. There are many techniques for reducing radiation exposure in X-rays without compromising their medical usefulness. Moreover, many X-rays are not made for medical purposes, but to protect hospitals and physicians against libel suits. Thus, a change in the legal structure could help us avoid unnecessary medical X-rays.

If we are all being struck by a million particles of radiation every minute, why don't we all develop cancer at an early age? The reason we don't is *not* because this level of radiation is "safe." Even a single particle of radiation can cause cancer, but the probability for it to do so is very small, about one chance in 30 quadrillion (i.e., 30 million billion). Hence, the million particles that strike us each minute have only one chance in 30 billion of causing a cancer. A human lifespan is about 30 million minutes; thus, all of the natural radiation to which we are exposed has one chance in 1000 (30 million/30 billion) of causing a cancer. Statistics show that our overall chance of dying from cancer is one in five, so only one in 200 of all cancers may be due to natural radiation.

The average exposure from a nuclear power plant to those who live closest to it is about one percent of their exposure to natural radiation; hence, if they live there for a lifetime, there is one chance in 100,000 that they will die of cancer as a result of exposure to radiation from the nuclear plant.

Scientific Basis for Risk Estimates

How do we know these risks so quantitatively? Few fields of science have been investigated as thoroughly as the health effects of radiation. The U.S. government has spent over $2 billion on this research since World War II, which has helped to produce over 40,000 scientific papers. Radiation measuring techniques are well developed, highly accurate, extremely sensitive, and relatively cheap. Even student laboratories have instruments capable of detecting radiation levels millions of times lower than those normally associated with harm to health. By contrast, many air pollutants are quite difficult to measure even at 10 percent of harmful levels.

Several prestigious scientific groups, notably the U.S. National Academy of Sciences Committee on Biological Effects of Ionizing[1] Radiation (BEIR), the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), and the U.S. National Council on Radiation Protection and Measurements (NCRP), provide frequent summaries and evaluations of available data and recommend future research directions. In the last four years, BEIR (1980), UNSCEAR (1977), and ICRP (1977) have issued reports assessing the cancer risk from low-level radiation. We shall now review their methodology.

Radiation doses are expressed in *millirem* (mr), with each mr roughly equivalent to 5 billion particles of radiation. The average dose from natural radiation is about 100 mr per year, and medical X-rays give the average American an additional 40 mr per year. The above-mentioned studies by BEIR, UNSCEAR, and ICRP estimated that there should be one extra cancer for every 8-million mr of exposure to humans; or equivalently, every mr of exposure produces a one-in-8-million chance of developing a fatal cancer.

The health effects of high-level radiation are rather well known. Among the survivors of the atomic bomb attacks in Japan, there were 24,000 people who received an average exposure of 130,000 mr; about 120 extra cancers developed among them up to 1974. There were 15,000 British patients treated with X-rays for ankylosing spondylitis (arthritis of the spine) with doses averaging 370,000 mr; they had about 115 extra cancers. More than 900 Germans were treated for that same disease and for bone tuberculosis with injections of radium to the bone averaging 4.4 million mr; 45 developed bone cancer (with 0.1 expected). About 1,700 American women employed during the 1920s painting radium on clock and watch dial numerals used their tongues to put a fine tip on the

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[1] "Ionizing" means knocking electrons loose from atoms.

brush, thereby allowing radium to enter their bodies; their average bone dose was 17 million mr, and 48 of them died of bone cancer (with 0.4 expected). Among 4,100 U.S. uranium miners exposed to excess levels of radon gas due to poor mine ventilation, the average exposure to bronchial surfaces was 4.7 million mr, and up to 1972 there were 135 lung cancer deaths among them (with 16 expected). There have been several other miner groups that have experienced excess lung cancers, such as the group of 800 Canadian fluorspar miners whose average bronchial exposure was 2.8 million mr, resulting in 51 lung cancer deaths (with 2.8 expected). Finally, there have been a number of situations where high exposures have resulted in approximately 10 extra cancers: Women in a Nova Scotia tuberculosis sanitarium exposed to excessive X-rays in the course of fluoroscopic examinations; U.S. women treated with X-rays for inflammation of the breasts following childbirth; various types of pelvic X-ray treatments; children treated with X-rays for enlargement of the thymus gland; patients in several countries fed a thorium compound to aid in X-ray contrast studies; and Marshall Islands natives exposed to fallout from a nuclear bomb test.

If one wants to find similar information on low-level radiation, however, the statistics are limited. For example, suppose one found a group of 10,000 white males who had received an extra 10,000 mr of whole-body radiation. The easiest evidence to find would be excess leukemias because that disease develops earliest and is among the most sensitive to radiation. As a first approximation, we might use the results of high-level radiation studies, which show that leukemias are induced at a rate of about 1.0×10^{-9}/yr per mr of exposure. We would then expect $(10{,}000 \times 10{,}000 \times 10^{-9} =)$0.1 *extra* leukemias per year among this group. In the absence of radiation, one would expect 0.88 leukemias if we take statistics for the entire U.S. In the 25 years over which radiation is effective in causing leukemias, we then expect 22 ± 4.7[2] cases from natural causes versus 2.5 from the 10,000 mr radiation exposures. Obviously, the statistics here are marginal at best. However, the problem goes much deeper, since the total U.S. population is not a suitable control group. Cancer is largely caused by environmental factors and hence is subject to wide variations in incidence rates. For instance, the 0.88 leukemias expected for the U.S. in the absence of radiation varies from 1.0 in MN and DC to 0.77 in ME and NM. This could

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[2] The ± indicates the range of variations expected due to statistical fluctuations. If studies were made on a large number of groups, two thirds of the results should lie between (22-4.7=) 17.3 and (2.2+4.7=) 26.7.

vary the number of expected cases from 19 to 25, making it still more difficult to ascertain that there are two or three extra. Moreover, a group of people with 10,000 mr of extra radiation would typically have more environmental factors in common than merely living in the same state.

Therefore, any experimental study of effects of low-level radiation would need large populations and there would be considerable difficulty in selecting a control group. One way to achieve large numbers of subjects would be to use variations in natural radiation. For example, we could select citizens of Colorado, Wyoming, and New Mexico, who are exposed to about 5,000 mr more than the U.S. average over their lifetimes. However, the leukemia rates in these states are considerably *below* the U.S. average: 8.11 versus 8.81 × 10^{-5}/year for white males and 5.13 versus 5.74 for white females. The same is true for all cancers. The high natural radiation states have annual rates of 140 × 10^{-5} for white males and 114 × 10^{-5} for white females, while the U.S. average is 174 and 130 respectively. The fact that states with high natural radiation have considerably lower cancer rates than average is generally dismissed as indicating only that radiation is very far from being the principal cause of cancer. This point is logically correct. Nevertheless, this author is highly skeptical about whether that attitude would be accepted if states with high natural radiation happened to have somewhat higher than average cancer rates.

Since there is little direct evidence on effects of low-level radiation, the simplest option is to obtain estimates from our abundant data on effects of high-level radiation, by assuming a linear dose-effect relationship. For example, if high-level dose D causes a cancer risk R, we assume that a dose 0.1 D will cause a risk 0.1 R, and so on down to extremely low doses.

This linear dose-effect relationship is nearly always used, with relatively minor variations, to estimate effects of low-level radiation. Moreover, when its use is recommended by the above-mentioned groups, it is accompanied by a statement that this is more likely to overestimate than to underestimate the effects of low-level radiation. There is a considerable variation in opinion about how much any overestimate is likely to be. On the one hand, a sizable number of experts claim that the overestimate is gross, say by a factor of 2-10, while an equally important body of opinion says that linearity does not give an overestimate. We now turn to the evidence behind these positions.[3] It comes from various sources.

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[3] See Cohen (1980).

Repair Processes

There is a great deal of evidence that nature provides mechanisms for repair of radiation damage to biological molecules. For example, a given dose of radiation is generally much less carcinogenic when spread out in time than when received all at once; this implies that damage from earlier doses was repaired before the later doses were administered. There is also direct microscopic observation of repair to chromosomes. From this we surmise that effects of low doses should be largely repaired, whereas repair of the much more extensive damage from high doses would be far less complete. This implies that the linear hypothesis overestimates effects of low-level radiation.

Mechanism for Radiation Induction of Cancer

One of the strongest reasons for believing that the linear hypothesis overstates the effects of low-level radiation derives from our understanding of how radiation induces cancer. While there are many gaps and uncertainties in our information, the general outline is strongly supported by experimental data and is widely accepted. If this understanding is correct, a linear dose-effect relationship overestimates low-dose effects in most cases, and never underestimates these effects.

Animal Data

The large body of data on radiation-induced cancer in animals, down to the 10,000 mr dose range, clearly indicates that the linear extrapolation from high doses overestimates effects at low doses.

Leukemia Among A-Bomb Survivors

Of all types of cancer, only leukemia data from the Japanese A-bomb survivors is sufficient to draw conclusions on low-dose behavior. For the lowest exposure categories, 10,000 mr — 50,000 mr, and 50,000 mr — 100,000 mr, there are definitely fewer cases than would be expected from a linear extrapolation from higher-dose data.

Bone Cancer Among Radium Dial Painters

Among the American women who ingested radium in painting radium on watch dials, there were fewer cases in the low-dose category then would be expected from a linear extrapolation from higher-dose data. The probability that this deficiency is due to statistical fluctuation is quite small, only a few percent.

Environmental Radon Exposure

If the data on lung cancer among miners exposed to radon gas are extrapolated linearly to the doses received by the general population from environmental radon, they predict higher rates of lung cancer among non-cigarette smokers than are actually observed. Moreover, 50 percent of the extra lung cancers among the miners were of one particular type (small cell undifferentiated), whereas only 5 percent of lung cancers among nonsmokers are of this type. When allowance is made for other causes of lung cancer among nonsmokers, the discrepancy is even larger. This is strong evidence that a linear dose-effect relationship overestimates effects at low doses.

Latent Period Increase with Decreasing Dose

The time delay between exposure to radiation and development of the resulting cancer, called the "latent period," seems to increase as doses decrease. There is evidence for this among the radium dial painters and in several animal studies. For example, beagle dogs whose bones were exposed to 100 million mr developed bone cancer in an average of two to three years, whereas those exposed to 5 million mr developed bone cancer only after about 10 years, which is nearly a full life expectancy. From this trend, we would expect cancer from low doses not to develop until long after the would-be victim has died from other causes. If this is true, low-level radiation becomes essentially harmless.

The best-known claim that linear extrapolation underestimates the effects of low-level radiation is a paper by T.F. Mancuso, A. Stewart, and G. Kneale (1977). The studies by T. Najarian and T. Colton (1978), and by I.D.J. Bross, M. Ball, and F. Falen (1979), reach a similar conclusion. All of these studies, however, have drawn heavy rebuttals in the scientific literature, and have been rejected by the prestigious committees charged with responsibility in this area.[4]

Radiation From the Nuclear Energy Industry

We now turn to sources of radiation from the nuclear energy industry. The three that have received the most public attention are routine emissions of radioactivity from nuclear plants, reactor meltdown accidents, and high-level radioactive waste.

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[4] See Cohen (1980).

Routine Emissions

When a nuclear power plant is operating normally, there are small quantities of radioactive gases and contaminants in water routinely released into the environment. More importantly, when the reactor fuel is chemically reprocessed, more radioactive gases are released at the reprocessing plant.

These routine releases have been studied in extensive detail (UNSCEAR 1977) and great effort and expense have been applied to keep them as small as possible. Currently, the average American receives a radiation exposure less than 0.05 mr per year from these releases, but if all of our electricity were derived from nuclear power, the average exposure would be about 0.2 mr per year. If this is multiplied by the U.S. population (2.3×10^8 people) and the cancer risk ($1/8 \times 10^6$), we find that this might cause about six extra cancers each year in the United States, or about 0.02 for each year of operation of a large power plant.[5] Some of the radioactive gases released drift around the world exposing people in other countries. This raises the fatality toll to 0.1/plant-year over the next 500 years. If we add up effects into the infinite future, the result is 0.3 eventual fatalities per plant-year. These numbers are far below typical estimates of effects of air pollution from coal burning, which are about 20 fatalities per plant-year.

Reactor Meltdown Accidents

Perhaps the most publicized source of release is in the reactor meltdown accident, which has the potential for releasing large quantities of radioactive dust into the environment. Since there has never been such an accident, there is a substantial degree of uncertainty as to its expected frequency and health impacts. Therefore, we give two estimates of these, one by a large study group sponsored by the U.S. Nuclear Regulatory Commission (1975), and the other by the Union of Concerned Scientists (1977), the most prominent antinuclear activist organization.

For the frequency of reactor meltdowns, NRC estimates one per 20,000 plant-years, whereas the UCS estimate is one per 2,000 plant-years. After 1,000 plant-years of commercial operation around the world and over 2,000 equivalent plant-years of naval reactor operation, all without a meltdown, the UCS estimate implies that we are lucky we haven't had one yet. Moreover, a

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[5] We take a large power plant to be 1 million kilowatts, which is capable of powering a city of about 750,000, and refer to the effects of one year of its operation as effects/plant-year.

necessary precursor of a meltdown is a loss of coolant accident (LOCA), with only a very small fraction of LOCAs expected to result in meltdown. There has been only a single LOCA to date (Three Mile Island). This fact would seem to make the UCS estimate overly pessimistic.

There is a widespread misunderstanding of the consequences of a meltdown. We often hear that it would kill tens of thousands of people and contaminate a whole state, but such statements are grossly misleading. As a protection for the public in the event of a meltdown, reactors are enclosed in a very powerfully built "containment" building, which would ordinarily contain the radioactive dust inside long enough (about one day) to clean it out of the air. For example, investigators of the Three Mile Island accident all agree that even if there had been a meltdown, there would have been little harm to the public, because there is no reason to believe that the integrity of the containment would have been compromised. In most meltdowns, *no* fatalities are expected.

There are events that could break open the containment, releasing radioactive dust into the environment, and if this happens, the consequences depend on the timing and on weather conditions. In the most unfavorable conditions with a large containment break early in the accident, NRC estimates 48,000 fatalities, but this unusual combination is expected only once in 100,000 meltdowns.

According to NRC, the average number of fatalities in a reactor meltdown is 400; according to UCS, it is 5,000. A median estimate of the fatality rate due to air pollution from coal-burning power plants is about 5,000 each year. For reactor meltdowns to be as harmful as coal-burning power plants, we would need a meltdown every month according to NRC, or once each year according to UCS. We have ample evidence that meltdowns will not occur that frequently.

When the frequency and consequence estimates are combined, NRC concludes that we may expect an average of 0.02 fatalities per plant-year; UCS predicts 2.4. Note that even the latter figure given by the leading antinuclear activist organization is still far less than the 20 fatalities per plant-year due to air pollution from coal-burning electricity generation.

Of course these fatalities from air pollution are not detectable in the U.S. population in which 2 million people die every year. But the same is true of 98 percent of the fatalities from reactor meltdown accidents. For example, in the worst such accident, according to NRC, there would be 45,000 extra cancer deaths in a population of 10 million over 50 years. For each of these 10 million, the risk of dying from cancer would be increased from the normal risk of 17 percent to 17.5 percent. The present risk in different states varies between 14 percent and 20 percent, so the cancer risk in moving from one state to another is often many times larger than the risk from being involved in the worst nuclear accident.

Detectable fatalities occurring shortly after the accident and clearly attributable to it are rather rare. According to NRC, 98 percent of all meltdowns would cause no detectable fatalities, the average number for all meltdowns is 10, and the worst meltdown (a one in 100,000 occurrence) would cause 3,500. The largest coal-related incident to date was an air pollution episode in London in 1952 that caused 3,500 fatalities within a few days. Thus, as far as detectable fatalities are concerned, the worst nuclear accident (expected only once in 100,000 meltdowns) has already been equalled by coal burning.

The extent of land contamination in a reactor meltdown accident depends on one's definition of "contamination." The whole earth can be said to be contaminated because there is naturally occurring radioactivity everywhere. Many areas like Colorado can be considered contaminated because they have larger than normal natural radiation levels.

But if we use the internationally accepted definition of the level of contamination that calls for remedial action, the worst meltdown (one in 10,000 according to NRC) would contaminate an area equal to a circle of 30-mile radius. About 90 percent of this could be easily decontaminated by use of fire hoses and plowing open fields, so the area where relocation of people is necessary would be equal to that of a 10-mile radius circle.

Forced relocation of people is not an unusual circumstance. It occurs in building dams where large areas are permanently flooded, in highway construction, in urban redevelopment, etc. In such situations, the major consideration is the cost of relocating the people. Therefore, it seems reasonable to consider land contamination by a nuclear accident on the basis of its monetary cost.

According to NRC, the cost in the worst 0.01 percent of accidents can exceed $15 billion, but the average cost for all meltdowns is $100 million. Air pollution from coal burning also does property damage by soiling clothing, disintegrating building materials, inhibiting plant growth, etc. Estimates of the annual costs of this damage are in the range of $10 billion per year. At an average of $100 million per meltdown, we would need a reactor meltdown every four days to be as costly as the property damage from coal burning.

High-Level Radioactive Waste[6]

When the fuel from a nuclear reactor has been mostly burned up, it is removed from the reactor. Currently, the plan is to ship it to a reprocessing plant where it would be put through chemical procedures to remove the valuable components. The residual material that contains nearly all of the radioactivity produced in the reactor is called high-level waste. Concern has been raised about its disposal.

One important aspect of the high-level waste disposal question is the quantities involved: The waste generated by one large nuclear power plant in one year is about six cubic yards. This waste is 2 million times smaller by weight and billions of times smaller by volume than wastes from a coal-burning plant. The electricity generated by a nuclear plant in a year sells for more than $200 million, so if only one percent of the sales price were diverted to waste disposal, $2 million might be spent to bury this waste. Obviously, some very elaborate protective measures can be afforded.

Once the radioactive waste is buried, the principal concern is that it will be contacted by ground water, dissolved into solution, and moved with the ground water to the surface where it can get into food and drinking water supplies. How dangerous is this material to eat or drink? To explain this, we will take the quantity that would have to be ingested to give a person a 50-percent chance of fatality. When the waste is first buried, it is highly toxic and a fatal dose is only 0.01 ounce. However, the radioactivity decays with time, so that after 600 years, a fatal dose is about one ounce, making it no more toxic than some things kept in homes. After 10,000 years, a lethal dose is 10 ounces.

When some people hear that nuclear waste must be carefully isolated for a few hundred years, they react with alarm. They point out that very few manmade structures and few of our political, economic, and social institutions can be expected to last for hundreds of years. Such worries stem from our experience on the surface of the earth, where most things are short-lived. However, 2,000 feet below the surface the environment is quite different. Things remain essentially unchanged for millions of years.

The natural radioactivity in the ground is a good comparison. The ground is full of naturally radioactive materials so that by adding

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[6] This section draws on Cohen (1977 and 1982a).

nuclear waste to it the total radioactivity in the top 2,000 feet of U.S. soil would increase by only one part per million per plant-year. Moreover, the radioactivity in the ground (except that very near the surface) does virtually no harm — it can be shown that it causes less than one fatality every 10 years in the United States. Therefore, adding to it by one part in a million would not be a serious problem.

Waste burial plans would delay the release of the waste to the environment for a very long time, thus giving near-perfect protection from the short-term problem. Under these plans, the rock formation chosen for burial will be well-isolated from ground water and be expected to remain isolated for a very long time. Also, if water did enter that rock formation, it would have to dissolve a reasonable fraction of the surrounding rock before reaching the waste. The least favorable situation for this factor would be if the waste were buried in a salt formation, because salt is readily dissolved in water. However, in the New Mexico area being considered for an experimental repository, if all the water now flowing through the ground were diverted through the salt formation, the quantities of salt are so vast and the amount of water so meager that it would take 100,000 years to dissolve the salt around the buried waste.

A third protection is the special backfill material surrounding the waste package. Clays selected for this purpose swell up to seal very tightly when wet, thereby keeping out any appreciable amount of water. These materials are also highly efficient filters; if ground water did get to the waste and dissolve some of it, these clays would filter the radioactive material out of solution before it could escape with the water.

Another safeguard is that the waste will be sealed in a corrosion-resistant casing. Casing materials are available that would not be dissolved even if soaked in ground water for a million years. Also, the waste itself will be a rock-like material that would require thousands of years of soaking in water before dissolving. Ground water is more like a "dampness" than a "soaking," thus dissolving things hundreds of times more slowly.

There is also a time delay. Ground water moves quite slowly, usually only inches per day, and ordinarily must travel many miles before reaching the surface from 2,000 feet underground. Hence, even if the dissolved radioactive material moved with the ground water, it would take about 1,000 years to reach the surface. Yet, there are processes by which the rock constantly filters the radioactive materials out of the ground water, causing it to migrate about a thousand times slower than the water itself. It would therefore take most of the radioactive materials a million years to reach the surface even if they were already dissolved in ground water. Most of the radioactive materials are highly insoluble under most geological conditions; thus, if they were in solution when the water encountered these conditions (chemically reducing, alkaline), they would precipitate out and form new rock material.

Finally, if radioactivity did reach surface waters, it would be detected easily — one millionth of the amounts that can be harmful are readily detected — and measures could be taken to prevent it from getting into drinking water or food.

With all these safeguards, it seems almost impossible for much harm to result during the first few hundred years while the waste is highly toxic, and there is substantial protection over the long term.

One way of estimating the distant effects is to assume that an atom of buried waste has the same chance of escaping and of getting into a person as an atom of average rock. Average rock material *submerged in flowing ground water* has less than a one in 100 million chance per year of escaping into surface waters. Moreover, once in surface waters, its chances of getting into a human body are about one in 10,000. If these probabilities are applied to buried radioactive waste, it would eventually cause .017 fatalities per plant-year over the next 15 million years. Note that this is still 1,000 times less than the health effects of air pollution from coal burning.

If there is a problem in the above arguments, it would be how buried radioactive waste differs from average rock. There are basically two differences: First, a shaft must be dug to bury the waste, giving a connection to the surface not usually present for rock; secondly, the radioactive waste emits heat, which is not a normal property of rock. Solving the first problem depends on our ability to seal the shaft, and the technical community seems highly confident that this can be done to make the area as secure as if the shaft had never been dug.

The heat radiated from buried waste is enough to raise the temperature of the surrounding rock by about 200 degrees Fahrenheit. There has been concern that this might crack the rock, producing new pathways by which ground water can reach the buried waste and through which the dissolved waste might escape. This problem has been studied intensively for over a decade, and the conclusion seems to be that there are no serious problems of this type. These studies are continuing, however.

If it is decided that the temperature must not be allowed to rise so high, there are two easy remedies: The waste can be distributed over a wider area to dilute the heating effect, or burial can be delayed to allow some of the radioactivity to decay. The latter option is especially effective since the rate of heat emission is decreased tenfold after 100 years and 100-fold after 200 years. Also, the protective casings in which the waste will be enclosed is highly resistant to high-temperature ground water.

Since we have mentioned the ways in which buried waste is less secure than most rock, the ways in which it is more secure should be pointed out. The geological environment for the waste will be carefully selected and will be much more favorable than for average rock. The waste will be buried in a region with little or no ground water, whereas our average rock is submerged in ground water. Finally, the buried waste will be sealed in a leach-resistant casing that provides a complete and independent safety system which should avert danger even if all other protections fail.

Since most of the health impact of radioactive waste is expected to occur millions of years in the future, it is instructive to compare this with the carcinogenic solid wastes released in coal burning.[7] Some of these, like arsenic and cadmium, are very long lasting and can therefore be calculated in the same way as for radioactive wastes. When this is done, they can be expected to cause hundreds of eventual fatalities per plant-year, over 10,000 times larger than the effects of nuclear waste. Also, solar electricity technologies require vast amounts of materials, and deriving these requires the burning of large quantities of coal — about 3 percent as much coal as would be used to produce the same amount of energy by direct coal burning. Consequently, the wastes from solar technologies are at least 300 times more harmful (.03 × 10,000) than nuclear waste. In addition, some solar technologies use large quantities of arsenic or cadmium, which increases the health consequences considerably.

Radon Problems[8]

There is one other aspect of nuclear power that involves important health impacts, namely the release of radon. As mentioned earlier, radon is a radioactive gas that naturally evolves from uranium. There has been some concern over increased releases of radon due to uranium mining and milling operations, but these problems have now been essentially eliminated. Nuclear power is

[7] See Cohen (1982b).

[8] This section draws from Cohen (1981).

important to the radon problem in that by mining uranium out of the ground, we avert future radon emissions and thus avoid future health impacts. Most of the uranium is mined from deep underground, so one might think the radon could not escape. However, the ground is constantly eroding away, so eventually the uranium that is mined would have come to the surface where its radon emissions could cause lung cancers. When these effects are calculated, the result is an eventual saving of 500 lives per plant-year of operation. This savings is thousands of times larger than the lives calculated to be lost from radioactive waste.

The influence of coal burning on the radon problem is not inconsequential. Coal contains small amounts of uranium which are released into the environment when coal is burned. Calculations of this effect indicate that coal-burning electric power production will eventually cause 30 fatalities per plant-year through its radon releases.

Risks From the Nuclear Industry in Perspective

For purposes of comparison we have discussed risks from producing equivalent energy by coal burning. These are summarized in Table 1.

TABLE 1

COMPARABLE RISKS OF FATALITIES FROM NUCLEAR RADIATION AND COAL BURNING*

	Fatalities per Plant-Year	
Source	Next 50 yrs	After 50 yrs
Nuclear — routine operation	.1	.2
Nuclear — accidents	.02(2.4)	0
Nuclear — waste	0	.017
Nuclear — radon	0	-500
Coal — air pollution	20	0
Coal — solid waste	0	100
Coal — radon	0	30

*For accidents, the table gives the NRC estimate, with the UCS estimate in parentheses. The minus sign corresponds to lives saved.

Radiation can cause genetic defects in later generations. The total number of such defects (the majority of which are nonfatal illnesses) is similar to the numbers of fatalities listed in Table 1. The number of nonfatal illnesses caused by coal burning is thousands of times larger than the number of fatalities.

Our discussion puts nuclear risks into perspective with risks from coal burning. However, it is also instructive to put these risks into perspective with other familiar risks. This has been done in terms of loss-of-life expectancy (Cohen and Lee 1979), with the following results.[9] If the U.S. depended solely on nuclear energy for its electricity, this would be as dangerous as: Smoking one cigarette every 10 years (10 weeks); increasing your weight (if you are at least 10 percent overweight) by 0.03 ounces (1.5 ounces); crossing a street one extra time every 20 weeks (three days); increasing the national speed limit from 55 miles per hour to 55.02 (56).

Alternative Sources of Electricity[10]

While 20 percent of the public believes nuclear energy is safer than coal, they would probably all agree that there are two alternatives much safer than either of these — solar energy and conservation. But this conflicts with careful analysis.

Let's start with conservation: How can conserving energy be dangerous? One example is that sealing houses more tightly to reduce heat leaks may increase the radon level enough to cause several thousand extra fatalities per year, if all American homeowners followed this practice.

More important is the relationship between energy use and wealth. There is a very strong correlation between the two among countries, at various times. Modern production technologies require a lot of energy; it is frequently said that the historically high level of U.S. industrial production was due largely to plentiful cheap energy. Energy brings wealth, and employment of wealth uses energy.

How does wealth relate to health? In the United States, well-to-do people live about four years longer than poor people. Death rates from diseases like tuberculosis, influenza, and pneumonia, and from accidents and suicide, are several times higher among the poor, and they are at least 10-30 percent higher from nearly every disease. Life expectancy in poor nations is typically 20 years less than in rich nations; it would be difficult to defend a position that the differences are racial, since American blacks live 20 years

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[9] The first figure in each case refers to the NRC accident risk estimate and the second (in parentheses) to the UCS estimate.

[10] This section draws from Cohen and Lee (1979) and Cohen (1982b).

longer than African blacks and Japanese live 11 years longer than other East Asians. Clearly, wealth adds years to life expectancy.

In contrast, the loss-of-life expectancy due to radiation if all U.S. electricity were nuclear is only about one hour if the NRC estimate on accidents is accepted, and still only two days if we accept the UCS estimate. Even with the latter, the effect of poverty is hundreds of times worse than the danger of using nuclear power. Therefore, if conserving energy reduces wealth, the ultimate health risks in conservation can be extremely large. This reasoning also applies to solar energy, which is expected to cost five times more than nuclear electricity.

There are also important pollution effects of solar energy on health. Producing the vast quantities of materials (steel, cement, glass) for solar systems requires burning a lot of coal, about 3 percent as much as would be used in producing the same energy by direct coal burning. Therefore, the fatality rates must be at least 3 percent of those listed in Table 1 for coal, which makes them larger than the rates for nuclear energy.

The Role of the Media

We conclude that nuclear energy is much safer than coal burning and safer than any alternative. This is certainly not the common understanding of the public. What is the reason for this discrepancy?

The public gets most of its information from the news media, so if the public is misinformed, the media must be held responsible. There is a serious problem here: The media, especially television, are primarily in the entertainment business. With a one-point increase in the Nielsen rating for network evening news worth $7 million per year in advertising revenue, every effort must be made to attract and maintain the interest of the audience. Stories about dangers of radiation excite the public and are therefore given wide coverage. Actually, there has not been a single fatal accident involving radiation for over 15 years, whereas there have been 2 million fatalities from other types of accidents in this country during this time period. Clearly, the media attention given radiation is far out of proportion to its actual dangers. As a result, the public has been instilled with a fear of radiation completely out of proportion with reality.

Members of the media generally do not read the scientific literature. Their contact with science is often through a handful of publicity-seeking scientists who tell them what they want to hear. Any scientist who reports the slightest evidence that makes radiation seem dangerous gets tremendous coverage, while contrary evidence is mostly ignored. As a result, we often hear reports that recent evidence indicates that radiation is more dangerous than it was believed to be 5 or 10 years ago, although there is no such accepted opinion in the scientific community.

The price we are paying for this breakdown in communication between competent scientists and the public is enormous. Not only is nuclear energy much safer than coal, it is also cheaper. There is solid evidence of this from plants that are now operating, and at least 95 percent of the economic analyses by people in that business — utilities (including publicly owned, non-profit utilities), banks that lend them money, and the economists whom they hire — conclude that this will remain true.[11] Nevertheless, as a result of the public misconception, all new power plants ordered for the past several years have been coal-burners. Every time a coal-burning plant is built instead of a nuclear plant, many hundreds of people are condemned to premature death, and hundreds of millions of dollars of public money is wasted. This is the price we are paying for failing to look at the facts.

References

Bross, I.D.J., M. Ball, and F. Falen. "A Dosage-Response Curve for the 1-Rad Range: Adult Risks from Diagnostic Radiation." *American Journal of Public Health* 69 (1979).

Cohen, B.L. "High Level Waste from Light Water Reactors." *Review of Modern Physics* 49 (1977).

Cohen, B.L. and I.S. Lee. "A Catalog of Risks." *Health Physics* 36 (1979).

Cohen, B.L. "The Cancer Risk from Low Level Radiation." *Health Physics* 39 (1980).

Cohen, B.L. "The Role of Radon in Comparisons of Environmental Effects of Nuclear Energy, Coal Burning, and Phosphate Mining." *Health Physics* 40 (1981).

Cohen, B.L. "Effects of ICRP Publication 30 and the 1980 BEIR Report on Hazard Estimates for High Level Radioactive Waste," *Health Physics* 41 (1982a).

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[11] Charles Komanoff, an economist who reached the opposite conclusion, was hired by antinuclear activists and has received a disproportionately large amount of publicity.

Cohen, B.L. "Long Term Consequences of the Linear-No Threshold Dose-Response Relationship for Chemical Carcinogens." *Risk Analysis* (1982b).

International Commission on Radiological Protection. "Recommendations of the International Commission on Radiological Protection." ICRP Publication 26 (Elmsford, N.Y.: Pergamon Press, 1977).

Mancuso, T.F., A. Stewart, and G. Kneale. "Radiation Exposures of Hanford Workers Dying From Cancer and Other Causes." *Health Physics* 33 (1977).

Najarian, T. and T. Colton. "Mortality From Leukemia and Cancer in Shipyard Nuclear Workers." *Lancet* 1978-I (1978).

National Academy of Sciences Committee on Biological Effects of Ionizing Radiation. "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." (Washington, D.C., 1980).

Union of Concerned Scientists. "The Risks of Nuclear Power Reactors." (Cambridge, Mass., 1977).

United Nations Scientific Committee on Effects of Atomic Radiation. "Sources and Effects of Ionizing Radiation." (New York, 1977).

U.S. Nuclear Regulatory Commission. "Reactor Safety Study." Document WASH-1400 (1975).

A COMMENT ON COHEN

Lynn R. Anspaugh

Dr. Cohen, in this and related papers,[1] has made a strong case for nuclear power. This case is based upon his analysis of the human health risks associated with nuclear radiation compared with burning coal. I particularly compliment Dr. Cohen on his attempts to deal with the entire nuclear fuel cycle from the mining of uranium through the disposal of radioactive waste. These calculations are extremely difficult, if not impossible, to perform exactly; however, Dr. Cohen has made reasonable assumptions and has arrived at results that provide an overall perspective of relative risk. Most of his calculations involve rather conservative assumptions, although I will later take issue with his calculation of the "lives saved" by the mining and use of uranium by the nuclear industry.

If nuclear power is indeed so safe, why is the nuclear power industry currently at a standstill? Surprisingly, Americans have yet to make a firm commitment to nuclear power. We may be approaching a point where we will lose the ability to manufacture nuclear power plants without a significant relearning effort. Dr. Cohen suggests that the media are an important factor in this paralysis, and one only has to compare media coverage of radiation issues with other issues to agree that the media are indeed biased. For example, most of us remember vividly the media event surrounding the Three Mile Island accident in March, 1979. Few people remember, however, that in August of that same year, a dam

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The author is Section Leader for Analysis and Assessment, Environmental Sciences Division, Lawrence Livermore National Laboratory, University of California, Livermore 94550.

[1] B.L. Cohen, "The Cancer Risk from Low-Level Radiation," *Health Physics* 39 (1980): 659-678; and idem, "The Role of Radon in Comparisons of Effects of Radioactivity Releases from Nuclear Power, Coal Burning and Phosphate Mining," *Health Physics* 40 (1981): 19-25.

broke in India and killed at least 1,000 people.[2] If this had been a nuclear reactor accident, I have little doubt that it would have had a profound impact on nuclear power in this country. The dam accident, however, has had no obvious effect on our hydroelectric power industry, even though there has been a significant number of deaths from dam failures in the U.S. (about 3600 since 1874).[3]

The media's position, however, is not based entirely on whim. We should search for more fundamental reasons if we want to understand this problem, but that is not my intent here. Instead, I shall examine the issue of disposal of high-level radioactive wastes. Dr. Cohen assures us that this is not a problem in terms of eventual health effects, but, in fact, we don't have a single operating, permanent waste-disposal facility. This is not consistent with the proposed assurances, and the responsibility for this rests squarely on the shoulders of the industry and its government promoters and regulators. Until such a facility is in place and is operating safely, I suggest that nuclear power will continue to be viewed with suspicion.

On a more positive note, I would reemphasize one of Dr. Cohen's points: We do indeed know a great deal about radiation and its effects on biological systems and about radionuclides and how they are transported through environmental media. There are predictive models of radionuclide movement, dose to man, and radiation-induced effects that are really quite good. By comparison, we know much less about pollutants from other major sources of energy. The nuclear industry and its government promoters and regulators deserve praise for evaluating the health effects of low-level radiation. This task has been difficult because the effects are so small that they are not observable in reasonably sized populations. We therefore must extrapolate from data based upon exposure to high levels of radiation.

Dr. Cohen has presented a good deal of evidence to explain why these extrapolations overestimate the harmful effects of low-level nuclear radiation. One of the most significant sets of data for these extrapolations is the mortality experience of the Japanese survivors of the atomic bombs at Hiroshima and Nagasaki. Great interest was aroused when Loewe and Mendelsohn[4] recalculated the doses from

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[2] "Dam Bursts in India — Flash Flood Kills 1,000," *San Francisco Chronicle* 13 August 1979.

[3] A. Coppola and R.E. Hall, *A Risk Comparison* NUREG/CR-1916, BNL-NUREG-51338, R7, RG (Upton, N.Y.: Brookhaven National Laboratory, 1981).

[4] W.E. Loewe and E. Mendelsohn, "Revised Dose Estimates at Hiroshima and Nagasaki," *Health Physics* 41 (1981): 663-666.

the bombs with advanced techniques. They reported that the neutron doses in both cities were lower than previously thought, but that the gamma-ray and total doses were higher in Hiroshima and lower in Nagasaki. These new doses results have been used by Straume and Dobson[5] to recalculate dose-response data for the induction of malignancies. While these results must be considered preliminary, the new response curves of the mortality from leukemia versus dose now show no intercity difference and are more consistent with other data. The data also indicate a linear-quadratic response, but the calculated risk coefficient is consistent at low doses with previously calculated values. Thus, we are encouraged that these new results will strengthen the basis of the calculation of risk from radiation.

I would advise caution in assuming that all chemical carcinogens exhibit a linear, no-threshold dose response. Dr. Cohen has apparently made this assumption for cadmium and arsenic. It is not certain that orally administered cadmium is carcinogenic at all,[6] and no dose-response function can be derived. The situation is even more confused for arsenic, as this element is now considered essential.[7] While it has been demonstrated to be carcinogenic at high doses,[8] the response function may be very complex and the addition of small amounts per individual may even be beneficial rather than detrimental.

Finally, I take issue with Dr. Cohen's conclusion that 500 lives per plant-year can be saved through the mining of uranium, the mining presumably preventing the emission of radon. Cohen's original calculations[9] were somewhat different; he calculated that release of radon from tailings piles would cause 150 deaths, which would mean a savings of 350 lives per plant-year of operation. This calculation is based on the assumption that the unmined uranium would eventually come to the surface (through erosion), release radon, and produce lung cancer. It would also have to be assumed the uranium used in a reactor would not lead to further radon emissions.

I don't find this credible for several reasons. First, the assumption

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[5] T. Straume and R.L. Dobson, "Implications of New Hiroshima and Nagasaki Dose Estimates: Cancer Risks and Neutron RBE," *Health Physics* 41 (1981): 666-671.

[6] U.S. Environmental Protection Agency, *Ambient Water Quality Criteria for Cadmium* EPA-440/5-80-025 (Washington, D.C.: EPA, 1980).

[7] W. Mertz, "The Essential Trace Elements," *Science* 213 (1981): 1332-1338.

[8] U.S. Environmental Protection Agency, *Ambient Water Quality Criteria for Arsenic* EPA 440/5-80-021 (Washington, D.C.: EPA, 1980).

that uranium used in a reactor will produce no further emissions of radon is questionable. Its half-life is 4.5×10^9 years, and it is probably as likely to resurface in that time as is the unmined uranium. Also, the process of mining and milling brings to the surface and leaves in tailings piles equal radioactivities of 230 Th (half-life = 7.7×10^4 years) and 226 Ra (half-life = 1600 years). These are daughter products of uranium that has *already decayed,* and each of them will subsequently decay to an atom of radon. Bringing them to the surface will result in the release of radon (half-life = 3.8 days) that otherwise would never have reached the surface, but would have decayed harmlessly underground.

While I generally support Mr. Cohen's calculations and results, I believe that the impact of nuclear power on the emission of radon should be recalculated.

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[9] Cohen, 1981.