# RADIATION RISK AND ETHICS

**The established worldwide practice of protecting people from radiation costs hundreds of billions of dollars a year to implement and may well determine the world's future energy system. But is it right?**

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The psychosomatic disorders observed in the 15 million people in Belarus, Ukraine, and Russia[1] who were affected by the April 1986 Chernobyl accident are probably the accident's most important effect on public health.[2] These disorders could not be attributed to the ionizing radiation, but were assumed to be linked to the popular belief that any amount of man-made radiation—even minuscule, close to zero doses—can cause harm, an assumption that gained wide currency when it was accepted in the 1950s, arbitrarily, as the basis for regulations on radiation and nuclear safety.

It was under the same assumption that an *ad hoc* Soviet government commission decided to evacuate and relocate more than 270 000 people from many areas of the former Soviet Union where the 1986–95 average radiation doses from the Chernobyl fallout ranged between 6 and 60 millisieverts. (See the box on page 28 for the definition of the sievert.) By comparison, the world's average individual lifetime dose due to natural background radiation is about 150 mSv. In the Chernobyl-contaminated regions of the former Soviet Union, the lifetime dose is 210 mSv—and in many regions of the world it is about 1000 mSv.[3] The forced evacuation of so many people from their—presumably—poisoned homes calls for ethical scrutiny. Examining the physical and moral basis of that evacuation action and other radiation policies is the subject of this article.

As they have developed over the last three decades, the principles and concepts of radiation protection seem to have gone astray and to have led to exceedingly prohibitive standards and impractical recommendations. Revision of these principles and concepts is now being proposed by an increasing number of scientists and several organizations. They include Roger Clarke, who chairs the International Commission on Radiological Protection, the Health Physics Society, and the French Academy of Sciences. In addition, in April this year, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) decided to study a possible revision of the basic dosimetric and biological concepts and quantities generally being applied in radiation protection. In the years to come, such reevaluations may trigger what I believe will be welcome changes in the basic worldwide approach to radiological protection.

## Natural and man-made radiation

We are all immersed in naturally occurring ionizing radiation. Radiation reaches us from outer space and it comes from radionuclides present in rocks, buildings, air, and even our own bodies. Each flake of snow, each grain of soil, every drop of rain—and even every person on this planet—emits radiation. And every day, at least a billion particles of natural radiation enter our bodies.

The individual dose rate of natural radiation the average inhabitant of Earth receives is about 2.2 mSv per year. In some regions—for example, parts of India, Iran, and Brazil—the natural dose rate is up to a hundred times higher. And no adverse genetic, carcinogenic, or other malign effects of those higher doses have ever been observed among the people, animals, and plants that have lived in those parts since time immemorial.[4,5]

In the case of man-made radiation, the global average dose has increased by about 20% since the beginning of the 20th century—mainly as a result of the broader application of x-ray diagnostics in medicine. Other major sources of man-made radiation, such as nuclear power, nuclear weapons tests (figure 1), and the Chernobyl accident, have contributed only a tiny proportion—less than 0.1%—to that increase.

In the regions of the former Soviet Union that were highly contaminated by the fallout from the Chernobyl accident, the increased radiation dose rate for local inhabitants is far less than the dose rate in areas of high natural radiation (see figure 2). In those places, the entire man-made contribution to radiation dose amounts to a mere 0.2% of the natural component.

Three and a half billion years ago, when life on Earth began, the natural level of ionizing radiation at the planet's surface was about three to five times higher than it is now.[6] Quite possibly, that radiation was needed to initiate life on Earth. And it may be essential to sustain extant life-forms, as suggested by experiments with protozoa and bacteria.[7]

At the early stages of evolution, increasingly complex organisms developed powerful defense mechanisms against such adverse radiation effects as mutation and malignant change. Those effects originate in the cell nucleus, where the DNA is their primary target. That evolution has apparently proceeded for so long is proof, in part, of the effectiveness of living things' defenses against radiation.

Other adverse effects—which lead to acute radiation sickness and premature death in humans—also originate in the cell, but outside its nucleus. For them to take place requires radiation doses thousands of times higher than those from natural sources. A nuclear explosion or cyclotron beam could deliver such a dose; so could a defective medical or industrial radiation source. (The malfunctioning Chernobyl reactor, whose radiation claimed 28 lives, is one example.)

The concern about large doses is obviously justified. However, the fear of small doses, such as those absorbed from the Chernobyl fallout by the inhabitants of central and western Europe, is about as justified as the fear that an atmospheric temperature of 20 °C may be hazardous because, at 200 °C, one can easily get third-degree burns—or the fear that sipping a glass of claret is harmful because gulping down a gallon of grain alcohol is fatal.

According to recent studies, by far the most DNA damage in humans is spontaneous and is caused by ther-

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FIGURE 1. ATMOSPHERIC NUCLEAR tests, like the one shown here (XX-27 Charlie, a 14 kiloton device exploded over Yucca Flats, Nevada, on 30 October 1951), released radioactive fallout but did not lead to high average doses of radiation—even for the inhabitants of Nevada. (Photo courtesy of US Department of Energy.)

modynamic decay processes and by reactive free radicals formed by the oxygen metabolism. Each mammalian cell suffers about 70 million spontaneous DNA-damaging events per year.[8] Only if armed with a powerful defense system could a living organism survive such a high rate of DNA damage.

An effective defense system consists of mechanisms that repair DNA, and other homeostatic mechanisms that maintain the integrity of organisms, both during the life of the individual and for thousands of generations. Among those homeostatic mechanisms are enzymatic reactions, apoptosis (that is, suicidal elimination of changed cells), cell cycle regulation, and intercellular interactions.

Ionizing radiation damages DNA also, but at a much lower rate. At the present average individual dose rate of 2.2 mSv per year, natural radiation could be responsible for no more than about 5 DNA-damaging events in one cell per year.

Perhaps we humans lack a specific organ for sensing ionizing radiation simply because we do not need one. Our bodies' defense mechanism provides ample protection over the whole range of natural radiation levels—that is, from below 1 mSv to above 280 mSv per year.[3,4] That range is much greater than the range of temperatures—about 50 K—that humans are normally exposed to. Increasing the water temperature in your bath tub by only 80 K, from a pleasant level of 293 K to boiling point at 373 K (that is, by a factor of only 1.3), or decreasing it below freezing point (that is, by a factor of 1.07), would eventually kill you.

Because such lethal high or low temperatures are often found in the biosphere, the evolutionary development of an organ that can sense heat and cold has been essential for survival. Organs of smell and taste have been even more vital as defenses against dangerously toxic or infected food. But a lethal dose of ionizing radiation delivered in one hour—which for an individual human is 3000 to 5000 mSv—is a factor of 10 million higher than the average natural radiation dose that one would receive over the same time period (0.00027 mSv). Compared with other noxious agents, ionizing radiation is rather feeble. Nature seems to have provided living organisms with an enormous safety margin for natural levels of ionizing radiation—and also, adventitiously, for man-made radiation from controlled, peacetime sources.

In short, conditions in which levels of ionizing radiation could be noxious do not normally occur in the biosphere, so no radiation-sensing organ has been needed in humans and none has evolved.

## Why radiophobia?

If radiation and radioactivity, though ubiquitous, are so innocuous at normal levels, why do they cause such universal apprehension? What is the cause of radiophobia—the irrational fear that any level of ionizing radiation is dangerous? Why have radiation protection authorities introduced a dose limit for the public of 1 mSv per year, which is less than half the average dose rate from natural radiation and less than 1% of the natural dose rates in many areas of the world? Why do the nations of the world spend hundreds of billions of dollars a year to maintain this standard?[9]

Here I propose some likely reasons:

▷ The psychological reaction to the devastation and loss of life caused by the atomic bombs dropped on Hiroshima and Nagasaki at the end of World War II.

▷ Psychological warfare during the cold war that played on the public's fear of nuclear weapons.

▷ Lobbying by fossil fuel industries.

▷ The interests of radiation researchers striving for

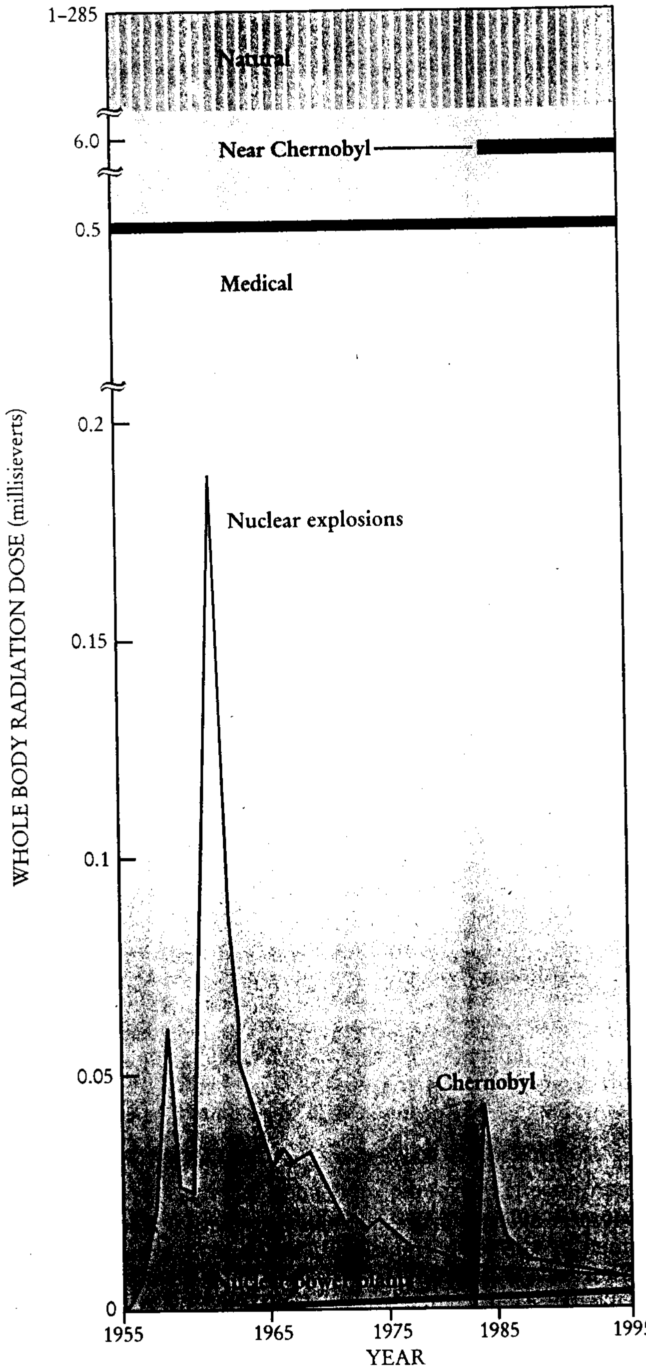


FIGURE 2. AVERAGE INDIVIDUAL GLOBAL RADIATION DOSE in the 1990s from nuclear explosions, the Chernobyl accident, and commercial nuclear power plants combined was about 0.4% of the average natural dose of 2.2 mSv per year. In areas of Belarus, Ukraine, and Russia that were highly contaminated by Chernobyl fallout, the average individual dose was actually much lower than that in the regions with high natural radiation. The greatest man-made contribution to radiation dose has been irradiation from x-ray diagnostics in medicine, which accounts for about 20% of the average natural radiation dose. Natural exposure is assumed to be stable. The temporal trends in medical and local Chernobyl exposures are not presented. (Based on data from UNSCEAR.)

recognition and budget.

▷ The interests of politicians for whom radiophobia has been a handy weapon in their power games (in the 1970s in the US, and in the 1980s and 1990s in eastern and western Europe and in the former Soviet Union).

▷ The interests of news media that profit by inducing public fear.

▷ The assumption of a linear, no-threshold relationship between radiation and biological effects.

Since nuclear weapons are regarded as a deterrent, naturally the countries that possess them wish to make radiation and its effects seem as dreadful as possible. Not surprisingly, national security agencies seldom qualify or correct even the most obviously false statements, such as "Radiation from a nuclear war can annihilate all mankind, or even all life," or "200 grams of plutonium could kill every human being on Earth."[10]

The facts say otherwise. Between 1945 and 1980, the 541 atmospheric nuclear tests that were performed together yielded an explosive energy equivalent to 440 megatons of TNT ($1.8 \times 10^{24}$ joules). After all those explosions, despite the injection into the global atmosphere of about 3 tons of plutonium (that is, almost 15 000 supposedly deadly 200-gram doses), somehow we are still alive! The average individual dose of radiation from all these nuclear explosions, accumulated between 1945 and 1998, is about 1 mSv, which is less than 1% of the natural dose for that period.

In the heyday of atmospheric testing, 1961 and 1962, there were 176 atmospheric explosions, with a total yield of 84 megatons. The maximum deposition on Earth's surface of radionuclides from those explosions took place in 1964. The average individual dose accumulated from the fallout between 1961 and 1964 was about 0.35 mSv.

At its cold war peak of 50 000 weapons, the global nuclear arsenal had a combined potential explosive power of about 13 000 megatons, which was only 30 times larger than the megatonnage already released in the atmosphere by all previous nuclear tests. If that whole global nuclear arsenal had been deployed in the same places as the previous nuclear tests, the average individual would have received a lifetime radiation dose of about 30 mSv from the ensuing worldwide fallout. If we use the years 1961 and 1962 as a yardstick instead, the dose would have risen to about 55 mSv. And even exploding all the nuclear weapons in just a few days rather than over a two-year period would not change that estimate by very much. Clearly, 55 mSv is a far cry from the short-term dose of 3000 mSv that would kill a human.

Of course, the approach taken above, based as it is on averages, fails to account for the immense loss of life and human suffering caused by the mechanical blast, fires, and local fallout that follow nuclear explosions in highly populated areas. However, no matter what the losses to those areas might be, it is certain that human and other life on Earth would survive even an all-out global nuclear war.

## A-bomb survivors and linear no-threshold

The survivors of the atomic bombing of Hiroshima and Nagasaki who received instantaneous radiation doses of less than 200 mSv have not suffered significant induction of cancers.[11] And so far, after 50 years of study, the progeny of survivors who were exposed to much higher, near-lethal doses have not developed adverse genetic effects.[12]

Until recently, such findings from the study of A-bomb survivors had been consistently ignored. In place of the actual findings—and driving the public's radiophobia—has been the theory of linear no-threshold (LNT), which presumes that the detrimental effects of radiation are proportional to the dose, and that there is no dose at which

## Values of Individual Truncated Natural Dose Commitment

| Human Species | Time since first appearance (years)* | (generations) | Dose commitment (sieverts) |
|---|---|---|---|
| Early Modern *Homo sapiens* | 130 000 | 4300 | 286 |
| Archaic *Homo sapiens* | 400 000 | 13 300 | 880 |
| *Homo erectus* | 1 800 000 | 60 000 | 3960 |
| *Homo habilis* | 2 400 000 | 80 000 | 5280 |

***The Cambridge Encyclopaedia of Human Evolution*, Cambridge U. P., Mass. (1994).

the effects of radiation are not detrimental.

It was LNT theory that the International Commission on Radiological Protection chose, in 1959, as the basis for its rules of radiation protection. At that time, applying LNT theory was regarded as an administrative decision, based on practical (not to mention political[13]) considerations. Adopting a linear relationship between dose and effect, along with no threshold, enabled doses in individual exposures to be added and enabled population-averaged quantities to be evaluated, and made the administration of radiation protection generally easier. Furthermore, the policy undertone—that even the smallest, near-zero amounts of radiation could cause harm—was politically useful at the time: It played an important part in effecting first a moratorium and then a ban on atmospheric nuclear tests. LNT theory was and still is the pillar of the international theory and practice of radiation protection.

Over the years, however, what started as just a working assumption for the leadership of ICRP came to be regarded—in public opinion and by the mass media, regulatory bodies, and many scientists, and even by some members of the ICRP—as a scientifically documented fact.

The absurdity of the LNT was brought to light after the Chernobyl accident in 1986, when minute doses of Chernobyl radiation were used by Marvin Goldman, Robert Catlin, and Lynn Anspaugh to calculate that 53 400 people would die of Chernobyl-induced cancer over the next 50 years.[14] The frightening death toll was derived simply by multiplying the trifling Chernobyl doses in the US (0.0046 mSv per person) by the vast number of people living in the Northern Hemisphere and by a cancer risk factor based on epidemiological studies of 75 000 atomic bomb survivors in Japan. But the A-bomb survivor data are irrelevant to such estimates, because of the difference in the individual doses and dose rates. A-bomb survivors were flashed within about one second by radiation doses at least 50 000 times higher than those which US inhabitants will ever receive, over a period of 50 years, from the Chernobyl fallout.

We have reliable epidemiological data for a dose rate of, say, 6000 mSv per second in Japanese A-bomb survivors. But there are no such data for human exposure at a dose rate of 0.0046 mSv over 50 years (nor will there ever be any). The dose rate in Japan was larger by $2 \times 10^{15}$ than the Chernobyl dose rate in the US. Extrapolating over such a vast span is neither scientifically justified nor epistemologically acceptable. Indeed, Lauriston Taylor, the former president of the US National Council on Radiological Protection and Measurements, deemed such extrapolations to be a "deeply immoral use of our scientific heritage."

## Radiation dose and eternity

An offspring of the LNT assumption is the concept of dose commitment, which was introduced in the early 1960s. At that time, the concept reflected the concern that harmful hereditary effects could be induced by fallout from nuclear tests. After almost four decades, the concept of dose commitment is still widely used, although both the concept and the concern ought to have faded into oblivion by now.

UNSCEAR, which first used "dose commitment" in 1962, defined it as "the integral over infinite time of the average dose rate in a given tissue for the world population, as a result of a given practice—for example, a given series of nuclear explosions." Such integration requires making some daring assumptions and having a superhuman omniscience about population dynamics and environmental changes for all the eons of time to come. Later, in a humbler frame of mind, UNSCEAR introduced the so-called truncated dose commitment, limited arbitrarily to 50, 500, 10 000 or many millions of years. However, the original "infinite" definition is still retained in recent UNSCEAR documents.

To accept the definitions of dose commitment and of collective dose, we must also accept the following premises:

▷ An LNT relationship between absorbed dose and risk to an individual.

▷ The additivity of risk (by means of the additivity of dose) during the lifetime of an individual.

▷ The additivity of risk (dose) across individuals of the same generation.

▷ The additivity of risk (dose) across the lifetimes of individuals over any number of generations.

▷ The expectation that late harm due to a dose accumulated over many years or generations (dose commitment) be the same as the harm done by an instantaneous dose of the same magnitude.

▷ The expectation that late harm due to a given value of collective dose or dose commitment calculated for a large number of people exposed to trifling doses be the same as that calculated for a small number of people exposed to large doses. (This expectation is contrary to the common practice of diluting or dispersing noxious agents below dangerous levels.)

In 1969, UNSCEAR advised making the level of natural radiation a convenient reference for comparing dose commitments from man-made sources. However, during the three decades since the introduction of the dose commitment concept, UNSCEAR has not followed its own advice. The collective dose commitment for the world population from natural sources, truncated to 50 years (650 000 000 man Sv), was published for the first time in UNSCEAR's 1993 report. But why stop at 50 years—when, for man-made radiation, UNSCEAR estimates the dose commitments over infinite time? It is easy to calculate the individual dose commitment from past exposures to natural radiation for periods comparable to those used for calculating man-made sources of radiation. In making the calculation, one may assume that during the past several million years the natural radiation dose rate has been the same as is now—that is, 2.2 mSv per year.

In the table on this page are presented the values of truncated natural dose commitment for various periods

## Definition of the Sievert

*Adapted from* Scientific Unit Conversion *by François Cardarelli, Springer-Verlag, London (1997).*

The sievert (Sv) is the SI-derived unit of equivalent radiation dose. An equivalent dose of 1 Sv is received when the actual absorbed dose of ionizing radiation, after being multiplied by the dimensionless factors $Q$ (the so-called quality factor) and $N$ (the product of any other multiplying factors), is 1 joule per kilogram. In this scheme, the relationship between the absorbed dose of radiation $D$ and the dose equivalent $H$ is, therefore, given by $H = QND$. Both $Q$ and $N$ are stipulated by the International Commission on Radiological Protection. Also known as the relative biological efficiency, $Q$ depends on the nature of the radiation and has a value of 1 for x rays, gamma rays, and beta particles; 10 for neutrons; and 20 for alpha particles. $N$ is a factor that takes into account the distribution of energy throughout the dose.

The unit is named after the pioneering Swedish clinical physicist Rolf Maximillian Sievert (1896–1960) and superseded the rem (short for rad equivalent mammals or man), which corresponds to 0.01 Sv for x rays of energy ranging from 200 to 250 keV.

since the putative appearance of some of our ancestors. One may compose a similar table for the collective truncated dose commitments for the global populations integrated over the past generations, information that is also given in the table. One may also calculate the future natural dose commitments of our descendants for tens or thousands of generations.

Each of us is burdened with these values of dose commitment. Do these values represent anything real, or are they just an academic abstraction? What are the medical effects of these enormously high doses?

In an international study, the collective dose for the world population from nuclear dumping operations in the Kara Sea (part of the Arctic Ocean), truncated to the year 3000 AD, has been estimated to be about 10 manSv.[15] Let us explore the implications of that value, which may be equivalent to:

▷ 10 Sv in 1 person in 1 day (lethal acute effect), or
▷ 10 Sv in 1 person in 1 year (chronic effect—for example, cancer),
▷ 0.5 Sv in 20 people in 1 day (chronic effect), or
▷ $10^{-5}$ Sv in 1000 people in 1000 years (no biological or medical concern), or
▷ $2 \times 10^{-12}$ Sv per each of $5 \times 10^9$ people now living and their descendants from 33 generations in 1000 years (no concern).

Obviously, the use of collective dose obliterates information on the patterns of dose deposition in space and time, which are of major importance for estimating their biological effects, in terms of risk to humans. Individual doses cannot be additive over generations, simply because humans are mortal, and the dose dies when an individual does. Similarly, individual doses cannot be added for individuals of the same generation because we do not contaminate one another with a dose that we have absorbed. The presence of biological repair processes and the multistage process of cancer induction render the linear addition of small contributions of individual dose to estimate the associated risk of cancer occurrence highly unlikely. Collective dose and dose commitment cannot have any biological meaning.

The large values of collective doses and collective dose commitments that have often been published were derived from minuscule individual doses. For example, UNSCEAR's calculations include the following: 100 000 man Sv from nuclear explosions during the past 54 years, 205 000 man Sv for the global population in the next 10 000 years from power reactors and reprocessing plants, 600 000 man Sv from Chernobyl fallout in the Northern Hemisphere for eternity, and 650 000 000 man Sv for the world's population from natural radiation in the past 50 years. These large values, terrifying as they are to the general public, do not imply that individuals or populations are harmfully burdened by nuclear explosions, nuclear power plants, Chernobyl fallout, or nature. In fact, they provide society with no relevant biological or medical information. Rather, they create a false image of the imminent danger of radiation, with all its actual negative social and psychosomatic consequences. If harm to the individual is trivial, then the total harm to members of his or her society over all past or future time must also be trivial—regardless of how many people are or will have been exposed to natural or man-made radiation. The intellectually invalid concepts of collective dose and dose commitment deserve to be hacked off with William of Occam's razor.

## Enter hormesis

The LNT theory is contradicted by the phenomenon of hormesis—that is, the stimulating and protective effect of small doses of radiation, which is also termed adaptive response. The first report on hormetic effects in algae appeared more than 100 years ago.[16] More recently published hormetic effects include A-bomb survivors' apparent lower-than-normal incidence of leukemia and their greater longevity.[17] Although more than 2000 scientific papers had been published on radiation hormesis, the phenomenon was forgotten after World War II and was ignored by the radiation-protection establishment. It was only in 1994 that UNSCEAR recognized and endorsed the very existence of radiation hormesis. It caused a revolutionary upheaval of radiology's ethical and technical foundations.

Many radiologists have come to realize that their overreaction to theoretical (actually imaginary) health-harming effects of radiation is unethical in that it leads to the consumption of funds that are desperately needed to deal with real health problems. Applying the no-threshold principle for the alleged protection of the public has led to the imposition of restrictive regulations on the nuclear utilities, restrictions that have virtually strangled the development of environmentally benign nuclear energy in the US and in other countries. My own country, Poland, spent billions of dollars on the construction of its first nuclear power reactor—only to abandon the project after what I regard as the politically motivated manipulation of public opinion by means of the LNT theory.

Each human life hypothetically saved in a Western industrial society by implementation of the present radiation protection regulations is estimated to cost about $2.5

billion. Such costs are absurd and immoral—especially when compared to the relatively low costs of saving lives by immunization against measles, diphtheria, and pertussis, which in developing countries entails costs of $50 to $99 per human life saved.[18] Billions of dollars for the imaginary protection of humans from radiation are actually spent year after year, while much smaller resources for the real saving of lives in poor countries are scandalously lacking.

## A practical alternative

There is an emerging awareness that radiation protection should be based on the principle of a practical threshold—one below which induction of detectable radiogenic cancers or genetic effects is not expected. Below such a threshold, radiation doses should not require regulation. Nor is any regulation required for extreme levels, such as those experienced at Hiroshima and Nagasaki, where dose rates were extremely high.

The practical threshold to be proposed could be based on epidemiological data from exposures in medicine, the nuclear industry, and regions with high natural radiation. The current population dose limit of 1 mSv per year could then be changed to 10 mSv per year or more. Individual doses could be evaluated at any level below the practical threshold, but radiation-protection authorities would be required to intervene only if individual doses above the threshold were involved. Adopting a practical threshold would be an important step taken toward dealing with radiation rationally and toward regaining the public's acceptance of radioactivity and radiation as blessings for mankind.

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