# Radiation risks in the 20th century: reality, illusions, and ethics

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*This is an edited version of a speech that the author will present at the Marie Sklodowska-Curie International Conference in Warsaw, on Sept. 17-20, celebrating the 100th anniversary of the discovery of polonium and radium. The conference's formal title is "The Discovery of Polonium and Radium: Its Scientific and Philosophical Consequences, Benefits and Threats for Mankind," and it will include many Nobel Laureate participants.*

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We are all exposed to natural ionizing radiation, which penetrates all living organisms. Radiation comes from the cosmos and from radionuclides present in rocks, walls, and air, and in our own body. Each flake of snow, grain of soil, drop of rain, each flower and even each man in the street is a source of this radiation.

The average individual dose of natural radiation received by the world population is now about 2.4 millisievert (mSv) per year. Every day, more than a billion particles of natural radiation impact our bodies.

However, in some regions, for example, in India and Iran, the natural radiation dose is up to 100 times higher than the world average. No adverse genetic, carcinogenic, or other effects of these higher doses have been observed among the people who have lived in these areas since time immemorial. In the 1990s, man-made radiation has increased the global average radiation dose by about 20%, mainly as a result of X-ray diagnostics in medicine. Other important man-made sources, like nuclear power systems, nuclear weapons tests, or the Chernobyl accident, contributed only a tiny fraction of the total increase.

In those regions of the former Soviet Union that were highly contaminated by Chernobyl fallout, the additional dose to inhabitants is much less than the dose in areas of high natural radiation (**Figure 1**). The entire man-made contribution to radiation amounts to only about 0.2% of the natural radiation dose in areas of high natural radiation.

Three and a half billion years ago, when life began, the natural level of ionizing radiation at the surface of the Earth was three times higher than it is now. It seems that this type of radiation might be needed for initiation of life on Earth, and experiments with protozoa and bacteria suggest that it may be essential for the extant life forms (Planel et al. 1987). At the early stages of evolution, organisms developed powerful defense mechanisms against such adverse radiation effects as mutation and malignant change. The sites of these effects are situated within the cell nucleus, and DNA is their primary target.

Most of the other adverse effects, leading to acute radiation sickness and early lethality, are located in the cell, outside its nucleus. These other effects require large radiation doses, thousands of times higher than natural ones, such as those that might be encountered in a nuclear war, in a beam of cyclotron radiation, or at a defective medical or industrial radiation source. (An example of such a source is the burning Chernobyl reactor, which claimed 28 victims.)

The concern about such large doses is obviously justified. However, the fear of small doses, such as those absorbed from the Chernobyl fallout by inhabitants of Central or Western Europe, is about as justified as a fear that an atmospheric temperature of 20°C may be hazardous, because at 200°C one can easily get third-degree burns.

According to recent studies, the vast majority of DNA damage in human beings is spontaneous, and is caused by thermodynamic decay processes, or by reactive free radicals formed by the metabolism of oxygen, such as OH, peroxides, and reactive oxygen species. Each mammalian cell has about 70 million spontaneous DNA damaging events per year (Billen 1994). No organism would survive such a gigantic rate of drastic, spontaneous DNA damages if it were not armed with a powerful defense system. This system consists of DNA repair mechanisms, and other mechanisms of homeostasis—enzymatic reactions, apoptosis (that is, suicidal elimination of changed cells), cell cycle regulation, intercellular interactions, and so on—which, in the stream of physico-chemical changes, maintain the integrity of organisms during an individual life and over thousands of generations.

The same types of damage are caused by ionizing radiation, but with much lower frequency. The present average natural radiation dose of 2.4 mSv per year causes only about five DNA damages per cell.

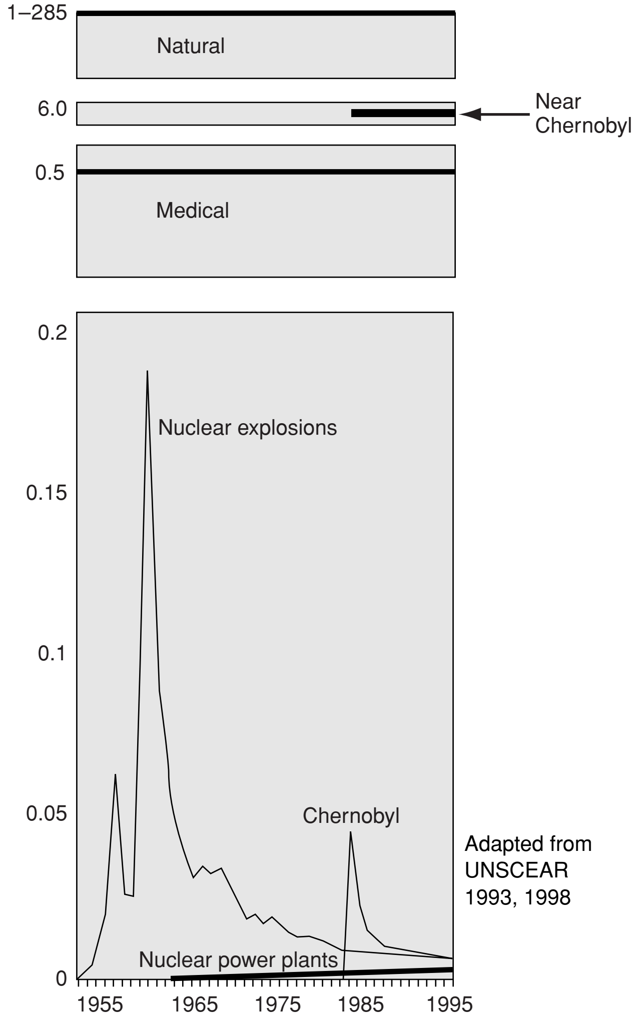
Man's lack of a specific sense organ for ionizing radiation is probably because the body's defense mechanisms already superfluously cover the whole range of natural radiation levels. The present natural radiation dose in various parts of the world ranges from less than 1 mSv, to 280 mSv per year (Sohrabi 1990; UNSCEAR 1993; Kesevan 1996). This range is much greater than the range of normal exposure to thermal energy, for example, which spans about 50°C. Increasing the water temperature in a bathtub by only 80°C, from a pleasant level of 293 kelvin to boiling at 373 kelvin (that is, by a factor of only 1.3), or decreasing it to the freezing point (that is, by a factor of 1.07), may cause death.

Such lethal high or low temperatures are often found in the biosphere; therefore, the development of an organ that could sense heat and cold was vital for survival. Organs of smell and taste were even more vital as a defense against dangerously toxic or infected food. But a lethal dose of ionizing radiation, delivered in one hour—which for man is 3,000

FIGURE 1

**Radiation exposure from all sources to world population and in Chernobyl regions**

(annual whole body doses in millisieverts)




*Average radiation exposure to world population and in regions of the former Soviet Union that were highly contaminated by Chernobyl fallout. In the 1990s, the average individual radiation dose from nuclear explosions, the Chernobyl accident, and nuclear power, was about 0.4% of the average natural dose of 2.4 mSv per year, or 0.0004% of the dose in high natural radiation regions. In areas of Belarus, Ukraine, and Russia that were highly contaminated by Chernobyl fallout, the average individual dose was much lower than that in regions with high natural radiation. The greatest man-made contribution to radiation dose is irradiation from X-ray diagnostics in medicine, which is about 20% of the average natural radiation dose.*

# UNSCEAR: New winds in radiation protection

The 47th session of the United Nations Committee on the Effects of Atomic Radiation (UNSCEAR), held in Vienna May 25-29, 1998, made it clear that the entrenched Linear No-Threshold (LNT) approach can be overturned, as more scientists are realizing its weakness. At the same time, as this potential revolution gains ground, there is a campaign in the United Nations General Assembly to dissolve this scientific body, perhaps because its scientific basis doesn't bend with the prevailing political winds.

During this session, UNSCEAR reviewed and corrected 11 draft documents on radiation: Exposures from Natural Radiation; Exposures from Man-Made Radiation; Medical Radiation Exposures; Occupational Radiation Exposures; Dose Assessment Methodologies; Epidemiological Evaluation of Radiation-Induced Cancer; DNA Repair and Mutagenesis; Hereditary Effects of Radiation; Combined Effects of Radiation and Other Agents; Radiation Response and Risk Assessment at Low Levels of Exposure; Local Exposures and Effects of the Chernobyl Accident.

A reason why UNSCEAR is viewed by some to be politically inexpedient can be seen from the conclusion of this last document:

"[A]part from the dramatic increase in thyroid cancer in those exposed as children, *there is no evidence of a major public health impact to date from the radiation ex-*

to 5,000 mSv—is a factor of 10 million higher than the average natural radiation dose that one would receive in that same time period (0.00027 mSv). This illustrates very weak noxiousness of ionizing radiation, as compared with other agents. Nature provided living organisms with an enormous safety margin for natural levels of ionizing radiation—and for man-made radiation from controlled, peacetime sources.

Conditions with lethal levels of ionizing radiation do not occur normally in the biosphere, and, therefore, a sense organ for radiation was not needed.

## Why radiophobia?

If radiation and radioactivity, although ubiquitous, are so innocuous at normal levels, and one of the lowest risks, why are they an object of universal apprehension? What is the cause of radiophobia—the irrational fear that any level of ionizing radiation is dangerous, which is perhaps the most widely spread and influential superstition of the second half of the 20th century? Why have radiation protection authorities introduced a dose limit for the public of 1 mSv per year, which is less than 1% of the natural dose in many areas of the world? Why do the nations of the world spend hundreds of billions of dollars a year to keep this unreasonable standard?

One important cause of the radiophobia that underlies today's irrational regulations was the psychological aftermath of military use of nuclear energy in Hiroshima and Nagasaki, and of the development of vast arsenals of nuclear weapons of mass destruction. These weapons are regarded as a deterrent: Those who possess them wish to make radiation, one of their effects, look as dreadful as possible. Therefore, there is rarely any refutation of even the most obviously false and often-voiced statements: "Radiation from nuclear war can annihilate all mankind, or even all life," or "200 grams of plutonium could kill every human being on Earth" (*International Herald Tribune,* 1996). The group interests of radiation protection researchers fighting for authority and budget—largely surpassing budgets for studies of other physical and chemical noxious agents—negatively influenced public opinion. The same is valid for political groups, which used radiophobia with great success as a handy argument in their power games, in the 1970s in the United States, and in the 1980s and 1990s in Eastern Europe and the Soviet Union.

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*posure caused by the Chernobyl accident in the three most affected countries. No major increase in all cancer incidence or mortality has been observed that could be attributed to the accident.* In particular, no major increase has been detected in rates of leukemia, even among the accident recovery workers, one of the major concerns after radiation exposure. This is generally consistent with experience from studies of other radiation-exposed populations, in particular the survivors of the atomic bombings in Japan" (emphasis added).

The document also stated that "screening must . . . play a role in the reported increases in thyroid cancers." In other words, the increases in thyroid cancers are partly the result of more people being screened for the disease, and not the result of an increase in incidence.

UNSCEAR plans to publish this material in the year 2000, and two more sessions will be held to review it. The final volume will be about 1,000 pages.

The good news from this session is that in general, the LNT theory seems to be losing ground in this body. The just-disclosed scandal about the manipulation of data on radiation mutations has played only a minor role in the turnaround. The greatest impact on those scientists holding to the LNT is the new information on the frequency of spontaneous DNA damage and repair mechanisms.

Most refreshing, the once-condemned words, "threshold" and "hormesis," which a few years ago would sound at an UNSCEAR meeting like swearing in the cathedral, are now used there freely and often. One representative even seriously proposed the term "practical threshold."

We may probably expect revolutionary changes in radiological protection, with revision of the philosophy of protection, of dose limits, and of such entities as "collective dose," "effective dose," "dose commitment," and a host of other unnecessary complications that were introduced by the International Committee on Radiation Protection (ICRP) during the past four decades. In my opinion, the best we can do is to come back to basics at the 1958 level.

One leading UNSCEAR representative proposed that we should stop quarreling about the LNT issue and work hand-in-hand to start a revolution in radiological protection, removing the issue from the grip of the LNT and its various derivatives. He noted, however, that there was forceful opposition coming from a few strong personalities inside the ICRP, so that such progress would require time.

One major problem discussed during this session was the very existence of UNSCEAR. There are forces in the UN General Assembly who wish to dissolve the committee, including one "major nation" that is pushing for its dissolution. But if UNSCEAR disappears, what nations will have enough scientific authority—and courage—to effectively oppose the "strong personalities" in ICRP or the U.S. National Committee on Radiation Protection, and to support the aforementioned revolution? Despite some weaknesses, in my view, UNSCEAR is the best international scientific committee in the world, and the only one placed so highly in the United Nations family.

The fate of UNSCEAR will be decided at the September session of the General Assembly. Some publicity and lobbying may help to save it.—*Z. Jaworowski*

Between 1945 and 1980, there were 541 nuclear atmospheric tests performed, with a total energy yield of 440 megatons. In these explosions, about three tons of plutonium (that is, almost 15,000 "deadly" 200-gram doses) were injected into the global atmosphere, and, behold, a miracle: We are still alive! The average individual radiation dose from all these nuclear explosions, accumulated between 1945 and 1998, is about 1 mSv; that is, less than 1% of the natural radiation dose (UNSCEAR 1998).

In the record years of 1961 and 1962, there were 176 atmospheric explosions, with a total yield of 84 megatons. The maximum deposition, on the surface of the Earth, of radionuclides from these explosions occurred in 1964. The average individual dose accumulated from this fallout, between 1961 and 1964, was about 0.35 mSv.

The global nuclear arsenal of about 50,000 weapons, with a combined explosive power of about 13,000 megatons (Waldheim 1981; Rotblat 1981), is only 30 times higher than the megatonnage already released by all previous nuclear tests in the atmosphere. If all the global nuclear arsenal were exploded, with a combat geographic distribution similar to that in past nuclear tests, the average individual would receive a long-term radiation dose of about 30 mSv, from the ensuing worldwide fallout. Using as a yardstick the years of 1961 and 1962, this dose would be about 55 mSv. Exploding all the nuclear weapons in a few days instead of two years, would not much change this estimate, which is a far cry from the short-term lethal dose of 3,000 mSv for man.

## The bomb and the 'linear no-threshold' theory

At Hiroshima and Nagasaki, short-term radiation doses of less than 200 mSv did *not* cause induction of cancers among the atomic bomb survivors (UNSCEAR 1993). Among survivors exposed to much higher doses, *no* adverse genetic effects in their progeny have been detected during the past 50 years of study (Sankaranarayanan 1997).

Until recently, such information from the study of survivors has been ignored. Instead, the driving force of radiophobia has been the linear no-threshold theory that is assumed to exist between radiation and its effects on the living organism (essentially, the assumption that the detrimental effects of radiation are proportional to the dose, and that there is no dose at which such effects are not detrimental). It is on this assumption, that the International Commission of Radiological Protection (ICRP) arbitrarily based its rules of radiation protection in 1959. This was an administrative decision, not the result of scientific study. It was based not on science, but on political considerations, which influenced the philosophy and practice of radiation protection (Taylor 1980).

Over the years, the working assumption of the ICRP stated that even the smallest amounts of radiation—close to zero dose—may cause harm. This assumption came to be regarded as a scientifically documented fact by the mass media, public opinion, regulatory bodies, and even by many scientists. The linear no-threshold theory, however, is not a scientific principle; it belongs solely to the realm of administration.

The absurdity of the linear no-threshold theory was brought to light after the Chernobyl accident in 1986, when minute doses—for example, those reaching the United States, which were 0.004% of the average natural dose, or 0.3% of the average natural dose in the rest of the Northern Hemisphere—were used to calculate that the Chernobyl accident would cause 53,400 cancer deaths over the next 50 years (Goldman et al. 1987). Such frightening numbers were derived simply by multiplying trifling Chernobyl doses, and the vast numbers of people living in the Northern Hemisphere, by a cancer risk factor based on epidemiological studies of 75,000 atomic bomb survivors in Japan. The bomb survivor data, however, are not relevant for such estimations, because of the difference in the dose rate. The bomb survivors were irradiated in a hundred-millionth fraction of a second, with doses more than 50,000 times higher than those U.S. inhabitants will receive from the Chernobyl fallout over 50 years.

For a dose rate of, say, 1,000 mSv per one-billionth of a second in Japanese bomb survivors, we have reliable epidemiological data. But there are no epidemiological data for a dose rate of 0.0046 mSv per 50 years in U.S. inhabitants. The dose rate in Japan was larger by $3.5 \times 10^{22}$ than the Chernobyl dose rate in the United States. Extrapolating over such a vast difference is epistemologically not acceptable. Estimates of cancer death based on such extrapolations was defined by Dr. Lauriston S. Taylor, the former president of the U.S. National Council on Radiological Protection and Measurements, as "deeply immoral uses of our scientific heritage."

Nevertheless, exactly such no-threshold extrapolations are the foundation of both the philosophy and practice of radiological protection during the second half of the 20th century.

## Enter hormesis

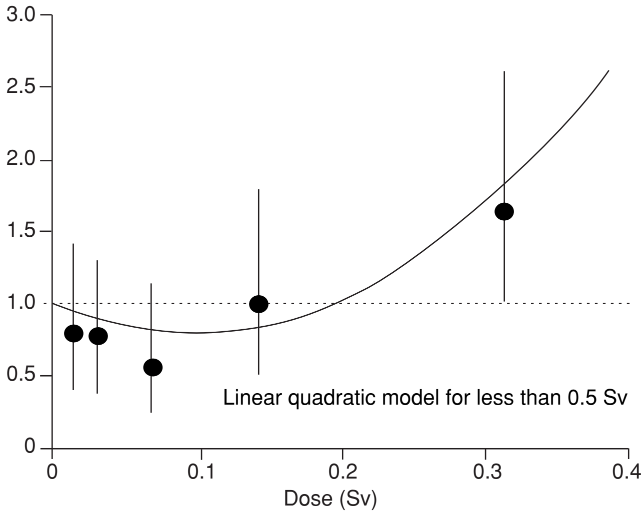
The linear no-threshold theory is contradicted by the phenomenon of hormesis, that is, the stimulating and protective effects of small radiation doses. The first report on hormetic effects in algae appeared 100 years ago (Atkinson 1898). One of the most recent hormetic effects can be seen in the lower-than-normal incidence of leukemia (**Figure 2**) and the greater longevity among atomic bomb survivors (Kondo 1993). Although more than 2,000 scientific papers were later published on radiation hormesis, after World War II, the phenomenon was forgotten and ignored by the radiation protection establishment. It was as late as 1994, that the United Nations Scientific Committee on the Effects of Atomic Radiation, the most distinguished scientific body on matters of radiation, recognized and rubber-stamped the very existence of radiation hormesis (UNSCEAR 1994). This caused a "revolutionary ferment" among the profession of radiologists, both ethical and technical.

Many radiologists realized that over the past decades they might have been unethically overreacting, diverting resources to be consumed in the "avoidance" of theoretical (actually

FIGURE 2

**Mortality from leukemia in survivors of Hiroshima and Nagasaki**

(relative risk)




After UNSCEAR, 1994.

*The hormetic effect is seen between a dose of 0 and 100 mSv.*

imaginary) health effects, thereby depriving society of funds that were desperately needed to deal with real health problems (Thomas 1998). Applying the no-threshold principle for the alleged protection of the public, imposed restrictive regulations on nuclear utilities, which virtually strangled the development of environmentally and people-friendly nuclear energy in the United States and in other countries. In my own country, after spending billions of dollars, the construction of the first nuclear power reactor was abandoned, as a result of public opinion distorted by the no-threshold principle.

Each human life that is hypothetically saved by implementing these excessive regulations costs about $2.5 billion! Such costs are absurd and immoral, especially when compared to the costs of saving lives by immunization against measles, diphtheria, and pertussis, which in developing countries range between $50 and $99 per each human life saved (Cohen 1992). But billions of dollars for such imaginary protection of human life are spent year after year, while much smaller resources for real life-saving in developing nations are notoriously lacking.

## An alternative based on reason

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 this threshold, radiation doses should be regarded as having no regulatory concern. Regulations are not needed for the situations such as experienced in Hiroshima and Nagasaki, with extremely high dose rates. Therefore, a practical threshold will probably be based on epidemiological data from exposures in medicine, nuclear industry, and regions with high natural radiation. The current population dose limit of 1 mSv per year may then be changed into 10 mSv per year or more. This would be an important step on the way to rationality and to gaining again the public acceptance of radioactivity and radiation as a blessing for humankind.

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### For further reading

For a comprehensive review of Chernobyl and radiation, see "All Chernobyl's Victims: A Realistic Assessment of Chernobyl's Health Effects," by Zbigniew Jaworowski, in *21st Century Science & Technology,* Spring 1998, pp. 14-25.

On low-level radiation effects, see "The Hazards of U.S. Policy on Low-Level Radiation," by Jim Muckerheide and Ted Rockwell, in *21st Century Science & Technology,* Fall 1997, p. 17.