1972

The Biological Effects of Low Level Nuclear Radiation on Human Health and Development

Ernest J. Sternglass

Department of Radiology, University of Pittsburgh
School of Medicine, Pittsburgh, Pennsylvania

Few areas of biomedical research have been explored as much as the action of ionizing radiation on animals and human beings during the nearly one hundred years since X-rays and radioactivity were discovered at the end of the last century. Yet in 1972, more than three quarters of a century and thousands of laboratory and human studies later, a simple, quite unplanned experiment on a biological membrane by a Canadian physician and biophysicist named Abram Petkau completely overturned all conventional ideas on the biological damage produced by extremely low doses of radiation comparable to those we experience from natural background sources. Suddenly it became clear that the scientific community had been completely misled into believing that low dose radiation is harmless by decades of lack of evidence for detectable adverse effects of low dose diagnostic X-rays on human health, by numerous animal studies showing very low effects on the genes of reproductive cells, and by the relatively low rate of leukemia and cancer deaths among the suvivors of the Hiroshima and Nagasaki nuclear bomb detonations.

The fact that high doses of radiation produce serious effects was learned very soon after the discovery of X-rays by Wilhelm Roentgen in 1895 and the discovery of radiaoactivity by Becquerel the following year. Skin burns that would not heal and eventually turned into skin tumors were reported by the pioneers in the application of X-rays to medical diagnosis and therapy within a few years, and most of the early workers in the field died prematurely of leukemia and cancer.

Genetic effects on future generations due to irradiation of the reproductive cells before conception were not discovered until 1927 in the course of studies on fruit-flies by H.J. Muller. However, the dose required to double the number of spontaneous mutations was found to be very high, thousands of times the annual dose from background sources such as radioactivity in the soil and cosmic rays from the sun, typically 100 millirads per year.(One millirad is one thousandth of a rad, a measure of the energy absorbed in tissue.) Thus, there seemed to be little reason for concern that ordinary

diagnostic X-rays,which gave doses of the same order of magnitude as background radiation, would have any detectable effects on the offspring or lead to significant increases in cancer since cancer induction was believed to be caused by similar effects on the genes as mutations.

In fact, the early evidence from the treatment of cancer by radiation where doses of thousands of rads are directed at tumor cells so as to kill them showed a remarkable ability of nearby healthy tissue to survive large doses and heal. Spreading the doses out over a series of treatments covering a few weeks to months helped to reduce any deleterious effects, and radiation therapy became a very widely used treatment for many types of cancers, further reducing the concern about low dose exposures.

Thus, the successful experience with medical uses of X-rays caused the scientists who developed the atomic bomb during World War II to believe that the principal effect of the bomb explosions would be produced by blast and fire, even though they emitted a short burst of gamma rays and neutrons.There was also some fallout believed to produce very low doses, much less than the annual background dose,except for ground bursts near the point of detonation, so there was no reason to expect any detectable health effects from nuclear bomb testing. And since the military were anxious not to have the biological damage from fallout widely known, all aspects of this subject were classified until 1957, when Congress held hearings on the need for fallout shelters.

There was even the hope that there might not be any health effects at all from very small doses, especially since for some cases such as immediate death, there seemed to be a safe threshold of the order of 50-100 rads, a thousand times the small annual background dose. And one study of cancer induction after another for animals in a laboratory setting done in this dose range showed that extended exposures were much less likely to lead to the development of cancer than single short exposures at the same total dose. Thus, it also appeaerd to be perfectly safe to go ahead with the construction of large nuclear reactors for peaceful purposes that would bring clean nuclear energy to replace dirty coal plants since it was widely believed that they would not release any significant amounts of radioactivity.

The first indication that there might be a problem from very low dose radiation came quite unexpectedly from a study undertaken by a British physician at Oxford University by the name of Alice Stewart. There had been a sharp rise in chilhood leukemia in England since World War II, so she sent out a few hundred questionairs to

women whose children had died of leukemia and to a matched control group. To her surprise, she found that there was no difference in family history or exposure to benzene and other chemicals for the two groups, but that women who had received two or three diagnostic X-rays during pregnancy had nearly twice as many children who died of leukemia before age 10 as the control group, as described in the British Medical Journal in 1958.

At first, no one in the medical community wanted to believe her results, but when a similar study carried by Dr. Bryan MacMahon at Harvard University confirmed her findings in a 1962 article in the Joural of the National Cancer Institute, some public health officials became concerned. It was at this time that I become aware of her findings in the course of a study of the likely result of a nuclear war by a group of scientists in Pittsburgh in 1962, following the end of a temporary halt in testing with the detonation of a 50 megaton hydrogen bomb by the Soviet Union the previous year. I realized that the resultant world-wide fallout would give the equivalent of an abdominal X-ray of about 200-300 millirads to some two billion persons in the northern hemisphere. Thus, if Dr. Stewart's data applied also to fallout exposures, there would be a 20% increase in childhood leukemia just from this one bomb detonation alone, a result that was published in June of 1963 in "Science".

With the conclusion of a treaty to end testing in the atmosphere later that year, the widespread concern about fallout in the milk and diet that had been started by Linus Pauling and Andrei Sakharov in 1958 subsided. But the continuing build-up of nuclear weapons arsenals and the the proposed construction of anti-ballistic missile systems carrying nuclear warheads caused me to undertake a study as to whether an increase in leukemia rates due to fallout had actually taken place.

In the course of this study, not only did I find evidence for a rise in leukemia rates in the area of Albany-Troy, New York, following a heavy rainstorm that occurred when a nuclear bomb cloud from the Nevada test-site passed over this region, but there was also a sharp rise in spontaneous miscarriages and infant deaths within a year of this fallout episode, a result that was published in April 1969 in The Bulletin of the Atomic Scientists. Since the number of infants that die of all causes is ten to twenty times larger than those who die of leukemia,the threat to human health from fallout was now much larger.

Public health statistics indicated that there was an upward deviation from the steady downward trend of about 4% per year for the U.S. as a whole. Furthermore, this abnormal increase was very

closely correlated with state-by-state data on the concentration of strontium-90 in the milk during the preceeding 3-4 years for all socio-economic groups, with the poorer non-white infants showing about twice the mortality rate for the white population with its better diet, prenatal care and access to medical treatment. Between 1945 and 1968, there was an excess of some 400,000 infant deaths above normal expectations in the U.S. alone.

Again, there was widespread disbelief in the scientific community that such small amounts of radiation could be a factor in leukemia and infant mortality. But in the course of preparing a critique of my findings for the Bulletin of the Atomic Scientists, Dr. John Gofman and Dr. Arthur Tamplin at the Livermore Laboratories of the Atomic Energy Commission not only calculated that there probably was such an effect of past nuclear tests, though on a much smaller scale using the risk for genetic effects as a basis. However, in U.S. Senate Hearings on the Underground Uses of Nuclear Energy in November 1969, they pointed out that the permitted doses from radioactive releases by commercial nuclear plants of 170 millirads to the general population would increase the cancer mortality rate by as much as 32,000 per year.

By 1970, Dr. Stewart had greatly extended her study and the results published in the journal "The Lancet" showed a direct increase in risk with the number of X-rays taken without any evidence for a safe threshold, lending still further support to the fallout hypothesis and the concern about nuclear plant releases that the public had been completely unaware of. Moreover, bacause a few percent of all women had received X-rays in the first three months of pregnancy, Dr. Stewart discovered that the risk for such early exposures was some ten to fifteen times greater still than for radiation exposures just before birth. This meant that a dose roughly equal to that due to the yearly background radiation, or as little as 50-100 millirads, was sufficient to double the risk of childhood cancer and leukemia, some 1000 times smaller than expected from the study of the Hiroshima-Nagasaki survivors.

By that time, I had found rises of infant mortality and underweight births around the Dresden nuclear plant near Chicago correlated with the reported gaseous emissions at calculated doses comparable to those from fallout. These findings, together with similar effects on infant mortality for seven other nuclear facilities were published in the Proceedings of a Conference on Pollution and Health held at the Statistical Laboratory of the University of California, Berkeley, in 1971 . This paper also reported sharp rises in deaths due to congenital defects in Utah following the

onset of Nevada tests in 1952, rises in childhood leukemia in nearby Utah and more distant areas such as Minnesota, sharp increases in non-infectious respiratory disease deaths due to bronchitis, emphysema, and asthma in such different areas as New Mexico, Wyoming, New York and Illinois following the onset of nuclear tests, as well as leukemia rises in Utah and Nassau County, Long Island, New York, all reached by the drifting fallout clouds. For Nassau County, yearly fallout dose measurements were available that showed an increase in risk of 0.48% per millirad, comparable to that observed by Dr. Stewart for X-rays in the first trimester.

Thus, not only infant mortality had shown an abnormal rise in the 1950's across the U.S., but also adult mortality at all ages. This had already been pointed out earlier by I. M. Moriyama in a 1960 article that appeared in Public Health Reports and a 1964 monograph published by the U.S. Center for Health Statistics. But there was no biological mechanism that could relate this to the low doses produced by fallout radiation until after the unexpected discovery of Petkau, published in the March 1972 issue of Health Physics under the innocuous title "Effect of Na-22 on a Phospholipid Membrane", that cell-membranes which could withstand radiation doses as large as tens of thousands of rads when exposed to a short burst of X-rays without breaking, ruptured at less than one rad when subjected to low intensity protracted radiation such as produced by radioactive chemicals. This was completely contrary to all previous observations of biological damage by radiation such as genetic effects and cancer induction in laboratory animals, which had shown little dependence on the rate at which radiation is delivered to tissue. In fact the data seemed to indicate that when the rate was reduced or the dose spread out over a few weeks, there was less permanent damage to the genes than for very high rates, presumably due to highly efficient repair mechanisms of the DNA in the nucleus of cells.

A series of subsequent investigations by Petkau and his coworkers showed that the cell-membrane damage was due to a completely different biological mechanism than the direct hit on the DNA molecules in the nucleus of cells that had been observed at the high doses and and dose-rates of the bomb detonation or medical exposures. It turned out that the lipid membranes were destroyed as the result of the action of a negatively charged, short-lived form of ordinary oxygen, the so-called O_2^- free-radical, produced by the absorbed radiation from the life-giving oxygen dissolved in the surrounding fluid. This highly toxic form of oxygen was attracted to the positive charge on the outside of lipid cell-membranes, where it

initiated a chain reaction that dissolved the membrane in a matter of minutes to hours, causing the cell to leak and die.

Thus, only a single O_2^- molecule was sufficient to destroy an entire cell, so that only a handful needed to be produced per unit volume at very low dose-rates. But at high dose-rates, many millions would be formed in the same volume in the life-time of the molecule, a form of "overkill", much like the case of a balloon, where a single dart is enough to destroy it, and throwing millions of darts at it only represents a waste of energy. In fact, the more free-radicals are created in a given volume, the more they tend to run into each other, causing them to become deactivated to harmless ordinary oxygen. As a result, as I published in an article in 1974, per unit of energy deposited in living tissue consisting of cells, high doses given at the rate of 10,000 rads per minute were found to be 100 billion times less efficient in destroying a cell than at one ten millionths of a rad per minute, the rate at which we experience background radiation.

A consequence of the enormously greater efficiency of radiation at very low as compareed to very high dose rates is that the dose-response curve rises very rapidly at small doses and dose-rates near those of background, and flattens out at the high doses and high dose-rates for environmental exposures. Mathematically, this turns out to be of the form of a logarithmic relation between dose and biological response for the case of individuals exposed to different amounts of radiation during a given time period as in the case of releases into the environment. By contrast, in the case of individuals exposed to a series of short medical exposures, where the rate at which the radiation is received is high and the same for every individual exposure, one gets a linear, straight-line relation between the dose and the response that is hundreds of times less steep at the low doses of a few millirads for a modern chest X-ray in the case of an adult.

Thus, the Hiroshima-Nagasaki data as reexamined by Gofman in his 1990 book "Radiation Induced Cancer from Low Dose Exposure" shows a dose-response that is concave downward, obeying a logarithmic form for the risk of cancer that rises rapidly at low doses and more slowly at high doses since these were received at a higher rate in rads per minute than the lower exposures of the more distant survivors. But since the more distant survivors also received fallout from the "black rain" of the order of tens of rads which was not taken into account when the data were analyzed, the very steep initial part of the dose-response curve was hidden and instead had a nearly flat shape. Thus, in the attempt to deduce the cancer risk near

background levels by curve-fitting all the way down to a few rads, extrapolation from high doses leads to an underestimate of the true risk of very small doses in the millirad range by a large factor, more so for a linear than for the fractional power law used by Gofman.

The indirect, free-radical type of damage that dominates at low dose-rates is particularly serious for the cells of the immune system, which must be constantly renewed from their progenitors in the bone marrow. This is especially true for strontium-90 and other bone-seeking isotopes chemically similar to calcium that concentrate in bone and emit relatively long-range beta particles or electrons that reach the marrow much more efficiently than the alpha particles emitted by naturally occurring radium in the environment, explaining why natural background radiation is not as serious as that due to strontioum-90 or 89. And laboratory studies of animals given radioactive strontium by Stokke and his coworkers at Oslo University published in 1968 have not only shown that the damage to marrow cells rises rapidly for doses in the millirad range and then levels off to a plateau, but as found by Heller and Wigzell at Upsala University in 1977, radioactive strontium acts to inhibit the normal function of the so-called Natural Killer (NK) cells that originate in the bone marrow and are vital in the defense against micro-organisms and cancer cells.

But an equally serious danger is the premature birth of infants whose mother's immune system has been damaged, leading to the rejection of the fetus as a foreign object, a biological mechanism that explains the delayed action of strontium-90 in the milk as it builds up in the mother's body in the years before pregnancy. The critical role of the immune system in the maternal-fetal rejection response as discussed by Charles Grossman in a 1985 article is yet another phenomenon whose connection to strontium-89 and 90 in the bone marrow was not recognized. Thus, not only infectious diseases during pregnancy can lead to premature birth, as has long been recognized, but also a mistake made by the mother's immune system.

The small ruptures of blood-vessels in the brain of babies born prematurely and below normal weight greatly increase the chance of neurological damage, in addition to the effect of raioactive iodine slowing the normal development of the brain. The result is an increased risk of learning disabilities as manifested by a decline in Scholastic Aptitude Test (SAT) scores seventeen years later as reported by Steven Bell and myself at a meeting of the American Psycholgical Associaion in Sepember 1979 and in a 1984 article. The neurological damage also manifests itself in behavioral problems such as an increased incidence of criminal violence as discussed by

Robert J.Pellegrini in The International Journal of Biosocial Research in 1987 .

It is therefore the subtle effects on the hormonal and immune system by the indirect chemical action of man-made radioactivity in the human body which explain the unexpectedly large effects on infant mortality, prematurity and the subsequent effect on learning ability, school failure, juvenile delinquincy, school drop-out, adolescent suicide, drug-use, juvenile pregnancy, and a rise in violence and crimes committed by the young that rose so sharply in the 1960's and 70's

This rise in infant mortality and prematurity associated with fallout has recently been independently confirmed in a study of the changes in neonatal mortality in England and the United States by Robin K. Whyte published in The British Medical Journal in February 1992. While examining the hypothesis that the rise in first-day neonatal mortality in the 1950's may have been due to a reduction in the amount of oxygen given to underweight babies in order to avoid blindness, Whyte found that the rise and decline of neo-natal mortality that led to some 320,000 excess deaths above normal expectations in England and the U.S between 1950 and1980 could not be explained by this hypotesis since the same pattern was found for still-births where oxygen concentrations in the crib could not be a factor. He concluded that there was no other known world-wide environmental, dietary or medical practice change that could explain the excess deaths than the rise and decline of strontium-90 from nuclear fallout.

Since exposure to radiation during early development and premature birth is also associated with a reduced immune system response of the ofspring that lasts for the life-time of the individual as first shown in laboratory studies on fish exposed to very low concentrations of tritium and published in two papers in 1977 and 1982 by John A. Strand and co-workers at the Pacific Northwest Laboratories, one would expect that mortality rates due to infectious diseases should also be affected among those who survive the critical neo-natal period. The first indication of an abnormal rise in infectious diseases manifested itself in the data for infant mortality due to pneumonia and influenza in the U.S. as well as in an epidemic of encephalitis in New York City. This was described in a paper by Jens Scheer and myself presented at a meeting of the American Association for the Advancement of Science in 1986 in connection with the hypothesis that damage to the immune system by strontium-89 and 90 during early

development may be a co-factor in the AIDS epidemic, as well as in a separate paper on the probable effects of Chernobyl.

As pointed out by Sakharov as early as 1958, fallout from nuclear tests could lower the immune competence of the human body as well as lead to the outbreak of new epidemics due to an accelerated rate of mutation of micro-organisms that could make them more virulent as well as able to defeat the action of antibiotics. This hypothesis would explain why the human immunodeficiency virus (HIV) seems to have first evolved in Sub-Saharan Africa with its very high rainfall, since 90% of all fallout comes down with rain or snow in mountain regions. In the case of Africa, it came down on the snow-covered mountains of eastern Africa near the equator from the clouds of fallout circulating the globe produced by the large hydrogen bomb tests in the Pacific at the same latitude beginning in 1952-3. Thus the lakes of East Africa were heavily contaminated with strontium-90 and other bone-seeking isotopes, and since sweet-water fish concentrate these elements some 1000 times more than salt-water fish, those who depended on them for their diet would receive high doses to the bone marrow where the cells of the blood and the immune system originate.

When the individuals exposed in early infancy reached sexual maturity some 15-17 yers later under conditions of great social upheaval, poverty and poor treatment of sexually transmitted diseases in the crowded cities, all the necessary conditions arose that would account for the outbreak of the AIDS epidemic in late 1970's, rapidly spreading as a result of air-travel to areas of the Carribean and to the Coastal cities with high rainfall such as New York and San Francico.

This hypothesis is strongly supported by the fact that in 1957 when the first measurements of strontium-90 concentration in the bones of adolescents were measured as reported by the United Nations Commission on the Effects of Atomic Radiation in 1962, the Congo reported the highest levels among the 22 nations studied.

It also can explain the recently discoverd fact that there are many cases of AIDS-like diseases in which there is a severe loss of immune competence wthout any evidence of HIV infection. Thus, early exposure to radioative fission products from nuclear tests repeated as a result of subsequent nuclear releases from reactor operations or accidents like Three Mile Island or Chernobyl could account for the sharp rise in AIDS deaths in 1986-87 in the U.S. and especially in such developed countries as Switzerland that received heavy fallout from the Chernobyl accident.

Such a widespread environmental factor known to compromise the immune defenses was in fact regarded as a possible consequence of fallout from nuclear war by Greer and Rifkin in a paper published in 1985 by the U.S. National Academy of Sciences and the Institute of Medicine. However, no relation to the fallout from bomb tests or nuclear accidents was considered since the doses from testing were hundreds to thousands of times smaller than from nuclear war. But in the light of the discovery by Petkau that small, protracted doses can produce almost the same biological damage as doses that are hundreds to thousands of times greater as confirmed by numerous recent studies, the danger of widespread new epidemics of infectious diseases caused by nuclear releases into the environment first made by Sakharov can no longer be ignored.

Indeed, as brought out in a series of articles in the August 21,1992 issue of Science, a sharp rise in many different infectious diseases has taken place during the last few decades that has been attributed to a rise in the resistance of bacteria to antibiotics. But the mutations in the micro-organisms that allow them to defeat the action of antibiotics, as well as the mutations in the white-cells of the human immune system, are greatly accelerated by low level radiation, as Sakharov predicted. Moreover, the effectiveness of very low dose-rates in producing mutations has now been found by Waldren and his co-workers to be more than two hundred times grater than short, high dose exposures.

This therefore explains the rise of salmonella infections in the U.S. since the mid-forties as described by Cohen, a rise that occurred in a series of steps following the onset of each major new release of radioactivity into the environment such as the beginning of the Nevada tests, the first H-bomb tests, the second large H-bomb series in1961-62, the Three Mile Island accident and the arrival of the Chernobyl fallout in the U.S.

Likewise, resistance of other clinically important bacteria such as shigella, dysenteria, gonnorrhea, typhoid and pneumonia accelerated sharply in the 1970's and 80's when the large 1000 Megawatt reactors began to operate near the major milk and beef producing areas supplying the major metropolitan regions such as Wisconsin, Pennsylvania and Upstate New York. Clearly, the combination of the growing use of antibiotics in both cattle and humans combined with a chronic, low dose-rate exposure of the dairy and cattle herds to such isotopes as iron-55, iodine -131, strontium-89 and barium-140 provided the evolutionary pressure and opportunity for the enormously rapid development of drug-resistance of human pathogens.

The most serious of all the newly rising epidemics is that of tuberculosis (TB) as described by Bloom and Murray in the Augaust 21,1992 issue of Science. Among all infectious diseases, TB is the leding cause of death. Each year there are an estimated 8 million new cases and 2.9 million deaths from the disease. And as the authors show in Figure 3 of their article, the first "exces deaths" in the U.S. above the previous decline occurred in 1980 to 1982, the years following the TMI accident, with a second rise occurring in 1986 and the following years, the time of the arrival of the Chernobyl fallout. Between 1987 and 1990, the number of cases of TB in U.S.-born children under 5 has increased 35%. And for all ages combined, the excess deaths that cannot be attributed to the AIDS epidemic is estimated by the authors to be13,700 between 1985 and 1991. And each year, there is a greater resistance to one or more of the available antibiotics.

This enormous new problem of rapidly growing drug-resistance is excacerbated by the fact that the individuals most likely to be exposed to TB and sexually transmitted diseases are those in the age group 25 to 45 years old who were born during the height of nuclear testing between 1947 and 1967, when strontium-90 in the bone and iron-55 in the blood reached its peak concentrations. It is therefore not surprising to find that the percentage of individuals in this age-group out of the total population who are dying each year rose sharply beginning in the late 1970's as discussed in detail by Gould in a paper prepared for the 2nd International Conference of Radiation Victims in Berlin September 1992.

Since a weakened immune defense such as a decrease in the effectiveness of the natural killer (NK) cells also leads to a more rapid spread of cancer cells as is seen in AIDS patients, one would also expect a sharp rise in the incidence of cancer to have taken place in the 1980's that parallels the rise in TB, and which cannot be attributed to smoking or the HIV virus. This is in fact found in the recent Cancer Statistics Review 1973-1988 published in 1991 by Ries and co-workes at the U.S. National Cancer Institute. Thus, childhood leukemia for individuals 0-14 years old rose from a low of 3.8 per 100,000 in 1979 to 4.6 by 1986, a highly significant 21% rise to a peak, followed by a renewed decline to 3.9 by 1988. Such a rapid rise to a peak following a known radiation exposure was first noted by Stewart for in utero exposures to X-rays, and therefore strongly supports an association with the 1979 TMI accident near Harrisburg, previously documented in cancer mortality rates in that area by Gould and Goldman in their 1992 book.

For the case of breast cancer for all races combined, the NIH Cancer review shows a similarly sharp rise. After declining from a high of 29.5 in 1976 to a low of 27.7 in1979, the incidence rose to 33.4 for women under 50 years of age, or by 20%. But for women over 50, it rose from 261.2 in 1979 to a peak of 356.3 in 1987, a rise by 36% in only 8 years.

`The likelihood that these large and rapid rises in cancer incidence resulted from exposure to nuclear isotopes released into the environment has now found overwhelming support from the study of thyroid cancers among children in Belarus, downwind from the Chernobyl plant. As reported by Kazakov and his co-workers in the September 3, 1992 issue of Nature, the incidence of thyroid cancer rose from 2 cases in a population of 2,5 million in 1986 to 55 cases in 1991, with the greatest number of cases occuring in the areas of highest fallout.

Such a surprisingly high and rapid rise in cancers following exposure to relatively low levels of ingested and inhaled radioactivity from nuclear sources has now been confirmed in a series of epidemiological studies of individuals exposed to low-level radiation in the environment produced by bomb-tests, by nuclear plant releases, and for the case of workers in government nuclear facilities as summarized in the 1990 BEIR V report by the U.S. National Academy of Sciences.

Thus, a large epidemiological study of 1177 indivduals living in Utah with known exposures to Nevada test fallout who died of leukemia was published by Stevens and associates in the August 1st issue of The Journal of the American Medical Association which showed a clear association between the radiation doses at levels comparable to those from the natural background and leukemia mortality, which was strongest for those under the age of 19, consistent with five previous studies that had been questioned for various methodological reasons overcome by the latest study. And in the March 20th 1991 issue of the same journal, an even more extensive study by Wing and coworkers involving 8318 men individually monitored for decades at the government's Oak Ridge National Laboratory showed that the risk of dying of leukemia, cancer and other causes of death was ten times higher than expected on the basis of the Hiroshima-Nagasaki survivors.

Tragically, the discoveries of Stewart and Petkau and their widespread epidemiological confirmation came long after nuclear weapons were tested on a large scale, and long after hundreds of military and civilian reactors were built all over the world. Moreover, in an effort to minimize the danger of accidental releases

of radioactivity to the population of large metropolitan areas that are difficult to evacuate quickly, the reactors were often located in rural dairy farming areas that supply most of the milk for the large cities by refrigerated tank trucks, a highly efficient pathway for the short-lived radioactivity not considered by the regulatory agency in the original estimates of the total dose to the population.

The most difficult task for society and the scientific community today is therefore to face these totally unexpected effects on human health and development and end the releases of fission products into the environment when hundreds of costly reactors are already operating around the globe and the major nations still regard nuclear weapons as absolutely essential for their military security.

But a failure to recognize past misconceptions can only have the most tragic consequences in continued high rates of underweight births as well as the rising mortality due to new types of infections that are otherwise unexplained. The same is true for cancer mortality as the ability to detect and destroy cancer cells is increasingly impaired by the continuing routine and accidental releases from nuclear reactors. And it applies to all forms of chronic diseases where fre-radical damage is now known to be involved.

These new results can explain the presently not understood sharp increase in cancer rates in the industrial countries that has recently been reported by Devra Lee Davis and her colleagues in an article in Lancet in 1990 and in a 1990 volume of the Annals of the New York Academy of Sciences dedicated to the problem of sharply rising cancer mortality in the industrial world during the last two decades. The rise in cancer types not related to smoking is greatest among individuals over the age of 55 for the U.S., England and France, and lowest in Japan.. But the U.s, England and France are exactly the nations where fission products have been released into the environment from weapons production reactors and reprocessing facilities, and where larege accidental releases have taken place since the 1950's. And although Japan now has many commercial nuclear plants, their releases have been much less than from U.S. reactors. Moreover, the Japanese diet relies mainly on deep ocean fish, sea vegetables and rice which have a much lower ratio of strontium-90 to calcium than milk, cheese and red meat than western diets, lending a high degree of protection that is also reflected in the low infant mortality and the small percentage of babies born below normal weight.

The greatest danger to human health lies in the future of the inner cities whose drinking water, milk and meat continues to be contaminated. The immune system of the newborn infants continue to be damaged by radioactive strontium, their blood contains levels radioactive iron, and the function of their thyroids controlling growth and development is affected by the iodine in the milk and diet, more so for the poor, but affecting all social classes.
The result is a tide of underweight births that in turn not only leads to a high rate of birth defects, infectious diseases and cancer, but also to impaired learning ability. As summarized in a 1990 report by Newman and Buka for the EducationalCommission of the States, this increases the chance of poor school performance, which in turn reduces job opportunities in a technological society, resulting in rising youth unemployment that produces a temptation to sell and use drugs, and that frequently involve young males in crime and early death.

At the same time, young females that drop out of school are more likely to become single mothers at an early age and give birth to more underweight babies, thus perpetuating a vicious cycle of poverty and hopelessness that drives up welfare and health-care costs and forces cities into mounting debts or insolvency. Income and tax revenues decrease, requiring a further redution in social services and educational opportunities for the poor, thereby accelerating the tragic process of decline

Thus, in a technological world where learning ability is increasingly the key to productivity, competitiveness and a high standard of living, refusing to face the role of low-level radiation effects on social problems can only accelerate the disintegration of the cities as the middle-class flees to the suburbs, and the spiral of rising disease, underweight births, single parent families, poverty, drugs, and crime destroys the centers of our civilization and robs the future from our children.

Fortunately the cold-war that spawned the nuclear arms race and the attendant need for secrecy about the effects of fallout on human health is ending. Thus there is hope that a new generation of political leaders, scientists and public health officals will be able to break this deadly cycle by phasing out forever the production and testing of nuclear wapons, and that nuclear reactors will be replaced with more benign ways to generate the energy that a modern society depends upon.

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