3 June 1987

Some Studies of Low Level Radiation and Cancer in the United States*

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The disaster at Chernobyl was brought to public attention through discovery of radioactive plumes sweeping across the Swedish countryside. The initial Russian denial of responsibility again illustrates that the public cannot know the full scope of such disasters without operating radiation monitoring equipment to detect radioactive gases and particulates, and an effective surveillance system to monitor the radionuclides in the air, water, soil and in the food chain. Because we live in a nuclear age and there is world-wide contamination by the nuclear power industry and nuclear bomb testing, local communities and concerned families should own radiation monitors to conduct their own surveillance.

The now public nature of Chernobyl may insure that in time we will know the full impact of its radiation releases in terms of illness and death from cancer and other radiation effects, such as birth defects and increased mortality. Unfortunately, we may never learn the total scope for nuclear disasters of the past because there has not been a concerted effort to accurately assess the impact of those radiation releases(1). Nuclear disasters at Kyshtym, Rocky Flats, the Savannah River Plant, Hanford and other plants, and at the nuclear test sites in the United States, Russia and the other nuclear powers, have not had the benefit of antecedent and prospective studies of health effects that should have been accomplished. Today the weight of public opinion may require disclosure to the public of such releases when they occur, and perhaps there will be funds available for such thorough prospective studies.

As health officer and medical epidemiologist for a large county health department in Colorado, I was requested to conduct a series of investigations of radionuclide contamination around a plutonium and uranium reprocessing plant in my district. I had the support of several federal agencies in these investigations. However, the studies were opposed by industry spokesmen, including several officials sympathetic to the nuclear industry. Federal agencies have now

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* Presented at the University of Basle on 9 June, 1987; the University of Zurich on 10 June; and the Universities of Bern and Lausanne on 11June,1987.

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corroborated these studies. In the most recent corroboration, the Los Alamos Laboratory has confirmed my report of excessive cancer rates in plutonium workers at the Rocky Flats nuclear plant, after seven years of study and more than one million dollars in funding (2-5). I will present a series of investigations of low level radiation and its effects on health as follows.

Environmental Studies

In my former health district in Jefferson County, Colorado, there is a large uranium mine, the Schwarzwalder mine, named after the man who discovered uranium deposits there. This mine has produced large amounts of uranium since the 1950's, and its value approaches one billion dollars (6). Large amounts of radioactive water are discharged each day to permit operations to continue. More than a million gallons (4,000,000 liters) of water were at times pumped from this mine into public water supplies in the Denver area. A nearby community received drinking water with more than 400 picocuries (pCi/l, or 880 nuclear disintegrations per minute/l) of alpha radiation, mostly from uranium. The Atomic Energy Commission (AEC) permissible limit for uranium in water was at one time 40,000 picocuries per liter, later reduced to 10,000 and then to 6,000 pCi/l. In 1978 the state limit in Colorado was also 6,000 pCi/l. The U.S. Environmental Protection Agency supported this concentration limit. The administrative board for the contaminated water district came to me for consultation concerning possible risks to health from continued use of this water. In reviewing a report of the National Academy of Science Committee on Water Quality, it was clear that levels much smaller than 400 pCi/l would result in important doses of radiation to bone and other organs over time. A limit of 10 pCi/l (0.37 Bequerel) would be consistent with current standards on radium concentration limits in water.

On four occasions I called for a public hearing on the mine's discharges into public water supplies, but received no response. I then urged the water district board to go to court with my support as expert witness. One week before the court hearing, the U.S. Environmental Protection Agency sent the first of two advisory letters recommending a concentration limit not of 6,000 pCi/l, but no more than 10 pCi/l, a 600-fold reduction in the permissible concentration limit.

This case history illustrates a fundamental problem in the nuclear industry. Many radiation protection standards are unrealistic and not protective, and appear to have been established to protect the industry against lawsuits by workers or by residents downwind or downstream claiming injury from radiation exposure. Such unprotective standards or guidelines also serve

to limit costs for equipment modifications necessary to minimize radiation releases and to protect workers.

In December of 1974, a county administrative officer called to inquire about the safety of constructing large numbers of homes downwind on 6 to 7 square kilometers of contaminated land directly adjacent to the Rocky Flats nuclear plant (RFP) After discussing the proposal with the National Center for Atmospheric Research, I opposed rezoning this vacant land for housing, since the land was contaminated with plutonium to more than seven times greater concentration than approved by the state for construction workers (7). Despite the excess concentrations of plutonium, the state had already approved use of the land for housing. The request for development of this area for housing was then rejected by the county government, and eventually landowners sued RFP, receiving a large settlement about ten years later.

Because of errors and conflicting results in soil studies around the plant, I proposed a validation survey to assess the accuracy of previous surveys. This was done, in collaboration with the U.S. Geological Survey (6). Laboratory support was at first provided by the Atomic Energy Commission, but withdrawn when results of the survey were known. Since the concern was the potential risk to health, we collected surface respirable dust samples from the soil at 72 locations, to a distance of 32 km around RFP. This included most of the Denver metropolitan area. With this approach we found much larger amounts of plutonium near the plant than found previously, and at greater distances found fallout levels to be less than previously found. Plutonium concentrations were about 44 times greater (average) than in previous surveys, and as much as 286 times greater. Cesium 137 concentrations on private farmland near the plant were 17 times greater than background from worldwide fallout (earlier AEC studies obtained in the legal proceedings reported excess soil concentrations of strontium 90 and curium 242).

The nuclear agencies had no criticism of the experimental design until the results were known, at which time many objections were raised. However, the Atomic Energy Commission funded a very similar study of the area around the Savannah River Plant which also yielded data with much better definition concerning the respiration hazard from contaminated surface soil (1,8).

Studies of Nuclear Plant Workers

Plutonium is extremely radiotoxic as are other transuranics such as curium and americium (3). In one study of plutonium carcinogenicity in animals (9), 27 percent developed mesothelioma, and a total of 38 percent developed sarcomas of various types, including

undifferentiated sarcoma, reticulum cell sarcoma, fibrosarcoma, liposarcoma, rhabdomyosarcoma and liomyosarcoma, with a median induction period of one year. There was also an excess incidence of mammary adenocarcinoma and a renal adenoma. There was a total excess incidence of cancer of 114.5 percent, because many animals had two different types of cancer(9). Another study found a marked excess of leukemia (10). As a recent report of the U.S. National Academy of Science notes, cancer may be induced in virtually any tissue in the body by ionizing radiation (11).

Much has been learned about the biological effects of plutonium, curium and the other transuranics in animals, and there is clear evidence of effects on man as well (12-14). In an autopsy study of nuclear plant workers, important concentrations of plutonium were found in every organ measured, including brain, skin, omentum, prostate and testes (16). There was a study of chromosome aberration rates among 241 plutonium workers at Rocky Flats. Those workers with the smallest deposits of plutonium in body organs (0.4 to 4 nanocuries, or billionths of a curie) had a chromosome aberration rate of 3.6 %. This was about 30% greater than that for fellow workers with less than 0.4 nanocuries (one nanocurie is equivalent to about 37 Bequerels, and 0.4 nanocuries is equivalent to about 15 Bq)(9). This was only one percent to ten percent of the U.S. Department of Energy (DOE) permissible body burden limit. These effects can be considered life-long because the excretion rate of plutonium from the body is very slow, about one-half in 200 years from bone, for example. Earlier reports by Morgan and Myers anticipated these effects (17,18).

There had been no health studies of these workers. The number of workers with cancer was reported annually by plant officials after 1978, usually concluding that cases were few among a large number of employees (19). However, I carried out in 1980 a proportionate morbidity analysis of the cases among the workers, comparing them to all white males in Colorado, and found an eight-fold incidence of brain tumors, a three-fold incidence of malignant melanoma, and a 23% excess of respiratory cancer (5). A more detailed analysis was not possible because the plant refused to release additional information.

I next analysed an autopsy study of 15 nuclear plant workers whose plutonium body burdens (0.4 nanocuries, or 14.7 Bequerels) were less than one percent of the maximum permissible body burden (20). These body burdens, or organ deposits, ranged from several picocuries (one picocurie, pCi, equals 0.037 Bq) to 360 pCi (13.2 Bq), or an average of 152 pCi (5.57 Bq). Eight of the 15 workers died of cancer where 2.79 cancer deaths were expected based on U.S. data, a risk ratio of 2.9. Three deaths of bronchogenic carcinoma were observed where only

1.05 were expected. The remaining five cases of cancer included two deaths of leukemia where 0.08 cases were expected (a risk ratio of 25), a brain tumor (astrocytoma), a malignant melanoma, and an adenocarcinoma of the kidney. One of the leukemia cases was an acute lymphoblastic leukemia (20).

The DOE launched a study of worker mortality and in their preliminary report (1982) admitted a small excess of tumors (designated as "benign and unspecified") (21,22). After seven years and over a million dollars in funds, they have corroborated my earlier results in a study published in February, 1987 (2-5).

Briefly, the Los Alamos National Laboratory reviewed cancer deaths among 5,413 white males employed at least two years at the Rocky Flats nuclear weapons plant (2). Employees who had more than two nanocuries (73.3 Bq) of plutonium deposits in body organs were compared to those with less than two nanocuries (5% of the official maximum permissible limit) with the following results.

o After an induction period (latency period) of two years there was a 7.7 fold excess of lymphopoietic neoplasms (lymphatic cancers); a two-fold excess (x 2.0) of lymphosarcoma and reticulum cell sarcoma; 3.3 times more esophageal cancer than expected; 80% more gastric cancer and 3.7 times more prostatic cancer.

o After five years there were 9.9 times more lymphatic cancers than expected; about a 5-fold (x 4.9) excess of cancer of prostate; a 3.7-fold excess of esophageal cancer; 2.5 times more lymphosarcoma and reticulum cell sarcoma; 2.2 times more stomach cancer; 1.7 times more digestive cancers combined, and 62% more cancer of colon.

o After ten years, there were 5.2 times more lymphatic cancers than expected; 61% more cancers of all types than expected; 10.6 times more prostate cancer; 5.7 times more cancer of colon; 4.8 times more stomach cancer and a 43% excess of lung cancer.

Those workers with recorded cumulative exposures to one rem (0.01 Sievert, or 10 millisieverts) or more of cumulative gamma radiation were compared to those who had less than one rem, with these results.

o After two years, there were 3.46 times more unspecified brain tumors than expected, 49% more lymphatic cancers and an excess of lymphosarcoma, reticulum cell sarcoma and myeloid leukemia.

o After a five years, there was a 73% excess of unspecified brain neoplasms; a 69% excess of liver cancer and a 65% excess of prostatic cancer.

o After ten years, there was a four-fold (x 4.0) excess of unspecified brain tumors; three

times more lymphosarcoma and reticulum cell sarcoma than expected, three times more myeloid leukemia, and 2.8 times more liver cancer. The authors qualify their results with a note that the numbers are small.

Because of the healthy worker effect for employees fit to work, well educated and able to pass a security clearance, the actual health impact for workers was probably greater than these results would indicate (3). It is surprising that there was no smoking history and no control for this very important factor. If the healthy, more highly educated workers able to pass security clearance smoked significantly less than the U.S. population, this would have a major effect on the results. One way of evaluating the effect of smoking is to compare the number of observed deaths of lung cancer with expected deaths, and 30 deaths from lung cancer occurred, 46 were expected (2). It is unfortunate that with the resources of the Department of Energy and the Centers for Disease Control, reliance is still placed on studies of mortality, since about one-half of persons contracting cancer do not actually die of cancer and are thus lost to such mortality studies, seriously compromising the results (3). Further, there is confounding by periods of survival after contracting cancer ranging from months to years to decades (3).

Population Effects from Offsite Contamination by a Nuclear Plant

After a review of the radiotoxicity of plutonium and other transuranics and the scope of such releases from the Rocky Flats plant (from internal documents released by the plant in discovery proceedings in a lawsuit brought by landowners), I became concerned about population effects downwind from the plant in the Denver area. In contrast to the nuclear plant workers who wear protective clothing, breathe carefully filtered air, are monitored frequently for radiation exposure and have medical supervision which may include chromosome aberration studies, families downwind from nuclear plants have no such protection. They are at times actually within the exhaust plumes from the plant. There are 29 smokestacks at the Rocky Flats plant that release plutonium and other radioactive particulates and gases.

Population exposures began in 1953 and reached highest levels in 1957 (23), when an explosion (perhaps a fission reaction) blew out all 600+ industrial filters in the main stack. This released a four-year accumulation of fine plutonium and uranium dust trapped in the filter system (1,23). The same filters had been in use over four years of reprocessing and refining operations. A heavy black plume of smoke from the plant passed over the Denver area for about 12 hours. A then secret survey by the Atomic Energy Commission (now DOE) after this incident found heavy contamination of soil with plutonium and weapons-grade uranium offsite, including

private land and two elementary school grounds 9.6 and 19.3 km distant (23). The period 1969-1971 in my study was chosen to utilize federal cancer incidence data available for the Denver Standard Metropolitan Statistical Area. This provided an adequate latency period of 12-16 years.

Plutonium is virtually 100 percent soluble in Denver area drinking water because of the presence of carbonate and fluoride in the water. This was confirmed by the appreciable amounts of plutonium (7,000-40,000 times background from world-wide fallout) found in Denver drinking water as recently as 1972 (25,26). Concentrations have been smaller since. The chlorination of water by water districts changes the valency state of plutonium so that its absorption in the gastrointestinal tract is enhanced by as much as 1750 times (27). In addition, plutonium is absorbed much more readily from the gastrointestinal tract of children, at least 100-fold in children less than one year of age (28), and 1000-fold in nursing animals (29). Moreover, when plutonium is taken up in the food chain and biologically incorporated, absorption is enhanced by a factor of ten (30).

I completed a preliminary study of leukemia death rates in census tracts near the plant in 1977, finding a significant excess of leukemia deaths, and the following year found an excess of lung cancer deaths and congenital malformations. In 1979 I obtained National Cancer Institute data on cancer incidence, and carried out an analysis of cancer incidence, corrected for age, race, sex and ethnicity (1969-1971) in census tracts within isopleth areas of plutonium contamination in the Denver area (23). In the suburban area to 21 kilometers downwind from the plant there was a 16% excess of all cancer; in the next area more distant, a 10% excess; and the area with least contamination, a 6% excess. The urban core of Denver had a much lower incidence of cancer than did the suburban area near the plant. The predominant types of cancer in excess were those of more radiosensitive organs, but included an excess of cancer of testis, prostate and ovary.

Copies of the report were sent to the nuclear agencies and many others and there was a barrage of criticism, mostly unfounded. A revised report was published by the Royal Swedish Academy of Science in 1981 (23). It has now been corroborated by a study funded by the Department of Energy which, however, also conducted studies with other approaches in an effort to show excessive cancer was due merely to urban effect (31). They were able to accomplish this only by selecting newly developed census tracts near the plant for comparison, and by combining the population nearest Rocky Flats together with the unexposed university city of Boulder which lies upwind of the plant. This is not a valid approach (32,33). Because of rapid population

growth in the Denver area, especially in the suburban area nearest the plant, continued follow-up of this population will require a cohort study similar to the design that I used in studies of the downwind population in Utah. I have developed a design for such a study.

The infant mortality rate for Jefferson County (including Area I) was less than the U.S. rate in 1950, rising above the U.S. rate after Rocky Flats began operations in 1953, and peaking between 1955 and 1958 (around the time of the 1957 fire and explosion)(33). Further, fetal death rates rose sharply after 1953. Leukemia death rates in children in Jefferson County were below the U.S. rate in the five year period before 1953, but increased afterwards to about twice the U. S. rate after 1957. An increase was also noted for other major childhood cancer deaths. Similar trends were observed in Denver County (Areas II and III). Children born after 1957 (age groups 0-14 in 1970) had a smaller incidence of cancer(33).

There was a strong upward trend in cancer incidence for the entire Denver metropolitan area from 1970 to 1980. Cancer incidence in exposure areas I-III, adjusted for age, race, sex and ethnicity, rose from an excess of 491 cases in 1969-71 to 1123 in 1979-81 (33). A study by Berg compared the cancer incidence in 1979-81 in the Denver metro area (including my Areas I -III and the control population in Area IV) to that in 1969-71 and found an excess of about 2000 cases of cancer after adjusting for changes in the population (34). Denver area residents in 1980 had a 30% risk of contracting a non-skin cancer, or a greater than 40% risk of all cancer. This was an increase in age-adjusted cancer incidence over a 10 year period of 15% in a largely non-industrial metropolitan area once known for its healthful environment (34). This can be compared to an increase of only 9.3% between 1973 and 1983 in a National Cancer Institute study of cancer incidence including about 13% of the U.S. population (35,36). The rate of increase in cancer incidence in the Denver area over this ten year period was thus about 61% greater than the national trend.

Health Effects of Radioactive Fallout

In 1980 a former U.S. Secretary of the Interior, Stewart Udall, invited me to respond to a request for proposal to study health effects in a population living downwind from the Nevada nuclear bomb test site. In my approach to this problem, I selected telephone directories in towns known to be in the path of fallout plumes and clouds in southwestern Utah and adjacent Nevada and Arizona (37,38). The largest town, St. George, was 225 km from the Nevada Test Site (NTS), and Bunkerville (Nevada) was the nearest, 180 km from ground zero (37). Fallout deposition was not uniform, due to the mountainous topography. A University of

California/Department of Energy report states that " a low (fallout) cloud will most likely follow the valleys. In that case, the cloud would probably not disperse the one mile in six assumed", and " with higher winds the greater local turbulence would likely increase local deposition, particularly on reverse slopes" (39).

Department of Energy estimates of population exposures to radiation in the area have been low, but these have been contradicted (37). Radiation instruments principally record gamma radiation. The DOE/AEC did not adequately monitor beta radiation, which may be several orders of magnitude greater than gamma radiation in nuclear bomb fallout plumes and clouds. Ratios of beta to gamma radiation of 130:1 and 157:1 in fallout were cited in one report. A survey of target ships in the 1946 and 1948 Pacific tests by K.Z. Morgan (then with the Atomic Energy Commission) also found high beta-gamma radiation ratios. In "many places the ratio was from 50 to 100" (to one) (K.Z. Morgan, personal communication, 1986). The hazards of inhalation of fallout particulates emitting beta, gamma and alpha radiation were recognized as early as 1951 by the Director of the University of California Los Alamos Scientific Laboratory (a DOE/AEC facility), who stated this was "the major problem in safety" rather than "any danger from external radiation dose" (40).

The alpha radiation emitted by fallout particulates is 20 times more injurious to tissue per rad than beta or gamma radiation. Yet, alpha radiation was not adequately monitored in the fallout area. Isotopes of uranium, plutonium, and other transuranics can contribute as much as 40 percent of the total radioactivity of the nuclear bomb debris in the period from 20 hours to two weeks after detonation. Much of this activity is due to alpha radiation (42). Alpha radiation is high "linear energy transfer" radiation, as is neutron radiation. Recent work by Hill et al. demonstrated considerably more injury with prolonged doses of small amounts of such radiation (43). Nine times more malignant transformations per rad were induced at low dose rates than at high dose rates. The greatest effect per rad occurred at the smallest dose, a total of 10 rad (43).

Fallout particles emitting gamma, beta and alpha radiation are inhaled and ingested and stored in body organs. This results in much higher organ doses over time than indicated by radiation monitors (39). Further, personal air monitors indicate radionuclide concentrations several orders of magnitude greater than area monitors (44). No such observations were made for residents in the high fallout towns, but these are of key importance in assessing the risk of health effects on residents of southwestern Utah during 1951-1962. The official DOE/AEC radiation estimates must not be relied upon. If cited, these DOE estimates must be qualified, and

note taken of evidence of much greater radiation exposures.

Every family or person listed in the phone directories in 1951, still listed in 1962, became part of the study population. The purpose was to select only people actually present throughout the years of atmospheric nuclear bomb testing. About 90% were members of the Mormon Church. Mormons are known to have a cancer rate 23% below the national rate, because of their life style, and so only Mormons were included in the study (45). Their experience with cancer since 1958 was compared to that for all Utah Mormons. Everyone in Utah had probably had some effect, so a high exposure population was compared to one with smaller exposures (37).

A preliminary report was presented to the American Association for the Advancement of Science in 1981. The final report was presented at the federal trial in 1982 in Salt Lake City of the Department of Energy, defendant against suits brought by over 1100 people claiming injury and death from cancer due to exposure to radioactive fallout. There was a peer review of this report at the trial for three days, and in the end the federal judge based his decision to award compensation on this report which was later published by the American Medical Association in 1984 (37).

There was a 61% excess of all cancer in the fallout population. Leukemia was most prominent early (1958-66), with 19 cases, five times more than expected (3.6). This excess persisted into the later period (1972-80), with 12 cases observed, 3.4 expected. There was an increase in lymphoma. Excess cases of thyroid cancer appeared early and a notable excess appeared later (14/1.7). An excess of breast cancer was noted later (27/14). There were more cancers of the gastrointestinal tract than expected. There was an excess of melanoma (12/4.5), bone cancer (8/0.7) and brain tumors (9/3.9). A subgroup with history of acute fallout effects had a higher cancer incidence. That these cases can be associated with their radiation exposures is supported by a comparison between groups of the ratio of cancers of more radiosensitive organs with all other types of cancer.

The position taken by the federal agencies was that their own area-based studies of leukemia deaths had not found an excess. However, there were many flaws in these studies based on death certificates (39). In January, 1987, the National Cancer Institute published a study of death certificates in which they acknowledged a significant excess of leukemia deaths downwind from the test site (46). No other types of cancer were found in excess. As in earlier studies, there were many errors and oversights with this approach (39). In particular, the National

Academy of Science has concluded that population exposures to radiation sufficient to induce one case of leukemia will also induce seven to nine additional cases of other types of cancer over time (11). Yet, the National Cancer Institute death study found no excess deaths of cancer, despite a significant excess of leukemia deaths. The problems with the area-based studies of death certificates are discussed in detail in a recent journal (39).

I recommend my study design for future studies of effects of nuclear bomb fallout and offsite contamination by nuclear facilities such as the Three Mile Island and Chernobyl reactors. A true cohort of persons living in the area of high exposure throughout the exposure period should be followed forward in time, noting blood lymphocyte counts, chromosomal aberration rates, radioisotope concentrations in breast milk and deciduous teeth, fetal and infant mortality, cancer incidence rates, etc. Data should be controlled for age, race, sex, religion, alcohol and smoking habits, and occupation. This approach can be adapted for studies of nuclear facility workers. The research design should establish subpopulations with greater exposures so that this study population itself can serve as a control, in addition to an appropriate local or regional external control.

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