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Letters to the Editor

A COHORT STUDY OF CANCER INCIDENCE IN MORMON FAMILIES EXPOSED TO NUCLEAR FALLOUT VERSUS AN AREA-BASED STUDY OF CANCER DEATHS IN WHITES IN SOUTHWESTERN UTAH

In their area-based study of death certificate data in southwestern Utah, published in this issue of the *American Journal of Epidemiology*, Machado et al. (1) found a significant excess of leukemia deaths (54 per cent for all ages and 67 per cent for children). An attempt is made to compare this to my study (2) that found an excess incidence of cancer (61 per cent, all ages) in a cohort of Mormon families who lived throughout the period of atmospheric nuclear bomb testing (from 1951–1962) in towns in southwestern Utah, adjacent Nevada and Arizona that received large amounts of fallout from the Nevada Test Site. A National Research Council report (BEIR-80) cites an estimate of seven radiation-induced cancer deaths for each radiation-induced leukemia death (relative risk model) (3). That the Machado et al. death certificate study did not find an excess of cancer deaths other than leukemia suggests serious flaws in their study design, similar to deficiencies in their earlier area-based study of leukemia reported on death certificates (4).

The Machado et al. mortality study (1) in southwestern Utah contrasts the findings of my study (2) with the experience of the Marshall Islanders, who were exposed to fallout for several days before evacuation; with the Japanese, who were exposed to direct radiation on one occasion at Hiroshima and Nagasaki; and with persons exposed to therapeutic penetrating radiation, usually shielded from radiation of all but the treated area, and not usually followed for 30 years. Yet none of these groups is comparable to the cohort incidence study population, which was exposed to penetrating radiation and inhalation and ingestion of large amounts of fallout radionuclides (visible as "ash" or dust) in the nuclear plumes and clouds from 26 nuclear bombs (and 11 of the underground nuclear bombs that escaped into the atmosphere). The extent of environmental contamination (from 1951–1980) to which they were exposed is suggested by a listing of 500 radionuclides of "potential importance in the environmental radiological assessment" around nuclear facilities (5).

A valid comparison cannot be made between an area study of cancer reported on death certificates and a study of cancer incidence in a specific cohort of Mormon families. Only about one-half of persons contracting cancer die of cancer (50 per cent of females, 65 per cent of males, according to one report (3)), i.e., many cancer cases are simply not counted in such studies of death certificates. There is confounding by survival periods of years to decades with a pronounced trend for longer survival during the course of studies of long duration. A trend in cancer incidence is not uniformly followed in "at most a few years" by cancer deaths, as claimed by Machado et al., especially in a nonsmoking population with little lung cancer. Such studies of cancer deaths based on death certificate data may corroborate diagnoses of cancer on death certificates by reference to individual medical records and histologic diagnosis. However, no such corroboration is attempted for the majority of deaths which include all those without a diagnosis of cancer on the death certificates. This then may introduce a strong conservative bias. The relation between cancer incidence and death certificate data, "official mortality statistics," is not as simple as represented by Machado et al., and the results of incidence studies may be significantly different from the results of mortality studies.

Area-based "cohort" studies cannot account for in-migration of many people not exposed to fallout nor for out-migration of those exposed who may die of cancer elsewhere (perhaps near a cancer treatment center). In contrast to the area-based "cohort" in the Machado et al. (1) death certificate study, the cohort incidence study (2) was a true cohort study, identifying individual persons in all Mormon families listed in both 1951 and 1962 phone directories in towns known to be exposed to fallout, i.e., living in these towns throughout 12 years of atmospheric testing. The study was designed to include a 100 per cent sample of such individuals (2). Recovery of data for persons leaving the area was facilitated by Mormon Church membership. The cohort of Mormon families exposed to fallout was directly compared with all Utah Mormons, since cancer incidence for Mormons is 23 per cent less than for the United States population (6). The Machado et al. death certificate study did *not* make use of this cohort definition.

The Machado et al. death certificate study did *not* separate Mormons and non-Mormons but carried out "adjustments" and assumed "additive" and "multiplicative" interactions with its white population. Further, dietary and cultural factors leading to lower cancer incidence rates among Mormons may improve survival. In the cohort incidence study of Mormon families, proportionately more persons contracted cancer in later years of the first and second nine-year study periods and more died of cancer in the later years (7). A report of cancer incidence in Utah Mormons over a nine-year period (6) provided a control population, together with the internal controls. Correspondingly, early (from 1958–1966) and later (from 1972–1980) nine-year study periods were selected.

The death certificate study periods are not comparable, including leukemia and bone cancer deaths between 1955–1980 and other cancers only between 1964–1980. The cohort incidence study (2) approach

provided an internal control with cancers of longer latency (colon, breast, etc.) by which urban-rural differences and fallout exposure in northern Utah can be addressed. Further, the death certificate study (1) incorrectly combines the cancer incidence data from early and later study periods in the cohort incidence study to make its estimate of cancer deaths.

In the death certificate study, persons born in the high fallout area in 1958 and after are simply not considered. There were important exposures to fallout in Utah after 1957.

Concerning the criticism by Machado et al. of the use of an area household survey rather than cancer registry data, the registry was not established until 14 years after exposures to nuclear fallout began. Further, such cancer registry data could not be used to establish a true cohort or to consider religion, smoking, and occupation, factors considered important in the cohort incidence study. Moreover, the histories given by persons outdoors in the path of fallout plumes and clouds, of burning of eyes or skin, changes in color or loss of hair, etc. are important observations suitable for establishing a subgroup at higher risk (2). Large exposures to carcinogens can lead to large risks of cancer (8). Establishing this group permitted internal comparisons.

The death certificate study area and population in the Machado et al. mortality study are defined by political boundaries (southwestern Utah), whereas the cohort incidence study included only towns in the path of fallout plumes and clouds, whether in Utah, Arizona, or Nevada. St. George in Utah is 225 km from ground zero. Bunkerville, Nevada, the town nearest the Nevada Test Site, is 180 km from ground zero. In contrast, the Machado et al. death certificate study included a 25,000 km^2 three-county area 200–500 km from ground zero.

The death certificate study states that "fallout deposition was reasonably uniform" within this area, citing Department of Energy surveys. The size of the area, field measurements at the time, reports by local residents, and the mountainous topography do not support this assertion (2). A University of California/Department of Energy report (9) 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."

The death certificate study relies on official Department of Energy/Atomic Energy Commission (DOE/AEC) radiation exposure estimates (1, 10, 11) that have been contradicted (2). Radiation instruments principally monitor 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 (12) and 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 (13). In "many places the ratio was from 50 to 100" (to one) and in "some places it ran as high as 1,000" (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" (9, 14).

The alpha radiation emitted by fallout particulates is 20 times more injurious to tissue per rad than beta or gamma radiation (15), and alpha radiation was not adequately monitored in the fallout area. Isotopes of uranium, plutonium, and other transuranics can contribute as much as 40 per cent of the total radioactivity of the nuclear bomb debris in the period from 20 hours to two weeks after detonation, and much of this activity is due to alpha radiation (16). Alpha radiation is high "linear energy transfer" radiation, as is neutron radiation, and recent work by Hill et al. (17) demonstrated considerably more injury with prolonged doses of small amounts of such radiation. Nine times more malignant transformations per rad were induced at low dose rates than at high doses rates. The greatest effect per rad occurred at the smallest dose, a total of 10 rad (17). Fallout particles emitting gamma, beta and alpha radiation are inhaled and ingested and stored in body organs resulting in much higher organ doses over time than indicated by radiation monitors. Further, personal air monitors indicate radionuclide concentrations several orders of magnitude greater than area monitors (18). No such observations were made for residents in the high fallout towns. None of these considerations are addressed in the death certificate study, but these are of key importance in assessing health effects on residents of southwestern Utah during 1951–1962. The official DOE/AEC radiation estimates must not be relied upon, and if cited, must be qualified, and note taken of evidence of much greater radiation exposures.

The death certificate study reported an excess mortality (52 per cent) of "presumably nonradiogenic" chronic lymphocytic leukemia, citing BEIR-80 (3). However, a study of radiation effects in men also found an excess of chronic lymphocytic leukemia with greater exposure ($p = 0.02$) (19). BEIR-80 relies on a report that chronic lymphocytic leukemia rates were not increased in Hiroshima/Nagasaki survivors (3). I believe these Japanese results are not applicable to whites, since SEER data indicate no chronic lymphocytic leukemia cases among male Hawaiian and Bay Area Japanese for 1973–1977 (20), where 28.2 and 3.3 cases, respectively, could have been expected, based on US white male rates.

I recommend my study design (2, 7) for future studies of effects of nuclear bomb fallout and of 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, 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 the study population itself can serve as a control,

in addition to an appropriate local or regional external control.

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Editor's note: In accordance with Journal *policy, an exchange of views by the respective authors of a paper in the Original Contributions section and a letter in the same issue constitutes a complete debate. Therefore, Machado et al.* were not invited to respond to Dr. Johnson's letter.