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CANCER MORTALITY NEAR OAK RIDGE, TENNESSEE

Joseph J. Mangano

Oak Ridge, Tennessee, is the site of one of the two oldest nuclear facilities in the United States. Although precise records have not been maintained, low levels of radioactive products have been released into the environment since the facility began operation in World War II. Changes in age-adjusted cancer mortality rates for whites between the periods 1950–1952 and 1987–1989 were analyzed to assess whether these radioactive releases have had any adverse effects on the population living near Oak Ridge. Results indicate that the increases in the local area (under 100 miles from Oak Ridge) exceeded regional increases and far exceeded national increases. Within the region, increases were greatest in rural areas, in Anderson County (where Oak Ridge is located), in mountainous counties, and in the region downwind of Oak Ridge. Each of these findings suggest that low levels of radiation, ingested gradually by local residents, were a factor in the increases in local cancer death rates. Results indicate that more studies of this type are called for and that cessation of all future radioactive emissions from nuclear facilities should be considered.

Ever since the beginning of the atomic age half a century ago, the health effects of low-level radiation generated from nuclear facilities has been debated. The original scientific belief that low-level radioactive emissions were never harmful has since been disputed. In 1958, Stewart and colleagues (1) demonstrated carcinogenic effects on fetuses from X-rays, which produce low doses of radiation. Years later, Stewart contributed to research that showed that fetal exposure to even small amounts of environmental radiation increased the risk of cancer and leukemia (2).

In 1971, Petkau (3) showed that at low levels over a prolonged period, the per-dose effects of ionizing radiation on cells were actually much greater than the effects of a higher, one-time dose. This finding is significant in that it raised doubt as to the linear dose-response curve, and instead postulated that a logarithmic or downward-shaped curve correctly depicts the true effects of protracted radiation on humans. Numerous studies have since demonstrated evidence of this relationship of more adverse effects per dose at lower levels.

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In 1990, the National Academy of Science's Committee on the Biological Effects of Ionizing Radiation (BEIR V) cited a number of studies that found large cancer and leukemia increases from low doses of radioactive fallout and weapons testing (4). The BEIR V report questioned scientific knowledge about the effects of low doses. Recently, Sternglass and Gould (5) demonstrated a correlation between low-dose radiation released from commercial nuclear plants and breast cancer mortality in the United States. The amount of radioactivity released from these plants (a total of 370 curies in the United States between 1970 and 1987) was previously not believed to be harmful.

Radioactive chemicals routinely released from nuclear facilities into the environment primarily reach the general population through the food chain. As a result, even short-lived isotopes such as iodine-131 and strontium-89 will affect humans, as they often reach the consumer in a matter of days after their release from the reactor. Because routine emissions from nuclear plants are gradual, the resulting dose is a chronic one. This type of exposure, first demonstrated by Petkau, appears to have a greater per-dose effect than a short exposure.

Studies of the consequences of radiation on populations living near nuclear facilities have been hampered by the long lag period between radiation exposure and disease or death. As many as 15 to 50 years may elapse between exposure and a diagnosis of cancer (6). However, the oldest of the 17 U.S. nuclear weapons facilities are now 50 years old; the true changes in health status of populations living near these facilities may only now be emerging.

This report examines cancer mortality in the area near Oak Ridge, Tennessee, one of the two oldest nuclear weapons installations in the United States. Oak Ridge was selected for study because its age and its large nearby population make it more likely to yield significant trends. Accurately measuring the amount of internal-organ doses received by the general population is impossible. Thus, there is no way of precisely knowing the radiation intake of each Oak Ridge area resident in the past 50 years; but in the absence of this information, health outcome data must be used instead to detect any possible effects. Mortality data are employed here, as there is a lack of available morbidity/incidence data for small areas in the United States. Cancer mortality is examined because of the known ability of ionizing radiation to cause cells to mutate, possibly leading to tumors (6).

BACKGROUND: OAK RIDGE

Oak Ridge, located in eastern Tennessee, lies at the junction of Anderson and Roane counties (Figure 1). In September 1942, the area was secretly selected by the U.S. Army as one of two sites to build the world's first nuclear weapons (Hanford in Washington state was the other) (7, p. 25). There were three principal plants (known as X-10, Y-12, and K-25) operating in Oak Ridge during World War II, beginning in 1943 (7, pp. 59, 81, 85). Materials produced at Oak Ridge were used in the Hiroshima bomb detonated in 1945. After the war, Oak Ridge

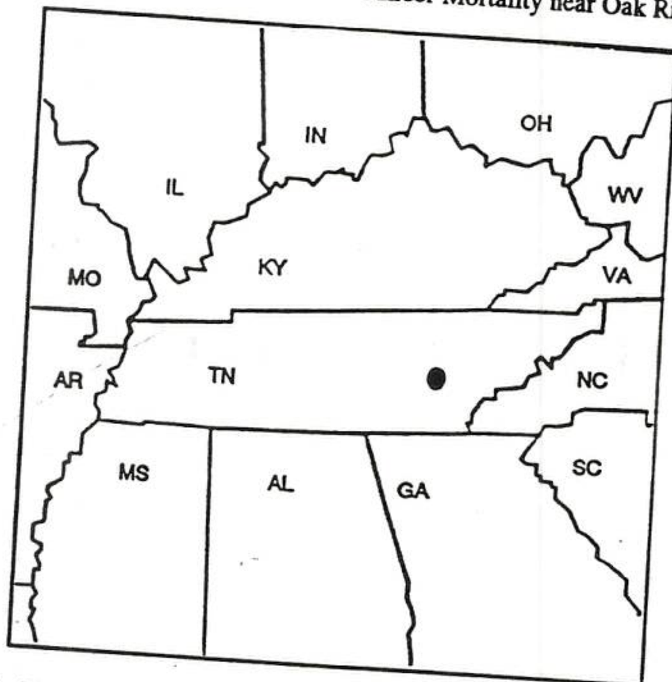

Figure 1. The location of Oak Ridge, eastern Tennessee. The surrounding states are Kentucky (KY), Illinois (IL), Indiana (IN), Ohio (OH), West Virginia (WV), Virginia (VA), North Carolina (NC), South Carolina (SC), Georgia (GA), Alabama (AL), Mississippi (MS), Arkansas (AR), and Missouri (MO).

continued to be a major producer of fuels for nuclear weapons, along with conducting research in the nuclear field.

Unlike other nuclear installations, such as Three Mile Island in Pennsylvania, Rocky Flats in Colorado, and Savannah River in South Carolina, there have been no major reported accidents at Oak Ridge. However, evidence of contamination of the local environment has surfaced. For example, in 1978 radioactive cobalt-60 was found in soil beneath the Oak Ridge National Laboratory (8). In 1983 it was disclosed that as much as 2.4 million pounds of mercury from Oak Ridge's Y-12 plant was "lost" into the environment between 1953 and 1977 (9).

Studies by the U.S. Department of Energy document the amount and types of historical releases of radioactive products from Oak Ridge. For example, from 1949 to 1987, Oak Ridge National Laboratory discharged 1197.8 curies of strontium-90, 693 curies of cesium-137, and 175.3 curies of iodine-131 into the local water supply, along with numerous other radionuclides into the air and water, mostly before 1960 (10). Considerably more was released from 1944 to 1948, but records did not subdivide emissions into specific radioactive products.

The Laboratory was the source of most of the radioactive releases, while the Y-12 plant emitted most of the heavy metals into the environment. Another study on cesium-137 by the Laboratory and Martin Marietta company (which now operates the Oak Ridge plant) showed evidence of the radioactive product as far away as Chattanooga, 80 miles from Oak Ridge (11). Again, these data fall short of making a precise dose-response analysis possible, but they do provide information on what types of materials were released, and in which direction they were emitted. Moreover, the data provide a means of comparing these doses with those from bomb test fallout.

Releases of these radioactive products, some of which are long-lived, have left an enduring legacy of contamination in the Oak Ridge area. In 1991 the U.S. Office of Technology Assessment (OTA) reported a wide variety of radioactive substances and heavy metals in Oak Ridge's air, soil, surface water, ground water, and sediment (12). New incidents of potential contamination continue to occur at Oak Ridge over the years. For example, in December 1992 a leak of radioactive cesium was reported to have contaminated 19 workers, nine of whom left the facility without knowing of their exposure (13).

There have been few extensive studies of health effects to the population living near Oak Ridge. Two analyses have looked at the change in cancer mortality rates. One of these only included data up to 1971 (14); the other looked at the two closest counties for the period 1950–1984, but found no unusually great increases (15).

The most thorough review thus far of effects on Oak Ridge workers demonstrated a rate of leukemia mortality 63 percent higher than expected (total, 28 deaths). It also reported 37 cancer deaths (compared with an expected 22) of plant workers at the Oak Ridge National Laboratory with a lifetime exposure greater than 4 rem (16).

HYPOTHESES AND METHODS

Even without knowing exact amounts of radiation added to the Oak Ridge area environment and how much was ingested by residents, five hypotheses can be tested to suggest whether substantial amounts of radiation have had an effect on cancer death rates. If environmental radiation has affected the region, then the following might be expected to be true:

1. The increase in the cancer mortality rate near Oak Ridge should exceed the national and regional increases. All Oak Ridge area residents live near a nuclear facility, while only a proportion of residents of the United States and the southeast do so; thus, the per capita amount of radiation ingested should be greater near Oak Ridge.

2. Within the Oak Ridge region, the increase in the cancer mortality rate should be greatest in rural areas. Before Oak Ridge began operating, local rural counties were relatively free of environmental contaminants; conversely, local urban areas already contained a greater level of potentially carcinogenic pollutants. Rural

areas thus received a lower dose of all types of contaminants, including radiation; and if the Petkau effect is true, cancer increases should be greatest in these areas.

3. Within the Oak Ridge region, the increase in the cancer mortality rate should be greatest near the weapons plant. As fallout moves away from its source, the same amount spreads over a greater area, diminishing its potency. In addition, the time needed to move from the source decreases the mass of the short-lived isotopes.

4. Within the Oak Ridge region, the increase in cancer mortality rates should be greatest in mountainous areas. These areas have greater than average amounts of precipitation, which is the dominant means of introducing radioactive products into the food chain.

5. Within the Oak Ridge region, the increases in the cancer mortality rate should be greatest in the area downwind of the weapons plant. Prevailing winds should carry a greater proportion of radioactive emissions to the downwind areas.

Sources used to compute death rates for all cancers (total) were the National Cancer Institute (county-specific deaths by age, race, and sex) and the U.S. Census Bureau (county-specific populations by age, race, and sex). Comparisons were made using rates (age adjusted to the 1950 standard) for the periods 1950–1952 and 1987–1989, the earliest and latest data available. Analysis was performed only for whites: the small local nonwhite population could not provide statistically significant results.

The area selected for study was the 94 counties that are completely or mostly situated within 100 miles of Oak Ridge, plus nine other nearby counties included in analysis of the fourth hypothesis. The 94 counties have a current population of just over 3 million and are located in five states: 46 in Tennessee, 19 in Kentucky, 16 in Georgia, 11 in North Carolina, and 2 in Virginia.

The limit of 100 miles was chosen since most of the milk and vegetables (which are the most important vectors for radioactivity) consumed in this region are produced therein. Furthermore, each of the 94 counties lies at least 100 miles from the nearest other weapons site, Savannah River (Aiken, South Carolina).

RESULTS

Local-National-Regional

Age-adjusted cancer mortality for whites in the 94-county area surrounding Oak Ridge increased by 34.1 percent between 1950–1952 and 1987–1989, compared with an increase of 5.1 percent for U.S. whites (Table 1). The P value of this difference is under .0001, which means that there is a less than a 1 in 10,000 chance that the difference is due to random fluctuation.

The Oak Ridge area rate, which was considerably below the corresponding U.S. figure in 1950–1952, had risen to a rate just exceeding the national standard in 1987–1989. The rate is still on the rise; the age-adjusted figure for the 94 counties

Table 1

Cancer deaths and death rates per 100,000, whites only, United States and Southeast versus 94 counties nearest Oak Ridge, 1950–1952 and 1987–1989

Area	1950–52 Number	1950–52 Rate	1987–89 Number	1987–89 Rate	Percent rate change
94 counties	6,259	111.6	19,714	149.7	34.1
United States	596,567	139.1	1,285,149	146.3	5.1
Southeast	27,056	114.0	92,000	146.2	28.2

$P < .0001$ (94-county area vs. United States)
$P < .0001$ (94-county area vs. Southeast)

increased from 148.2 to 151.6 between 1988 and 1989, slightly more than the U.S. increase (145.2 to 148.3).

The Oak Ridge area increase (34.1 percent) also exceeded that of the four-state southeast region (28.2 percent), consisting of Georgia, North Carolina, South Carolina, and Tennessee. The local-regional difference is significant ($P < .0001$).

Urban-Rural

Changes in cancer death rates were computed for the four counties in the Oak Ridge area with the largest populations (Buncombe in North Carolina, and Hamilton, Knox, and Sullivan in Tennessee). These four contain about 30 percent of the population in the area, while the remaining 90 counties have much smaller populations; many of these counties can be considered rural.

Table 2 shows that the cancer mortality increase in the nonurban counties (39.0 percent) was greater than that of the urban counties (22.9 percent). Although the urban rate was considerably greater 40 years ago, by 1987–1989 the rates in the two categories were nearly identical.

Proximity

To test whether cancer death increases were greatest in areas closest to the weapons complex, a comparison was made between Anderson County, where Oak Ridge is located and where most of the nuclear facility employees live, and the 12 Tennessee counties situated completely or mostly under 40 miles from the site: Blount, Campbell, Knox, Loudon, McMinn, Meigs, Morgan, Monroe, Rhea, Roane, Scott, and Union. Anderson was selected as the "closest" area, since virtually all contamination identified by the OTA is located in that county. A considerable proportion of Anderson County residents are current or former employees of the nuclear site, which has to be considered in the analysis. Nuclear

Table 2

Cancer deaths and death rates per 100,000, whites only, urban versus nonurban counties near Oak Ridge, 1950–1952 and 1987–1989

Area	1950–52		1987–89		Percent rate change
	Number	Rate	Number	Rate	
Urban	1,797	121.7	5,406	149.4	22.9
Nonurban	4,462	107.8	14,308	148.9	39.0

$P < .0001$ (urban vs. nonurban)

workers tend to be healthier than the general population, and some scientists believe that studying workers may underestimate the true effect of radiation on the general population. The altitude, and thus the average annual precipitation, of each of the 13 counties was relatively homogeneous. The area is also demographically homogeneous; with the exception of Knoxville, it is made up of rural areas and small cities.

The data reveal that the cancer mortality rate increased 39.1 percent in Anderson County, compared with a 29.5 percent increase in the 12 counties under 40 miles away (Table 3). The Anderson increase was greater, even though the "healthy worker" effect may have restricted increases in the county. Both rate increases far exceeded that for the United States. Local rates are now greater than the national standard, even though they were well below in the early 1950s. The difference between the two groups is substantial, but not statistically significant.

Mountains

Oak Ridge is flanked by two nearby mountain ranges: the Great Smoky Mountains to the east, and the Cumberland Plateau to the west. The analysis of any differences in rate changes in mountainous areas was done by creating five groups of "matched" pairs of adjacent mountainous and lowland areas, equidistant from Oak Ridge (Table 4).

The average elevation for each mountain group was at least 1500 feet above sea level, and 75 percent greater than the corresponding lowland group. Each of the 10 areas had a (1990) population of at least 60,000. Precipitation in mountainous areas is far greater than in lowland areas. All areas are made up of small cities and rural areas, with the exception of Chattanooga, Tennessee, located in Hamilton County.

The data show that overall, the cancer mortality rate increased 40.4 percent in the mountain areas, compared with 30.3 percent in the lowland regions; and in four of the five pairs, increases in rates were greater in the mountainous areas (Table 5). Each of the 10 categories far exceeded the 5.1 percent U.S. increase,

Table 3

Cancer deaths and death rates per 100,000, whites only, by proximity to Oak Ridge, 1950–1952 and 1987–1989

Area	1950–52		1987–89		Percent rate change
	Number	Rate	Number	Rate	
Anderson County	111	114.3	473	159.0	39.1
<40 miles	1,351	118.9	4,183	154.0	29.5

Table 4

Groups of "matched pairs" of adjacent mountainous and lowland areas, equidistant from Oak Ridge

Group 1	
Georgia mountains	*Georgia lowlands*
Fannin	Catoosa
Gilmer	Dade
Rabun	Murray
Towns	Walker
Union	Whitfield
Group 2	
Virginia mountains	*Kentucky lowlands*
Lee	Knott
Scott	Knox
Wise	Leslie
	Perry
Group 3	
North Carolina mountains	*Tennessee lowlands*
Avery	Carter
Madison	Greene
Mitchell	Unicoi
Yancey	Washington
Group 4	
North Carolina mountains	*Tennessee lowlands*
Cherokee	Bradley
Clay	Hamilton
Graham	Polk
Macon	
Swain	
Group 5	
Tennessee mountains	*Tennessee lowlands*
Cumberland	Bledsoe
Fentress	McMinn
Scott	Meigs
	Rhea

Table 5

Cancer deaths and death rates per 100,000, whites only, mountain versus lowland areas near Oak Ridge, 1950–1952 and 1987–1989

Area[a]	1950–52 Number	1950–52 Rate	1987–89 Number	1987–89 Rate	Percent rate change
Group 1					
Mts.	106	93.3	401	134.1	43.8
Low.	273	116.5	1,161	159.3	36.8
Group 2					
Mts.	317	123.0	666	163.2	32.6
Low.	198	94.1	555	178.0	89.1
Group 3					
Mts.	142	89.5	385	123.7	38.2
Low.	440	113.0	1,342	144.8	28.1
Group 4					
Mts.	139	97.9	501	137.4	40.3
Low.	686	125.2	1,901	145.9	16.6
Group 5					
Mts.	116	99.8	488	167.2	67.6
Low.	189	119.8	513	149.2	24.6
Total					
Mts.	820	103.9	2,441	146.0	40.4
Low.	1,786	116.2	5,472	151.3	30.3

[a]Groups 1–5 are listed in Table 4. Mts., mountains; Low., lowlands.
$P < .04$ (total mountains vs. total lowlands)

and eight exceeded the regional increase. In a number of groups, the 1987–1989 rates surpassed national figures, even though they were uniformly below U.S. rates 40 years ago. Another interesting finding is that the two largest mountain-lowland differences occurred in the pairs closest to Oak Ridge (Groups 4 and 5).

The only instance in which lowland increases were greater was in the four-county lowland area of southeastern Kentucky. These counties have traditionally been among the poorest in the nation, and their principal industry (coal mining) has exposed a number of residents (especially workers) to potential carcinogens; the influences of poverty and occupational exposure as contributors to higher mortality rates must be considered here.

Downwind

The area of Tennessee within 40 miles of Oak Ridge was divided into four quadrants. The region northwest of Oak Ridge is mountainous; the other three quadrants have relatively similar altitudes and similar precipitation levels. There are no major cities in the three regions; Knox County (which contains Knoxville) was excluded to preserve homogeneity in the analysis.

Prevailing winds in the Oak Ridge area emanate from the southwest and blow toward the northeast (17). The three downwind counties northeast of Oak Ridge (Anderson, Campbell, and Union) recorded an increase in cancer death rates of 50.8 percent (Table 6). In comparison, the upwind (southwest) counties (McMinn, Meigs, Rhea, and Roane) increased only 7.1 percent. Even if Knox County is included in the downwind group, the downwind increase of 31.4 percent is still far greater than the upwind increase of 7.1 percent.

The counties southeast of the Oak Ridge facility (Blount, Loudon, Monroe, and Sevier), neither upwind nor downwind, increased 19.5 percent. Those in the northwest (Cumberland, Morgan, and Scott) increased 88.2 percent, but these are mountainous counties with much greater precipitation than the other three quadrants. Previous analysis showed that precipitation's influence on cancer rate change is substantial.

Current rates for all four quadrants now exceed the U.S. rate.

DISCUSSION

Each of the five hypotheses was supported by the data presented here. Specifically, the cancer mortality rate increase in the Oak Ridge area exceeded the national and regional increases; the local urban areas experienced less of an increase; the change was greatest in the area closest to Oak Ridge; increases in mountain areas surpassed those in adjacent lowlands; and the increase was greatest in the area downwind of Oak Ridge. Cancer mortality rates in the region, which were uniformly below U.S. rates in 1950–1952, are now above national standards in many of the 103 counties.

It is clear from the mortality patterns, coupled with the known contamination near Oak Ridge, that the possibility of adverse health effects from nuclear

Table 6

Cancer deaths and death rates per 100,000, whites only, upwind versus downwind counties under 40 miles from Oak Ridge, 1950–1952 and 1987–1989

	1950–52		1987–89		
Area	Number	Rate	Number	Rate	Percent rate change
N.E. (downwind)	207	105.0	790	158.3	50.8
N.E. (with Knox county)	847	116.5	2,658	153.0	31.4
S.W. (upwind)	291	138.2	762	148.0	7.1
S.E. (neither)	352	123.4	1,216	147.4	19.5
N.W. (neither)	113	94.1	529	177.1	88.2

$P < .0001$ (downwind counties vs. upwind counties) operations exists. While there may be other explanations for these findings, none is apparent. Known contamination other than radiation is not likely to be a strong factor; heavy metals such as mercury, while hazardous to human health, are not acknowledged to be carcinogenic.

A brief review of demographic data reveals no other apparent reason for this distinct and consistent set of trends. For example, the rate of poverty in the Oak Ridge area has decreased sharply since 1950, and the area has "urbanized" (i.e., the population density has risen) at a slower rate than in the United States. Population in- and out-migration is unlikely to have any great effect; the percentage of current residents born in state (many of them, presumably, in the area) is greater in the Oak Ridge region than in the United States as a whole (18).

The influence of occupational exposure to radiation is also a negligible factor in this report. Only several thousand residents of Anderson and Roane counties have ever worked at the Oak Ridge facility, a tiny proportion of the more than 3 million residents of the 94-county area.

This analysis of changes in cancer mortality near Oak Ridge suggests a link between radiation contamination and increased cancer risk to populations living near nuclear sites. This finding has several implications.

First, cancer patterns near Oak Ridge lend credence to the belief that radioactive products, ingested gradually in small amounts, are more potent per dose than larger amounts of radiation absorbed in single exposures. The principle that Petkau first observed in his laboratory over 20 years ago is supported by the data.

Second, results of the present study are a call for stepped-up research on the health effects of low-level radiation. This research should be two pronged. It should include laboratory investigations testing the effects of small amounts of fission products, in particular the effects of beta-emitters on the cells of the immune system at very low dose rates.

Moreover, further epidemiological studies of large populations such as that presented here should be undertaken. Studying populations near other old nuclear installations such as Savannah River will likely produce the most meaningful results. Looking at trends for cancers of specific organ systems is also a logical followup to this study. Data on radioactive releases from Oak Ridge should also be reviewed, even though it is impossible to calculate a precise amount absorbed per person, prohibiting a true dose-response comparison for the general population.

In conclusion, the study strongly indicates that current U.S. nuclear policy and existing radiation standards for environmental releases must be reevaluated. Substantial evidence is building against the belief that routine, low-level releases from nuclear weapons plants and civilian nuclear reactors are not harmful. Only recently, a study of Hanford nuclear workers lowered the estimated radiation dose needed to increase cancer risk; this estimated dose was especially low for exposures in older persons (19). Most studies to date on the health of populations living near atomic facilities have produced at least one unusually high pattern of disease and/or death (20). Moreover, a number of these studies have only recently detected adverse effects, possibly due to the long lag time between exposure and disease or death. Large populations are potentially affected, such as the 3 million residents within 100 miles of Oak Ridge. The Sternglass and Gould (5) article concludes that many millions living in sections of the United States with the greatest concentration of civilian reactors are at excess risk for breast cancer.

Operating over 100 civilian nuclear reactors and 17 nuclear weapons facilities without fully understanding their effects on human health was clearly imprudent. In the past, during the debate over the effects of human health, nuclear operations continued unabated. The Cold War made the commitment to nuclear energy a matter of national security that superseded any issues of safety. The end of the Cold War now permits reforms to take place as needed. Merely waiting for the results of studies without first modifying nuclear policy may have disastrous consequences. Since alternative ways to provide energy are now available, the existing evidence appears to call for an end to all further releases of fission products into the environment.

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