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Original Contributions

Cancer Incidence in an Area of Radioactive Fallout Downwind From the Nevada Test Site

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• **Exposures in southwestern Utah to radioactive fallout (1951 through 1962) from atmospheric nuclear detonations at the Nevada Test Site (NTS) were followed by smaller exposures (1962 through 1979) from venting of underground nuclear detonations. The cancer incidence in a 1951 cohort (4,125) of Mormon families in southwestern Utah near the NTS was compared with that of all Utah Mormons (1967 through 1975). There were 109 more cases of cancer than expected (288[observed]/179[expected]). Leukemia was most prominent early (1958 through 1966), with 19 cases, five times more than expected (3.6). The excess of leukemia persisted into the later period (1972 through 1980), 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 radiation exposures is supported by a comparison between groups of the ratio of cancers of more radiosensitive organs with all other types of cancer.**

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LONG-TERM worldwide effects of nuclear weapons testing may cause 29,000 to 72,000 deaths from cancer (whole-body exposure) and 168,000 genetic effects (all generations) (Robert E. Alexander, Office of Standards Development, Nuclear Regulatory Commission, Washington, DC, written communication, Feb 26, 1979). There have been few studies of such health effects in local civilian populations downwind from nuclear test sites and subject to greater exposures to fallout. An extensive study of cancer deaths in Hiroshima and Nagasaki survivors assumed exposures to direct radiation from the nuclear detonation and only minimal exposure to radioactive fallout.[1] After a peak in leukemia deaths in the first five years, there was a persistent increase in other cancer deaths. In the last five-year period (27 to 32 years after the bombs), the excess cancer death rate increased by 2.4 times, caused by cancer of the esophagus, stomach, colon, lung, breast, and urinary tract, lymphoma, and multiple myeloma.[2] There was an increase in cancer of the thyroid gland and benign tumors as well.

See also p 197.

Detonation of a 15-megaton hydrogen bomb at the Bikini Atoll (March 1, 1954) caused radioactive fallout arriving at Rongelap, 180-km distant, in four to six hours and at Utirik, 440-km distant, in about 22 hours. The Rongelap islanders received 175 rad of gamma radiation and Utirik islanders received 14 rad before evacuation. About 90% of those exposed had skin burns and hair loss at Rongelap. Many had superficial skin lesions (14/16[observed/exposed]) and three had hair loss at Ailinginae Atoll (75 rad), and no one had skin lesions or hair loss on Utirik. The Rongelap islanders received a thyroid dose of 300 rad from ^{131}I, "but about 4,200 additional rad in ^{131}I equivalents" from the short-lived iodine isotopes (^{132}I, ^{133}I, and ^{135}I).[3] Children received a larger dose, up to 2,000 or more rad for a 1-year-old child. Estimated thyroid doses at Utirik ranged from 30 to 90 rad.[3] Primary hypothyroidism and thyroid nodules were first recognized in 1964, about ten years after exposure, and were earlier and more severe in children. About 77% of Rongelap children younger than 10 years at the time required surgery later for benign and malignant thyroid nodules.[3]

Construction of the Nevada Test

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Site (NTS) began in January 1951, and the first nuclear weapon was detonated then.[4] Of more than 600 detonations, 183 were in the atmosphere (1951 through 1962). Tests were usually conducted when winds were not blowing toward Las Vegas and Los Angeles, which were 140 km and 420 km from ground zero (GZ), respectively. At least 87 of the 121 atmospheric tests between 1951 and 1958 caused offsite contamination, and 28 (>620 kilotons [kt], totally) lay down a swath of radioactive fallout over Utah.[5] Exact patterns were unpredictable and depended on the presence of functioning monitoring devices in local areas. The nuclear bomb "Small Boy" of about 1 kt was detonated on a tower 3 m high (July 14, 1962) and produced a "hot spot" of 100 rad/hr 540 km downwind (48.5°) from GZ in the Orem, Utah, area.[6] Within a radius of 8 to 16 km around this spot, the radiation dosage rate increased by 25 times. There may have been many other such areas that were not detected. An infinite dose of 100 rad was calculated for an area on the highway between St George, Utah, and Cedar City, Utah (228 km and 276 km from GZ, respectively), after the detonation of "Harry," and offsite doses of similar magnitude were reported for detonations of "Nancy," "Simon," "Badger," and "Boltzman" (Harold A. Knapp, PhD, US Defense Communications Agency, oral communication, Nov 5, 1982). High explosive tests were later made to study the dispersion of plutonium or uranium from nuclear weapons, measurably contaminating over 250,000 sq km, with most contamination occurring in northern Nevada and Utah. The highest offsite plutonium concentration reported was 9.6 picocuries per square centimeter (pCi/sq cm), two orders of magnitude greater than that produced by weapons fallout for nearby states downwind from the NTS and three orders greater than for states more distant from the NTS.[7] (A picocurie of a radioactive isotope of an element is a quantity sufficient to produce 2.2 disintegrations per minute. Each disintegration releases ionizing radiation. There are eight important isotopes of plutonium, but ^{239}Pu is the predominant isotope and has a half-life of 24,390 years.[8]) Radioactive plumes and clouds from 40 subsurface blasts traveled beyond site boundaries, contaminating Utah, including the 100-kt "Sedan" in 1962 and "Coulomniers" in 1977. Official monitoring of fallout was compromised by failure to activate radiation monitoring apparatus during nuclear tests (*Deseret News*, Dec 4, 1979, p 8-B).

After a test on May 19, 1953, more than 300 mR per hour (mR/hr) were observed "in and out of cars" in St George. Former Atomic Energy Commission Chairman, Lewis Strauss noted that "East they got over Pioche and over St George which they apparently always plaster."[9] "Estimates of dosage delivered by radioactive iodine to the thyroids of children in St George, Utah, who were less than five years old in 1953, vary between 500 and 2,500 rads" (Michael May, PhD, Lawrence Radiation Laboratory, Berkeley, Calif, written communication, Nov 29, 1965). These doses are of the same order of magnitude as those sustained by the Rongelap children, who also received 175 rad of whole-body radiation.[3] Livestock received much higher doses, and deaths of more than 4,000 sheep in 1953 were associated with the passage of radioactive plumes or clouds. Harold Knapp, PhD, reported fetal lambs had received doses of 20,000 to 40,000 rad to the thyroid gland and sheep had received 1,500 to 6,000 rad to the gastrointestinal (GI) tract, where the external doses were estimated to be only 4 rad (oral communication, Nov 5, 1982). Sheep near Cedar City received 38 to 169 rad of external gamma radiation.[10] Despite reports of high levels of radiation in Utah and Nevada, and in Salt Lake City, Denver, and points more distant, there have been few investigations. Important exposures of the Los Angeles population went virtually unnoticed.[11] An increase in leukemia mortality in southwestern Utah (1950 through 1964) was reported in 1965 (Edward S. Weiss, MSPH, Public Health Service, written communication) and corroborated in a follow-up study of leukemia deaths in children 14 years later.[12]

More than 30 years have now passed since the first exposure of people in southwestern Utah to radioactive fallout. There have been external exposures to radioactive gases and particulates in the air, and from contaminated soil, and internal exposures to radioactive isotopes ingested in food and water, or inhaled, and stored in the body. Many persons in this area milk cows and raise their own produce and meat and are exposed to resuspended dust from agricultural activities. Of some 240 longer-lived radionuclides released by the fissioning of uranium and plutonium, there are radioactive isotopes of every trace element and other elements important in human nutrition.[8,13] Most are cumulative and become concentrated in the food chain.[14] The molecular, cellular, and developmental effects of these radionuclides have been poorly studied. This is especially true of long-term effects on human reproduction. Because of the possibility of an effect on residents of the high-fallout areas in the United States, an empirical investigation of the incidence of all cancer in Mormons was conducted in communities in southwestern Utah.

METHODS

Selection of the study group required that religion be considered as a potential confounding factor. Utah has the lowest cancer incidence of any state, attributed to the life-style of members of the Church of Jesus Christ of Latter Day Saints, or Mormons.[15] Utah Mormons (72% of the population) have a cancer incidence 23% less than the national average. Utah non-Mormons have a cancer incidence 16% greater than that of Mormons. Church members are urged to abstain from tobacco, alcohol, tea, and coffee, avoid extramarital sexual activity, conform to certain family customs, and pursue higher education. Furthermore, the Mormon population in Utah seems to have greater stability. The beneficial effects of the Mormon life-style were also reported in California. Because of these considerations, the cancer incidence in Mormons in the high-fallout area in southwestern Utah (4,125) was compared with the cancer incidence in all Utah Mormons (population, 781,735 in July 1971).

Towns with heavy fallout exposure included the St George area, Parowan, Paragonah, and Kanab, Utah; Fredonia, Ariz; and Bunkerville, Nev. A high-risk population was defined as those Mormon families or persons listed in 1951 telephone directories in these towns still listed in the 1962 directories and who could be located in 1981. This roster was checked against church records. "Family" included all persons related by blood or marriage in

Table 1.—Cancer Incidence in a Mormon Population Residing in Southwestern Utah Exposed to Radioactive Fallout Compared With Cancer Incidence for All Utah Mormons*

Type†	Class (International Classification of Diseases No., Revision 8)	Utah Mormons 1967-1975, Rate‡	High-Fallout Area[11]						Fallout-Effects Group					
			1958-1966			1972-1980			1958-1968			1972-1980		
			Rate	Observed§	Expected§	Rate	Observed	Expected	Rate	Observed	Expected	Rate	Observed	Expected
A + B	All sites (140-207)	228	354	118¶	76.0	377	170¶	102.8	1,322	31¶	5.3	1,064	33¶	7.1
A: Cancer of more radiosensitive organs	Lung, respiratory (162, 160, 163)	16.5	20.0	7	5.8	12.8	6	7.7	21	1	0.8	22	1	0.8
	Upper GI tract (141-150)	4.4	11.4	4	1.5	8.9	4	2.0	...	0	...	26	1	0.2
	Stomach (151)	7.0	34.5	9¶	1.8	12.5	5	2.8	138	3¶	0.2	36	2	0.4
	Colon (153)	19.7	14.0	5	7.0	34.1	14	8.1	66	2	0.6	87	3	0.7
	Breast (174)	**31.9**	**29.1**	**8**	**8.8**	**60.7**	**27¶**	**14.2**	**96**	**2**	**0.7**	**347**	**8¶**	**0.7**
	Thyroid (193)	3.7	16.3	6¶	1.4	30.8	14¶	1.7	...	0	...	26	1	0.1
	Leukemia	**7.9**	**41.7**	**19¶**	**3.6**	**28.1**	**12¶**	**3.4**	**307**	**9¶**	**0.2**	**70**	**1**	**0.1**
	Lymphoma	10.7	10.1	4	4.2	20.7	10	5.2	48	1	0.2	199	5¶	0.3
	Total	**101.8**	**177.1**	**62¶**	**34.1**	**208.6**	**92¶**	**45.1**	**676**	**18¶**	**2.7**	**813**	**22¶**	**3.3**
B: Other cancer	Melanoma (172)	5.7	9.0	3	1.9	19.5	9¶	2.6	85	2¶	0.1	13	1	0.4
	Brain, CNS (191, 192)	4.7	15.0	5#	1.6	8.2	4	2.3	131	2¶	0.1	70	1	0.1
	Bone, joint (170)	0.8	8.3	3¶	0.3	10.1	5¶	0.4	...	0	...	...	0	0.1
	Other	115.0	144.6	45	35.8	130.6	60	52.8	430	9¶	2.4	168	9	6.2
	Total	**126.2**	**176.9**	**56#**	**39.6**	**168.4**	**78**	**58.1**	**646**	**13¶**	**2.6**	**251**	**11**	**6.8**
A/B		0.807	1.001	...	...	1.239	...	...	1.046	...	...	3.239	...	...
$\left(\frac{A/B\ (subpopulation)}{A/B\ (Utah)}-1\right)\times 100$		...	+24%	...	...	+53.5%	...	...	+29.6%	...	...	+301.4%	...	...

*Radioactive fallout occurring from atmospheric detonations of nuclear weapons at the Nevada Test Site between 1951 and 1962. Data have been adjusted for age and sex; age adjustment for the three populations by the direct method with the 1970 US white population as the standard (*JNCI* 1980;65:1169).

†"A" classes of cancer (of the more radiosensitive organs) are those found in excess among the survivors of the nuclear bomb detonations at Hiroshima and Nagasaki: leukemia, lymphoma, cancer of thyroid gland, lung, esophagus (included here are other cancers of the upper gastrointestinal [GI] tract 141-150), stomach, colon, and breast.

‡All rates are average annual age-adjusted incidence of cancer per 100,000.

§The number of cases observed is compared with the number expected. Expected case numbers were calculated by the following approach: the number of cases in each class times the average annual age-adjusted cancer incidence rate for Utah Mormons divided by the average age-adjusted cancer incidence rate for the study population (*Environ Res* 1981;25:86).

‖High-fallout areas consist of the St George area, Parowan, Paragonah, and Kanab, Utah; Fredonia, Ariz; and Bunkerville, Nev. For some cases, dates of diagnosis of cancer were not recalled with certainty. These were allocated to the broad time periods indicated in the table above. Those not clearly falling in a time period were assigned to a time period in the sequence in which they appeared, with conservative effect, ie, assigned equally to the early (1958 through 1966), interim (1967 through 1971), and intermediate (1972 through 1980) time periods. The interim period was not studied because the design is to compare an early period with a later period.

¶Indicates significant at $P=.01$.

#Indicates significant at $P=.05$ (two-tailed test[16]).

each household, including children born to these families during the period 1951 through 1962 and those who died in 1962 or after. The period 1951 through 1962 was chosen to define the study population because the major exposures to fallout occurred in this time. However, the choice of 1962 as the end of this period is not intended to imply that fallout-induced neoplastic diseases of short latency such as leukemia could not have appeared before 1962.

Volunteers were trained in the smaller towns to carry out a survey of this population between April and December 1981. In St George, trained volunteers were augmented with persons hired for this purpose. The survey form was completed by the surveyor and the head of the family and included an inquiry about church membership. Other questions concerned effects felt immediately after fallout (skin burns, eye burns, hair loss, change in hair coloration, nausea, and diarrhea), smoking experience, employment, and diagnosis of cancer. Those who had a medical diagnosis of cancer were asked to supply information for a supplementary form: diagnosis, date of diagnosis, date of death if deceased, hospital where last treated, name of physician, and current address of the cancer patient or surviving relative. Cancer is a major life-threatening event that will be remembered by a person and by members of the family. The treating physician will inform the patient and/or the family of the diagnosis of the disease. A recent study reports that diagnosis in life correlated with death certificate cause and with unpublished data from the Utah Cancer Registry more than 90% of the time.[12]

Information was also requested about spontaneous abortions, stillbirths, and malformations, to be included in later reports. When necessary, telephone interviews were conducted. Telephone companies reported that about 2.5% of residents in this area did not have telephones. About 40% of the defined population could not be located in 1981. Loss of this portion of the population was thought to have a conservative effect on the data, ie, to be more likely to understate any association present. Less than 1% refused to cooperate. The year of diagnosis of cancer could not be recalled with certainty in about 18% of cases occurring between 1958 through 1980. These were assigned at random to periods 1958 through 1966, 1967 through 1971, or 1972 through 1980. Skin cancers not melanoma and benign tumors were not considered, although a high rate of the former was reported, and an increase of benign tumors could be expected in a population with radiation effects.[2]

The 1951 cohort at high risk was identified by 1962 telephone directories and availability for this study in 1981. The

Table 2.—Age Distribution by Sex in 1962 of Members of Latter Day Saints Families Compared With Age Distribution of Utah Mormons in 1971*

	Male: Age, yr							Female: Age, yr						
	0-14	15-44	45-54	55-64	65-74	75+	Total	0-14	15-44	45-54	55-64	65-74	75+	Total
Utah Mormons, ×1,000, 1971	122.1	175.6	32.2	26.2	14.5	10.0	**380.6**	123.4	181.0	35.1	28.5	19.6	13.3	400.9
Southwestern Utah, 1962	**593**	**955**	**250**	**167**	**110**	**56**	**2,131**	**541**	**937**	**246**	**145**	**87**	**38**	**1,994**
Fallout-effects group, 1962	15	47	35	20	14	3	**134**	18	43	25	13	6	0	**105**

*Latter Day Saints families consisting of those listed in both 1951 and 1962 directories of communities in southwestern Utah. Some of the families could not be located in this 1981 survey and are not included in this table or in the survey of cancer incidence. The study area includes St George, Kanab, Parowan, Paragonah, Gunlock, Hurricane, Ivins, Leeds, Santa Clara, Washington, and Veyo, Utah; Fredonia, Ariz; and Bunkerville, Nev. In some cases, respondents were uncertain of exact age of some family members, and these were placed in the broad age categories above by position in the family. Age distribution of Utah Mormons from Lyon JL, Gardner JM, West DW: Cancer incidence in Mormons and non-Mormons in Utah during 1967-1975 (*JNCI* 1980;65:1055).

population was too small to follow annual cancer incidence rates. Cancer incidence data for all Utah Mormons were available for a nine-year period (1967 through 1975), and 2 nine-year periods were selected for study of the cohort. Assuming that substantial radiation doses from fallout might have been sustained by the major part of the study population by 1953, an increase in leukemia incidence could be evident by 1958, and so an early period (1958 through 1966) was selected. Other cancers of more radiosensitive organs have longer latency periods, and the latest nine-year period available for study was selected (1972 through 1980). This design provided internal as well as external controls. Cancer incidence in the early period may be compared with cancer incidence in the later period, as well as with the control population (all Utah Mormons). Cancer incidence in the early period for the subgroup complaining of fallout effects may be compared with that for the subgroup in the later period, with the study population as a whole, and with all Utah Mormons. Furthermore, the ratios of cancer of more radiosensitive organs to all other cancer may be compared between the study and control populations.

Cancer incidence in the study population, the fallout-effects group, and the comparison group (all Utah Mormons) were age adjusted by the direct method, with the 1970 US white population as a standard. Expected case numbers were calculated for each category by the average annual age-adjusted cancer incidence rate for Utah Mormons divided by the average annual age-adjusted cancer incidence rate for the study population, times the number of cases of cancer in the study population (Table 1). Although the hypothesis to be evaluated is that there may be an excess of cancer of the more radiosensitive organs in a population exposed to radioactive fallout, a more conservative two-tailed test of significance was selected (Table 1).

Cancer registry data could not be used in this cohort study (1951 through 1980) because the registry was not established until 1966, fifteen years after the testing of nuclear weapons began. The registry could not be used to establish a specific high-risk cohort in 1951 and follow it through time. Registry data include larger populations that have immigrated into the area in recent years with smaller, more recent exposures to fallout and insufficient time to permit any latent cancers to appear. Many early residents would have left the area and had cancer develop elsewhere.

RESULTS

The age and sex distribution of the study population in 1962 is compared with that for all Utah Mormons in 1971 (Table 2). Although 59.3% of women in the study group were of childbearing age in 1962 or the decade before (1,183/1,994), compared with 53.8% for all Mormon women in Utah, only 27.5% of the study population are children, compared with 31% for the state, an apparent deficit in the fallout area for 1948 through 1962 of about 20%.

Average annual age-adjusted cancer incidence rates in Mormons in southwestern Utah in 1958 through 1966 and in 1972 through 1980 are compared with all Utah Mormons in 1967 through 1975 (Table 1). The ratio of cancers of the more radiosensitive organs (identified in studies of Japanese survivors) to other cancer in the study population in 1958 through 1966 is compared with that ratio in the same population in 1972 through 1980 and to that for all Utah Mormons in 1967 through 1975. In addition, cancer of certain other organs thought to be sensitive to radiation are considered separately. These are cancer of bone and brain and malignant melanoma.

There was an excess of 42 cases (P=.01)[16] of all cancer in the early period (1958 through 1966) and an excess of 67 cases (P=.01)[16] in the later period (1972 through 1980). The excess cases reflected principally an increase in the incidence of cancer of more radiosensitive organs. Most notably, there were 19 cases of leukemia (P=.01)[16] (3.6 expected) in the early period, and this persisted into the later period, with 12 cases observed (P=.01)[16] (3.4 expected). An early excess of cancer of the thyroid gland (6/1.4, P=.01)[16] was followed by a sharp increase later (14/1.7, P=.01).[16] There was a borderline increase in lymphoma in 1972 through 1980 (10/5.2, P=.040). The incidence of cancer of the breast was unremarkable in 1958 through 1966 (8/8.8), but a sharp increase was noted in 1972 through 1980 (27/14.2, P=.01).[16] There was a persistent excess of cancer of the upper GI tract (4/1.5 and 4/2.0) that was not significant. The incidence of cancer of the stomach showed an early increase (9/1.8, P=.01)[16] that persisted later (5/2.8). An excess number of cases of cancer of colon occurred later (14/8.1, P=.037). No increase in incidence of cancer of the lung was observed. There were more brain tumors, cancer of bone, and melanoma than expected in the early period (5/1.6, P=.05; 3/0.3, P=.01[16]; and 3/1.9, respectively) and this persisted (4/2.3; 5/0.4, P=.01[16]; and 9/2.6, P=.01[16], respectively).

The subgroup of 239 persons (134 males and 105 females) who reported effects from fallout had a much higher incidence of cancer (Table 1). In the early period (1958 through 1966), cancer developed in 31 (P=.01)[16] (only five cases expected) and cancer developed

in 33 (P=.01)[16] later (1972 through 1980), when seven cases were expected. Leukemia was most important in the early period (9/0.2, P=.01).[16] The classes of cancer in excess in the early period also included cancer of the stomach (3/0.2, P=.01),[16] melanoma (2/1.0, P=.01),[16] and brain tumor (2/0.1, P=.01).[16] In the later period, cancer of the breast (8/0.7, P=.01)[16] and lymphoma (5/0.3, P=.01)[16] were most important. Cancer of the colon was also higher (3/0.7, P=.034).

The ratio of cancer of more radiosensitive organs (Table 1) to all other cancers in the high-fallout area was 24.0% higher in the period 1958 through 1966 than that for all Utah Mormons, and for the later period, 1972 through 1980, the ratio was 53.5% higher. Among the fallout-effects group, this ratio was 29.6% higher than for Utah Mormons in the early period and about 300% higher in the later period.

Differences in the incidence of cancer by sex are given in Table 3. Although both sexes had an excess of leukemia, males had more cases. Males did not have an excess of lymphoma, as females did later (6/1.9, P=.05). Females had a larger excess of cancer of the thyroid gland (6/1.0 [P=.01][16] early and 9/1.3 [P=.01][16] later) than males, who had no cases in the early study period but had an excess (5/0.4, P=.01)[16] later. Females had a greater excess of stomach cancer early (6/0.6, P=.01)[16] that did not persist later (2/0.9). There were an excessive number of cases of cancer of the colon later among females (11/3.7, P=.01),[16] but not among males. Both males and females had an excess of melanoma later (4/1.2, P=.34; and 5/1.4, P=.05; respectively). Females had more brain tumors (3/0.7, P=.34, early; and 3/1.1 later), and males had more bone cancer (2/0.2 [P=.05] early and 4/0.3 [P=.05] later). Females had two more cases of bone cancer than expected throughout the study periods.

COMMENT

There was an excess of 109 cases of cancer (288 cases observed [P=.01][16], 179 expected) in this southwestern Utah population of 4,125 during the period of the study in this report (1958 through 1966 and 1972 through 1980), a total of about 72,000 person-years. Leukemia was preponderant early and persisted later, compatible with a prolonged period of exposure to radioactive fallout during 1951 through 1962 and afterward from the venting of 11 of the underground nuclear bomb tests (1962 through 1979). This is in contrast to the peak of leukemia deaths in about five years among the Hiroshima-Nagasaki survivors after one exposure in 1945. There was an increase of lymphoma in females of marginal significance (P=.05) in 1972 through 1980. There was only one case identified as multiple myeloma, in a 15-year-old boy. One person was reported to have had aplastic anemia (woman, aged 23 years), another was reported to have polycythemia (man, aged 73 years), and one death was attributed to radiation sickness. Major classes of cancer (chiefly breast, colon, and lung) in the early period (1958 through 1966) had virtually the same incidence as that for all Utah Mormons, consistent with the longer latency period for these cancers.

Cancer of the thyroid gland was prominent in the exposed group. A significant (P=.01) excess was noted early in females, and a notable excess was found in both sexes in 1972 through 1980. Many others in the study group complained of thyroid problems.

There was not an excess of cancer of the breast until the later period (1972 through 1980). There was a slight excess of cancer of the upper GI tract, the stomach, and of the colon occurring later in females. The incidence of lung cancer was not higher in the study population than for all Utah Mormons. The low prevalence of smoking in this group would decrease retention of inhaled radioactive particles of respiratory size. Moreover, most Utah Mormons live in urban areas with greater air pollution than in southwestern Utah, and so lung cancer rates here similar to those for all Utah Mormons may actually represent an increase. Females seemed to have no advantage over males with regard to lung cancer risk. Considering the excess incidence of other classes of cancer associated with radiation in this area, a larger study population may demonstrate an excess incidence of lung cancer.

A significant (P=.01) excess of melanoma was found in the later period (1972 through 1980), about equally in males and females. An excess incidence of melanoma has been reported in plutonium workers, and a possible mechanism for induction of melanoma by actinides has been described.[17] The actinides are chemically similar, mostly synthetic, radioactive elements such as actinium, thorium, uranium, and plutonium. Of the radionuclides of potential importance in routine releases from nuclear facilities, 47 are actinides.[8] Tests of plutonium dispersion devices at the NTS, as well as the detonation of weapons with plutonium components, have scattered plutonium over a wide area and this may be related to the excess cases of melanoma found there.

Plutonium workers have been reported to have a proportional morbidity ratio of brain tumors (gliomas) eight times greater than expected,[17] and a significant (P=.05) excess of

Table 3.—Age-Adjusted Cancer Incidence by

Type†	Class (International Classification of Disease No., Revision 8)
A + B	All sites (140-207)
A: Cancer of more radiosensitive organs	Lung, respiratory (162, 160, 163)
	Upper GI tract (141-150)
	Stomach (151)
	Colon (153)
	Breast (174)
	Thyroid (193)
	Leukemia
	Lymphoma
	Total
B: Other cancer	Melanoma (172)
	Brain, CNS (191, 192)
	Bone, joint (170)
	Other
	Total

A/B

$$\left(\frac{A/B\ (subpopulation)}{A/B\ (Utah)} - 1\right) \times 100$$

Sex in a Mormon Population Residing in Southwestern Utah Exposed to Radioactive Fallout Compared With Cancer Incidence for All Utah Mormons*

Male Utah Mormons 1967-1975, Rate‡	Male Mormons in the High-Fallout Area‖						Female Utah Mormons 1967-1975	Female Mormons in the High-Fallout Area					
	1958-1966			1972-1975				1958-1966			1972-1980		
	Rate	Observed§	Expected§	Rate	Observed	Expected	Rate	Rate	Observed	Expected	Rate	Observed	Expected
253	294	53	45.6	318	73	58.1	205	410	65¶	32.5	432	97¶	46.0
28.3	27.4	5	5.2	20.3	5	7.0	5.3	12.8	2	4.4	5.6	1	0.9
6.9	23.4	4	1.2	13.9	3	1.5	2.1	. . .	0	. . .	4.1	1	0.5
9.4	16.7	3	1.7	14.0	3	2.0	4.8	51.5	6¶	0.6	11.0	2	0.9
21.0	10.1	2	4.2	13.2	3	4.8	18.4	17.7	3	3.1	54.0	11¶	3.7
0.7	0	0	. . .	0	. . .	. . .	61.6	56.9	8	8.6	118.5	27¶	14.0
1.9	0	0	. . .	22.6	5¶	0.4	5.5	31.9	6¶	1.0	38.5	9¶	1.3
9.4	43.1	12¶	2.6	37.0	8¶	2.0	6.4	40.4	7¶	1.1	19.6	4	1.3
13.8	15.6	3	2.6	16.2	4	3.4	7.8	4.9	1	1.6	25.0	6#	1.9
91.4	**136.3**	**29**	**17.5**	**137.2**	**31**	**21.1**	**111.9**	**216.1**	**33¶**	**20.4**	**276.3**	**61¶**	**24.5**
5.6	12.8	2	0.9	18.9	4	1.2	5.8	5.3	1	1.1	20.1	5#	1.4
4.9	11.7	2	0.8	3.7	1	1.3	4.5	18.2	3	0.7	12.4	3	1.1
1.1	11.3	2#	0.2	16.6	4¶	0.3	0.5	5.5	1	0.1	4.0	1	0.1
150.0	121.9	18	22.1	141.6	33	35.0	82.3	164.9	27¶	13.5	119.2	27	18.6
161.6	**157.7**	**24**	**24**	**180.8**	**42**	**37.8**	**93.1**	**193.9**	**32¶**	**15.4**	**155.7**	**36¶**	**21.2**
0.566	0.864	. . .	. . .	0.759	. . .	. . .	1.202	1.114	. . .	. . .	1.775	. . .	. . .
. . .	+52.6%	. . .	. . .	+34.1%	. . .	. . .	. . .	−7.3%	. . .	. . .	+47.7%	. . .	. . .

*Radioactive fallout occurring from atmospheric detonations of nuclear weapons at the Nevada Test Site between 1951 and 1962. Data have been adjusted for age and sex; age adjustment for the three populations by the direct method with the 1970 US white population as the standard (*JNCI* 1980;65:1169).

†"A" classes of cancer (of the more radiosensitive organs) are those found in excess among the survivors of the nuclear bomb detonations at Hiroshima and Nagasaki: leukemia, lymphoma, cancer of thyroid gland, lung, esophagus (included here are other cancers of the upper gastrointestinal [GI] tract 141-150), stomach, colon, and breast.

‡All rates are average annual age-adjusted incidence of cancer per 100,000.

§The number of cases observed is compared with the number expected. Expected case numbers were calculated by the following approach: the number of cases in each class times the average annual age-adjusted cancer incidence rate for Utah Mormons divided by the average age-adjusted cancer incidence rate for the study population (*Environ Res* 1981;25:86).

‖High-fallout areas consist of the St George area, Parowan, Paragonah, and Kanab, Utah; Fredonia, Ariz; and Bunkerville, Nev. For some cases dates of diagnosis of cancer were not recalled with certainty. These were allocated to the broad time periods indicated in the table above. Those not clearly falling in a time period were assigned to a time period in the sequence in which they appeared, with conservative effect, ie, assigned equally to the early (1958 through 1966), interim (1967 through 1971), and intermediate (1972 through 1980) time periods. The interim period was not studied because the design is to compare an early period with a later period.

¶Indicates significant at $P=.01$.

#Indicates significant at $P=.05$ (two-tailed test[16]).

brain tumors were found in the early period of this investigation, slightly more in males than females. Females had a slight excess of brain tumors in the later period. Throughout both periods there were five more brain tumors than expected. Plutonium and other actinides are known to be able to induce bone cancer, and a significant ($P=.01$) excess of this cancer was found both in early and later periods. Although females had a slight excess of bone cancer, males had the most cases, and a larger number of cases in the later period than earlier. In total, there were eight cases of bone cancer, and 0.7 cases were expected.

The lower range of whole-body radiation associated with fallout symptoms is about 50 rad, and the subgroup of 134 men and 105 women with a history of fallout effects probably had much larger doses of radiation than did the rest. That this is true is supported by the high age-adjusted incidence of cancer found for this group. In general, this group has excess numbers of cancer in the classes found to be in excess for the group as a whole, but proportionately greater.

Comparison of the ratio of cases of cancer known to be in excess for the survivors of Hiroshima and Nagasaki with all other classes of cancer can help to confirm that the excess incidence of cancer in a population exposed to radiation is actually related to this exposure.[18] In this investigation, this comparison provides assurance that the excess incidence of cancer is actually caused by the exposures to radioactive fallout. No other explanations for these effects were discovered in the investigation, ie, smoking, occupational history, or industrial point sources of carcinogens.

The temporal trend of excess incidence of cancer seems to be consistent with the experience of the Japanese survivors, considering that the exposures to the southwestern Utah group began six years later and were sustained during a 12-year period and, to a lesser extent, during a subsequent 18-year period. The Japanese survivors have had a sudden acceleration of the increase in the cancer death rate, by about 2.4 times in the period 1972 to 1976.[2] It seems probable that the largest increment of cancer in Utah is yet to come. Additional study periods (ie, 1981 through 1990, 1991 through 2000, and 2001 through 2010) are necessary to evaluate this later phase of cancer induction. A survey of chromosomal aberration rates in persons who experienced fallout symptoms may be useful, and an evaluation of effects on reproduction during and after fallout exposures is needed. There is a need for more basic scientific research into the molecular, cellular, and developmental effects of

the multitude of radioisotopes to which people have been exposed.

The Nuclear Regulatory Commission's memorandum on casualties expected from worldwide fallout should lead us to anticipate greater effects in local populations exposed to much higher concentrations of radionuclides from fallout in the environment. Mormon populations in southwestern Utah and adjacent parts of Arizona and Nevada have certain statistical advantages for such investigations, because the cancer incidence data there may be compared with that for all Mormons in Utah, permitting comparisons of cancer incidence free from some of the variables that must be dealt with elsewhere. Allowance should be made for cancer induced by fallout for all Utah Mormons (although less than in southwestern Utah). A burden of radiation-induced cancer throughout the state can be expected, because an excess of childhood leukemia has been reported for the entire state, and this observation is an early warning of other classes of radiation-induced cancer to appear later.

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