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Cancer Mortality Among Uranium Mill Workers

Victor E. Archer, M.D.; Joseph K. Wagoner, S.D. Hyg.; and Frank E. Lundin, Jr., M.D., Ph.D.

The health of uranium workers has been of concern to health officials since 1950. In that year, the US Public Health Service in cooperation with other federal and state agencies and the uranium industry, initiated a long range program designed to detect and control the hazards to health of uranium workers.[1,2]

Reports from a central European uranium mining area had indicated a high rate of malignant pulmonary disease among miners[3] and among mill workers.[4] Since the causative agent of the disease was not definitely known at that time, the initial efforts of the US Public Health Service included examination of both uranium mill workers and miners. Attention later became focused on radon daughters as the principal radiation problem among uranium workers.[5] Since the radon daughter problem was limited to mines, little attention was given to the health of mill workers. Publications from these Public Health Service studies have dealt primarily with the uranium miners examined. Recent reports suggest that the retention patterns of uranium and thorium-230 from uranium ore may present a radiation hazard to uranium mill workers.[6,7] This report deals with the mortality experience of the limited number of uranium mill workers who were examined between 1950 and 1953 as part of the initial uranium worker studies.

From the Division of Field Studies and Clinical Investigations, National Institute for Occupational Safety and Health, Dept. of Health, Education and Welfare, Salt Lake City (Dr. Archer) and Cincinnati (Dr. Wagoner). Dr. Lundin is from the Epidemiology Branch, National Institute of Child Health and Human Development, Bethesda, Md.

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Methods

Medical examinations conducted on uranium workers in 1950, 1951, and 1953, included 715 examinations of men who were working in one of six different uranium mills at the time of examination. After eliminating duplicate examinations and examinations of men who were not working in a mill at the time of first examination, there were 662 men in the Study Group. These men gave the interviewer their occupational, medical, and social histories. The examination consisted mainly of a physical examination, chest films, and blood and urine analyses. All examined men were white.

From the time he was first examined, each man became a member of a Study Group in which every cause of death was recorded. Death information was obtained from a number of sources: the Social Security Administration, mail questionnaires, newspapers, employment, vital statistics and credit bureaus, and the Veterans Administration. The program was so effective that less than 1% of the Study Group was lost to observation.[2] Those men not located were considered to be alive so that the mortality would not be overstated.

A modified life table technique was used to obtain person-years of observation by five-year age group and calendar year. Death certificates were obtained for men who died prior to December 31, 1967, the end point for this analysis. The underlying cause of death was coded in the 6th revision of the International Lists of Causes of Death by a trained nosologist so that comparisons with published vital statistics could properly be made. Comparisons with the white male population of the Colorado Plateau states (Colorado, Utah, New Mexico, and Arizona) were made since the uranium mills were located in those states. The observed number of deaths was noted in relation to an expected number calculated from age, race, and cause-specific rates for each calendar year and from the number of person-years for which the mill workers were under observation at the same age and calendar years.

Results

During the period 1950 through 1967, a total of 104 deaths were observed among the mill workers, which was nearly the same as the 105.11 that would be expected if rates for the white male population of the area had prevailed (Table 1). Although the overall mortality was the same as expected, there were two "observed vs expected" items in Table 1 that appear to show significant differences. One item, the difference in "all other causes," is thought to have little meaning since the deficit of ten deaths was widely distributed throughout a large group of miscellaneous causes of death.

However, the excess deaths due to malignant diseases of the lymphatic and hematopoietic tissue other than leukemia *does* appear to be meaningful,

Table 1. — Observed and Expected Deaths According to Cause Among Uranium Mill Workers, 1950-1967.

Cause of Death	List No.*	Observed	Expected	SMR
Tuberculosis all forms	001-019	—	1.86	—
Respiratory	001-008	—	1.80	—
Other	010-019	—	.06	—
Malignant neoplasms including lymphatic and hematopoietic tissue	140-205	20	18.11	110
Digestive system	150-159	4	5.06	79
Respiratory system	160-164	4	4.26	94
Leukemia and aleukemia	204	1	0.79	127
Lymphatic and hematopoietic tissue other than leukemia	200-203, 205	4	1.02	392†
Other and unspecified	140-148, 165-170, 177-181, 190-199	7	6.98	100
Major cardiovascular-renal disease	330-334, 400-468, 592-594	52	47.72	109
Heart disease	400-443	42	38.57	109
Other cardiovascular-renal disease	330-334, 444-468, 592-594	10	9.15	109
Violent deaths	800-985	20	15.00	133
All other causes	Residual	12	22.42	54†
Total		104	105.11	99

* 6th Revision of International Lists
† Significant at p 0.05.

Table 2. — Data on Uranium Mill Workers who Died of Malignant Disease of Lymphatic and Hematopoietic Tissue Other Than Leukemia.

Case	Year of Birth	Year of Death	Diagnosis	Occupational Information
1	1913	1963	Giant follicular lymphoma	1941-50 Truck driver. 1950-63 Uranium mill.
(He worked throughout the mill as a laborer and maintenance mechanic most of the time, but he worked for about 2 months as acid leach operator and for 2 months as disc filter operator.)				
2	1909	1956	Multiple myeloma	1932-48 Coal miner. 1948-49 Worked in oil shale plant. 1949-55 Uranium mill.
(He worked in the mill as ore crusher for 6 months, and for the rest of the time as operator in the filter, acid leach, and digestion areas.)				
3	1898	1958	Lymphosarcoma	1918-36 Electrician, truck driver, appliance repair. 1936-48 Gold miner. 1948-50 Uranium mill. 1950-53 Electrician in construction work. 1954-57 Uranium mining.
(He worked in all parts of the mill as an electrician).				
4	1928	1954	Lymphosarcoma	1943-44 Uranium mill. 1944-50 School, mechanic, baker. 1950-54 Uranium mill.
(He worked in the mill as swamper, sandscreener, truck weigher, mechanic and as operator of the acid scrubber.)				

even though the numbers involved are small. Detailed information on the lymphoma and hematoporetic deaths other than leukemia are given in Table 2. It may be significant that all of these men either worked with the raw ore or worked throughout the plant. None of them worked in the "product end" or near the fusion furnaces where exposure to concentrated uranium dust or fume was greatest. In addition, the mill work for all these men was of relatively short duration (2 to 13 years). All of them, however, had exposure during the 1943 to 1953 period when industrial hygiene practices at the mills were minimal.[1]

Discussion

The excess of malignant disease of the lymphatic and hematopoietic tissue (mostly lymphomas) suggests that some agent present in uranium mills may have been responsible. Constituents of the ore which are suspect and which were known to be present in appreciable amounts in aerosol form in the uranium mills are vanadium and long-lived members of the uranium radioactive decay series: uranium-238, uranium-234, thorium-230, radium-228, and lead-210.

Vanadium is known to be toxic at high exposure levels, and uranium mill workers in the fusion furnace area have been observed to have symptoms of vanadium overexposure.[1] However, none of the men listed in Table 2 worked in the furnace area. Vanadium therefore appears to be removed from suspicion as a cause of the excess lymphomas.

Radiation has been implicated as a cause of malignant lymphomas.[8 9] Since the radioactive elements in uranium ore are usually found to be near secular equilibrium, long-lived components might present a radiation hazard if they tended to accumulate in any tissue.

After inhalation, the concentration of uranium and thorium is greater in pulmonary tissue and adjacent lymph nodes than in other organs, in both man and animals.[5 7 10-13] Bone tends to be the principal storage depot for radium and lead.[10 14 15] Tracheobronchial lymph nodes, however, tend to be the site of greatest concentration for inhaled uranium and thorium,[6 7 16-18] although some quantity is translocated to and stored in bone and other organs. In hamsters and dogs, after prolonged exposure

to uranium ore dust, the radioactivity due to the thorium content of tracheobronchial lymph nodes was found to be up to 20 and 50 times greater than that due to uranium-234 or uranium-238.[7 17 18] This means that even though uranium-234, uranium-238, and thorium-230 are inhaled in nearly equal curie amounts as ore dust, that after prolonged exposure, the concentration of thorium-230 would be considerably greater than that of uranium in tracheobronchial lymph nodes. Under this animal model, and noting that both uranium and thorium isotopes emit alpha particles of comparable energy, we should expect the radiation dose to tracheobronchial lymph nodes of uranium mill workers to be much greater from thorium-230 than from the other radioisotopes present in the ore.

It is impossible to quantitate the thorium-230 exposure of the five men listed in Table 2, let alone for all the mill workers in the Study Group. However, a rough estimate can be made. Urine was collected between 1950 and 1953 and was analyzed for uranium on 249 of the examined mill workers (private communication from D.E. Rushing, 1953). The uranium concentration in these samples is indicated in Table 3. These urine concentrations of uranium averaged about 8 μg/liter. There were 59 air measurements made in two of the uranium mills between August 1951 and August 1953 (private communication from D.A. Holaday and D.E. Rushing, 1953). These values ranged from 8 to 5100 μg/cu m, with a median of 110 and an average of 1351. The median is equivalent to about 7.2×10^{-11} microcuries/cc of air. This value divided by the urine concentration gives a ratio of about 9×10^{-12}. This is similar to the median ratio of 4 or 5×10^{-13} for these two values which has been calculated from later data[19] in uranium mills (personal communication from R.G. Beverly, July 1972, in which urine data and weighted job exposures from 1960 and 1961 in one uranium mill are summarized). A considerably different value (about 1×10^{15}) for the air: urine ratio appears to hold for uranium refinery workers.[20-22]

Assuming equilibrium, ^{230}Th activity in ore dust would be about half that of uranium (because of two uranium isotopes in the chain) or about 3.6×10^{-11} microcuries/cc of air for the median exposures. This may be compared to the maximum permissible concentration of 4×10^{12} microcuries/cc recommended by the International Commission on Radiological Protection (ICRP).[23]

There have been reports that increased intake of vanadium results in lowered cholesterol blood levels.[24-26] Such an effect might be expected to result in a decreased mortality from cardiovascular disease. There is no evidence of such an effect among the mill workers studied here. Because of some deposition and retention of uranium and thorium compounds in liver, lungs, kidneys, and bone, it is noteworthy that no excess malignant disease of these organs was observed.

If exposure to ^{230}Th concentrations on the order of 5×10^{11} microcuries/cc of air are indeed responsible for the excess lymphomas observed in the study of this small group of uranium mill workers, then there would appear to be little safety factor in the ICRP standard, and the warnings of Leach,[6] Duggan,[27] and Stuart[7] regarding the potential radiation hazard of natural thorium and ^{230}Th may be valid. Some of these warnings were directed at uranium also, but the concentrations of uranium in lymph nodes of autopsied uranium workers fail to reflect the degree of hazard anticipated,[12 28] whereas autopsy of Thorotrast patients appears to support the animal data.[16]

An enlarged study of uranium mill workers is being undertaken to confirm or reject the tentative finding of excess lymphomas reported above.

Table 3. — Frequency distribution of uranium concentrations in the urine of uranium mill workers, 1950-1953.*

Uranium Concentration μg/liter	No. of Samples	%	Cum. %
0- 1.5	32	12.9	12.9
1.6- 3.0	48	19.3	32.2
3.1- 4.5	47	18.9	51.1
4.6- 6.0	31	12.4	63.5
6.1- 9.0	38	15.3	78.8
9.1- 15.0	31	12.4	91.2
15.1- 30.0	15	6.0	97.2
30.1- 60.0	3	1.2	98.4
60.1-100.0	2	0.8	99.2
100.1-160.0	2	0.8	100.0
	249	100.0	

* Average Uranium Concentration: 8.2 μg/liter.

Summary

Mortality from all causes was determined for a small group of uranium mill workers. The only specific cause of death which demonstrated a significant excess was malignant disease of the lymphatic and hematopoietic tissue. Data from animal experiments suggests that this excess may have resulted from irradiation of lymph nodes by thorium-230.

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Progress — Too often, progress has been equated with mere growth, change, or exploitation rather than with a real improvement in the per capita quality of life. Thus a new smokestack has usually passed as progress, and the odors generated by new factories have been said to "smell like money." But getting rid of the stacks already in town may now be a more rational view of progress. Developing a smokeless process, a product that lasts longer, or a process that requires less expenditure of human energy, or something that makes life more meaningful — all these may better qualify as progress. — Wagar, JA: Growth versus the quality of life, *Science* **168**:1179-1184 (June 5) 1970
