Mortality Among Uranium Enrichment Workers

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16. Abstract (Limit: 200 words)

A retrospective cohort mortality study was conducted on workers at the Portsmouth Uranium Enrichment facility (SIC-1094) in Pike County, Ohio, in response to a request from the Oil, Chemical and Atomic Workers International Local 3-689 for information on long term health effects. Primary hazards included inhalation exposure to uranyl-fluoride (13536840) containing uranium-235 (15117961) and uranium-234 (13966295), technetium-99 (14133767) compounds, and hydrogen-fluoride (7664393). Uranium-238 (7440611) presented a nephrotoxic hazard. Analysis covered the period from September 1, 1954, to December 31, 1982. White males working for at least 1 week during this time were included (total 5,773). Statistically significant mortality deficits based on U.S. death rates were found for all causes, accidents, violence, and diseases of nervous, circulatory, respiratory, and digestive systems. Standardized mortality rates were 85 and 54 for all malignant neoplasms and for other genitourinary diseases, respectively. Deaths from stomach cancer and lymphatic/hematopoietic cancers were insignificantly increased. A subcohort selected for greatest potential uranium exposure had reduced deaths from these malignancies. Insignificantly increased stomach cancer mortality was found after 15 years employment and after 15 years latency. Routine urinalysis data suggested low internal uranium exposures. The authors conclude that there is no significant excess mortality among these workers.

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ABSTRACT

To evaluate the mortality experience of workers from an uranium enrichment facility, a retrospective cohort mortality study was conducted. The facility is one of three Government owned enrichment plants that uses the gaseous diffusion process and is the only plant that enriches uranium (present as gaseous uranium hexafluoride) up to 98% U-235. The study was conducted primarily to assess the risk of cancer mortality associated with exposure to uranium compounds at the plant. Uranyl fluoride, primarily an alpha emitter and very soluble, is the most prevalent uranium compound of interest. The uranyl fluoride is formed when uranium hexafluoride comes into contact with water vapor present in the air.

The study population included white male workers employed for at least one week between September, 1954 (beginning of plant operations) and February, 1982. There was a total of 5,773 workers who qualified for the analysis. Based on a comparison with U.S. mortality rates, the analysis for all causes of death combined indicates a strong healthy worker effect - 483 observed vs. 713 expected deaths, SMR = 68; $p < 0.05$. Mortality for all malignant neoplasms was also less than expected (125 observed vs. 146.2 expected deaths, SMR = 85). Only the number of deaths due to cancer of the stomach (10 observed vs. 5.9 expected, SMR = 169) and cancer of the lymphatic and hematopoietic system (23 observed vs. 15.8 expected, SMR = 146) were greater than expected. However, these SMRs were not significantly different from 100. The risk for lymphatic and hematopoietic cancer was not associated with

either duration of employment or latency. The risk for stomach cancer increased after 15 years of employment and 15 years after first employment at the facility. The findings were similar when Ohio state mortality rates were used to calculate the expected deaths. Based on urinalysis data (for uranium content), two subcohorts of workers with a relatively greater potential for exposure to uranium compounds were identified. The mortality analysis of these workers yielded results similar to those of the total cohort, except stomach cancer had a lower risk in the subcohort assumed to have the greatest potential for exposure to uranium compounds.

INTRODUCTION

Uranium as found in nature consists of two principal isotopes, U-238 and U-235. Natural uranium contains 0.71 percent U-235, by weight. Because of the fissionable characteristics of U-235, it is desirable to increase the concentration of the U-235 isotope contained in natural uranium with a corresponding depletion of the concentration of the U-238 isotope. This process is known as uranium enrichment. The Portsmouth Uranium Enrichment plant is one of three Government owned facilities in the United States that enriches uranium using the gaseous diffusion process and is the only facility that enriches up to 97.65% U-235. As the enrichment of U-235 increases there is a corresponding enrichment of U-234. It is this latter isotope that is the major contributor of alpha radiation at the plant, although other uranium isotopes also are alpha emitters to some degree. The enriched uranium is used in producing fuel for light water reactors in nuclear power plants, for high temperature gas-cooled reactors in nuclear submarines, and for nuclear weapons.

In 1979, the Oil, Chemical and Atomic Workers, International (OCAW) Local 3-689, which is the primary labor union at the plant, requested that NIOSH conduct an evaluation to determine whether or not there had been any long term health effects to workers from exposures at the uranium enrichment facility. To address this request, a retrospective cohort mortality study was conducted. An industrial hygiene/health physics evaluation was also conducted to determine potential exposures to chemical and physical agents. This report will focus primarily on the results of the mortality study.

DESCRIPTION OF FACILITY AND PROCESS:

The plant site, located in Pike County, Ohio, covers approximately 4,000 acres. The production process began operation in September, 1954. In 1981, the facility employed approximately 3,000 workers, 1,500 hourly, and 1,500 salaried. All employees must receive a security clearance ("Q" clearance) from the Department of Energy before they can actually work at the facility.

The enrichment process system, known as the "cascade", is housed in three large process buildings which are identified as -326, -330, and -333. The ancillary process systems serving the cascade include a primary cooling system, recirculatory water cooling system, sanitary water system, steam plant, dry air plant, nitrogen manufacturing facility and a sewage system. Major support functions for the cascade process include maintenance and refurbishment of process components (building 720), decontamination of process components (building 705), cleaning of components (building 700), assembly of converters (building 700), vaporization of uranium hexafluoride (building 342), and the weighing and sampling of process product (building 344). Other service functions include the laboratory (building 710), dispensary (building 101), and cafeteria (building 102).

The gaseous diffusion process used at the plant is based on Graham's law which states "the relative rates of diffusion of gases under the same conditions are inversely proportional to the square roots of the densities of those gases." Therefore, the lighter isotope, U-235, will have a diffusion velocity (through a porous membrane) slightly greater than that of the heavier isotope, U-238. It is this difference in diffusion velocity that allows the process to separate the isotopes.

During the process, the uranium is in the form of uranium hexafluoride (UF_6). The UF_6 is a solid at room temperature, but is maintained as a gas during the enrichment process by keeping the enclosed system under specific temperature and pressure conditions. Since UF_6 is highly reactive with water, forming HF, it is extremely corrosive to most metals. Therefore, materials used in the construction of the process system and its ancillary components consist primarily of nickel, Monel (copper/nickel alloy) and aluminum. The process system is made up of a multi-stage series of separation cells. Collectively, this entire series of stages and cells is called a cascade. At each stage, the UF_6 passes through a porous diffusion membrane where the uranium 235 and 238 isotopes of UF_6 undergo a small amount of separation. Because the amount of separation at each stage is very small, a large number of stages is required to achieve enrichment. The enriched product can be removed at several stages within the cascade depending on the enrichment required for the intended use. Because of the large amount of electricity needed to power the process, two power plants, located offsite, are dedicated specifically to the gaseous diffusion plant.

Potential Exposures and Biological Monitoring Program

In the enrichment process and related support operations at the plant, the inhalation of soluble uranium compounds is considered to be the primary exposure of interest. The primary compounds of concern are uranyl fluoride (UO_2F_2) ranging in assay from depleted (less than 0.7% of U-235) to fully enriched (greater than 95% U-235) and technetium-99 compounds (in the form of pertechnate-like compounds). As the enrichment increases, the radiological activity increases. This increase in activity is primarily a function of an increase in the concentration of U-234. The UO_2F_2 is formed along with HF, an acute pulmonary hazard, when UF_6 comes into contact with air and reacts with water vapor. Technetium-99 compounds are present as an impurity due to past enrichment of UF_6 received from production facilities producing UF_6 from reprocessed nuclear fuels. Soluable uranium/uranyl flouride is chemically, as well as radiologically active. Below 5% U-235, the chemical toxicity to the kidneys rather than the radiological hazard is a more significant health hazard. To monitor the amount of worker exposure to soluble uranium and technetium-99 compounds, the company has had a urinary bioassay program since the plant opened in 1954.

Individuals, who work in certain departments or areas of the plant where the company has determined there is potential exposure to uranium and/or technetium compounds, submit routine urine samples once a month. These individuals are automatically scheduled for the urinalysis on the last workday of the week closest to a one-month interval. In addition to routine monitoring, special monitoring in the event of a suspected uptake as well as special monitoring of known exposures, such as accidents, is undertaken. In addition, any employee has the option of requesting an urinalysis at any time.

The company provided NIOSH researchers with a computer data tape containing all of the individual recordings from the urinalysis program. Each record in the data set included the date of the urinalysis, the worker's name, badge number, department and the results (amount of uranium by weight and alpha activity, amount of technetium by activity, and amounts of fluoride, mercury, lead, chromium, nickel, zinc, and cadmium, by weight). Unfortunately, since the urinalyses were only performed monthly on certain individuals, and since most soluble forms of uranium are excreted within several days, the urine uranium data were judged to be inadequate in assigning specific radiation or uranium exposure levels to individuals. Therefore, the urine uranium data were only used to identify the departments where workers had potential exposure to soluble uranium compounds, and to rank these departments by relative degree of potential exposure to these compounds.

The urinalysis data file included approximately 134,000 records spread over 142 departments. Approximately 94% of the reported values for uranium in the data file were zero, or below detectable levels, 5.1% ranged from 10 μg -50 μg/l, and 0.6% ranged from 50 μg - 200 μg/l.

In addition to the urinalysis monitoring program, the company has maintained several other programs for monitoring radiation. These include, 1) continuous air sampling, 2) personal sampling of external radiation by use of film badges/dosimeters, 3) in vivo counting when necessary. Although some of this data was used in the companion industrial hygiene/health physics study, the data was not considered to be useful in the epidemiologic analysis. For more information on these programs the reader is referred to the industrial hygiene/health physics report.

Because of the nature and complexity of the enrichment system, the plant maintains a workforce that performs a variety of activities that are potentially associated with multiple occupational exposures. The specific type of exposure depends on the job and/or the area (building) of the facility in which the worker is assigned. Briefly, the potential exposures (chemical and physical) by area are as follow:

1. Cascade Process (including maintenance of process) -
inorganic fluorides, uranium compounds, chlorinated solvents, Freon 114, PCBs (from contaminated oil), technetium, asbestos, welding fumes, nickel fumes, heat stress, noise, and electric fields.

2. Decontamination -
uranium compounds, technetium compounds, PCBs (from contaminated oil), inorganic fluorides, nitric acid, citric acid, chlorinated solvents, Freon 114, sodium hydroxide, ammonium and sodium carbonate, noise.

3. Feed Vaporization and Uranium Materials Handling -
uranium compounds, technetium compounds, chlorinated solvents, Freon 114, fluorine, hydrofluoric acid, inorganic fluorides, noise, heat.

4. Maintenance -
uranium compounds, technetium compounds, chlorinated solvents, Freon 114, metal dusts and fumes (including nickel fumes), welding fumes, inorganic fluoride, noise.

5. Chemical Cleaning -

chromic acid, trichloroethylene, boric acid, sodium hydroxide, nitric acid, welding fumes, acetylacetone, heptane, silica (sand blasting), noise.

METHODS:

A retrospective cohort mortality analysis was used in this study to estimate the risk of cause specific mortality among the workforce. There were no well established *a priori* hypotheses in this study, however; there was concern that exposure to uranium compounds might be related to an increase in cancer mortality. The types of cancer that might be associated with exposure to the uranium compounds based on radiotoxicity include bone cancer, some types of lymphatic/hematopoietic cancers and lung cancer. Because of the solubility of these compounds and their excretion through the kidneys nephrotoxic effects were of concern,[1,2] and because of the corrosive properties of UF_6, non-malignant respiratory disease were also of concern.

Study Population:

Company personnel records were used to identify all workers from the facility. Included in the records were data to identify each worker (name, SSN, badge number, date of birth, etc.) and to document his/her work history at the enrichment facility (by date employed in specified departments). A computer file (masterfile) of this information was generated by the company. A verification of the completeness of this file was conducted by comparing the badge number for each record in the masterfile with the list of badge numbers assigned by the company. If a record for an assigned badge number was missing, the company located all the appropriate records and they were added to the masterfile.

The work history at the enrichment facility for each worker was also included on the computer file. Calendar time spent in specified departments was recorded based on the company personnel records. There were two complications involved in documenting an individual's work history. First, the three digit codes for many of the departments have changed since the company began operation in 1954 because of changes in the personnel system or reorganizations of the departments. A history of these changes was obtained from the plant and used to standardize the work history codes in the masterfile, yielding a unique number for each department. Certain departments underwent more complicated changes than others, although some of the most important departments in terms of potential exposures, (e.g., process area and decontamination) have experienced few changes in department numbers.

The second complication regarding work history, is the lack of specificity provided by certain department numbers. The department numbers are usually synonymous with a task (maintenance) or with an activity (decontamination), but, on occasion, workers in the same department may be assigned to different locations or buildings at the facility, where exposures may be vastly different. Therefore, for certain department numbers it is difficult to determine the specific exposures. Alternatively, the departments may be synonymous with a worker's job and location in a specific building, and a more accurate description of exposure can be ascertained for the worker.

Since it was unlikely that workers employed for less than one week actually worked at the enrichment facility, it was decided to exclude these individuals from the mortality analysis. Workers who left employment prior to September 1, 1954 were also excluded, because the process did not become operational until this time. In addition, because non-whites and females made up only nine percent of the overall mortality among the workforce, they were also excluded from the analysis.

Within this cohort, there was further selection in an attempt to estimate the risk of mortality among subcohorts of workers who may have had a greater potential for exposure to uranium compounds. Based on the urinalysis data two subcohorts were identified. Subcohort I was defined as, all workers included in the total study cohort ever employed in a department in which a total of one hundred or more uranium urinalyses had been conducted. Fifty-seven departments met this criterion. This subcohort represents workers employed in departments with potential exposure, as perceived by the company and/or workers, to uranium compounds.

Second, the 57 departments were ranked based on the percentage of uranium urinalysis values that exceeded a selected criterion. The criterion chosen was 50 µg/l, which represents an "investigative level" established by the company. Subcohort II was then defined as all workers in the study cohort ever employed in a department that was ranked in the top 50-percentile of the 57 departments. It was believed that this subcohort represents workers with the greatest potential for exposure to soluble uranium compounds. The departments included in the two subcohorts are given in Appendix A. A more detailed description of the urinalysis data evaluation and the procedure for ranking the departments by potential uranium exposure is given in Appendix B.

Retrospective Cohort Mortality Analysis:

The vital status (alive or dead) for approximately 90% of the cohort, was ascertained as of December 31, 1982. The remaining 10% were ascertained as of December 31, 1979. This was accomplished by searching the records maintained by the Social Security Administration, the Internal Revenue Service, the U.S. Post Office, the Ohio Bureau of Motor Vehicles, and company records. For those identified as being deceased, copies of their death certificates were obtained from the state vital statistics offices, and the underlying cause of death was coded by a trained nosologist according to the Revision of the International Classification of Diseases, in effect at the time of death. Those who died subsequent to the closing date of the study, i.e., December 31, 1982, were considered alive for purposes of analysis.

For the analysis of the full cohort, person-years-at-risk (PYAR) of dying began accumulating for each worker after the individual had worked for at least one week at the facility, after September 1, 1954. Accumulation of PYARs stopped at the date of death, the date last observed alive, or the closing date of the study, whichever occurred first. For the analysis of subcohorts I & II the PYARs did not begin to accumulate until the individual began working in one of the departments included in the definition of the subcohort. Using the NIOSH Life Table Analysis System (LTAS)[3], the PYARs for each worker were stratified by 5-year calendar time periods and 5-year age groups. Additionally PYARs were stratified by length of employment and by time since first employment (latency). For stratification of PYARs by length of employment and time since first employment in the subcohorts, all work history in departments other than those included in the definition of the subcohorts was ignored.

The PYARs stratified into age and calendar time periods were multiplied by the corresponding U.S. white/male cause specific mortality rates to yield expected number of deaths. Similarly, the expected numbers of deaths based on the Ohio mortality rates also were calculated.*

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* At the time of this study, the LTAS only maintained U.S. mortality rates through 1978, the end of the eighth revision of the ICD. To calculate expected deaths through 1982 the death rates for the time interval 1975-1979 were based on U.S. deaths occurring through 1978 and the death rates for the interval 1980-82 were assumed to be identical to the previous time period (1975-79). Since the comparison rates did not include deaths occurring in the ninth revision of the ICD, deaths observed in the study population after 1978 were also assigned codes according to the rules of the eighth revision of the ICD. Ohio death rates were used to calculate expected deaths due to cancer only. These rates are based on data through 1979, and the death rates for cancer during 1980-82 were assumed to be identical to the previous time period.

The observed and expected cause-specific deaths were compared and differences were tested assuming the Poisson distribution.[4] The risk is reported as a standardized mortality ratio (SMR), defined as observed/expected x 100.

There were no well established hypotheses in this study, therefore numerous causes of death were examined. The life table analysis program used, calculates the observed and expected deaths for 89 cause specific death categories. This multiple comparison approach may reveal some causes of death which have elevated risks due to chance alone.

RESULTS:

There had been a total of 7,917 workers employed at the enrichment facility at the time of data collection (February, 1982). Although not all workers were included in the analysis, the vital status of this total population was ascertained and the results are given in Table 1. The vast majority (91%) of deaths occurred among white males. Among white males 559 individuals were excluded from the study: those who did not work one week (N = 293); those who had inadequate documentation of work histories (N = 136); or those who experienced all their work prior to September 1, 1954 (N = 130), yielding a total of 5,773 workers included in the overall analysis. Among the 559 individuals excluded from the analysis there were 39 deaths, 20 of which were due to heart disease, and 14 from cancer. Among the cancer deaths 7 were due to respiratory system cancer and 3 were due to lymphatic/hematopoietic system cancer.

The results of the vital status ascertainment among the study cohort included in the analysis is given in Table 2. There were 4,876 workers who qualified for subcohort I and 3,545 who qualified for subcohort II. The vital status ascertainment for each of these subcohorts is also given in Table 2. A distribution of PYARs by age (Table 3) indicates that the cohort is relatively young; only 13 percent of the person-years are contributed by individuals age 55 years or more.

The distribution of workers by length of employment and by year first employed at the enrichment facility for the total study cohort included in the analysis is given in Table 4 and 5, respectively. Over fifty percent of the cohort had less than five years of total employment at the facility, and twelve percent had less than 1 year of employment. Forty percent of the workers in the cohort were first employed prior to 1955, during the year in which the process began. During subsequent 5 year time periods there was a fairly constant number of new workers hired (between 15-25% of cohort).

The results of the mortality analysis for all major causes of death among the total cohort are given in Table 6. These results are based on using U.S. death rates to calculate the expected numbers of death. There is a statistically significant deficit in mortality from all causes combined (483 observed vs. 712.8 expected, SMR = 68; CI = 62-74). This is primarily due to the statistically significant deficits in mortality from diseases of the nervous system, which includes stroke (13 observed vs. 32.7 expected, SMR = 40); diseases of the circulatory system (206 observed vs. 287.7 expected, SMR = 72); diseases if the respiratory system (14 observed vs. 33.5 expected, SMR = 42); diseases of the digestive system (18 observed vs. 33.2 expected, SMR = 54); accidents (35 observed vs. 75.2 expected, SMR = 46); and violence (13 observed vs. 36.0 expected, SMR = 36). A deficit in mortality due to non-malignant diseases of the genital-urinary system, an end point of interest, was observed (3 observed vs. 5.6 expected; SMR = 54). A deficit in mortality from all malignant neoplasms combined was also observed (125 observed vs. 146.2 expected, SMR = 85).

Table 7 gives the mortality for the total cohort by specific cancer site. The observed deaths were higher than expected for stomach cancer (10 observed vs. 5.9 expected, SMR = 169) and for all types of lymphatic/hematopoietic cancers combined (23 observed vs. 15.8 expected, SMR = 146). Neither of these SMRs was statistically significant. Each of the SMRs for the individual cause of death categories that made up the larger category lymphatic/hematopoietic cancer was slightly greater but not significantly different from 100. There was only one death from bone cancer (0.8 deaths expected). Expected deaths based on Ohio rates did not appreciably change the SMRs.

The mortality results for subcohort I are given in Tables 8 and 9. The pattern of mortality is very similar to the total cohort. The mortality results for subcohort II are given in Tables 10 and 11. Again, the mortality from all the major causes was similar to the total cohort. However, in this subcohort fewer than expected number of deaths due to stomach cancer were observed (3 observed vs. 3.6 expected, SMR = 83) and the SMR for lymphatic/hematopoietic cancers was slightly lower (12 observed vs. 9.6 expected, SMR = 125), than for the total cohort.

Cancer mortality by time since first employment at the facility or since first employment in departments included in the definition of the subcohorts (latency) is given in Table 12. There appears to be no pattern of increasing risk with an increase in the time since first employment among the total cohort or the subcohorts. Examination of cancer mortality by duration of employment revealed no increase in risk with increasing duration of employment (Table 13), which is a surrogate measure for exposure potential.

Lymphatic/hematopoietic cancer mortality for the total cohort was examined by length of employment (Table 14) and latency (Table 15). No trends were noted. Stomach cancer among the total cohort was also examined by length of employment and latency. There is an apparent increase in risk after 15 years of employment (5 observed vs. 1.7 expected; SMR = 294) and after 15 years of latency (9 observed vs. 4.2 expected; SMR = 214). However, these increases are not statistically significant.

Additional information regarding each of the deaths due to lymphatic and hematopoietic cancer is given in Table 16. Four of these deaths were excluded from the analysis because they did not meet the definition of the study cohort; three had left employment prior to start-up of the enrichment process, and one was a female. It is interesting to note that 15 of the remaining 23 deaths that were included in the analysis began employment prior to 1955, which seems excessive for this time period. However, an analysis of the cohort of workers first employed prior to 1955 indicated that 11.1 deaths were expected, yielding a SMR of 134. This risk is similar to that for the entire cohort which is 146 (23 observed vs. 15.8 expected).

DISCUSSION:

The mortality analysis of workers at the uranium enrichment facility resulted in a dramatic healthy worker effect.[5] Among those in the total cohort, there was a statistically significant deficit in overall mortality. In addition, the risk for cancer mortality was less than expected. When subcohorts of workers with a greater potential for exposure to uranium compounds were examined overall mortality and mortality from cancer was well below that expected. Similar deficits in overall mortality have been observed in other Department of Energy facilities where uranium is enriched.[6,7] This pattern of low mortality may be due to selection of "healthy" workers, required physical demands of the job, and because of the health maintenance available at the facility. Furthermore, the facility is located in a rural area of Ohio where many of the workers operate small farms in addition to their work at the plant. Although this type of active lifestyle may provide for better overall health, employment as a farmer has also been linked to an increased risk of mortality due to hematopoietic cancers.[8-10]

Among the non-malignant diseases of interest in this study, there were no observed excesses in mortality. Mortality from diseases of the genital-urinary system was less than expected and there was a significant deficit in non-malignant respiratory disease.

Among the specific cancer sites, mortality from the lymphatic/hematopoietic cancers was higher than expected. However, the risk for these causes is less among the two subcohorts thought to have a greater potential for exposure to uranium compounds. When each of the specific subcategories of lymphatic/hematopietic cancer are examined separately, none show a significant excess in mortality. Mortality from stomach cancer is higher than expected in the total cohort but the risk is less than expected in the subcohort (subcohort II) which was assumed to have a greater potential for exposure than the total cohort.

When mortality from all cancer or from lymphatic/hematopoietic cancer was examined by latency and length of employment, no trends consistent with an occupational exposure were observed. The risk for stomach cancer increased 15 years after first employment at the facility and after 15 years of employment among those in the total cohort, however, this risk appears unrelated to exposure to soluble uranium since no excess was observed in subcohort II.

The analysis of this study population, which is primarily focused on examining long latent disease, is not particularly powerful (i.e., statistically) because of the relatively short observation period. The plant became operational in September, 1954, allowing for a maximum of 28 years of observation and latency. Actually, 40% of the cohort was first employed after January, 1965, yielding only a maximum of 17 years of latency for this segment of the cohort. Since occupationally related cancer risks normally do not become apparent until 20 or more years after first exposure, these relatively short time periods provide limited data to address the association between occupational exposure and most cancer risks. For some of the hematopoietic cancers these short time periods may be adequate for the manifestation of the disease.

In addition to the relatively short observation period in this study, there is some evidence that the internal dose to soluble radioactive uranium compounds has been relatively low. According to the urinalyses data, approximately 94% of the samples for uranium (by mass) were reported as zero, probably reflecting a non-detectable measurement (detection limit: 10 µg/l). Only 0.74% of the samples were over the company established "investigative level" of 50 µg/l and 0.11% were greater than the "restrictive level" of 200 µg/l. The analysis for alpha radiation activity in the urinalysis samples revealed similar results; only 2.1% were above the "investigative level" of 10 dpm/100 ml and 0.2% were above the "restrictive level" of 100 dpm/100 ml. As noted earlier, the reliance on the urinalysis data to predict exposure by department or by individuals is limited, given the frequency of sample collection and the short biological half-life of the UO_2F_2, which is soluble and most of which will be excreted within days[2]. Therefore, among individual workers a monthly urinalysis may indicate urine uranium content that does not reflect the amount associated with the actual uptake on a daily basis.

Conclusion

No statistically significant excess of mortality was identified in the total study cohort nor in the subcohorts with the greatest likelihood of uranium exposure. However, given the limited data (young cohort, relatively short time interval since first employment among the cohort, and short observation period) available for this analysis, no definitive conclusions regarding occupational exposure at the enrichment facility and subsequent mortality of the plant workers can be made. It is recommended that this study be updated in several years. This will allow for a more adequate interval of time for the manifestation of occupational disease, if any, and more deaths will increase the validity of the results. At that time, the mortality risks associated with cancers of the lymphatic/hematopoietic system and cancer of the stomach should be re-evaluated. If warranted, a nested case/control analysis should be considered to determine if certain exposures, jobs, or areas of the facility are associated with these cancer risks.

Table 1

Vital Status Ascertainment of All Workers
at the Uranium Enrichment Facility
Employed Anytime Through February, 1982

Vital Status	White Males	Non-white Males	White Females	Non-white Females	Total
Alive	5,764	317	1,035	121	7,237
Dead	522	16	33	0	571
Unknown	46	4	57	2	109
Total	6,332	337	1,125	123	7,917

Table 2

Vital Status of the Study Cohort and of Subcohorts I and II
Included in the Analysis of Uranium Enrichment Facility

Vital Status	Study Cohort	Subcohort I	Subcohort II
Alive	5,244	4,429	3,227
Dead	483	414	295
Unknown	46	33	23
Total	5,773	4,876	3,545
Person-years	107,698	87,896	65,027

Table 3

Distribution of Person-years At Risk of Dying (PYAR) by Age of All White Males Included in the Analysis of the Uranium Enrichment Facility

Age	PYAR	Percent	Cumulative Percent
15-19	413	0.4	0.4
20-24	5,538	5.0	5.4
25-29	12,189	11.3	16.7
30-34	15,254	14.2	30.9
35-39	16,341	15.2	46.1
40-44	16,710	15.5	61.6
45-49	15,431	14.3	75.9
50-54	11,897	11.0	86.9
55-59	7,448	6.9	93.8
60-65	3,951	3.7	97.5
65-70	1,719	1.6	99.1
70-74	613	0.6	99.7
75 +	193	0.2	99.9
TOTAL	107,697		

Table 4

Distribution by Length of Employment of White/Male Employees Included in the Analysis of the Uranium Enrichment Facility

Length of Employment	Frequency	Percentage
1 week - 1 year	682	12
1 - 5 years	2,317	40
> 5 - 10 years	1,324	23
> 10 - 20 years	414	7
> 20 years	1,036	18
Total	5,773	100

Table 5

Distribution by Year First Employed of White/Male Employees Included in the Analysis of the Uranium Enrichment Facility

Year First Employed	Frequency	Percentage
Before 1/1/55	2,398	41
1/1/55 - 12/31/64	1,092	19
1/1/65 - 12/31/74	848	15
After 12/31/74	1,435	25
Total	5,773	100

Table 6

Mortality of White/Male Workers
Included in the Analysis of the Uranium Enrichment Facility

Cause of Death (7th Revision ICD Codes)	Observed	Expected[1]	SMR	95% C.I. for SMR
All Malignant Neoplasms (MN) (140-205)	125	146.2	85	71 - 102
Diabetes Mellitus (260)	5	9.6	52	17 - 122
Diseases of the Nervous System (330-334, 345)	13	32.7	40*	21 - 68
Diseases of the Circulatory System (400-468)	206	287.7	72*	62 - 82
Diseases of the Respiratory System (470-527)	14	33.5	42*	23 - 70
Diseases of the Digestive System (540-543, 560-570, 581)	18	33.2	54*	32 - 86
Diseases of Genito-urinary System (590-594, 600, 602, 604, 610-637, 650-652)	3	5.6	54	11 - 156
Accidents (800-962)	35	75.2	46*	32 - 65
Violence (963-985)	13	36.0	36*	19 - 62
All Other Causes	51	53.1	96	---

All Causes	483	712.8	68*	62 - 74

* $p < 0.05$.

1 Expected deaths are based on U.S. death rates.

Table 7

Mortality From Malignant Neoplasms Among White/Male Workers Included in the Analysis of the Uranium Enrichment Facility

Cause of Death (7th Revision ICD Codes)	Observed	Expected U.S. Rates	Expected Ohio Rates [1]	SMR [2]	95% C.I. for SMR
All Malignant Neoplasms	125	146.2	154.6	85	71 - 102
Buccal Cavity and Pharynx (140-148)	4	5.0	5.2	80	22 - 205
Digestive Organs and Peitoneum (150-159)	30	36.6	38.3	82	55 - 117
Stomach (151)	10	5.9	5.9	169	81 - 310
Intestine exp. Rectum (152, 153)	10	12.2	12.9	82	39 - 151
Pancreas (157)	7	7.7	7.5	91	36 - 187
Other	3	10.8	12.0	28	----
Respiratory System (160-164)	48	54.6	59.3	88	65 - 117
Male Genital Organs (177-179)	1	6.4	6.6	16*	0.3 - 86
Urinary Organs (180, 181)	6	7.1	7.7	85	31 - 185
Other and Unspecified sites (190-199, 156B, 165)	13	20.7	20.5	63	34 - 109
Lymphatic and hematopoietic (200-205)	23	15.8	16.9	146	92 - 218
Lymphosarcoma and reticulosarcoma (200)	8	5.1	3.8	157	68 - 311
Hodgkin's disease (201)	4	2.6	2.8	154	43 - 401
Leukemia and Aleukemia (204)	8	6.1	6.3	129	56 - 256
Other	3	2.0	4.0	150	30 - 429

1 Expected death based on Ohio death rates.

2 SMR based on expected deaths calculated from U.S. death rates.

* $p < 0.05$.

Table 8

Mortality of White/Male Workers Included in Subcohort I.

Cause of Death (7th Revision ICD Codes)	Observed	Expected	SMR	95% C.I. for SMR
All Malignant Neoplasms (140-205)	107	123.5	87	71 - 105
Diabetes Mellitus (260)	5	8.1	62	20 - 145
Diseases of the Nervous System (330-334, 345)	12	27.3	44*	23 - 77
Diseases of the Circulatory System (400-468)	107	242.6	70*	60 - 81
Diseases of the Respiratory System (470-527)	13	28.1	46*	24 - 79
Diseases of the Digestive System (540-543, 560-570, 581)	16	28.0	57*	33 - 93
Diseases of Genito-urinary System (590-594, 600, 602, 604, 610-637, 650-652)	3	4.6	65	13 - 189
Accidents (800-962)	32	60.8	53*	36 - 74
Violence (963-985)	13	29.6	44*	23 - 75
All Other Causes	43	44.3	97	----

All Causes	414	596.9	69*	63 - 76

* $p < 0.05$.

Table 9

Mortality from Malignant Neoplasms
Among White/Male Workers Included in Subcohort I.

Cause of Death	Observed	Expected	SMR	95% C.I. for SMR
All Malignant Neoplasms	107	123.5	86	71 - 105
Buccal Cavity and Pharynx (140-148)	2	4.2	48	5 - 171
Digestive Organs & Peritoneum (150-159)	25	30.9	81	52 - 119
Stomach (151)	9	5.0	180	82 - 342
Intestine exp. Rectum (152, 153)	8	10.3	78	33 - 153
Pancreas (157)	6	6.5	92	33 - 200
Other	2	9.1	22	----
Respiratory System (160-164)	43	46.4	93	67 - 125
Male Genital Organs (177-179)	1	5.4	19	0.4 - 104
Urinary Organs (180, 181)	6	6.0	100	37 - 218
Other and Unspecified Sites (190-199, 156B, 165)	12	17.4	69	40 - 122
Lymphatic & Hematopoietic (200-205)	18	13.2	136	81 - 215
Lymphosarcoma and Reticulosarcoma (200)	7	4.3	163	66 - 338
Hodgkin's Disease (201)	4	2.1	191	52 - 490
Leukemia & Aleukemia (204)	6	5.1	118	43 - 255
Other	1	1.7	59	----

Table 10

Mortality of White/Males Workers Included in Subcohort II.

Cause of Death	Observed	Expected	SMR	95% C.I. for SMR
Malignant Neoplasms (140-205)	78	89.1	88	69 - 109
Diabetes Mellitus (260)	4	5.8	69	19 - 176
Diseases of the Nervous System (330-334, 345)	5	19.3	26*	8 - 61
Diseases of the Circulatory System (400-468)	118	174.2	68*	56 - 81
Diseases of the Respiratory System (470-527)	8	19.9	40*	17 - 79
Diseases of the Digestive System (540-543, 560-570, 581)	13	20.6	63	34 - 108
Diseases of Genito-urinary System (590-594, 600, 602, 604, 610-637, 650-652)	2	3.3	61	7 - 217
Accidents (800-962)	24	44.8	54*	34 - 80
Violence (963-985)	9	21.8	41*	19 - 78
All Other Causes	34	32.2	106	----

All Causes	295	431.0	68*	61 - 77

* $p < 0.05$.

Table 11

Mortality From Malignant Neoplasms Among White/Male Workers Included in Subcohort II.

Cause of Death	Observed	Expected	SMR	95% C.I. for SMR
All Malignant Neoplasms	78	89.1	88	69 - 109
Buccal Cavity and Pharynx (140-148)	1	3.1	32	0.8 - 182
Digestive Organs and Peitoneum (150-159)	15	22.1	68	38 - 112
Stomach (151)	3	3.6	83	17 - 246
Intestine exp. Rectum (152, 153)	5	7.4	68	22 - 158
Pancreas (157)	5	4.7	106	34 - 249
Other	2	6.4	31	----
Respiratory System (160-164)	35	33.6	104	73 - 145
Male Genital Organs (177-179)	1	3.7	27	0.7 - 150
Urinary Organs (180, 181)	5	4.3	116	38 - 273
Other and Unspecified sites (190-199, 156B, 165)	9	12.7	71	33 - 136
Lymphatic and Hematopoietic (200-205)	12	9.6	125	64 - 218
Lymphosarcoma and Reticulosarcoma (200)	4	3.1	129	35 - 329
Hodgkin's disease (201)	3	1.5	200	40 - 570
Leukemia and Aleukemia (204)	4	3.7	108	29 - 275
Other	1	1.2	83	2 - 447

Table 12

Mortality for All Malignant Neoplasms by
Latency Among White/Male Workers
Included in the Analysis of the Uranium Enrichment Facility.

Latency* (years)	Total Cohort SMR (O/E)**	Subcohort I SMR (O/E)	Subcohort II SMR (O/E)
< 5	125 (12/9.6)	94 (9/9.6)	90 (6/6.7)
5 - 10	66 (8/12.1)	69 (8/11.6)	95 (8/8.4)
10 - 15	108 (18/16.7)	105 (16/15.3)	99 (11/11.1)
15 - 20	60 (16/26.7)	63 (15/24.0)	40 (7/17.6)
20 - 25	91 (37/40.8)	92 (33/35.9)	111 (29/26.2)
> 25	84 (34/40.4)	96 (26/27.0)	89 (17/19.2)

* Latency is defined as time since first employment at the facility or first employment in departments included in defining subcohorts I and II.

**(O/E) = Observed/Expected deaths.

Table 13

Mortality for All Malignant Neoplasms by
Length of Employment Among White/Male Workers
Included in the Analysis of the Uranium Enrichment Facility

Length Employment[1] (years)	Total Cohort SMR (O/E)[2]	Subcohort I SMR (O/E)	Subcohort II SMR (O/E)
< 1	122 (18/14.8)	103 (14/13.6)	92 (10/10.9)
1 - 5	89 (35/39.3)	85 (32/37.5)	82 (23/28.2)
5 - 10	83 (28/33.7)	95 (29/30.6)	86 (21/24.3)
10 - 15	112 (15/13.4)	103 (13/12.6)	165 (13/7.9)
15 - 20	30 (4/13.5)	31 (4/12.8)	53 (4/7.6)
> 20	79 (25/31.5)	92 (15/16.3)	69 (7/10.2)

1. For Subcohorts I and II length of employment is based only on work in departments used to define subcohorts.

2. (O/E) = Observed/Expected deaths.

Table 14

Mortality from All Types of Lymphatic/Hematopoietic Cancer Combined by Length of Employment for All White/Male Workers Included in the Analysis of the Uranium Enrichment Facility

Length Employed (years)	Observed Deaths	Expected Deaths	SMR
< 5	12	6.7	179
5 - 10	5	3.6	135
10 - 15	2	1.5	133
15 - 20	0	1.3	----
> 20	4	2.6	154
Total	23	15.8	146

Table 15

Mortality from All Types of Lymphatic/Hematopoietic Cancer Combined by Latency* for All White/Male Workers Included in the Analysis of the Uranium Enrichment Facility

Latency (years)	Observed Deaths	Expected Deaths	SMR
< 5	7	1.9	368
5 - 10	3	2.0	150
10 - 15	4	2.2	182
15 - 20	2	2.8	71
20 - 25	3	3.6	83
25 - 30	4	2.8	143
> 30	0	0.5	----
Total	23	15.8	146

* Latency is defined as time since first employment at the facility.

Table 16

Deaths From Lymphatic and Hematopoietic Cancer Among Uranium Enrichment Workers

Case No.	JOB HISTORY		Date 1st Employed	Date of Death	Underlying Cause of Death
	Department	Duration			
1	Electrical Maintenance	7.0 years	3/11/57	8/5/70	Reticulum-cell Sarcoma (200.0)
2	Water Treatment	6.5 years	8/17/53	1/10/66	Reticulum-cell Sarcoma (200.0)
3	Shipping and Receiving Janitor	1.5 years 5.5 years	2/15/54	4/6/71	Reticulum-cell Sarcoma (200.0)
4	Process Maintenance Cascade Maintenance	4.0 months 7.0 years	2/14/55	11/16/62	Reticulum-cell Sarcoma (200.0)
5	Instrumentation Development	2.5 years	11/1/66	5/29/69	Reticulum-cell Sarcoma (200.0)
6	Engineering	5.0 months	9/1/55	1/23/56	Reticulum-cell Sarcoma (200.0)
7	Electrical Maintenance	2.5 years	6/7/54	12/2/62	Malignant Lymphoma (200.0)
8	Development Laboratory Safety	1.0 year 1.0 year	1/3/55	2/27/70	Hodgkin's Disease (201)
* 9	Power and Utilities Administration	2.0 years 6.0 months	8/3/53	12/17/55	Hodgkin's Disease (201)
10	Machine Shop	3.0 years	4/21/69	2/28/78	Hodgkin's Disease (201)
11	Electrical Maintenance	3.0 years	5/24/54	10/2/57	Hodgkin's Disease (201)
12	Material Sampling and Test-Physical Measure.	3.5 years 11.5 years	5/3/54	4/28/67	Hodgkin's Disease (201)

Table 16
(Continued)

Case No.	JOB HISTORY Department	Duration	Date 1st Employed	Date of Death	Underlying Cause of Death
13	Electrical Maintenance Electrical & Instrument Maintenance	20.0 years 3.0 months	3/16/54	3/30/75	Malignant Lymphoma (202.0)
14	Engineering/Maintenance Garage Utilities Maintenance Cascade Elec. Mainten.	2.0 years 12.0 years 8.5 years 6.0 months	8/9/54	10/6/82	Lymphoma (202.2)
15	General Training	3.0 years	5/19/54	6/15/57	Multiple Myeloma (203)
** 16	Uranium Operations Admin.(Production)	9.0 years 6.0 months	11/9/52	10/22/62	Multiple Myeloma (202)
*** 17	Janitor	< 1.0 month	5/19/54	10/2/79	Multiple Myeloma (203)
18	Stores Control Surplus Salvage	6.0 years 6.0 months	3/1/54	1/24/82	Chronic Lymphatic Leukemia (204.1)
19	Cascade Operation Process Area IV Process Area III	2.0 years 6.0 years 3.0 years	6/21/54	8/10/65	Acute Myelogenous Leukemia (204.3)
20	General Training	6.0 months	11/22/54	12/3/58	Acute Myelogenous Leukemia (204.3)
21	Cascade Maintenance	9.0 months	5/21/56	2/15/57	Acute Lymphatic Leukemia (204.3)
22	Personal Services Computer Services Physical Measurements	6.0 months 1.5 years 1.0 year	7/2/56	8/19/59	Acute Lymphatic Leukemia (204.3)
*** 23	Cascade Operator Spec. & Mechanic Shop	6.0 months 3.0 months	6/29/53	4/8/69	Acute Myelogenous Leukemia (205)

Table 16
(Continued)

Case No.	JOB HISTORY Department	Duration	Date 1st Employed	Date of Death	Underlying Cause of Death
24	Maintenance Engineering	2.0 years	9/28/54	6/14/79	Acute Myelogenous Leukemia (205)
*** 25	Works Laboratory Materials Sampling/Test	4.0 months 1.0 year	2/12/53	8/13/71	Chronic Myelogenous Leukemia (205.1)
26	Chemical Operator Quality Control Flourine Generation Decontamination Furnace Stand Material Recovery	6.0 months 1.0 month 6.0 months 8.5 years 1.0 year 11.0 years	3/15/54	9/16/71	Myelocytic Leukemia (205.1)
27	Mechanical Shop	1.3 years	8/5/53	2/17/81	Leukemia (207.9)

* Not included in cohort analysis because worker was female.

** Started as a Goodyear Employee at another plant in 1937.

*** Not included in cohort analysis because all work history occurred before September, 1954.

References

1. Stokinger HE. The Metals in Patty's Industrial Hygiene and Toxicology (third edition) Volume IIA, Clayton GD and Clayton FE (eds). John Wiley and Sons, New York, 1981, pp 1995-2013.

2. Hursh JB, Spoor NL. Data on Man in Uranium, Plutonium, Transplutonic Elements (Hodge HC, Stannard JN, Hursh JB, eds). Springer-Verlag, New York, 1973, pp 197-239.

3. Waxweiler RJ, Beaumont JJ, Henry JA, et al. A Modified Life-Table Analysis System for Cohort Studies, JOM 25:115-124, 1983.

4. Breslow NE, Lubin JH, Langholz B. Multiplicative Models and Cohort Analysis. J Am Stat Assn 78:1-12, 1983.

5. McMichael AJ, Haynes SG, Tyroler HA. Observations on the Evaluation of Occupational Mortality Data, JOM 17:128-131. 1977.

6. Polednak AP, Frome EL. Mortality Among Men Employed Between 1943 and 1947 at a Uranium - Processing Plant, JOM 23:169-178, 1981.

7. Scott LM, Bahler KW, De La Garza A, Lincoln TA. Mortality Experience of Uranium and Non-uranium Workers, Health Physics 23:555-557, 1972.

8. Milham S Jr. Leukemia and Multiple Myeloma in Farmers. Amer J Epid 94:307-310, 1971.

9. Blair A, Malker H, Cantor KP, et al. Cancer Among Farmers; A Review, Scan J Work Environ Health 11:397-407, 1985.

10. Pearce NE, Sheppard RA, Howard JK. et al. Leukemia Among New Zealand Agricultural Workers, Am J Epid 124:402-209, 1986.

APPENDIX A

Departments Included in Subcohorts I and II[1]

Dept. No.	Dept. Name
* 072	Plant/Shift Supervisor
231	Administrative Services
242	Co-op
321	Insurance
424	Stores
* 120	Security
122	Police
* 123	Fire
426	Janitor
521	Process Technician
522	Physical Measurements
523	Materials Technology
527	Electronics
534	Equipment Testing
535	Instrumentation Development
* 551	Materials Sampling and Testing
552	Uranium Analysis
554	Mass Spectrometry
561	Experimental Shops
581	Operations Analysis
* 582	Process Technical Services
* 601	Engineering Staff, Technical, Admin., QA
* 711	Electrical Maintenance
* 712	Instrument Maintenance
713	Electronic Maintenance
* 714	Utilities Maintenance
* 721	Machine Shop
722	Sheet Metal Shop
723	Weld Shop
* 724	Special and Mechanical Shop
725	Converter Fabrication and Assembly
726	Carpentry/Paint Shop
* 727	Buildings and Grounds
* 731	Cascade Mechanical Maintenance
* 732	Cascade Instrument Maintenance
733	Cascade Electrical Maintenance
* 734	Cascade Welders
* 742	Maintenance Services
752	Garage
* 810	Cascade Operations
* 811	Process Area I

1 Those indicated with an asterisk are included in Subcohort II.

Dept. No.	Dept. Name
* 812	Process Area II/III
* 814	Process Area IV/V
816	Process Area V
* 817	Cascade Coordinator
* 821	Flourine Generation
* 822	Feed Vaporization
* 823	Decontamination
* 824	Furnace Stand
* 826	Chemical Cleaning
* 827	UNH and Oxide Conversion
* 828	Laundry
* 829	Uranium Materials Handling
852	Water Treating
911	Quality Control
921	Safety
923	Health Physics and Industrial Hygiene.

APPENDIX B

SELECTION OF EXPOSED SUBCOHORT GROUPS BASED UPON URINALYSIS DATA

Introduction

The urinalysis data provided by the company was used to select subcohorts of workers who may have had a greater potential for exposure to uranium compounds. Urine uranium and urine alpha values were used. The former values will be used to establish sub cohorts on the basis of uranium chemical effects; the latter value to be used for sub cohort establishment on the basis of radiologic effects.

The Urinalysis Program

For their urinary bioassay program, the company reported that (as of April, 1979) all individuals who could inhale uranium and/or technetium compounds submit urine samples once a month for assessment. These individuals are automatically scheduled for the urinalysis on the last workday of the week closest to a one-month interval. In addition to routine monitoring, special monitoring in the event of a suspected uptake (e.g., due to inadvertent product release) as well as a special monitoring of individuals with known exposures is undertaken. In addition, any employee has the option of requesting a urinalysis at any time. Available information suggests that in prior years, the urinalysis program was broader in scope, with no restriction regarding exposure potential. As of 1979, monthly urinalysis were done on employees who have some definitive potential for exposure.

EVALUATION OF URINALYSIS DATA

Data Set Preparation

In connection with our evaluation, the plant provided NIOSH researchers with a computer data tape containing urinalysis records covering the period from plant start-up (1954) to 1981. After making a duplicate copy of the data tape, NIOSH researchers standardized department designations on all records to designations as they existed on April 1, 1980 using an historical account of original department designations and subsequent modifications provided by the plant. This would allow compilation (and subsequent analysis) of data as it related to currently designated departments. As a final step in the data set preparation, the data set was scanned for missing or inappropriate characters in the data fields of interest. Records so identified were removed from the duplicate so as not to impair execution of the data analysis computer programs.

As previously stated, two data fields were of interest: the urine uranium values and the urine alpha values. After removal of all flawed records related to urine uranium data (974 records) the data set submitted for computer analysis contained 133,927 records. These records were spread over

142 departments. After removal of all flawed records relates to urine alpha data (14,497 records) the data set submitted for computer analyses contained 120,404 records. These records were also spread over 142 departments. An examination of the flawed records in the urine uranium data set indicated that 898 records contained an asterisk in the last column of the Department field; the remaining 76 records contained missing or non-numeric characters in the last column of the uranium field (representing one-one hundredths of a milligram/liter). An explanation of these occurrences was not available. An examination of a sample of 500 of the flawed records in the urine alpha data set indicated that, beside the 898 asterisk records, the records contained missing or non-numeric characters in the last column of the alpha field (representing one-tenth of a dpm per 100 milliliter). At best, it is difficult (if not inappropriate) to draw any definitive conclusions regarding the effect on data characterization if the flawed records were, in fact, "not flawed." Assumptions regarding column values would probably raise more questions then answers. Accordingly, the data analysis proceeded without inclusion of the flawed records.

Focus/Objective of Data Analysis

The data evaluation focused on the urine uranium and urine alpha values in each record. The former values is used by the company in the determination of potential adverse health effects of uranium exposure from a chemical toxicity standpoint; the latter value is used by the company in the determination of adverse health effects of uranium exposure from a radiologic toxicity standpoint.

The primary objective of this data evaluation was to develop indices of relative quantitative exposure level indices -- from chemical and radiologic standpoints. A department index would be "relative" in that its index value (for definition of quantitative exposure) would be determined relative to the base index of 1 which would be assigned to the department having the lowest quantitative exposure potential on the basis of some definable criterion.

ESTABLISHMENT OF EVALUATION METHOD AND CRITERIA

An initial compilation of urine uranium values indicated the following distribution ranges of data:

1) 94% of all reported values were zero (i.e., below limit of detection: 10 µg/L)
2) 5.3% of all reported values ranged from 10 µg/L - 50 µg/L
3) 0.7% of all reported values were greater than 50 µg/L

While examination of the department by department distributions showed varying percentages pertaining to the aforementioned ranges, no department had lower than 47% of total values (within that department) reported as zero.

An initial compilation of urine alpha values indicated the following distribution ranges of data:

1. 67% of all reported values were zero.
2. 31% of all reported values ranged from 1 dpm/100mL - 10 dpm/100mL.
3. 2% of all reported values were greater than 10 dpm/100mL.

For urine alpha data no department had lower than 44% of total values (within that department) reported as zero.

For both data fields overall data distributions as well as data distributions within individual departments are strongly indicative of skew or asymmetric data distributions. Since calculation of an arithmetic mean of a distribution(s) of data (for use as a distribution descriptor) proceeds from the assumption that the data is normally, i.e., symmetrically distributed, it follows that an asymmetric distribution cannot be characterized by an arithmetic mean calculated from such a distribution. In summary, then, a department arithmetic mean used as a quantitative exposure estimate for that department would not, from a statistical viewpoint, be considered a valid estimate.

Because of the statistical drawback associated with use of the department arithmetic mean as a quantitative exposure estimate, it was decided to develop department quantitative exposure estimates on the basis of the percentage of reported values within a department that exceeded a selected urine uranium or urine alpha value. Departments would be ranked on the basis of that percentage. The department which has the lowest percentage of reported values exceeding the selected value would be given an index of one. Other departments would be given an index based on their percentages. For example, if all 142 departments were considered, the department with the highest percentage of reported values exceeding the selected urine value would be given an index of 142. The next highest department would be given an index of

141, and so on down to the base index (the department with the lowest percentage). This method, which places comparatively more emphasis on the number of values (of a given magnitude) as opposed to the absolute magnitude of the individual values, has the statistical advantage in that its use is not predicated on the assumption of any underlying data distribution (e.g., normal). At the same time, it provides a mechanism (as will be discussed later) to evaluate the urine uranium data in a manner that provides relative quantitative exposure potential indices that are defensible from a scientific basis.

For the urine uranium criterion (chemical toxicity related criterion) 50 µg/L (an investigative level presently used by the company) was chosen; for the urine alpha criterion (radiologic toxicity related criterion) 100 dpm/100mL (also an investigative level was chosen). (It should be pointed out that, technically, a zero value could have been used as the criterion for either parameter--with departments ranked on the basis of the percentage of 0 values reported. However, the two criteria chosen represent finite measurements thus allowing rank (an indicator of quantitative exposure potential) to be determined on the basis of measurable phenomena (urine uranium and urine alpha levels)).

From a scientific perspective, the use of the percentage technique as a mechanism to determine quantitative exposure potential from a chemical and radiologic toxicity perspective among departments can be defended by considering a characteristic of soluble uranium (UO_2F_2) important in assessment of adverse effect potential--the biological half-life. It should first be pointed out that the short biological half-life of UO_2F_2 combined with the periodicity (more recently, it is reportedly done monthly but the frequency in earlier years is not known) of urine measurement, makes the urine uranium urine or alpha values determined of limited value in predicting day-to-day exposure among individuals. This is because the value so determined may be reflective of only the more recent uptake. Higher uranium uptakes (with attendant increase in chemical and radiation exposure) which may have occurred sometime previous to the urinalysis may not be discernible from the urine uranium or urine alpha value determined. The short biological half-life notwithstanding, however, one may still obtain a reasonable idea of past exposure by considering the following argument. The biological half-life of UO_2F_2 is approximately 6 hours, i.e., the time it takes for 50% of the original concentration present (due to uptake of the compound) to exit the kidney) is approximately 6 hours. Applying this definition to a hypothetical case, one can state the following: if two individuals simultaneously incur a UO_2F_2 uptake which results in measured urine uranium concentrations of 30 µg/L and 20 µg/L, respectively, at time X, then the theoretical urine concentrations 6 hours later would be 15 µg/L and 10 µg/L respectively. (A similar logic could be applied to urine alpha concentrations). A corollary to this hypothetical case would be that an individual who is exposed (or incurs an uptake) daily to a higher UO_2F_2 concentration than another individual (who incurs a daily uptake) would likely have a higher measurable urine uranium or urine alpha concentration at some future time T. This same logic could be extended to the plant departments which employ a number of individuals. For a given criterion, those departments reporting comparatively greater percentages of values exceeding that criterion are likely to be departments in which a greater quantitative exposure (as indicated by the urine uranium or urine alpha value) occurs.

It should be pointed out however that given the variations observed in number of data points among the departments, in the periodicity of data collection among the departments, and the understatement or overstatement of exposure potential due to the varying assay product, the aforementioned ranking technique will produce rank values that have an inherent degree of imprecision as regards relative rank position. The degree of imprecision notwithstanding though, the assumption for this data analysis will be that a department having a greater ranking than another department has a greater quantitative exposure potential.

It should be kept clearly in mind that the rank values determined are relative values. The values represent a rank relationship among the departments. The values are not to be considered as indicators of absolute exposure. Accordingly, a department with a rank of 40 should not be considered to have an exposure twice that of a department with a rank of 20.

ANALYSIS OF DATA

Because many of the 142 departments were associated with relatively small numbers of records, it was decided to evaluate/rank only those departments associated with 100 or more values reported over the life of the data. This decision was based, in part, on the assumption that such departments were perceived by the company (or it employees) to involve a significant quantitative exposure potential to the extent that a urine sample was requested either by GAT or by the employee(s) on a significant number of occasions. Also, from a characterization point-of-view, these departments were associated with enough data points (urine uranium values) such that a conclusion (with some degree of certainty/confidence) could be drawn as regards the relative quantitative exposure on a day-to-day basis over the years of the plant's operation.

After removing those departments associated with fewer than 100 records, 57 (of the 142) departments remained. For the urine uranium data these 57 departments reported a total of 131, 939 records or 98% of that contained on the original data set (133,927 records). For the urine alpha data, 117,995 records were reported.

These 57 departments were then ranked by the two criterion using the percentage method previously described. The data time frame encompassed all data (within the respective departments) reported up until the computer tape cut off date.

Table 1 is the data compilation showing rank by the two criteria for the 57 departments. The 57 departments have been categorized by generic activity; within the categories, departments are listed by ascending numerical order. Table 1 also shows building locations (where feasible) associated with the individual department's primary functions.

DISCUSSIONS

Cohort Identification

Two subcohorts were identified for the purpose of the epidemiologic evaluation. The first subcohort would include all workers ever employed in a department where there had been at least 100 urinalysis obtained. There were 57 departments in this subcohort. This subcohort would represent workers employed in departments with potential radiation exposure, as perceived by the company and/or its employees.

To obtain the second subcohort, the 50 µg/L criterion was used. Subcohort II would then include all workers in the study cohort ever employed in a department that was ranked in the top 50-percentile of these departments. It was believed that this subcohort would represent workers with an even greater potential for exposure from a chemical toxicity standpoint to soluble uranium compounds.

TABLE 1B

URINE URANIUM/URINE ALPHA DATA
DEPARTMENT RANK:[1] REFLECTING PERCENTAGE OF REPORTED VALUES WITHIN SPECIFIED DEPARTMENTS [ACCORDING TO THE SPECIFIED CRITERIA]

			CRITERIA	
			N 50 ug/L	N 10 dpm/100mL
DEPT	ACTIVITY	CATEGORY		
072	Plant/Shift Supt	Admin	56	36
231	Admin Services	Admin	11	9
242	Co-op	Admin	13	8
321	Insurance	Admin	14	3
424	Stores	Admin	6	17
120	Security	Security	34	30
122	Police	Security	24	14
123	Fire	Security	52	45
426	Janitor	Janitor	8	12
521	Pr Techn	Tech Serv	9	5
522	Phy Measurement	Tech Serv	4	28
523	Mat Tech	Tech Serv	28	37
527	Electronics	Tech Serv	3	25
534	Eq Test/Mech Dvlp	Tech Serv	18	40
535	Instr Dev	Tech Serv	1	24
551	Mat Samp & Test	Chem	33	55
552	Ur Analysis	Chem	19	35
554	Mass Spec	Chem	23	32
561	Exp Shops	Admin Eng	25	13
581	Opr Analysis	Admin Eng	15	31
582	Pr Tech Serv	Admin Eng	37	41
601	Eng Staff	Admin Eng	48	38

1 Column rankings reflect consideration of all data reported within the respective departments.

TABLE 1B (CONT.)

URINE URANIUM/URINE ALPHA DATA
DEPARTMENT RANK:[1] REFLECTING PERCENTAGE OF REPORTED VALUES WITHIN SPECIFIED DEPARTMENTS [ACCORDING TO THE SPECIFIED CRITERIA]

			CRITERIA	
DEPT	ACTIVITY	CATEGORY	N 50 ug/L	N 10dpm/100mL
711	El Maint	Maint (720)	29	16
712	Instr Maint	Maint (720)	36	27
713	Electronic Maint	Maint (720)	5	6
714	Ut. Maint	Maint (720)	30	23
721	Mach Shop	Maint (720)	35	19
722	Sh Metal Shop	Maint (720)	7	7
723	Weld Shop	Maint (720)	21	34
724	Sp & Mech Shop	Maint (720)	47	49
725	Conv Sh Maint	Maint (720)	20	10
726	Carp/Paint Shop	Maint (720)	16	18
727	Bldgs & Grds	Maint B&G	38	1
731	Cas Mech Maint	Maint Prod (326/330/333)	50	46
732	Cas Instr Maint	Maint Prod (326/330/333)	43	42
733	Cas Elec Maint	Maint Prod (326/330/333)	17	11
734	Cas Welders	Maint Prod (326/330/333)	31	20
742	Maint Services	Maint Gen	32	26
752	Garage	Maint Gen	2	2
810	Cas Opr	Admin Prod (326/330/333)	40	40
817	Cas Coord	Admin Prod (326/330/333)	44	39
811	Process I	Prod (333)	41	21
812	Process II/III	Prod (330)	46	29
814	Process IV/V	Prod (326)	49	48
816	Process V	Prod (326)	27	51

1 Column rankings reflect consideration of all data reported within the respective departments.

TABLE 1B (CONT.)

URINE URANIUM/URINE ALPHA DATA
DEPARTMENT RANK:[1] REFLECTING PERCENTAGE OF REPORTED VALUES WITHIN SPECIFIED DEPARTMENTS [ACCORDING TO THE SPECIFIED CRITERIA]

			CRITERIA	
DEPT	ACTIVITY	CATEGORY	N 50 ug/L	N 10dpm/100mL
821	Fl Generation	Prod Flr (342)	55	53
822	Fd Vaporization	Prod (342) Product	54	43
823	Decontamination	Dec (705)	45	52
824	Fr Stand	Dec (705)	53	50
827	Ur Ox Conv	Dec (705)	42	56
826	Ch Cleaning	Chem Clea(700)	51	47
828	Laundry	Laun (705)	57	57
829	Ur Mat Hand	Mat Hand	39	54
852	Water Treat	Maint Until	12	33
911	Qual Control	QC	22	15
921	Safety	IHHPS	10	4
923	HP Survey	IHHPS	26	44

1 Column rankings reflect consideration of all data reported within the respective departments.