2991

G-000-800.4

REPORT OF MEDICAL STUDY HETA 83-144 FEED MATERIALS PRODUCTION CENTER FERNALD, OHIO JULY 1987

07/01/~~88~~ 87

~~40~~ 35

REPORT

DEPARTMENT OF HEALTH AND HUMAN SERVICES
CENTERS FOR DISEASE CONTROL
NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH
CINCINNATI, OHIO 45226

Report of Medical Study
HETA 83-144

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO

JULY 1987

I. SUMMARY

In September 1985, personnel from the National Institute for Occupational Safety and Health (NIOSH) conducted a cross-sectional medical study of workers at the Feed Materials Production Center (FMPC), a uranium processing facility owned by the United States Department of Energy and operated, at the time of the study, by NLO, Inc. The study included a medical and occupational history questionnaire, urine and blood tests for several indicators of renal function and damage, a chest x-ray, pulmonary function tests, and determination of uranium concentration in a post-shift urine sample. Company personnel records and urine uranium monitoring data were used to construct work and exposure histories.

One hundred forty-six (70%) of 208 eligible long-term employees participated. They had worked at the FMPC from 10 to 34 years, with a median of 32. Indicators of uranium exposure included self-reported uranium exposure "incidents", having been told of a high radiation badge reading, having been told of being overexposed to uranium, length of time at FMPC, current job exposure category, and an index of cumulative uranium exposure derived from the job history and historical urine uranium data. [The 118 urine uranium concentrations measured during the NIOSH survey were all less than 15 micrograms per liter (ug/l); 109 were less than 5 ug/l.]

The study demomstrated some associations between respiratory effects and indicators of uranium exposure. The ratio of the one-second forced expiratory volume to the forced vital capacity (FEV_1/FVC) was associated with the uranium exposure index, even after accounting for cigarette smoking. Shortness of breath was not associated with the uranium exposure index, but was significantly associated with self-reported uranium exposure incidents. Neither chronic cough nor chronic bronchitis was associated with any of the indicators of uranium exposure. Pleural thickening on x-ray was not associated with indicators of uranium exposure or with self-reported history of asbestos exposure. None of the 130 x-rays had increased interstitial markings suggestive of pneumoconiosis.

Renal effects were evaluated treating blood and urine test results as both dichotomous variables (abnormal/normal) and continuous variables. There were no associations between test results and any indicator of uranium exposure, using both raw and creatinine-standardized test results. This apparent lack of any exposure-related renal effects might have been due to limitations of the study, including participation bias, recall bias, an imperfect uranium exposure index, and inadequately sensitive measures of uranium nephrotoxicity.

Future activities will include (a) an environmental evaluation of various exposures at the FMPC, and (b) additional analyses of the company's urine uranium monitoring data in conjunction with the NIOSH renal test results to determine if there is any association between renal effects and the amount of individually measured past uranium exposure.

II. INTRODUCTION

In February 1983, the National Institute for Occupational Safety and Health (NIOSH) received a request from District 34, International Association of Machinists, to evaluate potentially hazardous exposures at the Feed Materials Production Center (FMPC), Fernald, Ohio. The plant is owned by the U.S. Department of Energy (DOE), was operated at the time of the request by NLO, Inc. (NLO), and since January 1, 1986, has been operated by Westinghouse Materials Company of Ohio (WMCO). The requester and other employee representatives expressed concern about a number of potential health problems and exposures.

NIOSH investigators conducted a walk-through inspection of the facility on October 12, 1983. Among the numerous potential exposures noted at the time were uranium (both metallic and various soluble and insoluble compounds, including uranium oxides and fluorides), hydrogen fluoride, nitric acid, tributylphosphate, and other chemicals. Although the FMPC had authorization to handle uranium up to 19.99% enriched, relatively little uranium of more than 10% enrichment was used;[1] in most work areas at the FMPC, the uranium was low-enriched (<2%) or depleted. [Natural uranium contains 99.3% U^{238} and 0.7% U^{235}, which is a greater radiologic health hazard than U^{238}. Enriched uranium contains more than 0.7% U^{235}, the percent enrichment denoting the amount. Depleted uranium contains less than 0.7% U^{235}.] Thorium had been processed in the past, as had material containing plutonium. Also, asbestos was used in the construction of some buildings.

After discussions with the requester, other union representatives and consultants, and representativies of DOE and NLO, the NIOSH investigators decided to concentrate the medical component of the hazard evaluation on screening for evidence of lung and kidney toxicity. This decision was based on (a) case reports by the requester and union medical consultants of several instances of lung disease among past and present workers, (b) the known toxic effects of soluble forms of uranium on the kidney, (c) the respiratory effects of several

substances used at the plant, and (d) the relatively low enrichment of uranium at the plant, making chemical, rather than radiologic, toxicity the predominant concern.

The investigation encountered considerable delay as a result of administrative procedures required by DOE before allowing NIOSH access to necessary employee medical and personnel records. NIOSH personnel finally conducted a medical field survey September 16-27, 1985. Individual employees were notified of their pulmonary function test and chest x-ray results June 25, 1986, and of their blood and urine test results July 23, 1986. This report presents the results of the medical survey.

III. METHODS

The medical study was designed to detect evidence of pulmonary (lung) and renal (kidney) damage or dysfunction attributable to uranium exposure. Accordingly, employees meeting the following criteria were eligible to participate: (a) current hourly employees (production and maintenance workers and security guards) who had worked at the plant continuously for at least 10 years; (b) current salaried employees who had previously been hourly employees and who had been at the plant at least 10 years; (c) salaried employees who had worked at the plant continuously for at least 10 years and whose current job category, according to consensus of management and union representatives, involved potential exposure to uranium; and (d) former hourly employees who had retired within the preceding two years after having worked continuously at the plant for at least 10 years. (Considering both total dose of uranium and disease latency, any effects of chronic exposure to uranium would most likely be found among those employees with the longest exposure. Ten years represented a period of sufficient latency that still provided an adequately large population for study.)

Eligible current employees were identified through employee rosters and scheduled by the company for a meeting with NIOSH personnel, who explained the study and requested worker participation. The NIOSH investigators also sent to all eligible retirees who could be identified from company records a letter describing the study and inviting their participation. Finally, the NIOSH investigators contacted current workers on sickness or disability leave to determine the cause of their absence.

The medical study included a medical and occupational history questionnaire, a chest x-ray, standard screening spirometry, blood and urine analyses for several parameters of kidney function, and determination of urine uranium concentration.

The questionnaire was self-administered in small groups under the direction of NIOSH personnel. It elicited basic demographic

information, presence of respiratory symptoms, history of urinary tract problems, history of medical conditions known to predispose to renal dysfunction, use of medications that might affect the test results, current job information, past and present workplace exposures (at NLO and elsewhere), and use of cigarettes and alcoholic beverages. The respiratory questions were adapted from the American Thoracic Society questionnaire.[2] For the epidemiologic purposes of this study, we defined chronic bronchitis as cough and phlegm on most days, for at least three consecutive months a year, for at least two years.[3] By analogy, we defined chronic cough as cough on most days, at least three consecutive months a year, for at least two years. We categorized the degree of breathlessness (dyspnea) according to the responses to the five pertinent questions on the questionnaire.

Grade 1 -- troubled by shortness of breath when hurrying on the level or walking up a slight hill.

Grade 2 -- having to walk slower (on the level) than people of the same age because of shortness of breath.

Grade 3 -- having to stop for breath when walking at one's own pace on the level.

Grade 4 -- having to stop for breath after walking about 100 yards (or after a few minutes) on the level.

Grade 5 -- too breathless to leave the house or breathlessness on dressing or undressing.

Chest x-rays were interpreted according to the ILO 1980 International Classification of Radiographs of Pneumoconioses.[4] Each x-ray was read independently by two radiologists certified in the use of the ILO system ("B readers"). In cases of disagreement, the x-ray was read independently by a third B reader, and the majority opinion (or median value) of a disputed finding was used for analysis (and for reporting results to the participants). None of the radiologists knew the exposure status of the persons whose x-rays they were interpreting.

One-second forced expiratory volume (FEV_1) and forced vital capacity (FVC) were measured with an Ohio Medical Model 822 dry rolling seal spirometer attached to a Spirotech 200B dedicated computer. Equipment and test procedures conformed to the American Thoracic Society's criteria for screening spirometry.[5] Predicted values for FEV_1 and FVC were calculated using the equations of Knudson;[6] these values were multiplied by 0.85 to obtain the predicted values for Blacks.[7] We used FVC <80% of predicted with FEV_1/FVC $\geq$70% as the criterion for a pure restrictive pulmonary function pattern, and FEV_1/FVC <70% with FVC $\geq$80% of predicted as the criterion for a pure obstructive pattern. We defined FVC <80% of predicted with FEV_1/FVC <70% as a combined obstructive/restrictive pattern.

Venous blood and urine were analyzed for several indicators of renal function and damage, both glomerular and tubular. Specific tests, analytical procedures, and reference ranges are listed in Table 1. We attempted to obtain the first morning urine for all analyses except uranium, which was measured in a post-shift urine specimen obtained on the "clean" side of the employee locker room following the employee's shower. When a first morning urine specimen could not be obtained, we accepted whatever specimen was available.

We abstracted work histories from company personnel records. Each job title was categorized according to potential for uranium exposure and combined into high-, medium-, low-, or no-exposure groups, based on the consensus of company and union representatives and our observations (Appendix A). We extracted information on all previous urine uranium measurements for study participants, which was available from a computerized record of the company's urine uranium monitoring program. We used this historical urine uranium data to validate the exposure categories and to estimate quantitatively the differences between them, that is, to "weight" the categories. For each participant, we then constructed an index estimating cumulative uranium exposure by multiplying the time (in months) spent in each job by the derived category weight for the appropriate job category and summing over all jobs. (Individual urine uranium results were not used to calculate the index.) In essence, this exposure index represents the length of time an employee worked at the FMPC, weighted according to the potential for uranium exposure in the jobs he or she has held there. Finally, we obtained the uranium lung burden data (whole-body radiation counts) for participants who had undergone this examination in the most recent round of testing, which had, coincindentally, occurred during the few weeks preceding our field survey. Radiation measurements were made in a DOE mobile unit; equipment, procedures, minimum detection level, and calculation of maximum permissible lung burden (MPLB) are described in a previous NIOSH report.[1]

Statistical analysis was performed on an IBM Mainframe computer using the Statistical Analysis System (SAS), version 5.08 (SAS Institute, Inc., Carey, NC, 1985).

VI. RESULTS

A. Participants

The current employees eligible for the study included 147 wage and 61 salaried workers. One hundred-forty six (70%) of these 208 persons participated, although not all completed all parts of the survey. Unless otherwise noted, the terms "participant" and "study participants" will hereafter refer to these 146. Of the 28 eligible retirees, only 8 (29%) took part in the study. Because of the likely selection bias, these, as well as four other (self-referred) current or former employees who did not meet the

eligibility criteria, were excluded from the data analysis. None of the non-participating current employees were on disability or extended sick leave because of lung or kidney problems.

The 146 participants included 142 men and 4 women. There were 138 Whites, 6 Blacks, 1 Native American, and 1 person of unspecified race. They ranged in age from 31 to 68 years, with a median of 58 and mean of 56. One hundred-three (71%) had reached the twelfth grade, and 27 (18%) had had formal education beyond high school. Forty-eight (33%) of the 144 persons answering the question were non-smokers, 65 (45%) were former smokers, and 31 (22%) were current smokers. (The percentages referring to smoking status are based on the 144 participants who answered the question. Hereafter, unless there are more than seven (5%) non-respondents, percentages will be based on a denominator of 146.)

B. Exposures

The participants had worked at the FMPC from 10 to 34 years, with a median of 32 and a mean of 29. Seventy-eight (53%) reported at least 1 uranium exposure "incident," 49 (34%) reported 10 or more, and 38 (26%) reported 20 or more. Although only 22 (15%) reported having ever been told by NLO management or health and safety personnel, or by an outside physician, that they had been overexposed to uranium or radiation, 9 said that they had been told by NLO at least once that their urine uranium level was above the company's action level [40 micrograms per liter (ug/l)], and 29 said that they had been told at least once by NLO that their radiation badge showed excessive radiation exposure. Eight persons (5%) reported having ever been reassigned to a different job because of a high urine uranium level, and 9 (6%) reported a job reassignment for a high radiation badge reading.

Ninety-three (64%) of the participants reported "regular or frequent" exposure to uranium at the FMPC, and another 41 (28%) reported "occasional" exposure (Table 2). A majority also reported at least occasional exposure to thorium, nitric acid, hydrogen fluoride, ammonia, and machining fluids. Seventeen (12%) persons reported regular or frequent exposure to asbestos at the FMPC, and another 38 (26%) reported occasional exposure. None of these questions distinquished between past and present exposures. Four persons reported previous occupational exposure to uranium or other radioactive materials (plutonium, thorium, and polonium) somewhere other than at the FMPC.

Forty-eight (33%) of the participants had had a whole body radiation count in the round of testing preceeding the NIOSH survey. Percent MPLB ranged from 0 to 54 percent, with a median of 11% and a mean of 14%. Percent MPLB was not associated with self-reported uranium exposure incidents (Table 3). For both

self-reported history of a high radiation badge reading and being told of overexposure to uranium or radiation, those with such a history had a numerically higher mean percent MPLB than those without, but the differences were not statistically significant. [Because of the low sensitivity of the DOE mobile counter, and the deficiencies (at least prior to the time of our field survey) in the company's method of reporting percent MPLB,[1] the numerical accuracy of most of the percent MPLB values reported above is questionable. Any differences between them are thus also questionable, and any association, or lack of association, between percent MPLB and either other indicators of exposure or indicators of effect may be spurious.]

The mean urine uranium levels associated with the no-, low-, medium-, and high-exposure job categories were 6.2, 6.7, 11.0, and 17.8 ug/l, respectively. These were calculated using all routine and "incident" urine uranium determinations (but excluding follow-up tests) for every study participant recorded on the company's data file. Each of these 12,215 results was allocated to the job the worker had held at the time the respective urine specimen was obtained. Based on the above mean urine uranium concentrations, the no-, low-, medium-, and high-exposure categories were assigned weights (ratio of category mean to no-exposure category mean) of 1, 1.08, 1.77, and 2.87, respectively.

The urine uranium concentrations measured in the 118 study participants ranged up to 13 ug/l; 109 (92%) were less than 5 ug/l, the limit of detection for the analytical method used.

C. Pulmonary effects

Forty-five (31%) participants reported having been on medical disability at least once. Five of them had had one or more lung problems (asthma, bronchitis, pneumonia, chemical pneumonitis due to hydrogen fluoride, benign tumor, and an unspecified lung problem), and two had had unspecified kidney problems.

Fourteen (10%) persons met the criteria for chronic cough; 11 (8%) met the criteria for chronic bronchitis. Neither condition was associated with uranium exposure index (Table 4). Chronic bronchitis, but not chronic cough, was associated with a history of one or more uranium exposure "incidents," but the association with multiple incidents ($\geq$20 versus <20) was weaker (Table 5). Neither chronic cough nor chronic bronchitis was associated with a self-reported high radiation badge reading or with having been told of overexposure to uranium or radiation (Table 5), and neither condition was associated with higher percent MPLB (Table 7). [The lack of accuracy of the percent MPLB values was discussed above (Section IV B).]

Forty-seven (32%) participants reported shortness of breath; 18 (13%) had grade 2 or worse. Of the 10 (7%) with symptoms more severe than grade 2, one had grade 3 and nine had grade 4. Shortness of breath was not associated with the uranium exposure index (Table 4), but was associated with self-reported uranium exposure incidents. Both for those with ≥ 1 and ≥ 20 incidents, the relative risk of being symptomatic tended to increase with increasing degree of shortness of breath, and for those with ≥ 20 incidents the 95% confidence intervals excluded 1 for all grades (Table 5). Similar trends were seen with self-reported high radiation badge readings and with having been told of uranium or radiation overexposure, but the relative risks were smaller and the 95% confidence intervals included 1 (Table 6). Shortness of breath was not associated with higher percent MPLB (Table 7).

One hundred-thirty (89%) of the participants had pulmonary function tests; 112 (86%) of the tests met the validity criteria for epidemiologic analysis.[4] Fourteen (13%) of the valid tests demonstrated a restrictive pattern, and 23 (21%) had an obstructive pattern. (These totals included 5 with a mixed restrictive/obstructive pattern.)

Participants with an obstructive pulmonary function pattern had a significantly higher uranium exposure index than those without an obstructive pattern (Table 4). A similar tendency was also seen for restrictive PFT pattern, but the difference was not statistically significant. Using multiple regression analysis, FEV_1/FVC was associated with both uranium exposure index ($B = -0.0081$, $p = 0.014$) and current smoking status (0 = no, 1 = yes) ($B = -9.18$, $p = 0.0001$), but not with age (years) ($B = -0.095$, $p = 0.53$), duration of employment at the FMPC (months) ($B = -0.0071$, $p = 0.60$), or cumulative smoking (pack-years) ($B = -0.017$, $p = 0.67$). Percent predicted FEV_1 was associated with both current and cumulative smoking ($B = -17.75$, $p = 0.0001$, and $B = -0.154$, $p = 0.033$, respectively), but not with age ($B = -0.071$, $p = 0.80$), duration of employment ($B = -0.021$, $p = 0.40$), or uranium exposure index ($B = -0.0090$, $p = 0.14$). Percent predicted FVC was associated with both current and cumulative smoking ($B = -8.73$, $p = 0.026$, and $B = -0.136$, $p = 0.050$, respectively), but not with age ($B = -0.053$, $p = 0.84$), duration of employment ($B = -0.012$, $p = 0.605$), or uranium exposure index ($B = 0.00044$, $p = 0.95$).

Neither restrictive nor obstructive PFT pattern was associated with a self-reported history of uranium exposure incidents (Table 5), high radiation badge readings, or having been told of overexposure to uranium or radiation (Table 6), and neither pattern was associated with percent MPLB (Table 7). Furthermore, neither percent predicted FVC nor FEV_1/FVC was associated with any of the self-reported indicators of exposure (Table 8). Finally, none of

the three pulmonary function parameters was associated with current percent MPLB ($r^2 < 0.01$, $p > 0.5$, in regression analyses for each).

One hundred thirty (89%) of the study participants were examined by chest x-ray (posterior-anterior view); none of the x-rays demonstrated increased interstitial lung markings suggestive of pneumoconiosis. Eleven (8.5%) of the x-rays showed evidence of pleural thickening, which was bilateral in seven cases. Although suggestive of past asbestos exposure, x-ray signs of pleural thickening were not associated with self-reported history of "regular or frequent" asbestos exposure. Some evidence of pleural thickening was present in one (7%) of 15 asbestos-exposed and 10 (9%) of 115 unexposed workers [relative risk (RR) = 0.77, 95% confidence interval (CI): 0.11 - 5.49], bilateral evidence was present in one (7%) of 15 exposed and 6 (5%) of 115 unexposed (RR = 1.28, 95% CI: 0.16 - 10.05).

Pleural thickening was not associated with the uranium exposure index (Table 4) or self-reported incidents of uranium exposure (Table 4). Although relative risks greater than 1 suggested possible associations between bilateral pleural thickening and the two other indicators of uranium exposure, the 95% confidence intervals for these measures were fairly wide and included 1 (Table 6).

D. Renal Effects

Eighteen (12%) of the participants reported ever having been told by a doctor that they had had a kidney stone; thirty (21%) persons reported having been told that they had had a kidney infection. Neither of these conditions was associated with the uranium exposure index, nor were recurrent or currently present kidney stones or infections (Table 4). Both participants who reported a current kidney stone currently had jobs in the low-exposure category, as did one of the four persons reporting a current kidney infection. The other three reporting a current kidney infection currently had jobs in the high-exposure category. (There were, respectively, 1, 35, 57, and 49 participants currently in the no-, low-, medium-, and high-exposure job categories.)

One hundred twenty-six (86%) of the participants provided specimens for one or more of the tests of renal function or damage. Concentrations of the various substances measured were not associated with current job exposure category (Table 9), duration of employment at the FMPC (Table 10), or the uranium exposure index (Tables 10 and 11). Neither were they associated with self-reported uranium exposure incidents, self-reported high radiation badge reading, or having been told of overexposure to uranium or radiation (Tables 5, 6, and 12a and b). [The apparently

increasing relative risk of serum beta-2-microglobulin with increasing number of uranium exposure incidents (Table 4) could be an artifact attributable to the small number of abnormal results.] [Results for a particular test may have been omitted from a Table if (a) there was not a substantial number of abnormalities, and/or (b) the test was relatively non-specific for tubular dysfunction or damage, the expected effect of uranium.]

Additional comparisons that showed no consistent association between renal tests and exposure variables included: (a) test results dichotomized as abnormal (above the reference range) and normal (within or below the reference range) versus duration of employment (whether dichotomized at the median or at a suggestive point on the scatterplot); (b) test results dichotomized as in (a) versus uranium exposure index (whether dichotomized at the median or at a suggestive point on the scatterplot); (c) correlation (Pearson's) between creatinine-standardized renal test results (as a continuous variable) and duration of employment at the FMPC; and (d) renal test results (expressed as mean concentrations) for the three groups of participants who have always had jobs in the same (low-, medium-, high-) exposure category.

Beta-2-microglobulin is degraded in an acid environment, as, for example, in urine with a pH below 6. Since this circumstance can occur both in the bladder and in the collection container before the urine is processed, we evaluated this phenomenon as a potential source of error in the data. Only six urine specimens, however, had a pre-processing pH below 6; the mean beta-2-microglobulin concentration for these samples was 181 ug/l. The mean of the 103 beta-2-microglobulin analyses in urine with a pH of 6 was 226, and means of the 6 in urine with a pH of 7, and the 7 in urine with a pH of 8, were 221 and 172, respectively. Thus, even if the measured beta-2-microglobulin concentrations in the specimens with a pH less than 6 were erroneously low, the relatively small number of such cases could not have substantially affected the data analyses.

There was a high correlation among the urine concentrations of the three tubular enzymes (based on 113 sets of results: for N-acetyl glucosaminidase and gamma glutamyltranspeptidase, Pearson's $r = 0.298$, $p = 0.0014$; for N-acetyl glucosaminidase and alanine aminopeptidase, $r = 0.534$, $p = 0.0001$; for alanine aminopeptidase and gamma glutamyltranspeptidase, $r = 0.671$, $p = 0.0001$), but not between the urine concentrations of beta-2-microglobulin and retinol binding protein ($r = 0.043$, $p = 0.63$, 123 pairs). To identify individuals with the epidemiologically most convincing evidence of renal tubular dysfunction/damage, we listed those participants whose test results were in the highest 5% of the distribution of the creatinine-standardized urine concentrations of any of the three tubular enzymes, beta-2-microglobulin, or retinol

binding protein. There were 21 participants with at least one such high value. Six had two or more such high values (Table 13). Two of the six reported numerous uranium exposure incidents, but these two were not among the three persons with more than two high test results. One person had a self-reported history of a high radiation badge reading, and another reported having been told of overexposure to uranium or radiation, but again these individuals were not among the three with more than two high test results.

No more than two of the six persons with two or more high test results had any one job or work area, past or present, in common. The median age of the six was 57 years; the median for the entire study group was 58 years. Curiously, the two participants with high values for all five tests were the oldest and youngest of the six. The median duration of employment at the FMPC was 31 years for the six; the median for the entire study group was 32 years. Neither of the two participants with high values for all five tests were above the median. (The individual age and seniority data have been omitted from Table 12 to prevent identification of the individuals.) Finally, the median uranium exposure index for the six workers was 663 exposure-months. The median for the entire study group was 665, and the 5th, 25th, 75th, 95th, and 99th percentiles were 285, 429, 1015, 1138, and 1149, respectively. Thus, the six workers with the most extreme renal test results did not appear to differ from the rest of the study group with respect to indicators of uranium exposure.

V. DISCUSSION

This study demonstrated associations between indirect estimates of past or cumulative uranium exposure at the FMPC and both symptoms of shortness of breath and, even after accounting for cigarette smoking, spirometric evidence of obstructive pulmonary function. No such associations with renal effects were found. The study had several limitations, however. First, it was limited to current employees. Although, to our knowledge, no current workers were unable to participate because of pulmonary or renal disability, this may have been a reason for non-participation of some retired workers. Only a few of the recently retired workers accepted our invitation to participate in the study -- too few to be meaningfully included in the analysis. Furthermore, the study could not include information on deceased employees who had had pulmonary or renal problems.

Second, several of the indicators of uranium exposure were derived from the questionnaire responses and thus depended on the accuracy of the participants' memories. Furthermore, even the most objective measure of exposure used in the analyses -- a calculated cumulative uranium exposure index based on job category -- was only semi-quantitative. Although each participant had had individual urine uranium tests performed periodically since beginning work at the FMPC, the number of

samples, timing, and reasons for testing (routine, exposure incident, follow-up, etc.) varied from person to person. This presented statistical analytical problems (see Future Actions, below). Also, the differences in solubility in body fluids of the various uranium compounds present at the FMPC result in different retention times in the lungs and different urine uranium levels (reflecting a different pattern of kidney exposure). Thus, similar urine uranium levels may not necessarily indicate biologically equivalent exposures.

Finally, the renal tests included in our study may not have been the most sensitive indicators of uranium nephrotoxicity. In retrospect, tubular reabsorption of phosphorus, urinary amino acid concentrations, or other tests of renal tubular function or damage might have proven to be more sensitive.

The urine uranium concentrations found during our survey suggest that current uranium exposures are within currently acceptable limits for occupationally exposed persons. The company data, however, suggest that exposures were higher in the past. Also, during the survey, none of the participants was involved in an "incident" of potentially higher exposure.

VI. RECOMMENDATIONS

A. The medical monitoring program for workers exposed to uranium should include, in addition to the periodic determinations of uranium lung burden and urine uranium concentration, annual assessment of pulmonary and renal function:

1. Pulmonary function tests should be performed using standardized procedures.[5] This is necessary for (a) more accurate evaluation of an individual's pulmonary function, especially over time, and (b) analysis of group data.

2. Renal function tests should include (a) dipstick (pH, glucose, protein, occult blood) and microscopic urine analysis; (b) serum creatinine concentration, preferably with determination of creatinine clearance; and (c) some measure of renal tubular function, such as tubular reabsorption of phosphorus (which is calculated from concurrent serum and urine phosphate and creatinine concentrations).

3. Anyone with an abnormal test result, or a larger decrease in pulmonary or renal function than expected by age alone, should have appropriate medical evaluation.

B. A medical monitoring program should be available to anyone exposed to asbestos. Details of such a program are described in the OSHA asbestos standard (29 CFR 1910.1001).

VII. FUTURE ACTIONS

1. NIOSH industrial hygienists will conduct an environmental evaluation of various exposures at the FMPC.

2. NIOSH epidemiologists will attempt to analyze the company's urine uranium monitoring data in conjunction with the NIOSH renal test results to determine if there is any association between renal effects and the amount of individually measured past uranium exposure.

VIII. REFERENCES

1. National Institute for Occupational Safety and Health. Health hazard evaluation report no. HETA 85-111-1770. Cincinnati, OH: National Institute for Occupational Safety and Health, 1987.

2. Ferris BG. Epidemiology standardization project. II. Recommended respiratory disease questionnaire for use with adults and children in epidemiological research. Am Rev Respir Dis 1978;118:7S-53S.

3. American Thoracic Society. Chronic bronchitis, ashtma, and pulmonary emphysema. Am Rev Respir Dis 1962;85:762-8.

4. International Labour Organisation. Guidelines for the use of the ILO international classification of radiographs of pnenumoconioses, revised ed. Geneva: International Labour Organisation, 1980. [Occupational safety and health series, no. 22 (rev.)].

5. American Thoracic Society. ATS statement -- Snowbird workshop on standardization of spirometry. Am Rev Respir Dis 1979;119:831-8.

6. Knudson RJ, Slatin RC, Lebowitz MD, Burrows B. The maximal expiratory flow-volume curve. Normal standards, variability and effects of age. Am Rev Respir Dis 1976;113:587:600.

7. Lanese RR, Keller MD, Foley MF, Underwood EH. Differences in pulmonary function tests among whites, blacks, and American Indians in a textile company. J Occup Med 1978;20:39-44.

IX. AUTHORSHIP AND ACKNOWLEDGEMENTS

Report Prepared by:	Mitchell Singal, M.D, M.P.H. Supervisory Medical Officer Medical Section Hazard Evaluations and Technical Assistance Branch
	Richard L. Ehrenberg, M.D. Senior Medical Epidemiologist Office of the Director, NIOSH
Epidemiologic and Medical Consultation:	Elizabeth M. Ward, Ph.D. Assistant Chief
	Michael J. Thun, M.D. Chief Epidemiology II Section Industrywide Studies Branch
Originating Office:	Hazard Evaluations and Technical Assistance Branch Division of Surveillance, Hazard Evaluations, and Field Studies
Report Typed By:	Jenise Brassell

X. DISTRIBUTION:

Department of Energy
Westinghouse Materials Company of Ohio
NLO, Inc.
Fernald Atomic Trades Labor Council
Independent Guards Union
District 34, International Association of Machinists
International Chemical Workers Union
Metal Trades Council, AFL-CIO
Oak Ridge Association Universities
Ohio Department of Health

TABLE 1

Blood and Urine Tests

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144

Test	Analytical Method	Reference Range
Blood (serum)		
Beta-2-microglobulin	Pharmacia Diagnostics Phadebas Beta-2-Microglobulin Test Kit, Uppsala, Sweden	age <59: <2400 ug/l age >59: <3000 ug/l
Retinol binding protein	Radial immunodiffusion Kits, Calbiochem-Behring, LaJolla, CA 92037	3 - 6 mg/dl
Albumin	Dupont ACA Chemistry Manual, Wilmington, Delaware, 1983	3.4 - 5.0 g/dl
Total protein	Dupont ACA Chemistry Manual, Wilmington, Delaware, 1983	6.4 - 8.2 g/dl
Creatinine	Dupont ACA Chemistry Manual, Wilmington, Delaware, 1983	male: 0.8 - 1.3 mg/dl female: 0.6 - 1.0 mg/d
Urine		
Uranium	Health and Safety Manual, 26th Edition of EML Procedure Manual, 1983, Department of Energy	<5 ug/l*
Beta-2-microglobulin	Pharmacia Diagnositics Phadebas Beta-2-Microglobulin Test Kit, Uppsala, Sweden	<300 ug/l
Retinol binding protein	Radial Immunodiffusion Kits, Calbiochem-Behring, LaJolla, CA 92037	0.03 - 0.19 ug/ml

TABLE 1 (continued)

Test	Analytical Method	Reference Range
N-acetyl glucosaminidase	D. Leaback, P. Walker, Biochem. J., 78:151-156, 1961	0.17 - 3.50 U/l
Gamma glutamyl transpeptidase	Calbiochem-Behring Gamma-GT Reagent Cat. No. 869813, Calbiochem-Behring Corp., LaJolla, CA 92037	5.47 - 50.88 U/l
Alanine aminopeptidase	K. Jung and D. Scholz, Clin. Chem 26:1251-1254, 1980	1.80 - 8.91 U/l
Creatinine	DuPont ACA Chemistry Manual Wilmington, Delaware, 1983	male: 0.6 - 2.5 g/24 hr female: 0.6 - 1.5 g/24 h
Total Protein	Dupont ACA Chemistry Manual Wilmington, Delaware, 1983	<136 mg/l
Albumin	B. Fielding, D. Price, and C. Houlton, Enzyme Immunoassay for Urinary Albumin, Clin. Chem. 29: 355-357	33.2 mg/l
Specific gravity	J. Roth, Renal Function Tests. In: fundamentals of clinical chemistry, edited by Norbert Tietz, W.B. Saunders Co., Philadelphia, PA, 1976, pp 1005-1008	1.001 - 1.035
pH	Dipstick	4.6 - 8.0

- Using a more sensitive analytical method, the reference range for the general population would be <1 ug/l.

TABLE 2

Self-reported Workplace Exposures

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Exposure	Number of Employees Exposed and (Percent* of Participants)		
	Regularly or Frequently	Occasionally	Infrequently or Never
Uranium	93 (64)	41 (28)	11 (8)
Thorium	25 (17)	69 (48)	50 (35)
Nitric acid	49 (34)	67 (46)	29 (20)
Hydrogen fluoride	31 (21)	58 (40)	56 (39)
Ammonia	36 (25)	78 (54)	31 (21)
Tributyl phosphate	16 (11)	46 (32)	80 (56)
Grinding or cutting oils or coolants	28 (19)	52 (36)	64 (44)
Solvents (other than nitric acid or kerosene/tributyl phosphate)	22 (15)	48 (33)	74 (51)
Asbestos	17 (12)	38 (26)	89 (62)

* - Row total percentages may not add to 100 because of rounding.

TABLE 3

Uranium Lung Burden and Self-reported Exposure Indicators

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Exposure Indicator	Percent Maximum Permissible Lung Burden		
	Mean	Standard error of the mean	Number of participants
Uranium exposure incidents			
≥1	15	2.2	29
0	14	3.6	17
≥20	14	4.0	13
<20	15	2.2	33
High radiation badge reading			
Yes	18[A]	3.9	15
No	12[A]	2.0	33
Told overexposed to uranium or radiation			
Yes	23[B]	5.4	10
No	12[B]	1.8	38

A - p = 0.11 (t-test, variances equal).
B - p = 0.07 (t-test, variances unequal).

TABLE 4

Pulmonary Outcomes and Uranium Exposure Index (see text)

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Condition[1]	Condition Present		Condition Absent	
	Number	Exposure-months, Mean and (S.E.M)[2]	Number	Exposure-months, Mean and (S.E.M.)
Chronic cough	14	695 (68.0)	132	695 (25.4)
Chronic bronchitis	11	776 (82.8)	135	689 (24.9)
Shortness of breath				
≥ grade 1	47	688 (38.6)	98	702 (30.3)
≥ grade 2	18	678 (67.7)	126	697 (25.7)
≥ grade 3	10	731 (91.1)	134	695 (24.9)
≥ grade 4	9	747 (100.6)	135	691 (24.7)
Pulmonary function pattern				
Restrictive[3]	14	801[A] (75.1)	97	664[A] (28.5)
Obstructive[3]	23	846[B] (54.2)	88	638[B] (29.3)
X-ray abnormalities				
Pleural thickening	11	816 (85.5)	119	675 (25.8)
Bilateral pleural thickening	7	831 (111.0)	123	678 (25.4)
History of kidney stone	18	625 (58.9)	128	705 (25.8)
Recurrent or continuing	3	484 (66.5)	143	700 (24.2)
Currently present	2	518 (99.3)	144	698 (24.1)
History of Kidney infection	30	627 (44.5)	116	712 (27.6)
Recurrent or continuing	10	587 (51.7)	136	703 (25.2)
Currently present	4	587 (114.6)	142	698 (24.3)

1 - See text for definition.
2 - Standard error of the mean.
3 - Includes mixed restrictive/obstructive pattern.
A - p = 0.093 (t-test, variances equal).
B - p = 0.014 (t-test, variances equal).

TABLE 5

Health Parameters and Self-reported Uranium Exposure Incidents

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Condition[1]	>1 Incident	0 Incidents	Relative risk	95% Confidence Interval	>20 Incidents	<20 Incidents	Relative risk	95% Confidence Interval
Chronic cough	9/78 (12)[2]	4/63 (6)	1.82	0.60 - 5.51	4/38 (11)	9/103 (9)	1.20	0.39 - 3.71
Chronic bronchitis	9/78 (12)	1/63 (2)	7.27	1.32 - 38.99	5/38 (13)	5/103 (5)	2.71	0.86 - 8.57
Shortness of breath								
≥ grade 1	27/78 (35)	17/62 (27)	1.26	0.76 - 2.09	18/38 (47)	26/102 (25)	1.86	1.14 - 3.04
≥ grade 2	13/77 (17)	4/62 (6)	2.62	0.95 - 7.22	8/37 (21)	9/102 (9)	2.45	0.99 - 5.83
≥ grade 3	8/77 (11)	1/62 (2)	6.44	1.12 - 37.2	6/37 (16)	3/102 (3)	5.51	1.67 - 18.2
≥ grade 4	9/77 (11)	1/62 (2)	6.44	1.12 - 37.2	6/37 (14)	4/102 (4)	3.45	1.04 - 11.4
Pulmonary function pattern								
Restrictive[3]	9/61 (15)	5/49 (10)	1.45	0.52 - 4.01	4/29 (14)	10/81 (12)	1.12	0.38 - 3.31
Obstructive[3]	13/61 (21)	10/49 (20)	1.04	0.50 - 2.18	5/29 (17)	18/81 (22)	0.78	0.32 - 1.88
X-ray abnormalities								
Pleural thickening	4/70 (6)	6/59 (10)	0.56	0.17 - 1.87	2/34 (6)	8/95 (8)	0.70	0.16 - 3.09
Bilateral pleural thickening	2/70 (3)	4/59 (7)	0.42	0.08 - 2.12	1/34 (3)	5/95 (5)	0.56	0.07 - 4.45
Selected Renal test abnormalities[4]								
Serum								
Beta-2-microglobulin	2/69 (3)	1/55 (2)	1.59	0.15 - 16.86	2/34 (6)	1/90 (1)	5.29	0.63 - 44.4
Retinol binding protein	18/69 (26)	11/55 (20)	1.30	0.68 - 2.52	11/34 (32)	18/90 (20)	1.62	0.84 - 3.11
Urine								
Beta-2-microglobulin	7/66 (11)	10/57 (18)	0.60	0.25 - 1.47	3/31 (10)	14/92 (15)	0.64	0.20 - 2.01
Retinol binding protein	4/67 (6)	9/58 (16)	0.38	0.13 - 1.13	3/33 (9)	10/92 (11)	0.84	0.25 - 2.84
Alanine aminopeptidase	8/61 (13)	10/51 (20)	0.67	0.29 - 1.57	6/30 (20)	12/82 (15)	1.37	0.56 - 3.36

1 - See text for definitions.
2 - Number with condition/number in category and (percent).
3 - Includes mixed restrictive/obstructive pattern.
4 - Only concentrations above the reference ranges (see Table 1) are considered abnormal for the purpose of these analyses.

TABLE 6

Health Parameters and Self-reported Exposure Indicators

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Condition[1]	Ever Told Radiation Badge Showed Excessive Exposure				Ever Told Overexposed to Uranium or Radiation			
	Yes	No	Relative Risk	95% Confidence Interval	Yes	No	Relative Risk	95% Confidence Interval
Chronic cough	2/29 (7)[2]	12/117 (10)	0.67	0.16 - 2.78	2/22 (9)	12/124 (10)	0.94	0.23 - 3.88
Chronic bronchitis	2/29 (7)	9/117 (8)	0.90	0.21 - 3.92	2/22 (9)	9/124 (7)	1.25	0.29 - 5.47
Shortness of breath								
≥ grade 1	11/29 (38)	36/116 (31)	1.22	0.70 - 2.13	9/22 (41)	38/123 (31)	1.32	0.73 - 2.41
≥ grade 2	5/29 (17)	13/115 (9)	1.53	0.58 - 3.99	5/22 (23)	13/122 (11)	2.13	0.83 - 5.49
≥ grade 3	3/29 (10)	7/115 (6)	1.70	0.47 - 6.20	3/22 (14)	7/122 (6)	2.38	0.67 - 8.46
≥ grade 4	2/29 (7)	7/115 (6)	1.13	0.25 - 5.21	2/22 (9)	7/122 (6)	1.58	0.35 - 7.20
Pulmonary function pattern								
Restrictive[3]	3/23 (13)	11/88 (13)	1.04	0.32 - 3.42	5/19 (26)	15/111 (14)	1.95	0.78 - 4.87
Obstructive	4/23 (17)	19/88 (22)	0.81	0.31 - 2.11	6/19 (32)	24/111 (22)	1.46	0.67 - 3.20
X-ray abnormalities								
Pleural thickening	3/25 (12)	8/105 (8)	1.58	0.45 - 5.58	3/19 (16)	8/111 (7)	2.19	0.63 - 7.59
Bilateral pleural thickening	2/25 (8)	5/105 (5)	1.68	0.35 - 8.18	2/19 (11)	5/111 (5)	2.34	0.49 - 11.06
Selected renal tests, abnormalities[4]								
Serum								
Beta-2-microglobulin	0/23 (0)	3/102 (3)	0	--	1/18 (6)	2/107 (2)	2.97	0.31 - 28.7
Retinol binding protein	5/23 (22)	25/102 (25)	0.89	0.38 - 2.05	7/18 (39)	23/107 (22)	1.81	0.87 - 3.75
Urine								
Beta-2-microglobulin	5/24 (21)	12/100 (12)	1.74	0.66 - 4.54	2/17 (12)	15/107 (14)	0.84	0.21 - 3.31
Retinol binding protein	2/24 (8)	11/102 (11)	0.77	0.19 - 3.22	1/18 (6)	12/108 (11)	0.50	0.08 - 3.35
Alanine aminopeptidase	3/22 (14)	15/91 (16)	0.83	0.27 - 2.59	3/17 (18)	15/96 (16)	1.13	0.36 - 3.53

1 - See text for definitions.
2 - Number with condition/number in category and (percent).
3 - Includes mixed restrictive/obstructive pattern.
4 - Only concentrations above reference range (see Table 1) are considered abnormal for the purpose of these analyses.

TABLE 7

Respiratory Outcomes and Percent Maximum Permissible Uranium Lung Burden (%MPLB)

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Outcome[1]	Outcome present	
	Yes	No
Chronic cough	9 (2.3) [5][2]	15 (13.6) [43]
Chronic bronchitis	17 (7.0) [5]	14 (2.0) [43]
Shortness of breath		
≥ grade 1	11 (2.8) [16]	16 (2.4) [32]
≥ grade 2	16 (6.6) [5]	14 (2.0) [42]
≥ grade 3	12 (8.1) [3]	14 (2.0) [44]
≥ grade 4	12 (8.1) [3]	14 (2.0) [44]
Pulmonary function pattern		
Restrictive[3]	12 (6.5) [5]	13 (2.0) [32]
Obstructive[3]	12 (2.9) [12]	14 (2.4) [25]
X-ray abnormalities		
Pleural thickening	16 (5.5) [5]	15 (2.2) [38]
Bilateral pleural thickening	19 (9.4) [3]	15 (2.1) [40]

1 - See text for definitions.
2 - Mean %MPLB, standard error of the mean (in parentheses), and (in brackets) number of participants in category.
3 - Includes mixed restrictive/obstructive pattern.

TABLE 8

Pulmonary Function Abnormalities and Self-reported Exposure Indicators

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Exposure Indicator	Number of Participants	Percent predicted FVC	FEV_1/FVC
Uranium exposure incidents			
≥1	61	97 (1.9)*	74 (1.2)
0	50	96 (2.2)	76 (1.3)
≥20	29	95 (2.3)	75 (1.8)
<20	82	97 (1.8)	75 (1.0)
High radiation badge reading			
Yes	23	97 (3.0)	75 (1.7)
No	89	97 (1.6)	75 (1.0)
Told overexposed to uranium or radiation			
Yes	15	94 (4.1)	75 (2.2)
No	97	97 (1.5)	75 (1.0)

*Mean and (standard error of the mean)

TABLE 9

Selected Renal Tests and Current Job Exposure Category[1]

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Test	Job Exposure Category		
	Low	Medium	High
Serum			
Beta-2-microglobulin	1500 (74) [34][A]	1467 (56) [48]	1555 (64) [43]
Retinol binding protein	5.4 (0.19) [34]	5.2 (0.12) [48]	5.4 (0.17) [43]
Creatinine	1.02 (0.023) [33]	0.97(0.026) [47]	0.93 (0.028) [43]
Urine			
Beta-2-microglobulin	239 (13.2) [33]	214 (8.0) [49]	216 (9.0) [42]
Retinol binding protein	0.14 (0.012) [34]	0.094 (0.0077) [49]	0.10 (0.0088) [43]
N-acetyl glucosaminidase	1.14 (0.16) [33]	0.88 (0.061) [48]	0.85 (0.10) [42]
Gamma glutamyltranspeptidase	23.8 (1.77) [31]	23.0 (1.78) [44]	20.9 (1.90) [38]
Total protein	26.2 (7.4) [32]	28.6 (6.4) [47]	28.5 (7.8) [41]
Albumin	6.58 (1.07) [33]	6.19 (0.85) [48]	5.11 (0.51) [41]
Specific gravity	1.014 (0.0011) [33]	1.014 (0.0009) [48]	1.014 (1.011) [41]
Alanine aminopeptidase	7.28 (0.55) [31]	5.91 (0.35) [44]	6.53 (0.52) [38]
Urine, creatinine-standardized[2]			
Beta-2-microglobulin	274 (35.2) [32]	329 (67.3) [48]	313 (33.2) [40]
Retinol binding protein	155 (24.1) [33]	153 (42.4) [48]	152 (18.6) [41]
N-acetyl glucosaminidose	1.14 (0.17) [32]	1.14 (0.14) [48]	1.06 (0.13) [41]
Gamma glutamyl transpeptidase	23.4 (1.3) [31]	25.6 (2.5) [44]	23.9 (1.7) [38]
Total protein	17.4 (5.1) [32]	21.8 (5.3) [47]	20.1 (5.4) [41]
Albumin	6.10 (0.96) [33]	7.56 (1.31) [48]	6.18 (0.79) [41]
Alanine aminopeptidose	7.35[B] (0.53) [31]	7.87[B] (1.14) [44]	8.16[B] (0.68) [38]

1 - See text for explanation.
A - Mean (see Table 1 for units), standard error of the mean (in parentheses), and (in brackets) number of participants in category.
2 - Concentrations expressed as mass or activity units (see Table 1) per gram of creatinine.
B - Differences in means not significant at alpha = 0.05, Ducan's multiple-range test.

TABLE 10

Selected Renal Test Results, Duration of Employment, and Uranium Exposure Index

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Test	Duration of employment (months)		Uranium exposure index (exposure-months)	
	Normal	Abnormal	Normal	Abnormal
Serum				
Beta-2-microglobulin	347 (7.4) [122][A]	335 (62.0) [3]	679 (25.5) [122]	802 (165) [3]
Retinol binding protein	342 (8.8) [95]	363 (12.2) [30]	666 (27.2) [95]	736 (60.0) [30]
Urine				
Beta-2-microglobulin	345 (8.1) [107]	357 (17.7) [17]	678 (26.9) [107]	676 (72.1) [17]
Retinol binding protein	343[B] (8.2) [113]	373[B] (5.5) [13]	695 (26.8) [113]	520 (58.4) [13]
Alanine aminopeptidase	342[C] (9.1) [95]	377[C] (4.6) [18]	684 (29.5) [95]	688 (73.1) [18]

A - Mean, standard error of the mean (in parentheses), and (in brackets) number of participants in category.
B - $p = 0.23$ (t-test, variances unequal).
C - $p = 0.0008$ (t-test, variances unequal).

TABLE 11

Correlations between Selected Renal Tests
and Uranium Exposure Index[1]

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Test	Number of Participants	Correlation (Pearson's) r	p
Serum			
Beta-2-microglobulin	125	0.11	0.21
Retinol binding protein	125	0.16	0.07
Urine[2]			
Beta-2-microglobulin	120	-0.064	0.48
Retinol binding protein	122	-0.093	0.31
N-acetyl glucosaminidase	121	-0.091	0.32
Gamma glutamyltranspeptidase	113	0.002	0.99
Total protein	120	0.067	0.47
Albumin	122	-0.067	0.46
Alanine aminopeptidase	113	-0.006	0.95

1 - See text.
2 - Concentrations (see Table 1) expressed as mass or activity units per gram of creatinine.

TABLE 12a

Selected Renal Test Results
and Self-Reported Exposure Indicators

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

	Parameter Mean*, (Standard Error of the Mean), and [Number of Participants in Category]			
	Serum		Urine	
Exposure Indicator	Beta-2-microglobulin	Retinol binding protein	Beta-2-microglobulin	Retinol binding protein
Uranium exposure incidents				
≥1	1456 (47) [69]	5.39 (0.13) [69]	218 (7.7) [66]	0.104 (0.0068) [67]
0	1558 (58) [55]	5.27 (0.12) [55]	226 (8.5) [57]	0.117 (0.0090) [58]
≥20	1520 (82) [34]	5.45 (0.21) [34]	213 (11.7) [31]	0.106 (0.0098) [33]
<20	1495 (40) [90]	5.29 (0.09) [90]	224 (6.6) [92]	0.111 (0.0067) [92]
High radiation badge reading				
Yes	1492 (80) [23]	5.10 (0.22) [23]	222 (15.9) [24]	0.108 (0.0116) [24]
No	1509 (41) [102]	5.40 (0.97) [102]	221 (5.9) [100]	0.109 (0.0064) [102]
Told overexposed to uranium or radiation				
Yes	1473 (105) [18]	5.56 (0.29) [18]	225 (13.7) [17]	0.112 (0.014) [18]
No	1511 (39) [107]	5.31 (0.09) [107]	221 (6.2) [107]	0.109 (0.0061) [108]

* - See Table 1 for units.

TABLE 12b

Selected Renal Test Results
and Self-reported Exposure Indicators

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Exposure Indicator	Parameter Mean*, (Standard Error of the Mean), and [Number of Participants in Category] Urine: N-acetyl glucosaminidase	Gamma glutamyl transpeptidase	Total Protein	Albumin	Alanine amino-peptidase
Uranium exposure incidents					
≥1	0.934 (0.090) [66]	22.7 (1.49) [61]	27.6 (5.87) [63]	5.60 (0.45) [65]	6.38 (0.37) [61]
0	0.960 (0.082) [56]	22.4 (1.53) [51]	28.8 (5.91) [56]	6.40 (0.89) [56]	6.68 (0.41) [51]
≥20	1.066 (0.161) [32]	23.9 (2.10) [30]	34.6 (9.77) [30]	5.75 (0.65) [31]	7.03 (0.61) [30]
<20	0.903 (0.060) [90]	22.1 (1.23) [82]	26.0 (4.48) [89]	6.05 (0.60) [90]	6.33 (0.30) [82]
High radiation badge reading					
Yes	0.905 (0.149) [24]	21.9 (2.21) [22]	27.9 (11.1) [22]	5.88 (1.48) [23]	6.58 (0.50) [22]
No	0.947 (0.067) [99]	22.7 (1.20) [91]	27.9 (4.41) [98]	5.95 (0.48) [99]	6.48 (0.32) [91]
Told overexposed to uranium or radiation					
Yes	0.892 (0.163) [18]	2.52 (2.92) [17]	31.9 (12.3) [18]	6.77 (0.92) [18]	7.14 (0.87) [17]
No	0.947 (0.066) [105]	22.0 (1.13) [96]	27.2 (4.36) [102]	5.79 (0.53) [104]	6.38 (0.28) [96]

* - See Table 1 for units.

2991

TABLE 13

Participants Having Results of 2 or More Urine Tests
in the Highest 5% of the Distribution of
Creatinine-standardized Concentrations

FEED MATERIALS PRODUCTION CENTER
FERNALD, OHIO
HETA 83-144
SEPTEMBER 16-27, 1985

Participant	High Test Result					Number of Self-reported Uranium Exposure Incidents	Self-reported History of High Radiation Badge Reading	Ever told of Overexposure to Uranium or Radiation	Uranium Exposure Index Exposure-months
	B2M*	RBP*	NAG*	GGT*	AAP*				
A	Yes	Yes	Yes	Yes	Yes	0	No	No	775
B	Yes	Yes	Yes	Yes	Yes	1	No	No	217
C	No	Yes	Yes	No	Yes	0	No	No	552
D	Yes	No	No	Yes	No	≥100	No	Yes	1147
E	No	No	No	Yes	Yes	0	No	No	446
F	No	Yes	No	No	Yes	≥100	Yes	No	1013

*B2M = beta-2-microglobulin, RBP = retinol binding protein, NAG = N-acetylglucosaminidase, GGT = gamma glutamyl transpeptidase, AAP = alanine aminopeptidase

APPENDIX A

Uranium Exposure Categories (See Text for Explanation)

Feed Materials Production Center
Fernald, Ohio
HETA 83-144

Note: Jobs never held by any of the study participants might not be included in this list. A close grouping of job titles indicates either different titles (both official and informal) for the same job or jobs that are similar with respect to potential uranium exposure.

NO EXPOSURE

Nuclear Material Technology Control Administrator

Accounting Clerk I
Accounting Clerk II
Chief Clerk (in Control Prod)
Clerk II (in Records Prod)
Clerk IIA
Clerk III (in Control Prod, AP Adm, Records Prod, Acct)
Clerk IV
Invoice Clerk
Typist Clerk I

Secretary
Steno-Secretary
Stenographer

Utility Man-Cafeteria

LOW EXPOSURE

Section Leader II, except as listed under medium exposure
Technical Assistant, except as listed under medium exposure
Technician "B", except as listed under medium exposure
Technician I (in Anal Tech)
Technician II (in Anal Tech)
Technician III (in Anal Tech)
Technologist I, except as listed under medium exposure
Technologist III (in Anal Tech)

Oiler

Coal Handler

Assistant Pumpman

APPENDIX A

LOW EXPOSURE (continued)

Data Reporting Coordinator

Chief, Nuclear Safety

Scheduler

Storekeeper

Bulldozer Operator
Coal Operator

Tool Room Machinist

Police Sergeant

Senior Engineer
Senior Staff Engineer

Chief Clerk, except as listed under no exposure
Clerk II, except as listed under no exposure
Clerk III, except as listed under no exposure
Clerk V

Power Plant Oiler

Water Plant Operator

Stores Warehouse Attendant
Stores Warehouseman
Warehouseman

Stationary Engineer

Operator "A" (Pumpman)
Pump Operator
Pumpman
Pumpman Operator

Porter

Boiler operator helper (in PP&U, P&WT Engr, PP Engr, Engr)
Fireman's Helper

Assistant Fireman

LOW EXPOSURE (continued)

Boiler operator
Boiler operator helper (other than in PP&U, P&WT Engr, PP Engr, Engr)
Fireman

Security Police
Security Police Officer

Checker
Material Checker

MEDIUM EXPOSURE

Area Maintenance Supervisor
Area Supervisor
Department Superintendent
Department Supervisor
General Supervisor
Group Supervisor
Maintenance Supervisor
Night Shift Supervisor
Production Supervisor
Stores Supervisor
Supervisor
Warehouse Supervisor
Water Plant Supervisor

Carpenter
Carpenter Apprentice

Degreaser
Degreaser Helper

Ind. Truck Operator
Ind. Truck Operator "A"
Operator "A" (Ind. Truck)

Furnace Operator Heater

Gauge Set-up

Heavy Equipment Operator

Inspector
Operator "A" (Inspector)
Operator "B" (Inspector)
Operator "C" (Inspector)

MEDIUM EXPOSURE (continued)

Chief Technician
Tech Asst (Adm Prod, Met Tech, PT Tech, Adm Tech, Chem Tech, Anal Tech)
Technician "B" (in Met Tech)
Technician "C"

Technician I (in H & S)
Technician II (in Met Tech, H & S)
Technician III (in Adm Tech, Met Tech, Prod Tech)
Technologist "A"
Technologist "C"
Technologist I (in PT Tech, Chem Tech, H & S)
Techologist II
Technologist III, except as listed under low exposure

Laundry Worker
Laundryman

Motor Vehicle Operator

Fire and Safety Inspector

Machinist

Assistant Water Plant Operator

Helper
Mill Hand
Mill Helper
Mill Man

Rigger
Rigger Trainee

Machine Set-up
Set-up Man

Laborer (in Trans Prod; 3, 6, & 9 Prod)
Operator "A" (6 Prod)
Operator "B" (other than Inspection), except as listed under high exposure
Operator "C" (other than Inspection and Lab)
Operator "C" (Laborer)

Stamper

Packer

Straightener
Straightener Operator

MEDIUM EXPOSURE (continued)

Hook-up Man

Crop Shear Operator

Cooling Bed Operator

Electrician
Electrician Apprentice (1st Year)
Electrician Apprentice (2nd Year)

Operator "A" (FI Tech)

Section Leader I
Section Leader II (in Chem Tech, PT Tech, Met Tech)

Area Foreman
Area Maintenance Foreman
Craft Foreman
Foreman
Maintenance Foreman

Machine Operator

Tool Maker

Recorder

Guide Setter "B"

Looper Operator

Operator "C" (Lab)

HIGH EXPOSURE

Chemical Operator
Chemical Operator Helper
Chemical Process Trainee
Leaderman

Laborer (in 1, 5, & 8 Prod)
Operator "A" (other than MTOH), except as noted under medium and low exposure
Operator "B" (PP Tech, 5 & 9 Prod)

HIGH EXPOSURE (continued)

Saw Operator

Laborer (in PLP Prod)

Mason

Millwright
Millwright Apprentice 1st, 2nd, 3rd, & 4th
Trades Helper (Millwright)

Instrument Mechanic
Instrument Mechanic Apprentice (1st year)
Trades Helper (Instrument Mechanic)

Dry Cleaner

Painter

Pipefitter
Pipefitter Apprentice

Utilities & Utilities Engineer

Graphite Shop Machinist

Decontaminator

Welder

Crane Operator

Automotive Mechanic
Ind. Mechanic

Machine Tool Operator
Machine Tool Operator Helper
Operator "A" (MTO)
Operator "B" (MTOH)

Lab Machinist