# Health Surveillance of Rocky Flats Radiation Workers

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## SUMMARY

The Former Radiation Worker Medical Surveillance Program at Rocky Flats was formalized in 1992 and provided updated internal dose reassessments and obtained health surveillance information for 12 years. The purpose of this report is to present an analysis of the medical outcomes of the 1,166 program participants, many of whom acquired occupational exposure over several decades, including high internal depositions of plutonium. Approximately 10% of these former workers were found to have received internal exposures higher than reported in health physics records. All participants were included in descriptive analysis. In addition, Standardized Prevalence Ratios were calculated for the 1,096 white males, comparing self-reported cancer and non-cancer chronic medical conditions to occurrences in U.S. white males. The Standardized Prevalence Ratio was statistically significantly elevated for prostate cancer (1.36, lower 95% confidence bound 1.12) and bladder cancer (1. 63, lower 95% confidence bound 1.08). All male participants were offered prostate-specific antigen tests since 1998; this may have contributed to the increased detection of prostate cancer. Among the other medical conditions investigated, the observed number of occurrences was greater than the expected number for all cancers, malignant melanoma, and thyroid cancer, and less than the expected number for digestive cancer, lung cancer, arthritis, diabetes, and emphysema.

## INTRODUCTION

In 1992 the Former Radiation Worker Medical Surveillance Program at Rocky Flats (FRWMSPRF) was formally established when the Department of Energy (DOE) began supporting an expansion of an informal dosimetry recall program that had been in existence since 1980. The FRWMSPRF objectives were to provide medical surveillance for former radiation workers, many with high internal depositions of plutonium, and update their internal radiation dosimetry information. This article focuses on the medical outcomes with the intent of presenting information on the long-term health of these 1,166 former radiation workers, who were unique in their employment stability and occupational exposure potential. The FRWMSPRF continued to operate through 2004 and was adapted during its 12-year duration as knowledge was gained and applicable federal legislation was enacted. Although entrance criteria changed over time (Daugherty et al., 2001), original entrance criteria for this voluntary program included potential exposure to at least 0.2 Sv of radiation. After August 2001 all former workers became eligible to participate, pending available funding. Daugherty et al., (2001) and Final Program Report (2004) provided details of the establishment and operation of the FRWMSPRF.

In addition to Rocky Flats, DOE sites with potential for occupational plutonium exposure included Hanford Engineer Works, Los Alamos National Laboratory (LANL), Mound Site, Pantex Plant, Pinellas Plant, and Savannah River Site. In 1951, a group of 26 LANL plutonium workers highly exposed during World War II was identified with medical outcomes followed for over 50 years. Three deaths in this group were attributed to cancer (bone, lung, and prostate), giving a Standardized Mortality Ratio of 0.75. Additional cancers reported among these 26 individuals include prostate, bladder, malignant melanoma, and non-melanoma skin cancers (Voelz et al., 1997). A cancer incidence study of white non-Hispanic LANL employees, using the New Mexico tumor registry for comparison, found 61 cancers in males and 32 in females for Standardized Incidence Ratios of 0.60 and 1.21, respectively. A recent study of more than 26,000 Hanford Site workers found that the subgroup having routine exposure to plutonium experienced lower mortality rates, especially for cancers, than Hanford workers who never worked with plutonium (Wing et al., 2004).

## METHODS

All 1,166 program participants received a full medical examination, and 513 individuals who met evolving entrance criteria based on dose levels were recalled for follow-up examinations approximately every three years. The medical examinations generally included analyses of urine and blood samples for selected health indicators, including optional prostate-specific antigen (PSA) test for males; measurements of height, weight, blood pressure and pulse; hearing and vision tests; pulmonary function tests; electrocardiograms; screening tests

for occult blood in a stool sample to detect colon cancer; and chest x rays. Also provided were lung counts and urine analyses to provide information for internal radiation dose calculations.

The FRWMSPRF physician performed a physical examination and reviewed medical history with each participant. Participants were mailed copies of their medical examination results with the recommendation to share the information with personal physicians. All medical outcomes reported by participants during the medical history reviews were coded using a standardized coding methodology based on the International Classification of Diseases, 9th Revision, Clinical Modification (Hart and Hopkins, 2003).

The program protocol, including consent forms, procedures, provisions for data confidentiality, protection of participant's rights, and report information, was reviewed annually by an institutional review board. A scientific advisory committee, charged with providing independent technical and management review, was formed in 1993 and functioned throughout the program.

Total effective dose equivalent (TEDE) of external and internal radiation combined was calculated for all program participants except for two who did not provide urine samples or lung counts during their examinations to allow calculation of internal doses. The main sources of high doses were internal depositions of plutonium and its radioactive decay products from accidents and work-related incidents that were well-documented. The annual internal doses were the updated effective dose equivalents from any internal deposition of plutonium, americium, or uranium based on lung count and urine analysis results from the examination and any applicable data from plant health physics records. Internal dose reassessments were performed using CINDY© (Stenge et al., 1992) which is a computer code developed by Battelle, Pacific Northwest Laboratory based on International Commission on Radiological Protection (ICRP-30, 1982) biokinetic and dosimetry. Annual external doses were whole body doses from gamma rays and neutrons. External dose equivalents from film badge or thermoluminescent dosimeter measurements made at the time of exposure were used as recorded in plant health physics records. For employees working in plutonium-related buildings between 1952 and 1970, updated neutron worker exposure data generated by the Neutron Dose Reconstruction Project (Falk et al., 2004) were included. A nominal quality factor of 10 was used to determine the neutron doses.

In addition to TEDE, 10-year latency cumulative external doses and internal doses were calculated for each participant who reported a malignant melanoma or cancer of the bladder, colon, lung, or prostate. These doses were determined by accumulating annual doses through 10 years before diagnosis date (lag 10) since a 10-year latency period between exposure and cancer diagnosis is generally accepted.

Morbidity rates were needed to compare the prevalence of cancer and other medical outcomes in program participants to rates in the U.S. population of the same age, gender, and race. A search was conducted for data that would provide a suitable basis for this assessment. Valid comparison data would be based on self-reported medical outcomes that included both new and chronic conditions, since the medical outcomes data for the FRWMSPRF included both recently diagnosed and long-standing diseases.

The annual National Health Interview Survey (NHIS) conducted by the National Center for Health Statistics statistically samples non-military, non-institutionalized adults throughout the United States and collects self-reported medical information as well as demographic data such as age, race, and gender, and other supplemental information. A series of survey questions ask whether the subject has ever been told by a health professional that he or she has a specifically named disease, which is equivalent to the medical outcome information gathered by the FRWMSPRF. Questions of this type measure the prevalence of a disease in the population at a point in time. More details on these annual surveys can be found at www.cdc.gov/nchs/nhis.htm (National Center for Health Statistics, 2004).

Using the NHIS prevalence data from 1997 to 2001 for medical conditions and the individual sampling weights assigned in the NHIS databases, morbidity prevalence rates in the U.S. population for certain commonly occurring chronic diseases were calculated separately by race and gender in five-year age groups. These NHIS-based rates allowed comparison with the prevalence of certain diseases at the date of the last exam for 1,096 white male program participants. There were not enough non-white female (2), white female (26), or non-white male (42) participants to include these groups in the prevalence analysis. Relevant medical conditions with sufficient data for analysis were diabetes, emphysema, arthritis, all cancers combined (except non-melanoma skin cancer), and selected cancers, including bladder, digestive, lung, melanoma, prostate, and thyroid.

Standardized Prevalence Ratios (SPRs) were calculated using the AMFIT module of EPICURE (Preston et al., 1988-1993). An SPR is defined as O/E*, where O is the sum of the number of participants in each cell who report the medical diagnosis and E* is the sum of the "expected number$_c$" of diagnoses for each cell. The "expected number$_c$" of diagnoses is the product of the comparison population rate for the cell and the number of participants in the cell. Likelihood ratio methods for Poisson-distributed variables were used to determine one-sided lower 95% confidence bounds to test whether any SPRs were significantly elevated.

## RESULTS

### Dosimetry information

Fig. 1 presents the number of participants in each category determined by TEDE. Approximately one-half of the program participants had TEDEs of 0.2 Sv or more, two-thirds had TEDEs of 0.1 Sv or more, and three-fourths had TEDEs of 0.05 Sv or more. Updated internal doses revealed that approximately 10% of the participants received internal exposures higher than reported in their Rocky Flats health physics records, with the largest discrepancy more than 5 Sv. No internal doses were found to be lower than recorded.

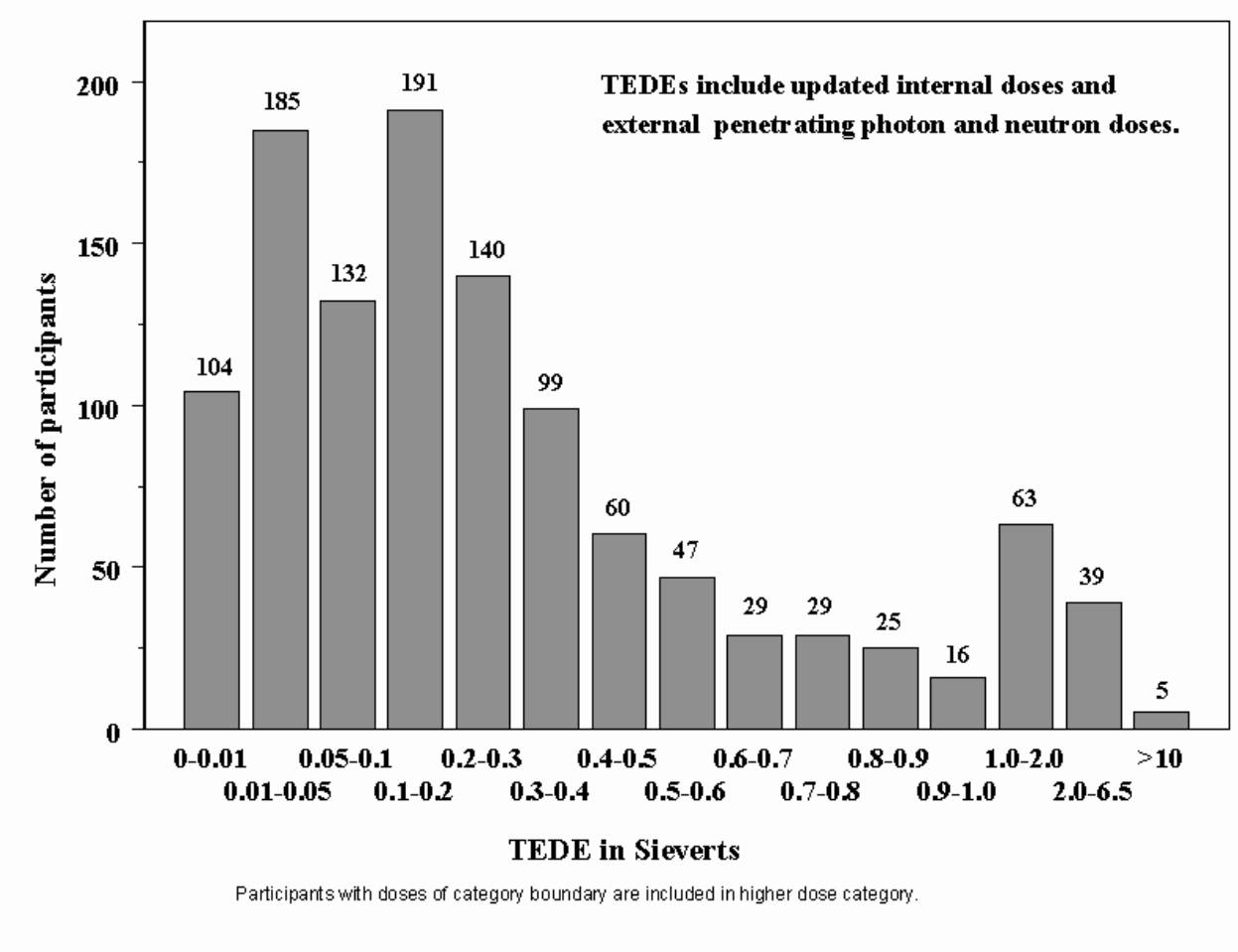


Fig. 1. Updated Total Effective Dose Equivalents for Program Participants

**Descriptive analysis of medical outcome**

Medical examinations uncovered a number of potential medical conditions, although all participants were referred to their personal physicians for definitive diagnosis and follow-up care. The following list of medical findings reflects the types of health conditions identified.

- Abdominal aneurysm
- Anemia
- Cancer (predominantly prostate)
- Cardiac arrhythmia
- Cataracts
- Diabetes mellitus
- Elevated liver enzymes
- Elevated PSA
- Hearing loss requiring hearing aids
- Hypercalcemia
- Hypercholesterolemia
- Hypertension
- Hyperthyroidism
- Hypothyroidism
- Lung nodules
- Obesity
- Occult gastro-intestinal bleeding
- Prostate enlargement
- Pulmonary function deficits
- Renal insufficiency
- Skin lesions, cancerous and precancerous
- Urinary tract infections
- Urinary tract obstruction
- Vision defects requiring correction to drive

**TABLE I. Age at First Cancer Diagnosis for 173 Participants Reporting Cancer**

| Age group | Number | Percent |
|---|---|---|
| < 50 years old | 18 | 11 |
| 50 – 59 | 33 | 19 |
| 60 – 69 | 76 | 44 |
| 70 – 79 | 42 | 24 |
| 80 or older | 2 | 1 |
| Unknown | 2 | 1 |
| Total | 173 | 100 |

FRWMSPRF participants were hired between 1950 and 1996 with 86% hired before 1970. These participants included 1,096 white males, 42 non-white males, 26 white females, and two non-white females, with 161, 9, 2, and 1, respectively, self-reporting one or more cancers (excluding non-melanoma skin cancers). These 173 individuals reporting cancer comprised 15% of the program participants. At the time of first cancer diagnosis nearly 90% of participants reporting cancer were at least 50 years old, which is the age when cancer rates in the general population begin a steady rise. Age at first cancer is presented in Table I. The median age at first cancer diagnosis was 64, ranging from 27 to 83 years old.

Smoking status is of interest because smoking has been shown to raise the risk of developing certain cancers, including bladder and lung cancer (Augustine et al., 1988; Doll and Hill, 1952; Doll and Peto, 1978; IARC, 1986). Among program participants with cancer 25% had never smoked, 71% were current or former smokers, and smoking status was unknown for 4%.

**TABLE II. Type of Cancer First Diagnosed in Each Individual**

| First cancer type | Number (percent) of first cancers |
|---|---|
| Genitourinary (13 bladder, 2 kidney, 81 prostate, 2 testes, 1 male breast, 1 female breast, 1 cervix) | 101 (58) |
| Digestive (4 oral, 17 colon, 1 rectum, 1 liver, 1 pancreas, 1 general digestive) | 25 (14) |
| Melanoma | 20 (12) |
| Respiratory (7 lung, 1 sinus, 3 larynx) | 11 (6) |
| Lymphopoietic (4 leukemia, 5 lymphoma) | 9 (5) |
| Other (1 bone, 4 thyroid, 1 endocrine, 1 unspecified) | 7 (4) |
| Total | 173 |

Altogether 202 cancers were reported by program participants, including 173 first and 29 subsequent cancers. Table II presents the type of cancer first diagnosed for each participant who reported cancer.

**TABLE III. Subsequent Cancers for 24 Participants with Multiple Cancers**

| Type of cancer | Number of cancers |
|---|---|
| Bladder | 5 |
| Colon | 3 |
| Eye | 1 |
| Kidney | 1 |
| Lung | 2 |
| Lymphopoietic | 2 |
| Melanoma | 4 |
| Prostate | 3 |
| Unspecified/Ill-defined | 3 |
| Secondary | 5 |
| Total | 29 |

Genitourinary cancers, which include prostate and bladder cancer, were most frequent. Also prominent were digestive cancers, especially colon cancer, followed by malignant melanomas. Sites for subsequent cancers are presented in Table III, with bladder cancer being most frequently named.

Table IV presents the number of cancer cases associated with each external and internal dose range for the more frequently reported cancers. An individual case was assigned to a category depending upon the lag 10 cumulative external and cumulative internal doses acquired by the date of diagnosis.

**TABLE IV. Number of Participants with External and Internal Doses[a] Accumulated with a 10-Year Latency Period by Cancer Diagnosis**

| | Bladder cancer | | Colon cancer | | Lung cancer | | Malignant melanoma | | Prostate cancer | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Dose in Sv[b]** | **Ext** | **Int** | **Ext** | **Int** | **Ext** | **Int** | **Ext** | **Int** | **Ext** | **Int** |
| **0 - 0.01** | **1** | **6** | **1** | **5** | **0** | **2** | **5** | **7** | **4** | **23** |
| **0.01 - 0.05** | **4** | **0** | **1** | **6** | **1** | **2** | **2** | **6** | **17** | **13** |
| **0.05 - 0.1** | **2** | **0** | **3** | **3** | **1** | **1** | **2** | **2** | **13** | **13** |
| **0.1 - 0.2** | **3** | **5** | **5** | **2** | **3** | **1** | **8** | **2** | **17** | **13** |
| **0.2 - 0.3** | **2** | **3** | **3** | **1** | **2** | **1** | **1** | **3** | **11** | **4** |
| **0.3 - 0.5** | **3** | **0** | **5** | **1** | **1** | **0** | **3** | **3** | **9** | **6** |
| **0.5 - 1.0** | **2** | **3** | **1** | **2** | **0** | **1** | **0** | **1** | **9** | **5** |
| **1.0 or more** | **0** | **0** | **1** | **0** | **0** | **0** | **3** | **0** | **0** | **3** |
| **Unknown** | **1[c]** | **1[c]** | **0** | **0** | **1[d]** | **1[d]** | **0** | **0** | **1[d]** | **1[d]** |
| **Total cases** | **18** | **18** | **20** | **20** | **9** | **9** | **24** | **24** | **84** | **84** |

**[a]Annual external (Ext) and internal (Int) doses in Sv accumulated through 10 years before diagnosis. External dose includes updated neutron doses from NDRP. If dose was on category boundary, participant was counted in higher dose group.**

**[b]Category dose range does not include the listed upper boundary.**

**[c]Doses not calculated because lung count and urine sample not provided.**

**[d]Doses with 10 year lag could not be determined because year of cancer diagnosis was not available.**

## Prevalence analysis

Table V shows that for the 1,096 white male participants the all cancer SPR of 1.03 had a lower 95% confidence bound of 0.90, indicating that the excess in observed cancers was not more than would be anticipated from random variation. Prostate cancer, with 81 observed and 60 expected cases, provided statistical evidence of an elevated SPR, having a lower 95% confidence bound of 1.12. Likewise, bladder cancer with 18 observed and 11 expected cases was significantly elevated with a lower 95% confidence bound of 1.08. Malignant melanoma, with an SPR of 147, showed a suggestion of an increase in prevalence over U.S. white males their age with a lower 95% confidence bound of 0.99. Thyroid cancer had an SPR of 2.96, but

there was substantial uncertainty associated with this estimate since it was based on only three observed cases.

**TABLE V. Standardized Prevalence Ratios for Selected Chronic Medical Outcomes in 1,096 White Male Participants**

| Condition | Observed | Expected | SPR | Lower 95% CL |
|---|---|---|---|---|
| **All cancers** | **161** | **156.49** | **1.03** | **0.90** |
| **Bladder cancer** | **18** | **11.02** | **1.63** | **1.08** |
| **Digestive cancer** | **20** | **22.82** | **0.88** | **0.59** |
| **Lung cancer** | **9** | **9.06** | **0.99** | **0.54** |
| **Malignant melanoma** | **21** | **13.60** | **1.47** | **0.99** |
| **Prostate cancer** | **81** | **59.64** | **1.36** | **1.12** |
| **Thyroid cancer** | **3** | **1.01** | **2.96** | **0.96** |
| **Arthritis** | **401** | **466.69** | **0.86** | **0.79** |
| **Diabetes** | **104** | **139.19** | **0.75** | **0.63** |
| **Emphysema** | **30** | **64.78** | **0.46** | **0.34** |

## DISCUSSION

The FRWMSPRF provided medical surveillance for former radiation workers, many with high internal depositions of plutonium that are now rarely received, and updated internal radiation dosimetry information for participants and the scientific community. Medical conditions identified by the FRWMSPRF are commonly seen in a predominantly elderly male population and could have been found by a personal physician during a comprehensive examination. However, most physicians do not survey a sufficient number of former nuclear-weapons-complex workers to detect possible increases in medical outcomes that might be associated with occupational exposures.

Extreme caution must be used when interpreting the results of this study, particularly in regards to the relationship between radiation dose and cancer in former radiation workers. Several biases, some conflicting, may have resulted from the participant selection process. The original goal of enrolling former Rocky Flats workers who likely had the highest radiation exposures would tend to link higher doses with cancers. Ascertainment of medical outcomes could also be expected to be increased for higher dose participants, who were invited for additional examinations, allowing opportunities to report later diagnoses. The incentive of potential monetary gain from recently legislated federal compensation programs and the

acceptance of call-in volunteers since 2001, regardless of estimated TEDE, may have increased the participation of former workers with cancer. On the other hand, to accept the invitation to participate in the FRWMSPRF an individual must have been alive and healthy enough to attend the medical examination, so cancer and other diagnoses may have been missed among deceased or unhealthy former workers who were non-participants. This particular bias should have been balanced somewhat by the unique survey data set that was used to construct the comparison population rates. Because the NHIS comparison rates were for prevalence, individuals who were potential members of the NHIS sample but were previously deceased from cancer did not contribute to the comparison rates, just as pre-deceased potential participants did not contribute cancers to the program medical outcomes, lessening the chance of bias in the SPR analysis. Also, medical outcomes were self-reported for both the comparison rates and the FRWMSPRF participants. All these biases discussed, and possibly others, were in operation, and their combined effects on the medical outcome data were undoubtedly complex, adding ambiguity to the interpretation of results.

A possible explanation for the statistically elevated prostate cancer SPR (1.36 with lower 95% confidence bound of 1.12) was that the PSA test was offered to all male program participants beginning in 1998, while many men in the general population do not receive this test. A positive PSA test might lead to a prostate cancer diagnosis that otherwise would be missed, since prostate cancer can exist for many years without causing serious symptoms.

The bladder cancer SPR of 1.63 with lower 95% confidence interval of 1.08 also provided statistical evidence of increased risk. Cigarette smoking is well-established as a cause of bladder cancer with this association being observed in numerous epidemiologic studies (IARC, 1986). Although lung cancer and emphysema prevalence rates were low for this group of former workers, 16 of the 18 (89%) participants who reported bladder cancer were current or former smokers. Investigating smoking rates in occupational groups, Lee et al. (2004) found that average smoking rates ranged from 58% in roofers to 4% in physicians and that blue-collar workers continue to smoke in large numbers. However, Lee's data included only current smokers, whereas interest in smoking outcomes related to cancer includes participants who were former smokers as well as current smokers.

Although bladder cancer has also been associated with certain industrial chemicals, none of the most commonly used chemicals at Rocky Flats, carbon tetrachloride, trichloroethylene, tetrachlorothylene, and 1, 1, 1-trichloroethane, are known bladder carcinogens. Studies among workers employed as machinists have indicated that their risk of being diagnosed with bladder cancer is potentially greater than that of other skilled workers. In particular, the cutting oils used in the machining process as coolants and lubricants contain possible carcinogenic substances (Silverman et al., 1983; Vineis et al., 1983). Prior to 1980 Rocky Flats machinists working in

open air non-inert glove-boxes and pipe fitters were likely to have been exposed to cutting oils. Four of the 18 (22%) bladder cancer cases may have had such exposure.

Malignant melanoma also had a marginally elevated SPR (1.47 with lower 95% confidence bound 0.99). One factor contributing to this increase may have been higher ultraviolet exposures due to the thinner atmosphere at Colorado altitudes. The Colorado incidence rates for malignant melanomas for males and females were 33% and 40% higher, respectively, than U.S. rates during the period of FRWMSPRF operation (Finch and Karp, 2004).

Both diabetes screening and the encouragement of healthy lifestyles were a featured part of the routine occupational health program while these former workers were active workers, and these features continued with the FRWMSPRF. It is possible that continuing reinforcement of good health practices contributed to the lower rates of non malignant diseases in these workers.

## CONCLUSIONS

The FRWMSPRF has been a conduit of unique data on one of the largest populations of U.S. radiation workers exposed to plutonium. Because of the biases inherent in this group of program participants, as discussed above, it is not possible to come to firm conclusions on the general health of highly exposed radiation workers. Nonetheless, based on the medical outcomes data generated by the program during the 12 years of operation, the white male former workers do not appear to be experiencing an excessive number of debilitating medical conditions compared to the U.S. population. Further follow-up of these aging program participants could provide valuable information on cancer risk for this unique group of highly exposed workers. Of particular value would be updated SPR analyses to examine whether the significantly increased prevalence of prostate and bladder cancers persists as these individuals grow older and to determine whether the suggested increased risk in malignant melanoma becomes stronger.

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