Cancer in Thirty-nine Nuclear Industry Workers: A Preliminary Report

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We constructed job-exposure profiles and assessed quality of health care in 39 of 47 current and former workers from a nuclear installation in the Negev whose files were referred to us for assessment of a possible work-related aspect of their tumors. The workers, all male except one, began employment at various times from the reactor construction and were engaged in different tasks in laboratory research, construction, maintenance, and service. Of those workers still living the average age was 57.9 years, with a range from 42 to 77 years of age. The average age at the time of death for the deceased workers was 57.3 years, with a range from 41 to 69 years of age. Information on past exposures to radiation and chemical agents came from employee records, dosimetry, and interviews. Personal monitoring (urine assays) in 29 workers indicated the presence of various radionuclides, with higher levels found in persons with work histories in laboratory/research and development and technical/inspector job categories compared to those in administrative/service job categories. Among the 39 workers, latency between onset of exposure and first appearance of illness from tumor was 24.2 years, with a range of 5 to 34 years. Tumor distribution for these workers was as follows: hematolymphatic (n = 11 workers), gastrointestinal (n = 9), breast (n = 1 [male]), brain (n = 1), renal-urogenital (n = 8), skin (n = 1), and pulmonary (n = 8) (5 known smokers). For all tumors except those of the respiratory tract, the first diagnosis was made more frequently in those patients under the age of 55. Observed/expected comparisons for tumor proportional incidence showed excess fractions of blood tumors in persons <55 and >55 years of age. Ratios were greater than unity for breast, blood (n = 1), gastrointestinal, and urogenital tumors in patients <55 years of age and pulmonary tumors in persons >55 years of age. The odds ratio for smoking history in patients with lung tumors compared to those with other tumors was 4.8. Nonmalignant conditions appeared at relatively younger ages. After the exposure episodes two children with major congenital anomalies were born to wives of the workers; one anomaly was fatal. Not all patients were first diagnosed for cancer following referral from the plant medical service, and delays between warning signs and symptoms and medical evaluation occurred in some. Although we lacked data on cancer incidence and population at risk, our findings suggest that earlier assessment of risk should be reconsidered. There is a need for population-based monitoring of risk to nuclear industry workers, external quality control of medical surveillance and care, and improvements in information delivery. — Environ Health Perspect 105(Suppl 6):1511–1517 (1997)

Key words: nuclear industry workers, exposures, cancer, health effects

Introduction

Forty-seven Israeli nuclear industry workers were referred to us for assessment of a possible work-related aspect of their illnesses. Of these 47 workers 24 had already died, 20 were still alive, and 3 workers could not be traced. Our objectives were to examine the exposure histories of these workers in relation to their tumor types, and to evaluate the quality of their environmental and personal protection and the health care they received. We were guided in this preliminary examination by past epidemiologic studies on the excess risks of individuals exposed to ionizing radiation. Among the diagnoses explored in these studies were leukemia (1–5); lymphoma (5,6); multiple myeloma (3,7); solid cancers (8); bone marrow cancer (7); and cancer of the stomach (6,9), pancreas (7), lung (6,7), prostate (6), gastrointestinal tract (5,6), and brain (5).

An unpublished epidemiologic report by the Ministry of Environmental Quality indicated that there was no evidence of an increased risk for all cancers or specific tumors among nuclear industry workers at the same plant (10).

In Israel the worker exposure standard is 5000 mrem or 50 mSv (whole-body exposure) per year, as recommended by the International Commission on Radiological Protection in 1976 (11).

Methods

Most of the workers were referred to us through their trade union representatives. All of the workers had resided in the northern Negev in Israel, and their work involved nuclear reprocessing and research and development (R&D). All of the 47 patients studied except 1 had been diagnosed at least once with cancer between 1965 and 1995 Nineteen patients were diagnosed before 1991 and 17 were diagnosed after 1991. The date of diagnosis was unknown for three workers; 7 had incomplete data. We have no precise information on what fraction these workers represented of all persons with or without tumors from this worksite.

We abstracted information from government worksite medical and employment records of the 47 workers. Interviews of the patients who were still alive substantiated and augmented this database. We have no way of determining, in absolute terms, the degree of reliability and completeness of the data recorded in these records, although files of all or nearly all individual patients clearly contained data gaps concerning exposure records and findings from periodic medical examinations.

We collected data on age, sex, onset of employment, job dates, types of jobs, work tasks, work conditions, personal work practices, and types of agents to which
workers were exposed in each job. Reportable mishaps, environmental safeguards and personal protection (whole body and respiratory), environmental/personal dosimetry, medical history, frequency of medical examinations, and urine assays were evaluated for radionuclides. It is unclear, however, which methods were used by the reactor's management to measure nonpenetrating and penetrating radiation. Internal body burden measurements were rarely done and rarely recorded; therefore, it is not known how the measurements of penetrating and nonpenetrating radiation were assessed. Therefore, in evaluating the measurement data that came to us it may be more prudent to combine measurements of penetrating and nonpenetrating ionizing radiation to provide a possibly more reliable estimate of cumulative exposure.

Based on information collected from the charts and interviews on job description, worksite, degree of expertise required for specified tasks, and mode of contact with hazards, we assigned workers to three general job categories: laboratory/R&D, technical/inspector, and administrative/service. We also asked if there was disclosure of results of environmental and medical exams.

Data from medical records and interviews were used to record best estimates of tumor type, when and where tumors were first suspected or diagnosed, number and types of illnesses other than cancer, and number and types of congenital anomalies in children. Findings were considered adequate to report on 39 of the 47 workers (83%). Seven had cancers for which information was lacking concerning primary tumor site, information on exposure dates or types, or case history; therefore, data on their status are not included in this report.

Information is provided on the years from date of first employment at the installation and occupational status subsequent to employment in relation to tumor types. The observed proportional distribution of tumors in this group of patients (age groups from 35–54 and 55–75+ years of age) was compared with an expected distribution based on data from cases in the entire Jewish male population in 1989 as reported by the Israel Cancer Registry (1/). Because of the uneventful completeness of this group of workers with cancer and our lack of a denominator (i.e., an at-risk population), only crude comparisons could be made of past exposures such as job category, radionuclides, or smoking histories in persons with different tumor types.

**Results**

**Age, Jobs, and Tasks**

Of the 39 workers, all were male except one. Mean age of the survivors was 57.9 years, ranging from 42 to 77 years of age. Mean age of deceased workers was 57.3 years, with a range from 41 to 69 years of age. Most patients began work in the 1960s (range 1959–1975). The average age at start of employment was 29 years (range 18–49 years). All received their job training in Israel and none had prior job experience in environments with exposures to toxic substances or radiation. Their job descriptions included varying tasks in laboratory research, construction, maintenance, and service. Most of the workers were employed at three or more sites and the sites often varied in location, job task and type, and degree and pattern of potential exposures. The subgroups by job titles for the three occupational-job taskgroupings are:

- Laboratory/R&D (lab technician, research and development, chemist, metallurgy, chemical engineer)
- Technical/maintenance (waste disposal, machine technician, nuclear technician, general laborer, inspection engineer of the core, welder, carpenter, equipment technician, supervisor, construction)
- Administrative/service (gardener, administrator, security, laundry).

**Reported Potential Exposures**

Information abstracted from patient records and interviews of the 39 patients on reported or confirmed exposures to ionizing radiation, radionuclides, various metals, solvents, synthetic materials, plastics, natural elements, alcohols, phenols, lubricating oils and noise pollution is as follows:

- Elements and other agents—\(^{25}I\), \(^{131}I\), tritium, \(^{3}Cs\), Pb (vapors, liquid, gas), \(^{40}K\), Hg (purified), \(^{239}Pu\), U (several isotopes), \(^{239}Th\), Li, He (gas), Be, fluorine, C\(_{d}\), Mg, heavy H\(_{2}\)O, NF\(_{3}\), HNO\(_{3}\), NaNO\(_{2}\).
- Metals—Ni, brass, iron, chrome
- Synthetic materials and plastics—Okelon, Locoplex, Teflon, polyvinyl chloride
- Solvents, alcohols, phenols—tribromotoluene, dawex, phenols (liquid, vapor), trichloroethylene, carbon tetrachloride, Genclean (1,1,1-TCHE), benzene, ethanol, aceton, chloroform, tetrachloride (dust)
- Others—lubricating oils, silica gel, Plasmos B, aerosols, coal, noise (85 dB and higher)
- Suspected exposures—nitrosamines, vinyl chloride

Workers in laboratory/R&D and technical/maintenance jobs were estimated to be more heavily exposed than those working in administration/service, based on information on job task descriptions, types of agents, information on mishaps, and estimates of potential exposure derived from tissue levels of radionuclides (see "Radionuclides: Biological Monitoring").

**Protection of Workers from Potential Exposures**

We found suggestions that spatial zoning of work areas was sometimes used as a substitute for rigid enclosure and separation of hazardous processes.

The worksite reportedly had provided most of the workers with recommended standard means of personal protection i.e., clothing, showers, and separate eating areas, although exceptions were noted. Several workers reported that in the past, eating and drinking while working in the lab was not prohibited by the supervisors. Many workers reported that they occasionally did not shower at the end of the work day to avoid missing the company bus ride home. They also reported not having their clothing cleaned or replaced as required.

**Environmental and Personal Monitoring**

Reportedly, the site was equipped with the proper Geiger-Muller counters (and possibly scintillation crystal counters and semiconductor counters as well), pocket ionization chambers (PICs), and thermoluminescence detectors. All workers reported at least one of the above environmental or personal detectors was present in each of the working environments at all times, although the usual custom was to pin the PICs on white laboratory coats that frequently were not worn and were left in clothes lockers.

**Radionuclides: Biological Monitoring**

Results from urine assays for radionuclides were collected from 29 available medical files and analyzed. Radionuclides were observed in the urine of cancer patients from the three job categories. The data indicated the presence of the following...
elements: U (n = 28 workers), $^{239}$Pu (n = 13), $^{137}$Cs (n = 23), $^{40}$K (n = 24), tritium (n = 10), Li (n = 2), F (n = 4), $^{131}$I (n = 3), $^{125}$I (n = 20), Hg (n = 2), and $^{234}$Th (n = 1). Many of these agents emit $\alpha$ and $\beta$ particles as well as $\gamma$-rays.

Mean values and ranges per radionuclide assay aggregated by the three major occupational groupings are shown in Table 1. Mean and maximum tritium levels were much higher in cancer patients from laboratory/R&D and technical/inspector categories than from patients in the administrative/service category. For other radionuclides, maximum values per assay were more commonly found among those with work histories in the technical/inspector category.

Lifetime estimates of exposure (penetrating and nonpenetrating ionizing radiation) compiled by the management of the reactor on the basis of dosimetry readings were available for 23 of the workers. Three of the readings were excluded because they lacked differentiation between penetrating and nonpenetrating ionizing radiation. There were findings on penetrating radiation for 20 workers and on nonpenetrating radiation for 17 workers. Three workers had dosimetry counts for penetrating radiation only.

For the 20 workers with measurements on penetrating ionizing radiation, mean lifetime estimates were 30 mSv (n = 20; range 5.9–75.8). For 16 workers the lifetime or cumulative dose was < 50 mSv; for four workers the average was > 50 mSv.

For the 17 workers with measurements on nonpenetrating ionizing radiation, mean lifetime estimates were 46 mSv (range 0.72–421.8). In one worker, mean lifetime estimate was < 1 mSv; in 12 workers it was < 50 mSv and in four it was > 50 mSv.

Worker Protection: Self-assessment of Control Measure Adequacy

Between 1959 and 1980 workers reported situations suggesting that inadequate protection from exposures was not uncommon. In the 1960s exposure monitoring was fragmentary according to one worker (kidney cancer, diagnosed at age 41). Many of the workers noted long work shifts, inadequate job rotation, inadequate measures for enclosure and separation, malfunctioning hoods and vents, protective garments with rips or openings, and inconsistent provision of respiratory protective gear. One worker related that only three showers were available for his entire unit of 30 people. Information was not routinely provided on the availability, appropriateness, or adequacy of respiratory protective gear or its use and maintenance specifications. As noted, PICs often were not worn during work shifts because they were pinned to lab coats left behind in the lockers.

Worker Protection during Emergency Response

One worker, diagnosed at 53 years of age with multiple myeloma, reported two mishaps. In the first incident elements ignited and caught fire and the worker was required to guard the fire so that no other worker would enter the site. In the second incident he was burned while casting a radioactive element into a vacuum container that broke. Immediately after the incident only urine assay was taken (with a negative result) and no follow-up exams took place. A second worker, a welder with Hodgkin’s lymphoma diagnosed at 45 years of age, reported that small uranium fires were almost daily occurrences. A third worker with cancer of the bladder at age 35 and a recurrence at age 51 reported an incident in the 1960s. Following an explosion of a uranium container in an open room, dust was scattered throughout the area. There was no emergency decontamination at the time, nor were measurements conducted to determine if there was a residual hazard. Additionally, such uranium containers often were not sealed. A fourth worker, diagnosed at age 59 as having hairy cell leukemia, reported that certain tasks required inserting his hands into the center of a process for welding radioactive elements without the use of a mask or gloves. A worker diagnosed with bowel cancer at age 49 related an episode in which a drop of radioactive iodine splashed into his eye. No first aid or medical treatment was provided.

Several workers reported they and many others were required to clean up spills and were not supplied with adequate protective gear. One worker reported a leak from a break in a pipe; after the leak five workers reported suffering from severe nausea, vomiting, and diarrhea.

Outcomes: Tumors and Latency from Onset of Work Exposure

Table 2 presents data on age at onset of cancer, mean ages of those alive and deceased, and years from age of employment to age of diagnosis listed by target organ system for the primary cancer. The mean latency between onset of exposure and first sign or symptoms from cancer was 23.7 years (range 5–34 years). The mean age for diagnosis of cancer was 53.3 years (range 36–77 years). The average latency between start of employment and tumor appearance exceeded 10 years for all tumor categories; the shortest latencies

Table 1. Radionuclides and job category.

| Radionuclide       | Lab/R&D n=8 workers | Technical/inspector n=17 workers | Administrative/service n=4 workers |
|--------------------|---------------------|---------------------------------|-----------------------------------|
| $^{238}$U, gamma/liter | 33                  | 168                             | 59                                |
| $^{239}$Pu, pCi/liter | 5                   | 33                              | 27                                |
| $^{137}$Cs, pCi/kg   | 17                  | 101                             | 14                                |
| $^{40}$K, g/kg       | 24                  | 112                             | 18                                |
| Tritium (pCi/ml)    | 9                   | 45                              | 9                                 |
| Fe                  | 10                  | 10                              | 0                                 |
| $^{125}$I, $^{129}$I | 10                  | 0                               | 0                                 |
| $^{131}$I, pCi        | 2                   | 1                               | 0                                 |
| $^{32}$P            | 0                   | 0                               | 0                                 |
| Total assays, n     | 13                  | 19                              | 0                                 |
| Total assays        | 88                  | 459                             | 127                               |

Abbreviations: pCi, nanocurie; pCi, picocurie. *Units were not available. †All assays were in one individual. 2Values were not available for these assays.
were < 10 years for hematopoietic tumors and gastrointestinal tumors.

Many of the patients (17 of the 39 workers) first became clinically ill after 1991, which was the last year of follow-up for cancer risk in the report to the Ministry of Environmental Quality (10).

Outcomes: Tumor Types and Age of Onset

Table 3 presents patients by the age at the first tumor diagnosis. The peak age group for first diagnosis was 45 to 54 years. In 23 of the 39 patients (59%), first diagnosis was younger than 55 years of age. Table 3 shows that 8 of 11 hematopoietic tumors (79%), 6 of 9 gastrointestinal tumors (67%), 1 of 1 breast tumor (100%), and 5 of 8 tumors of the urogenital tract (63%) appeared in persons younger than 55 years of age. Only one of eight cancers of the respiratory tract was diagnosed in an individual younger than 55 years of age.

Tumors and Past Work History

Table 4 shows that within this group of 39 workers with cancer there were differing patterns of past occupational exposure for the various tumors. Persons with leukemia, multiple myeloma, lymphoma, and tumors of the stomach and brain had a relatively lengthy work history in technical/inspector jobs relative to administrative/service jobs. In persons with renal-urogenital tumors the exposure pattern of laboratory/R&D was high. In contrast, persons with lung tumors had equal numbers of work histories in technical/inspector and administrative/service categories.

Estimated Tumor Proportional Incidence Ratios (Observed/Expected Fraction)

Table 5 provides the proportional incidence ratios for tumor types in this patient series subdivided into age groups 35 to 54 and 55 to > 75 years and compared to the expected distribution in Jewish males in Israel in 1989 (12). Despite the small numbers it is noteworthy that for all blood tumors combined the observed fraction is greater than expected in both the younger and older age brackets. These findings suggest that risks may have increased, in particular for hematopoietic cancers but possibly for pulmonary cancers in older persons as well. There also is a suggestion of possible increases in fractional distribution of tumors in the gastrointestinal and urogenital tracts in persons in the 35 to 54 year age group but this statement must be regarded as speculative.

Table 2. Age at onset, latency, and death.

|                           | n  | Mean, years | Range, years |
|---------------------------|----|-------------|--------------|
| Age at onset of first cancer | NA | 53.3        | 36–77        |
| Mean age of those currently living | NA | 57.9        | 42–77        |
| Mean age at death          | NA | 57.25       | 41–69        |

Table 3. Age at first diagnosis, in years.

| Target organ          | 35–44 | 45–54 | 55–64 | 65–75 | 75+ | Total |
|-----------------------|-------|-------|-------|-------|-----|-------|
| Blood                 | 3     | 5     | 2     | 0     | 1   | 11    |
| Lymphatic             | 2     | 3     | 0     | 0     | 1   | 6     |
| Hematopoietic         | 1     | 2     | 2     | 0     | 0   | 5     |
| Gastrointestinal      | 1     | 5     | 2     | 1     | 0   | 9     |
| Stomach               | 0     | 2     | 0     | 1     | 0   | 3     |
| Large and Small Bowel | 1     | 3     | 2     | 0     | 0   | 6     |
| Breast                | 1     | 0     | 0     | 0     | 0   | 1     |
| Brain                 | 0     | 1     | 0     | 0     | 0   | 1     |
| Renal–urogenital      | 2     | 3     | 2     | 1     | 0   | 8     |
| Prostate              | 0     | 1     | 1     | 1     | 0   | 3     |
| Bladder               | 1     | 2     | 0     | 0     | 0   | 3     |
| Renal                 | 0     | 1     | 1     | 0     | 0   | 2     |
| Skin                  | 0     | 1     | 0     | 0     | 0   | 1     |
| Pulmonary             | 0     | 1     | 1     | 0     | 0   | 3     |
| Total                 | 7     | 16    | 10    | 5     | 1   | 39    |

Table 4. Distribution and proportional fraction by job category.

| Target organ          | I, n(%) | II, n(%) | III, n(%) | (I + II)/III |
|-----------------------|---------|----------|-----------|--------------|
| Hematolymphatic       | 0 (0%)  | 10 (40%) | 1 (14%)   | 10.01        |
| Gastrointestinal      | 2 (29%) | 7 (29%)  | 0 (0%)    | 9.00         |
| Breast                | 0 (0%)  | 1 (4%)   | 0 (0%)    | 1.00         |
| Brain                 | 0 (0%)  | 1 (4%)   | 0 (0%)    | 1.00         |
| Renal–urogenital      | 3 (43%) | 3 (12%)  | 2 (29%)   | 6.20         |
| Skin                  | 0 (0%)  | 1 (4%)   | 0 (0%)    | 1.00         |
| Pulmonary             | 2 (29%) | 2 (8%)   | 4 (57%)   | 4.40         |
| Total                 | 7       | 25       | 7         | 32.7         |

Job categories classified as follows: I, laboratory/R&D; II, technical/inspector; III, administrative/service.

Other data on these patients suggest that second tumors at other sites were probably metastatic. However, one patient whose primary cancer was cancer of the bladder previously had cancer of the vocal cords and just prior to his death had an orbital melanoma. Another patient, a chemist whose work involved contact with radionuclides, was diagnosed with cancer of the large bowel at 49 years of age. After surgery he was transferred to another lab, where he mixed phenols and solvents under heat and without a mask for 4 years (1984–1988); at 54 years of age he was diagnosed with liver cancer.

Tumors and Smoking History

Among the 39 patients there were 13 reported smokers (33.3%). Five of 8 persons with lung tumors (62.5%) and 8 of
Table 5. Observed and expected distribution of tumors by primary site and age group.

| Site                  | Age 35–54 years | Age 55–75+ years |
|-----------------------|-----------------|-----------------|
|                       | Observed n(%)   | Expected* n(%)  | O/E   | Observed n(%) | Expected* n(%) | O/E |
| Blood                 | 103 (21.4)      | 103 (21.4)      | 1.00  | 348 (10.2)    | 348 (10.2)     | 1.00 |
| Lymphatic (all)       | 65 (13.5)       | 65 (13.5)       | 1.00  | 168 (4.5)     | 168 (4.5)      | 1.00 |
| Hodgkin’s             | 21 (4.4)        | 21 (4.4)        | 1.00  | 21 (4.4)      | 21 (4.4)       | 1.00 |
| Non-Hodgkin’s         | 44 (9.1)        | 44 (9.1)        | 1.00  | 163 (4.6)     | 163 (4.6)      | 1.00 |
| Hematopoietic         | 38 (7.9)        | 38 (7.9)        | 1.00  | 180 (5.3)     | 180 (5.3)      | 1.00 |
| Leukemia (all)        | 31 (6.4)        | 31 (6.4)        | 1.00  | 127 (3.7)     | 127 (3.7)      | 1.00 |
| Multiple myeloma      | 7 (1.5)         | 7 (1.5)         | 1.00  | 53 (1.6)      | 53 (1.6)       | 1.00 |
| Gastrointestinal      | 76 (15.8)       | 76 (15.8)       | 1.00  | 115 (32.5)    | 115 (32.5)     | 1.00 |
| Stomach               | 18 (3.7)        | 18 (3.7)        | 1.00  | 264 (7.7)     | 264 (7.7)      | 1.00 |
| Large and small bowel | 58 (12.1)       | 58 (12.1)       | 1.00  | 851 (24.8)    | 851 (24.8)     | 1.00 |
| Breast                | 1 (0.2)         | 1 (0.2)         | 1.00  | 16 (0.5)      | 16 (0.5)       | 1.00 |
| Brain                 | 42 (8.7)        | 42 (8.7)        | 1.00  | 115 (3.6)     | 115 (3.6)      | 1.00 |
| Renal–urogenital      | 88 (18.3)       | 88 (18.3)       | 1.00  | 115 (3.6)     | 115 (3.6)      | 1.00 |
| Prostate              | 8 (1.6)         | 8 (1.6)         | 1.00  | 518 (15.1)    | 518 (15.1)     | 1.00 |
| Bladder               | 57 (11.9)       | 57 (11.9)       | 1.00  | 469 (13.7)    | 469 (13.7)     | 1.00 |
| Renal                 | 24 (4.8)        | 24 (4.8)        | 1.00  | 170 (5.0)     | 170 (5.0)      | 1.00 |
| Skin                  | 64 (13.3)       | 64 (13.3)       | 1.00  | 64 (13.9)     | 64 (13.9)      | 1.00 |
| Pulmonary             | 102 (21.2)      | 102 (21.2)      | 1.00  | 612 (17.9)    | 612 (17.9)     | 1.00 |
| Total                 | 481 (100.0)     | 481 (100.0)     | —     | 3427 (100.4)  | 3427 (100.4)   | —    |

O/E, observed-expected ratio. *Numbers are cases (all males) reported by Israel Cancer Registry (11) in 1989.

31 persons with tumors at other target organs (25.8%) had histories of smoking. This meant that the odds were 4.8 times greater that persons with lung tumors had a history of smoking compared to persons with tumors at other sites. Histories of smoking were reported in two of three patients with prostate cancer, two of three with bladder cancer, one of six with gastrointestinal cancer, two of six patients with blood cancers, and one male with breast cancer.

**Chronic Illnesses and Conditions Other than Cancer**

We had access to the medical files of 26 of the 39 workers (67%) and most records were incomplete. Fifteen patients (five smokers) had cardiocirculatory problems and four (one smoker) had chronic chest conditions. Complaints of dizziness, nausea, headaches, and fatigue during working hours were also reported (Table 6). An examination of Table 6 suggests that the onset of some of these conditions occurred at fairly young ages, i.e., < 55 years of age.

One patient, a chemical technician with breast cancer, had exposures to solvents and ionizing radiation, reported high-exposure mishaps, and was diagnosed at 45 years of age with proliferative glomerulonephritis. Another patient, a lab manager later diagnosed with cancer of the rectum, had exposures to solvents and suffered from chronic thrombocytopenia from age 27 onward, as well as unspecified lung disease. After a splenectomy the worker continued to have thrombocytopenia and later suffered from obesity, diabetes, and retinal detachments. A patient with cancer of the prostate was a heavy smoker who developed hypertension at 35 years of age following massive exposure to lead from smelting and later developed chronic obstructive lung disease.

One male worker reported that within a year and a half after an episode of acute radiation illness from a reported mishap, he fathered a male child who suffers from a clubbed foot, asthma, problems with growth hormones, atopic dermatitis, and celiac disorder. Another male worker reported that his child died at 6 years of age due to congenital heart disease.

**Medical Examinations and Communication of Information**

As a medical routine the workers were tested to undergo a 6-month periodic examinations and an annual whole-body checkup. Yet there were large fluctuations in the frequency of medical exams (1 to 2/year) and large documentation gaps for a majority of the person-years of employment follow-up. On average, for each of the 29 medical records, information gaps totaled an average of 9.3 years/patient, which usually meant two examinations per year. Patients reported that they received interpretations of the results of their exams without the raw numbers. The overall impression was that a systematic approach linking outcomes to information from job exposure matrices and including data on atypical episodes was not fully developed and in the case of exposures to chemicals was nonexistent.

Thirty-one of the 39 patients (80%) had their cancers first diagnosed by the regional referral hospital. Ten of 17 patients who developed cancer while employed at the site were diagnosed following a referral by the plant physician, but in no case was the worker told of the diagnosis. For seven other patients the referral pattern did not involve the plant physician. Four workers were diagnosed after retirement. For 18 patients no information on the referral pattern was available.

These workers included an inspector with managerial responsibilities who was diagnosed with malignant lymphoma of the parotid gland at age 52. He had documented urine levels for many radionuclides and was told by the plant physician that the reason for the referral was suspicion of cancer. Another worker, a security manager with no direct exposures, was diagnosed at 62 years of age with tracheobronchial cancer with metastasis to the brain. After complaining for 3 years of continual pain and difficulty raising his arm he was finally referred by the plant physician. A third patient, 57 years of age, was manager of a technician unit and was exposed to ionizing radiation and solvents. After an unspecified acute medical emergency at work he was diagnosed at the hospital with cancer of the ascending colon. A fourth patient, a technician with exposures to solvents and radionuclides (specifically iodine), had a 4-month history of headaches. He was diagnosed at 48 years of age with a meningioma, the size of which suggested that it had been present for 6 years. A fifth patient,
Table 6. Reported nonmalignant diseases.

| Site and disease                                      | n  | Mean age, years | Range | <50 years | >50 years |
|-------------------------------------------------------|----|----------------|-------|-----------|-----------|
| Cardiovascular                                        |    |                |       |           |           |
| Chest pains                                           | 1  | 31.00          | N/A   | 0         | 0         |
| Hypertension                                          | 2  | 55.00          | 47-63 | 1         | 1         |
| Angina pectoris                                       | 3  | 53.00          | 47-63 | 2         | 1         |
| Chronic ischemic heart disease                       | 1  | 43.00          | N/A   | 0         | 1         |
| Severe varicose veins                                 | 2  | 47.00          | 40-54 | 1         | 1         |
| Myocardial infarction                                 | 1  | 46.00          | N/A   | 0         | 1         |
| Hypertension                                          | 1  | 51.00          | N/A   | 0         | 1         |
| Pulmonary                                             |    |                |       |           |           |
| Granulomatous lung disease                            | 1  | 51.00          | N/A   | 0         | 1         |
| Lung disease (unspecified)                            | 1  | 37.00          | N/A   | 0         | 1         |
| Cold                                                  | 2  | 60.00          | 52-68 | 1         | 1         |
| Asthma                                                | 1  | 63.00          | N/A   | 0         | 1         |
| Renal                                                 |    |                |       |           |           |
| Hydronephrosis                                        | 1  | 53.00          | N/A   | 0         | 1         |
| Proliferative glomerulonephritis                      | 1  | 44.00          | N/A   | 0         | 1         |
| Renal colic                                           | 1  | 28.00          | N/A   | 0         | 1         |
| Nephrolithotomy                                       | 1  | 63.00          | N/A   | 0         | 1         |
| Phonics                                               |    |                |       |           |           |
| Hearing loss (≥85%)                                   | 4  | 52.50          | 49-56 | 1         | 3         |
| Optic                                                 |    |                |       |           |           |
| Retinal detachment                                    | 3  | 57.33          | 50-63 | 1         | 2         |
| Cataract                                              | 1  | 56.00          | N/A   | 0         | 1         |
| Glaucoma                                              | 1  | 62.00          | N/A   | 0         | 1         |
| Hematopoietic                                         |    |                |       |           |           |
| Anemia                                                | 3  | 55.67          | 44-68 | 1         | 2         |
| Microhematuria                                        | 1  | 55.00          | N/A   | 0         | 1         |
| Chronic thrombocytopenia                              | 1  | 37.00          | N/A   | 0         | 1         |
| Splenectomy                                           | 1  | 40.00          | N/A   | 0         | 1         |
| Endocrine                                             |    |                |       |           |           |
| Diabetes                                              | 2  | 40.00          | 29-51 | 1         | 1         |
| Gynecomastia                                          | 1  | 37.00          | N/A   | 0         | 1         |
| Musculoskeletal                                       |    |                |       |           |           |
| Hernia                                                | 5  | 59.00          | 46-64 | 2         | 3         |
| Periodontal disease                                   | 1  | 55.00          | N/A   | 0         | 1         |
| Gastrointestinal                                      |    |                |       |           |           |
| Hemorrhoids                                           | 2  | 51.00          | 41-61 | 1         | 1         |
| Polypos, colon                                        | 1  | 53.00          | N/A   | 0         | 1         |
| Ulcer                                                 | 2  | 54.00          | 50-68 | 1         | 1         |
| Appendectomy                                          | 1  | 28.00          | N/A   | 0         | 1         |
| Psychological                                          |    |                |       |           |           |
| Depression                                            | 2  | 56.50          | 52-61 | 0         | 2         |
| Post traumatic stress disorder                       | 1  | 39.00          | N/A   | 0         | 1         |
| Other                                                 |    |                |       |           |           |
| Obesity                                               | 2  | 57.00          | 51-63 | 0         | 2         |
| Migraine                                              | 1  | 44.00          | N/A   | 0         | 1         |
| Scabies                                               | 1  | 51.00          | N/A   | 0         | 1         |
| Allergy to penicillin                                 | 2  | N/A            | N/A   | N/A       | N/A       |

N/A, not applicable. Where age at diagnosis was unavailable, present age or age of death was used as date of diagnosis.

Discussion

This preliminary study suggests that for the 39 workers with cancer there were plausible relationships between prior exposures to ionizing radiation, smoking, and other agents, and their illnesses. However, definitive statements on risk and causation are premature, given the absence of data on appropriate comparative individuals without cancer and the population at risk.

Urine assays showed radionuclides in all three major job categories of workers but highest levels were seen in technical/inspection and laboratory/R&D groupings compared to administrative/service. As indicated from the descriptions of workplace design, protective systems, personal protection equipment, and practices, there were sporadic or episodic hazardous exposures that perhaps were not infrequent. However, there were many indications that all these areas had improved in recent years. This holds true for exposures both to sources of ionizing radiation and to toxic chemicals.

Nevertheless, the exposure–morbidity relationships described in this preliminary report are similar to those frequently cited, as is the observed versus expected proportional incidence of tumor type (3, 5-9). In this case series the preliminary proportional incidence ratios suggest that for tumors other than lung, histories of technical/inspector and laboratory/R&D work were more common, whereas for lung tumors there was a much greater representation of administrative/service workers. Histories of smoking were more common in persons with pulmonary tumors. Medical conditions other than cancer in these workers were not uncommon both in the younger and older cases, but as with cancer, no statement as to risk can be made. Medical response to warning signs and symptoms was not always rapid. In particular, the periodic examinations for radiation exposure based on radionuclides in tissues or whole-body counts did not distinguish between high exposures received in a brief period of time, as in a mishap, and cumulative, low-level, routine exposure.

Kneale and Stewart (13) state that cumulative exposure levels to external penetrating radiation at mean group levels of 22.3 mSv were found in persons with employment periods at a mean of 6.5 years. Of those exposed >10 years, one-third (33.3%) had an average dose of 63.9 mSv. Higher mean cumulative doses were found in cohorts first hired from 1944 to 1960 and there was a low-to-high
Tumor onset was only recently diagnosed in many of the individuals in this series. This suggests that the previously cited government investigation (10) that reported unremarkable or lower than expected risks for all tumors and specific organ sites for workers at this industrial site up to 1991 must be updated given the importance of latency for an occupational population and the need for risk assessment in specified exposure subgroups using the standard methods of cohort studies. Given the high selection standards for work in the nuclear industry these risks must be assessed in light of the influence of the healthy worker effect for this cohort.

All carcinogens including ionizing radiation have noncarcinogenic effects as well, usually from higher exposures. These effects appear earlier and are more widespread. The occurrence of these outcomes in persons with exposures to ionizing radiation could be regarded as sentinel markers for such exposures and therefore is of interest. Our findings list those nonmalignant outcomes that in some cases are associated with hazardous exposures and in others are from smoking or other circumstances. However, no statement can be made about risk.

In conclusion, because our findings are based on a patient series we cannot draw any inferences as to whether there were excess risks for cancer or other outcomes at this nuclear installation. However, the findings do suggest the need for testing the hypothesis that there were possible excess cancer risks for certain organ sites, notably in persons with past work in the technical/inspector and laboratory/R&D job categories. Without complete data on cancer incidence and data on population at risk it cannot be determined whether these risks exceed unity.

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