# Cancer Mortality and Morbidity Among Rubber Workers [1,2]

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ABSTRACT—Mortality and morbidity from cancer among a cohort of 13,570 white male rubber workers were examined. Each worked for at least 5 years at the Akron, Ohio, plant of the B. F. Goodrich Company. The potential period of follow-up was from January 1, 1940 to June 30, 1976. Departmental work histories were based primarily on records maintained by Local 5, United Rubber Workers. The occurrence of cancer was measured by death certificates and by a survey of Akron-area hospital tumor registries from 1964 to 1974. Two types of analyses were made: 1) an external comparison of mortality rates of rubber workers versus rates of U.S. white males, and 2) an internal comparison of cancer morbidity rates among persons who were employed in various work areas of the plant. Excess cases of specific cancers (observed/expected numbers) among workers in specific work areas included: stomach and intestine: rubber making (30/14.4); lung: tire curing (31/14.1), fuel cells and/or deicers (46/29.1); bladder: chemical plant (6/2.4), and tire building (16/10.7); skin cancer: tire assembly (12/1.9); brain cancer: tire assembly (8/2.0); lymphatic cancer: tire building (8/3.2); and leukemia: calendering (8/2.2), tire curing (8/2.6), tire building (12/7.5), elevators (4/1.4), tubes (4/1.6), and rubber fabrics (4/1.1). Agents that may be responsible for these excesses were considered.—J Natl Cancer Inst 61: 1047–1053, 1978.

In March 1976 two reports were published in which the mortality experience of rubber workers at the B. F. Goodrich Company, Akron, Ohio, between January 1, 0, and June 30, 1974, was described (*1*, *2*). Excesses several cancers were seen in groups of employees who worked in specific departments. An employee was ca dered to have died from cancer only if cancer was sp ied as the underlying cause of death on the death ertificate. Most of the analyses were based on the department in which an employee had worked the longest.

In the present report, more details are considered with respect to the cancer experience and the work experience of the Akron employees. Two additional years of cancer mortality have been accumulated, and all cases of cancer that have been identified have been included. An employee's departmental work experience has been defined as the number of years he was estimated to have worked in the various departments. This estimate provides a rough measure of exposure to the environmental conditions that prevailed.

## METHODS

*Definition of population.*—B. F. Goodrich employees included in this report were the white male union members whose mortality experience was previously described (*1*). (Since the early 1940's, all wage employees have been union members.) One person was excluded because of an error in the data; this left a study population of 13,570. Included was any Akron employee who worked for at least 5 years prior to July 1, 1971. The potential period of follow-up was from January 1, 1940, through June 30, 1976.

*Definition of cancer.*—In the previous report (*1*), a person was defined as having cancer only if it was the underlying cause of death. In the present report, two additional criteria have been used: 1) Cancers that were listed on the death certificate but were not the underlying cause of death were included. 2) A survey was made of the tumor registries of four Akron-area hospitals (Akron City, Akron General, St. Thomas, and Barberton Citizens). B. F. Goodrich employees whose cancers were diagnosed between approximately 1964 and 1974 were identified in this survey; these cancers were also included.

In the original report, 980 men were determined to have died from cancer between January 1940 and June 30, 1974. In the current study, an additional 379 cases of cancer have been identified. Of these, 68 were the primary cause of death between June 30, 1974, and June 30, 1976; 81 were a secondary cause of death between January 1, 1940, and June 3, 1976; and 230 were incident cases identified solely from the Akron registries.

We have essentially complete identification of fatal cancers in this population and an incomplete ascertainment of the nonfatal cancers. Therefore, a comparison with an external population can be made only for mortality data. In analyses with morbidity data, we have used internal comparisons (*see* "Analysis of data"). Inasmuch as the identification of nonfatal cases of cancer was made without knowledge of a person's work experience, the incomplete ascertainment should not lead to any important bias in within-plant comparisons.

*Validation of diagnosis of cancer.*—The diagnosis of cancer among Akron employees was made initially from death certificates or from rosters compiled from hospital tumor registries. For each person who worked

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ABBREVIATIONS USED: BNA=β-naphthylamine; ICD=International Classification of Diseases; PAH=polycyclic aromatic hydrocarbons; PBNA=phenyl-β-naphthylamine.

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in a department whose employees were found to have an excess rate of a specific cancer, an attempt was made to verify the diagnosis. If a person died in a hospital, that hospital was contacted and more details from the medical record were sought. If a person was identified from a hospital tumor registry, the patient's medical record was reviewed by the hospital to verify the diagnosis.

In general, the initial data were accurate. However, autopsy sometimes revealed that the person did not have cancer, or we found in a few instances that the person was not the B. F. Goodrich employee of the same name. Because corrections were made only for departments in which excess cancer was suspected, no false-positive associations were made. If anything, this procedure led to a slight underestimate of the size of an association between a department and a type of cancer.

*Definition of departmental work experience.*—No precise data were available from company or union records as to the work experience of employees. The data used were obtained primarily from the files of the union. On the dues cards was entered the four-digit number of the department in which the employee was working. Whenever an employee changed departments, the new departmental number was entered in sequence. Although the date of the change was not recorded, a new card was made out every 4 or 6 years. Therefore, the period when an employee worked in a specific department was known, and the actual year of entry into the department could be estimated.

Prior to 1933, no departmental information was available from union records. All that was generally available from company records was the service date, that is, the year of employment adjusted for layoffs. In this analysis, the years between the service date and 1933 were assumed to be spent in the same department that the employee was in when the union was organized in 1933. This probably is a reasonable approximation: Prior to 1952 transfers from one plant division to another were uncommon, and consequently the opportunity to transfer from one department to another was limited.

*Analysis of data.*—The first step was to an mortality experience from January 1, 1940, to 1976, of all employees as compared to U.S. whi (3). On the basis of an apparent excess of one cancers, specific departments were selected for analysis. Grouping of departments was done excess of specific cancers was seen in departme had similar industrial processes or exposur ployees in departments with no excess of a cancer were grouped together as "residual" em

Next, age- and time-standardized morbidi were computed for specific cancers in specific ments, with the use of data on all incident The standard used was the age-specific pers distribution of all 13,570 employees. The standa of the standardized rate was computed (4).

Analyses were next done according to the nu years an employee worked in a department or g departments. If an excess of cancer was seen men who had worked some minimum number in a department (for example, 5), in subsequen ses men who worked 0–4 years were not inclu advantage of this exclusion was that overlap of mental experience was greatly reduced. Th whereas a hierarchical grouping of work exp was used, there was no important uncertainty which department an individual belonged.

Finally, a direct comparison was made b employees in departments with an excess of a cancer and employees in residual department observed numbers of cancer among employees lected departments were distributed according t acteristics of age and time. The numbers ex among these employees were computed on the b the age-specific rate of cancer in the group of re employees. These comparisons are illustrated it 2.

## RESULTS

### Stomach and Intestinal Cancer

As seen in table 1, stomach cancer (ICD code 15

TABLE 1.—*Mortality and morbidity from cancer of the stomach or intestine according to work area*

| Work area and minimum years in area[a] | No. of persons[b] | Reported No. of deaths[c] | | | | Cumulative No. of cases[d] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Observed | | Expected[e] | | Total cases | | Standardized rate[f] | | Rate rati | |
| | | Stomach | Intestine | Stomach | Intestine | Stomach | Intestine | Stomach | Intestine | Stomach | Inu |
| Rubber making,[g] 5+ yr | 718 | 12 | 13 | 5.7 | 6.5 | 13 | 17 | 63 (18) | 78 (19) | 2.2 | |
| Solid tires/track, 5+ yr | 307 | 4 | 8 | 2.1 | 3.0 | 4 | 9 | 41 (20) | 89 (30) | 1.4 | |
| Residual | 12,545 | 82 | 86 | 86.1 | 94.5 | 92 | 122 | 29 (3) | 38 (3) | 1.0 | |
| Total | 13,570 | 98 | 107 | 93.9 | 104.0 | 109 | 148 | — | — | — | |

[a] Employment in work areas is mutually exclusive and hierarchical from the top.
[b] No. of persons who worked at least the minimum number of years in the area.
[c] Deaths occurring during the period January 1, 1940–June 30, 1974.
[d] Cases occurring during the period January 1, 1940–June 30, 1976.
[e] Calculated on the basis of U.S. mortality rates for white males.
[f] Rate/100,000 persons/yr. Standardized by the direct method to the age-specific person-year distribution of all 13,570 pe
*Values in parentheses* are SE.
[g] Includes compounding, mixing, milling, and testing.

*—Observed and expected cases of stomach and intestine cancer in selected departments, according to selected characteristics*

| Characteristic | Category | No. of cases among workers in rubber making* | | No. of cases among workers in solid tires/tracks* | |
|---|---|---|---|---|---|
| | | Observed | Expected | Observed | Expected |
| started working in department, yr | <35 | 13 | 6.7 | 5 | 2.2 |
| | 35-44 | 15 | 4.5 | 2 | 1.9 |
| | ≥45 | 2 | 3.2 | 6 | 2.2 |
| started working in department | <1925 | 3 | 3.9 | 5 | 1.6 |
| | 1925-1939 | 20 | 7.4 | 3 | 1.3 |
| | ≥1940 | 7 | 3.0 | 5 | 3.4 |
| of yr worked in department | 5–14 | 11 | 5.8 | 7 | 3.8 |
| | 15–24 | 11 | 4.7 | 1 | 0.9 |
| | ≥25 | 8 | 3.8 | 5 | 1.6 |
| at cancer occurrence, yr | <65 | 10 | 5.8 | 2 | 2.6 |
| | 65-74 | 11 | 4.9 | 5 | 2.0 |
| | ≥75 | 9 | 3.6 | 6 | 1.7 |
| Yr of occurrence | <1960 | 6 | 5.6 | 4 | 2.2 |
| | 1960-1969 | 16 | 5.5 | 5 | 2.5 |
| | ≥1970 | 8 | 3.2 | 4 | 1.6 |

*Expected cases were calculated on the basis of age-specific morbidity rates for residual employees, as defined in table 1.
†Minimum of 5 yr in work area.

vision) was increased in men who worked at least 5 years in rubber making (compounding, mixing, milling, and testing laboratories). Intestinal cancer (ICD 152, 153) was increased in men who worked at least 5 years in rubber making and in those who worked at least 5 years in solid tires/tracks. As seen in table 2, the excess of cancers of the stomach and intestine among men who worked at least 5 years in rubber making occurred primarily in those who started working before age 45, who started working after 1925, and who developed cancer since 1959. For men who worked at least 5 years in solid tires/tracks, the excess was seen only at age 65 and above.

## Pancreas Cancer

Pancreas cancer (ICD 157) was increased in two dissimilar departments—elevators and tire curing (table 3). The age-standardized rates in these departments were, respectively, 3.0 and 2.5 times higher than in men who did not work at least 5 years in one of these departments.

## Lung Cancer

Excess lung cancer (ICD 162, 163) was seen in three departmental groupings: tire curing, tire molds, and fuel cells/deicers (table 3). The excess lung cancer occurred only in men who worked at least 5 years in curing or in molds. For fuel cells/deicers, the excess was greater in men who worked 0–4 years than in those who worked a longer period of time. Although several men worked both in fuel cells and deicers, the excess lung cancer was associated with each department independently.

For men who worked in tire curing, an excess of lung cancer was seen in each category of the age- and time-standardized characteristics, except for those who started working after age 45 (1 observed, 2.5 expected). The major employment in the fuel cell/deicers departments was during World War II; therefore, few men started working there prior to 1940. The predominant excess of lung cancer in these men occurred under age 65 (30 observed, 17.6 expected), before 1970 (30 observed, 16.2 expected), and in men who worked fewer than 25 years (45 observed, 28.8 expected).

## Prostate Gland Cancer

Two apparently unrelated departments—material conservation and final finish—were identified in which 4 men who had worked at least 25 years developed (and died from) prostate gland cancer (ICD 177). Even though these men were older than the residual group, the age-standardized rates of prostate gland cancer were considerably elevated (table 3). Excess cancer of the prostate gland was also seen in men who worked in machine maintenance, with the greatest excess being seen in those who worked a relatively short time.

## Bladder Cancer

Bladder cancer (ICD 181) was seen to the greatest excess in men who ever worked in the chemical plant and in those who worked at least 5 years in tire building (which includes band, bead, and tread production as well as tire assembly). In the previous study (*1*), men who worked in warehouse/shipping had the greatest excess of bladder cancer. In the data presented in table 3, the excess in these departments is minimal.

Among men who worked in the chemical plant or in tire building, excess bladder cancer was seen only in those who started working in the departments between 1925 and 1940 (13 observed, 5.9 expected) and who worked at least 15 years in the department (18 observed, 9.9 expected).

## Skin Cancer

Skin cancer (ICD 190, 191) was seen to excess in men who worked in tire assembly (table 3). This is the work

...2.—*Observed and expected cases of stomach and intestine cancer in selected departments, according to selected characteristics*[a]

| Characteristic | Category | No. of cases among workers in rubber making[b] | | No. of cases among workers in solid tires/tracks[b] | |
|---|---|---|---|---|---|
| | | Observed | Expected | Observed | Expected |
| ...e started working in department, yr | <35 | 13 | 6.7 | 5 | 2.2 |
| | 35-44 | 15 | 4.5 | 2 | 1.9 |
| | ≥45 | 2 | 3.2 | 6 | 2.2 |
| ...started working in department | <1925 | 3 | 3.9 | 5 | 1.6 |
| | 1925-1939 | 20 | 7.4 | 3 | 1.3 |
| | ≥1940 | 7 | 3.0 | 5 | 3.4 |
| ...of yr worked in department | 5–14 | 11 | 5.8 | 7 | 3.8 |
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| ...r of occurrence | <1960 | 6 | 5.6 | 4 | 2.2 |
| | 1960-1969 | 16 | 5.5 | 5 | 2.5 |
| | ≥1970 | 8 | 3.2 | 4 | 1.6 |

[a] Expected cases were calculated on the basis of age-specific morbidity rates for residual employees, as defined in table 1.
[b] Minimum of 5 yr in work area.

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| Work area and minimum years in area[a] | No. of persons[b] | Reported No. of deaths[c] | | Cumulative No. of cases[d] | | |
|---|---|---|---|---|---|---|
| | | Observed | Expected[e] | Total cases | Standardized rate[f] | Rat rati |
| **Pancreas cancer** | | | | | | |
| Elevators, 5+ | 259 | 5 | 2.0 | 6 | 47 (20) | 3.0 |
| Tire curing, 5+ | 660 | 6 | 3.6 | 8 | 41 (15) | 2.5 |
| Residual | 12,651 | 42 | 54.7 | 52 | 16 (2) | 1.0 |
| Total | 13,570 | 53 | 60.3 | 66 | — | — |
| **Lung cancer** | | | | | | |
| Tire curing, 5+ | 661 | 26 | 15.0 | 31 | 150 (27) | 2.2 |
| Tire molds, 5+ | 272 | 9 | 5.7 | 10 | 136 (43) | 2.0 |
| Fuel cells/deicers, 5+ | 1,139 | 23 | 20.0 | 26 | 97 (20) | 1.4 |
| Fuel cells/deicers, 0–4 | 1,051 | 20 | 12.8 | 20 | 134 (34) | 1.9 |
| Residual | 10,447 | 156 | 199.6 | 196 | 69 (5) | 1.0 |
| Total | 13,570 | 234 | 253.1 | 283 | — | — |
| **Prostate gland cancer** | | | | | | |
| Material conservation, 25+ | 28 | 4 | 0.4 | 4 | 274 (136) | 7.6 |
| Final finish, 25+ | 88 | 4 | 1.2 | 4 | 88 (46) | 2.4 |
| Machine maintainance, 5+ | 846 | 7 | 6.8 | 15 | 59 (15) | 1.6 |
| Machine maintainance, 0–4 | 402 | 1 | 2.0 | 7 | 75 (28) | 2.1 |
| Residual | 12,206 | 66 | 78.6 | 111 | 36 (3) | 1.0 |
| Total | 13,570 | 82 | 89.0 | 141 | — | — |
| **Bladder cancer** | | | | | | |
| Chemical, 0+ | 784 | 2 | 1.2 | 6 | 61 (25) | 2.5 |
| Tire building, 5+ | 1,969 | 7 | 5.3 | 16 | 36 (9) | 1.5 |
| Raw material warehouse/shipping, 0+ | 513 | 4 | 1.7 | 4 | 26 (13) | 1.1 |
| Finished goods warehouse, 0+ | 445 | 4 | 1.5 | 5 | 36 (16) | 1.5 |
| Residual | 9,859 | 31 | 29.8 | 64 | 24 (3) | 1.0 |
| Total | 13,570 | 48 | 39.5 | 95 | — | — |
| **Skin cancer** | | | | | | |
| Tire assembly, 5+ | 1,299 | 2 | 1.8 | 12 | 47.0 (14.1) | 6.5 |
| Residual | 12,271 | 7 | 15.2 | 23 | 7.2 (1.5) | 1.0 |
| Total | 13,570 | 9 | 17.0 | 35 | — | — |
| **Brain cancer** | | | | | | |
| Tire assembly, 5+ | 1,299 | 7 | 4.3 | 8 | 22.2 (7.9) | 4.1 |
| Residual | 12,271 | 13 | 20.8 | 17 | 5.4 (1.3) | 1.0 |
| Total | 13,570 | 20 | 25.1 | 25 | — | — |
| **Lymphatic cancer** | | | | | | |
| Tire building, 5+ | 1,969 | 6 | 2.3 | 8 | 15.7 (5.6) | 2.5 |
| Residual | 11,601 | 15 | 18.9 | 19 | 6.4 (1.5) | 1.0 |
| Total | 13,570 | 21 | 21.2 | 27 | — | — |
| **Leukemia** | | | | | | |
| Calendering, 5+ | 316 | 4 | 1.5 | 8 | 57 (21) | 3.6 |
| Tire curing, 15+ | 421 | 5 | 1.8 | 8 | 50 (18) | 3.1 |
| Tire building, 5+ | 1,957 | 7 | 6.1 | 12 | 26 (7) | 1.6 |
| Elevators, 5+ | 252 | 3 | 1.2 | 4 | 46 (29) | 2.9 |
| Tubes, 5+ | 339 | 4 | 1.3 | 4 | 40 (20) | 2.5 |
| Rubber fabrics, 0+ | 280 | 4 | 0.9 | 4 | 55 (28) | 3.5 |
| Residual | 10,005 | 28 | 30.2 | 38 | 16 (3) | 1.0 |
| Total | 13,570 | 55 | 43.0 | 78 | — | — |

[a] Employment in work areas is mutually exclusive and hierarchical from the top.
[b] No. of persons who worked at least the minimum number of years in the area.
[c] Deaths occurring during the period January 1, 1940–June 30, 1974.
[d] Cases occurring during the period January 1, 1940–June 30, 1976.
[e] Calculated on the basis of U.S. mortality rates for white males.
[f] Rate/100,000 persons/yr. Standardized by the direct method to the age-specific person-year distribution of all 13,570 pers
*Values in parentheses* are SE.

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area where the components of the tire are put together. Most of the skin cancers were of the squamous cell type and 4 were fatal. Since skin cancer is usually not fatal, most of the skin cancer was ascertained in hospital tumor registry review, which covered period 1964–1974. The excess occurred mainly in

worked at least 25 years in tire assembly (8 rved. 0.9 expected).

### ain Cancer

Brain cancer (ICD 193) was seen to excess in men o worked in tire assembly (table 3). It occurred only men under the age of 65 (8 observed. 1.3 expected) in those who started working after 1925 (8 observed. 1.3 expected). Brain cancer was seen mainly in n who worked less than 15 years in the department observed. 1.4 expected).

### ymphatic Cancer and Leukemia

Lymphatic tumors (ICD 200, 202) were seen to excess men who worked at least 5 years in tire building able 3). Leukemia (ICD 204) was seen to excess in en who worked in six different departments. Except tire building, the rate for leukemia in each of these partments was at least 2.5 times the rate in the sidual workers.

These two diagnostic categories were grouped in rther analyses. An association of interest is with the ar that work in the department started. For men ho started working after 1945, no excess leukemia or mphatic cancer was seen (4 observed, 4.5 expected). Also, only a slight excess was seen in men who worked ss than 15 years in one of these departments (10 bserved. 8.2 expected).

The specific diagnosis of the leukemias or lymphatic mors among the men who worked in one of the departments specified in table 3 were: lymphosarcoma, cases; reticulum cell sarcoma, 1 case; malignant lymphoma, 1; lymphatic leukemia, 19; myeloid leukemia, 15; monocytic leukemia, 2; and other and unspecified leukemia, 4.

## DISCUSSION

In analyzing these data, we relied heavily upon searching for associations between specific cancers and work in departments in which specific substances were used. We grouped such departments when consistent associations were seen. This strategy was used because of the complexity of the work patterns within the plant and because of general uncertainty as to the nature of the hazard of working in the rubber industry. This strategy requires cautious interpretation of any association. To judge whether any cancer-department association is likely to be causal, independent data must be evaluated. Such data include other studies of mortality and morbidity among human populations and toxicologic studies on animals.

Also, internal consistency in the data can be used. If excesses of a specific cancer are found in departments that have a common exposure, it seems reasonable to consider the possibility that the association is causal. In the analyses in which the cancer morbidity rates in "residual" workers were used to compute the expected number of cases of cancer among workers in specific departments, the resultant patterns of observed-to-expected ratios would largely be independent of the data searching process used. To the extent that these patterns are in accord with knowledge of exposure patterns, inferences as to causality may be made.

### Gastrointestinal Cancer

The excess of cancers of the stomach and th intestines among men who worked in processing tend to support causal association. Excesses of these cancer have been reported in other studies of rubber worker (*5–7*). These excesses also tended to occur in area where the ingredients of rubber are compounded an mixed (*8–10*).

Traditionally, the processing area has been dusty with a large fraction of the nonrespirable airborn particulates likely to be trapped on the surface of th respiratory tract and eventually swallowed. Followin are several compounds that should be considered as th agents responsible for the excess stomach and intestina cancer.

*Carbon black.*—Carbon blacks were introduced int the rubber industry during World War I. Three com mon types of carbon blacks have been used: 1) channe black (average particle diameter, 5–30 nm), 2) furnac black (30–80 nm), and 3) thermal black (120–150 nm) The furnace type is the most common. Many furnac blacks have surface-adsorbed PAH that can be extracte by organic solvents (*11*). Some of these adsorbed PAH have been shown to be carcinogenic and mutagenic ir animals or bacterial test systems (*11–15*). Whereas current exposure to carbon black rarely exceeds 1 mg/m³ (mass respirable), past exposures were probably higher, inasmuch as the threshold level is 3 mg/m³ (*16*). In one study of workers exposed to carbon black during its production, no excesses of cancers were found (*17*).

*Softeners, extenders, and plasticizers.*— In the processing area, these substances are added to nearly all rubber compounds. Many are petroleum or coal tar products (*18*). Processing oils, common softeners, contain modest amounts of PAH. Other compounds used as softeners or plasticizers include coal tars, asphaltum fluxes,[6] and petroleum-derived waxes. Coal tars have been suspected of causing a wide range of human cancers (*19*).

*Antioxidants and accelerators.*—Several of these agents are suspected of being carcinogenic on the basis of animal studies (A), of forming carcinogenic metabolites (B), or of being mutagenic in bacterial systems (C) (*20–23*): *antioxidants*—4-isopropoxydiphenylamine (A), *N, N*-diphenyl-*p*-phenylene diamine (C), PBNA (B), and *sym*-2*β*-naphthyl-*p*-phenylene (C); *accelerators*—2-mercaptobenzothiazole (A), *N*-oxydiethylene-2-benzothiazole (A), hexamethylenetetramine (A), and bis(dimethyldithiocarbamato)zinc (A).

Several compounds have been extensively used. For example, 1 million pounds of PBNA were used each

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[6] Asphaltum oil or fluxes are black, tarry materials obtained by partial blowing (oxidation) of still residues from the distillation of petroleum.



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year. Although PBNA is metabolized to BNA, a potent bladder carcinogen (*22*), we found no excess bladder cancer among processing workers. It is interesting that no excess lung cancer was found in the processing area. We earlier reported an increase of respiratory morbidity among processing room workers (*24*).

### Pancreas Cancer

The excess pancreas cancer in men who worked in elevators and in tire curing is of questionable importance. The excesses are based on relatively small numbers, and these departments do not share any common exposure.

### Lung Cancer

The excess lung cancer in men who work in tire curing is based on relatively large numbers. A similar excess among curing workers has been reported (*6*). Curing workers in Akron had increased death rates from pneumonia (*1*). We also reported an increase in respiratory morbidity among current curing workers in other tire plants (*25*). In the curing area, the likely causal agents are the constituents of the curing fume. This fume is the result of the volatilization of the basic ingredients in the tires. The major constituents are rubber polymers, antioxidants, accelerators, and low-boiling constituents of softeners (*26*). The amount of PAH in the curing fume would not be great because of their high boiling points. Another possible exposure was to talc, which was used to dust some types of tires. An excess of lung cancer has been reported in talc miners (*27*).

The excess of lung cancer in men who work in the tire molds area is small. This is a standard metal machining shop and the only likely adverse exposure is to cutting oils. Nitrosamines, which are animal carcinogens, are present in cutting oils (*28*). However, no excess of lung cancer was seen in a study of exposure to cutting oils (*29*).

The data on lung cancer in men who worked in fuel cells/deicers is unusual in that the excess was seen mainly in men who worked a relatively short time. This is not surprising, inasmuch as employment in this department occurred largely during World War II. If this is a causal association, a chlorinated organic solvent or acetylene black most likely was responsible because exposure to these agents was higher here than in other departments. In the deicer operation, acetylene black was sprayed on metal. Also, ethylene dichloride was used predominantly in these areas. This substance has been reported to be a bacterial mutagen (*30*).

### Prostate Gland Cancer

Excesses of prostate gland cancer among all rubber workers have been reported (*5, 7*). The excess cases of prostate gland cancer are not likely due to a common exposure, because no apparent link exists among the departments. Machine maintenance is a standard engineering shop; the most likely causal exposure would be to cutting oils (*28*). Although cadmium expos has been reported to be associated with prostate gla cancer (*31*), exposure in this plant was not appreciat

### Bladder Cancer

Cancer of the urinary bladder has long been rec nized as a disease of rubber workers (*32*). However, one recent study of rubber workers, no excess bladder cancer was found (*5*).

The excess of bladder cancer in chemical workers relatively small. Two of the men worked only for year in the chemical plant. However, two oth worked for at least 15 years with the PBNA autocla therefore, a causal connection must be seriously co sidered. (A third man who worked with PBNA fro 1952 to 1962 died from bladder cancer on October 1976.) BNA or one of its metabolites is the substar believed to have caused bladder cancer in rubb workers in earlier studies. PBNA has been demo strated to metabolize to BNA in the body (22).

### Skin Cancer and Brain Cancer

Excesses of cancers of the skin and brain we observed among men who worked in tire assemb departments. Both types of cancers have large ra ratios: 6.5 and 4.1, respectively. Most of the sk cancers were of the basal cell or squamous types a were located predominantly on the neck and head. T skin cancer excess occurred in men who started wor ing before 1940, whereas the brain cancer excess w present in men who started working after 1940.

Few unique exposures were noted in this area. O possibility was carbon tetrachloride, a potent anim carcinogen (*33*). This solvent was added to oth solvents to reduce flammability. Two exposures may related to the excess skin cancer. One is exposure to d drum resins, which contained coal tars and which ha been associated with skin cancer in other industri (*19*). The second is exposure to the accelerator hex methylenetetramine, a suspected animal carcinog that has been described as a common cause of derm titis among tire builders (*21, 34*).

### Leukemia and Lymphatic Cancer

Excesses of leukemia were found in many depar ments where solvents were extensively used. Solven were used in calendering, extrusion, tire buildin tubes, and rubberized fabrics. An association betwee solvent exposure and lymphatic and hematopoiet cancer has been reported in another group of rubb workers (*35*). Also, excesses have been reported rubber workers in general (*1, 6, 7*).

We have examined work practice manuals and so vent recipes and have discussed work practices wi older employees to identify the predominant solve exposure during the late 1920's to the early 1940's. It clear that benzene was not used as a general-purpo solvent. Its use was restricted to special rubber cement and adhesives, particularly those for use in bondi

...etal to rubber, and to some repair or patching ...ements. The most common solvents used in this ...ompany were refined petroleum solvents, principally ...igh-test gasoline and varnish maker's naphtha. All ...efined petroleum solvents are complex mixtures of ...ydrocarbons and contain a low percentage of benzene. Any substance responsible for the excess of leukemia or lymphatic cancer is believed to have been removed or reduced in the work environment, inasmuch as men who started work after 1945 do not have an excess rate of these diseases.

For two other reasons, we hesitate to attribute the excess of leukemia solely to benzene. First, the predominant leukemia was lymphatic. Epidemiologic evidence for an association between benzene and lymphatic leukemia is less convincing than the evidence for an association with other leukemias (*36*, *37*). Second, one of the areas with excess leukemia deaths also has an excess of lymphosarcoma, a tumor not known to be associated with benzene.

In summary, several associations between work area and specific sites of cancer are likely to be causal. These are the association of gastrointestinal cancer with the processing area, lung cancer with curing, leukemia with extensive organic solvent exposures, and cancers of the skin and other sites with the tire assembly area. Fortunately, many of these associations no longer hold for workers who started jobs after 1940. Whether specific chemicals can be identified as having been responsible is problematic because of the complex nature of the work environment. The only realistic approach to prevention must be based on a general reduction in exposure to substances used in the manufacture of rubber products.

## REFERENCES


(*1*) Monson RR, Nakano KK: Mortality among rubber workers. I. White male union employees in Akron, Ohio. Am J Epidemiol 103:284–296, 1976

(*2*) ———: Mortality among rubber workers. II. Other employees. Am J Epidemiol 103:297–303, 1976

(*3*) M...on RR: Analysis of relative survival and proportional mortality. Comput Biomed Res 7:325–332, 1974

(*4*) Doering CR, Forbes AL: Adjusted death rates. Proc Natl Acad Sci USA 25:461–467, 1939

(*5*) McMichael AJ, Spirtas R, Kupper LL: An epidemiologic study of mortality within a cohort of rubber workers, 1964–1972. J Occup Med 16:458–464, 1974

(*6*) Fox AJ, Collier PF: A survey of occupational cancer in the rubber and cablemaking industries: Analysis of deaths occurring in 1972–74. Br J Ind Med 33:249–264, 1976

(*7*) Andjelkovich D, Taulbee J, Symons M: Mortality experience of a cohort of rubber workers, 1964–1973. J Occup Med 18: 497–394, 1976

(*8*) M...ichael AJ, Spirtas R, Gamble JF, et al: Mortality among ...ber workers: Relationship to specific jobs. J Occup Med 18:178–185, 1976

(*9*) Andjelkovich D, Taulbee J, Symons M, et al: Mortality of rubber workers with reference to work experience. J Occup Med 19:397–405, 1977

(*10*) Mancuso TF: Epidemiological investigation of occupational cancers in the rubber industry. *In* The New Multinational Health Hazards (Levinson C, ed). Geneva: International Chemical Federation, 1975, pp 80–136

(*11*) Nau CA, Neal J, Stembridge VA: A study of the physiologi effects of carbon black. I. Ingestion. Arch Ind Health 17: 28, 1958

(*12*) Neal J, Trieff NM: Isolation of an unknown carcinoge polycyclic hydro-carbon from carbon blacks. Health Lab 9:32–38, 1972

(*13*) Gold A: Carbon black adsorbates: Separation and identificat of a carcinogen and some oxygenated polyaromatics. A Chem 47:1469–1472, 1975

(*14*) Eisenstadt E, Gold A: Cyclopenta(*c,d*)pyrene: A highly mu genic polycyclic aromatic hydrocarbon: Proc Natl Acad USA 78:1667–1669, 1978

(*15*) McCann J, Choi E, Yamasaki E, et al: Detection of carcinog as mutagens in the Salmonella/microsome test: Assay of chemicals. Proc Natl Acad Sci USA 72:5135–5139, 1975

(*16*) McCormick WE: Environmental Health Control for the rubb industry. Rubber Chem Technol 44:512–530, 1971

(*17*) Ingalls TH, Risquez-Ibarren R: Periodic search for can in the carbon black industry. Arch Environ Health 2:429–4 1961

(*18*) B. F. Goodrich Rubber Company: Manual of Rubber Manuf ture. Akron: B. F. Goodrich Rubber Co., 1953, p 181

(*19*) Certain polycyclic aromatic hydrocarbons and heterocyclic co pounds. IARC Monogr Eval Carcinog Risk Chem Man 3:2 29, 1973

(*20*) Bionetics Research Labs, Inc: Evaluation of carcinogenic, tera genic, and mutagenic activities of selected pesticides and i dustrial chemicals, vol. I. Carcinogenic study. Kensingto Md.: Bionetics Research Labs, Inc., pp 66, 86–87, 1968

(*21*) National Institute of Occupational Safety and Health: Suspect Carcinogens, 2d ed. Washington, D.C.: U.S. Govt Print C 1976

(*22*) Kummer R, Tordoir WF: Phenylbetanaphthylamine (PBN), another carcinogenic agent? Tyschr Soc Geneeskd 53:415–41 1975

(*23*) Batten PL, Hathway DE: Dephenylation of *N*-phenyl-2-nap thylamine in dogs and its possible oncogenic implications. J Cancer 35:342–346, 1977

(*24*) Fine LJ, Peters JM: Studies of respiratory morbidity in rubb workers. III. Respiratory morbidity in processing worke Arch Environ Health 31:136–140, 1976

(*25*) ———: Respiratory morbidity in rubber workers. I. Prevalen of respiratory symptoms and disease in curing workers. Ar Environ Health 31:5–14, 1976

(*26*) Rappaport SM, Fraser DA: Gas chromatographic-mass spe trometric identification of volatiles released from a rubb stock during simulated vulcanization. Anal Chem 48:476–48 1976

(*27*) Kleinfeld M, Messite J, Zaki MH: Mortality experience amor talc workers: A follow-up study. J Occup Med 16:345–34 1974

(*28*) Finklea JF: Nitrosamines in cutting fluids. *In* Current Intell gence Bulletin. Rockville, Md: NIOSH, October 6, 1976

(*29*) Decouffle P: Cancer mortality among workers exposed to cu ting oil mist. Ann NY Acad Sci 271:94–101, 1976

(*30*) Cerna M, Kypenova H: Mutagenic activity of chloroethylen analysed by screening system tests. Mutat Res 46:214–215, 19

(*31*) Lemen RA, Lee JS, Wagoner JK, et al: Cancer mortali among cadmium production workers. Ann NY Acad Sci 27 273–279, 1976

(*32*) Case RA, Hasker ME: Tumors of the urinary bladder as an o cupational disease in the rubber industry. Br J Prev Soc Me 8:39–50, 1954

(*33*) Weisberger EK: Carcinogenicity studies of halogenated hydr carbons. Environ Health Perspect 21:7–16, 1977

(*34*) Kober GM, Haythurst ER: Poisonings in the rubber industr *In* Industrial Health. Philadelphia: P. Blakiston, 1924, p 535–545

(*35*) McMichael AJ, Spirtas R, Kupper LL: Solvent exposure an leukemia among rubber workers: An epidemiologic study Occup Med 17:234–239, 1974

(*36*) Vigliani EC: Leukemia associated with benzene exposure. An NY Acad Sci 271:143–151, 1976

(*37*) Infante PF, Rinsky RA, Wagoner JK, et al: Leukemia in ben zene workers. Lancet 2:76–78, 1977