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Screening for Occupational Health Hazards in the Rubber Industry. Part I

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Multiphasic health testing (MHT) is often offered to populations of workers usually with the objective of identifying individuals who may be ill. Results are typically not analyzed in relation to estimates of workplace exposure. We describe the results of combining MHT with industrial hygiene assessment of workplace exposures as a method of identifying possible health hazards rather than merely potentially ill individuals. MHT was offered to all production and maintenance workers employed at a tire manufacturing plant. Of 954, 744 participated. We measured worker exposure to respirable particulates, solvent vapor, and noise. We computed the frequency of positive screens among workers classified by exposure and compared these frequencies with expected values adjusted for confounding variables including age, sex, race, and smoking and drinking habits. Workers exposed to higher concentrations of respirable particulates exhibited signs of respiratory and gastrointestinal morbidity. Workers exposed to emissions from heated, uncured rubber undergoing plastic deformation reported chest tightness on return to work. We conclude that combining MHT with assessment of workplace exposure is a valid method for identifying possible occupational health hazards.

Key words: multiphasic health testing, occupational health hazard detection, industrial hygiene assessment, respiratory morbidity among rubber workers, gastrointestinal morbidity among rubber workers

INTRODUCTION

The purpose of most screening programs is to identify diseased individuals and to offer medical treatment. Multiphasic health testing is one type of screening program commonly offered to populations of workers. When combined with medical follow-up, its efficacy for reducing morbidity and mortality has not, however, been clearly demonstrated.

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Typically, workplace screening programs measure outcome, ie, the results of the screening tests, but not workplace exposure. We report here the results of a multiphasic health testing program combined with assessment of exposure to potential occupational health hazards as a method of identifying such hazards. Our purpose is to evaluate this use of screening as a method for identifying possible occupational health hazards and to suggest an alternative use for screening: to identify hazards and not merely individuals who may have disease.

Multiphasic Health Testing

The first reported population offered "multiphasic" screening was a group of 945 employees in four industrial establishments in San Jose, California [Canelo et al, 1949], who were screened for pulmonary tuberculosis, diabetes, syphilis, and heart disease. Since that time, multiphasic health testing has grown to include hundreds of biological parameters that can be measured in any one application. In 1975 there were about 3 million individuals screened [Collen, 1978]. Multiphasic testing is considered by its proponents to be a useful tool in the control of chronic disease since it enables identification of asymptomatic disease in apparently well persons [Collen, 1978].

Multiphasic testing has not been demonstrated to be successful in reducing morbidity or mortality. Wylie [1961] demonstrated that screened persons had a better survivorship than nonscreened persons, but other studies of these same populations attributed these results to selection bias [Kuller and Tonascia, 1970]. Later studies, in which persons were randomly allocated to screened and nonscreened groups, failed to show differences in either the morbidity or mortality of the populations studied [Cutler et al, 1973; Olsen et al, 1976; South East London Screening Study Group, 1977; Stone and Crisp, 1978]. Certain simple tests that revealed asymptomatic and treatable conditions were useful in reducing morbidity and mortality [Cutler et al, 1973; Lannerstad et al, 1977].

Industrial workers are a common target population for multiphasic health testing. Published reports of these applications have been descriptive and not analytical. Cannery workers [Yedidia et al, 1969; Yedidia, 1973], longshoremen [Weinerman et al, 1952], electrical machinery makers [Burr, 1960; Grimaldi, 1965], public utility workers [Craig, 1973; Franco et al, 1961], pharmaceutical workers [Reichart, 1971], and others [California Medical Association, 1971; Collins et al, 1972; La Dou et al, 1975] have been tested on a regular or episodic basis. Multiphasic health testing has been used for preemployment examinations [Bernauer and Bonanno, 1975; Schussler et al, 1975], case findings, as an introduction to regular medical care in an occupational medical service [Collen, 1978; Howe, 1975], and to detect and monitor the progress of occupational disease [Cherry and Hamrick, 1971].

Occupational Disease in the Rubber Industry

Occupational disease in the rubber industry has been examined by studies of mortality and morbidity of various cohorts of rubber workers. Studies of mortality have identified more deaths than expected from cancer of the urinary bladder [Cole et al, 1972; Fox and Collier, 1976; Monson and Fine, 1978; Case and Hosker, 1954]. Deaths from leukemia have been reported among workers exposed to solvent vapors [McMichael et al, 1975]. Workers in the compounding and mixing areas of rubber

processing plants have higher mortality than expected from stomach cancer [Monson and Nakano, 1976: McMichael et al, 1976a, c], and cancer of the prostate [Goldsmith et al, 1980], and workers exposed to curing press emissions have higher mortality from lung cancer [Fox and Collier, 1976; Monson and Fine, 1978].

Occupational morbidity in the industry, with few exceptions, has been examined by studies of subpopulations with common exposure. Numerous studies of respiratory morbidity have shown chronic bronchitis, decreases in ventilatory function, and other respiratory problems among compounders and mixers, manual curing press operators, and workers exposed to talc dust [Fine and Peters, 1976a, b, c; Fine et al, 1976; McMichael et al, 1976b]. Airborne contaminants have also been a cause of temporary and permanent respiratory disability among rubber workers [California State Department of Public Health, 1961; do Pico et al, 1975; Lednar, 1975; Lednar et al, 1977].

Solvents used in rubber processing and tire manufacturing are well known as causes of central nervous system depression, dermatitis, and other problems [Browning, 1965]. Gastrointestinal disorders have been reported among rubber workers [Alekperov, 1965; Bashirov, 1968] as has disturbed renal function [Konstantinovskaja, 1970].

The primary objective of this study is to evaluate using multiphasic health testing as described. A derivative objective is also to generate hypotheses for further study of occupational disease in the rubber industry.

POPULATION, MATERIALS, METHODS

We offered a multiphasic health testing service to all of 954 rubber workers employed in the production area of a single tire manufacturing plant in Ohio as of February 20, 1976. Of these workers 744 participated, and 210 did not. None of these workers had been employed at this plant for less than 5 years.

Each worker received an audiometric exam, PA chest X-ray, forced expiratory ventilatory function test, and analysis of constituents of blood and urine. Manual audiometry was conducted in a Maico Hearing Instrument pure tone audiometer with frequencies of 500, 1,000, 2,000, 4,000, and 8,000 Hz and with increments of 5 dB at each frequency. The audiometric exam was conducted in a sound-isolated booth that had been examined to insure compliance with ANSI standards [ANSI S3.6-R1973; ANSI S3.1-R1971]. Forced expiratory ventilatory function tests were performed on an 8-liter Collins spirometer. Each subject was asked to perform maximum forced expirations for a minimum of 6 seconds. Temperature-corrected (BTPS) 1-second forced expiratory volume (FEV-1) and forced vital capacity (FVC) were based on the average of the best three of five technically satisfactory maneuvers. The urine sample was examined with a dip stick (Ames) for pH, evidence of blood, proteins, glucose, bilirubin, and ketones. Participants had been asked to fast for at least 4 hours prior to being examined. Blood samples were preserved and shipped to a laboratory (Metpath) for complete blood count (CBC), assay of certain serum enzyme activity (SGOT, SGPT, alkaline phosphatase, LDH, amylase, and gamma-GTP), electrolytes (Ca, Na, K, Cl, P), proteins (total, and albumin:globulin ratio), and other serum chemistry (BUN, creatinine, uric acid, glucose, cholesterol, total lipids, bilirubin (total and direct), and iron). The chemical analyses were performed on two SMA 12/60 automatic analyzers, and the CBC was performed on a Coulter Counter.

Chest X-rays were taken on a 35 cm × 43 cm film at approximately 60-80 kV and an exposure time of from 0.1 to 0.5 seconds. Films were read and classified by a radiologist according to clinical categories used by the screening service employed for this study.

Each worker who participated in the examination filled out a standardized questionnaire that elicited personal information as well as work experience in other industries, and diagnosed prior illnesses and symptoms of chronic heart, lung, or hearing problems. The questionnaire included a modification of the British Medical Research Council series of questions on respiratory symptons. We asked workers about a variety of other symptoms such as gastrointestinal complaints, dizziness, and tingling and numbness in their extremities. We asked about personal habits including alcohol and tobacco consumption, use of medication, and exposure to health hazards from sources other than work at this plant.

For all 954 workers currently employed we gathered information from their personnel files about what departments in the plant they had worked in and when, their total length of employment in the production areas of the plant (exclusive of layoff, leaves of absence, and military leave), and the department and particular job they had at the time the survey was made. For workers who did not participate in the examination, we determined their race, sex, and date of birth from company records so as to compare participants with nonparticipants on these variables.

For the purposes of this study, we categorized workers into one of 13 departments described in Table I and Figure 1. There were 33 different departments in the production and maintenance areas of this plant. Those that involved potentially similar exposure (shipping and receiving and repair and salvage) were categorized together, and small departments involving miscellaneous and minimal exposures (sanitation, factory casual, and power house operators) were grouped together as "other."

Environmental Samples

We measured worker exposure to respirable mass particulates for Banbury, drop mill, and curing press operators, and for bookers and workers in the cleaning and inner tube departments. Environmental samples were taken among a representative sample of workers on all three shifts. Personal air samples were taken with a two-stage sampler at the worker's lapel connected to an air pump suspended on the belt and operated at 1.7 liters/minute [Lippman, 1970]. Sample times ranged from 4 to 7 hours. The first stage of the sampler was a 10-mm cyclone that removed the nonrespirable portion of the suspended particulates. The second stage was a preweighed PVC filter (pore size of 5 μm) in a casette (Table II).

We took personal air samples for exposure to organic vapors for representative samples of bead spray operators, curing preparation workers, tread tuber operators, and tire builders on all shifts. We used a 150-mg activated charcoal tube and a personal sampler pump operated at a flow rate of 50–100 ml/min. Sample times ranged from 90 to 180 minutes depending on the operation. We eluted the organic vapor samples with carbon disulphide, and the sample was separated by gas chromatography and analyzed with a flame ionization detector (Table III).

We evaluated exposure to noise for mill workers, Banbury operators, cleaning department workers, and curing press operators. We estimated time-weighted average noise exposure with a hand-held type II (General Radio) sound level meter

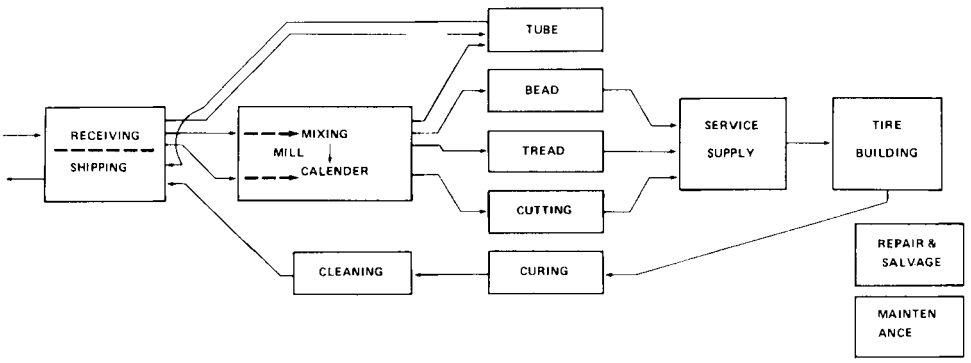

Fig. 1. Production organization and materials flow in tire manufacturing.

with periodic measurements taken to get a representative sample of noise exposure. Mill workers and cleaning department workers experienced more or less steady-state noise exposure during their work, and therefore measurements were taken approximately every 5 minutes over an hour out of a work day. Banbury operators and curing press operators, however, went through a regular work cycle (about 7 minutes and 30 minutes, respectively) that involved considerable variation in noise exposure. Consequently, we took measurements every 30 seconds over at least one entire work cycle. The sound level meter was calibrated before and after each shift (Table IV).

For none of the jobs do we have documented levels of exposure for time periods prior to this investigation, since measurements were not made by the employer or anybody else. Discussions with persons familiar with the plant's history, however, suggest that conditions were stable over the past 20 years. The most recent major change in the production technology was in the mid 1950's when pot healers (which cured several tires simultaneously in separate molds in one large vulcanizing oven) were replaced with the manually loaded curing presses in use at the time the study was undertaken. Minor changes in other production technology included moving one Banbury mixer and modifying cleaning machines in the early 1960's. We therefore assume that our measurements of air contaminants and noise are reasonable estimates of workers' exposure at least over the past 20 years.

Criteria for Evaluating Positive Screens

In the evaluation of ventilatory function, we used the prediction equations for FEV-1 and FVC developed by Morris et al [1971]. Black persons' predicted lung functions were taken as 87% of the Morris prediction [Damon, 1966]. Persons were classified as having depressed FEV-1 or FVC if their value was less than 80% of the predicted. Depressed FEV-1/FVC was considered as less than 70%. Persons were considered to have noise-induced hearing loss if they had greater than 40 dB loss at 4,000 Hz in their better ear.

For the evaluation of abnormalities in blood sera and hematology, we used sex- and age-specific standards that had been developed by the laboratory that did the analyses. These laboratory standards were based on a minimum of 1,000

TABLE I. Production Jobs and Potential Exposures in Tire Manufacturing

Department	Major job title, description	Potential exposures			
		Respirable particulates	Solvent vapors	Noise	Other
Mill	Banbury operator and helper: Load rubber, carbon black, and other additives by batch into banbury mixer	X		X	a
	Mill operators: Operates roller mill that mixes, softens, and warms rubber batch	X		X	b,c
	Calender operators: A team of workers operates the calender that rolls rubber and fabric together		X		d
	Cement house attendant: Manages centralized supply room for mixing and supplying solvent		X		
Bead	Bead maker: Operates machine that extrudes rubber around a wire core and forms into bead				b
	Bead preparer: Wraps or winds bead, and sprays to prepare for tire builder		X		f
Cutting	Cutter: A team of workers cuts rubberized fabric to appropriate length and width				f
Tread	Tread tuber operator: Operates machine that extrudes rubber into tread and cuts to length				b
	Take-off: Applies cement to end of tread, removes tread, and places on a specialized pallet or "book"	X	X		c
	Mill operator: (see under Mill department above)				
Tire	Tire builder: Receives tread, fabric, bead, and other supplies to build tire on a tire building machine		X		
Curing	Curing press operator: Manually loads and unloads tires into curing or vulcanizing presses	X		X	g
	Curing preparation: Presses uncured tire at lap splices and sprays with cement		X		
Cleaning	Buff: Buffs tires to remove imperfections or highlight embossing	X		X	
	Balance: Apply "dough" or mixture of rubber and cement to balance tires		X		
Repair, salvage	Repair: Repair tires that are imperfect or damaged				

(Continued on Next Page)

TABLE I. Production Jobs and Potential Exposures in Tire Manufacturing (cont.)

Department	Major job title, description	Potential exposures: Respirable particulates	Solvent vapors	Noise	Other
Tube	Tuber operator: Extrudes rubber into inner tube and splices	X			b,e
	Booker: Removes tube and places on booking pallet	X			c
	Mill operator: (see under Mill department above)				b
	Curing press operator: Manually loads and unloads tubes into curing or vulcanizing presses				g
Ship, receive	Fork lift truck operator: (see under Mill department above)				e
Service, supply	Most of the jobs in this department are concerned with transporting supplies about the plant, often on hand trucks				
Maintenance	Mechanics: all around maintenance mechanics				h
	Machinists Electricians				f,i
	Instrument repair workers				
	Plumbers				
	Welders				j
	Mold repair				
	Other				

[a] Banbury operators are exposed primarily to carbon black and to other dusty additives used in the rubber batch.

[b] Mill operators, tuber operators, and bead makers are all exposed to emissions from hot uncured rubber undergoing mastication or extrusion.

[c] Some mill operators in the mill department, take-off workers on the tread tuber, and workers on the tuber are exposed to talc dust.

[d] Fabric is dipped in a resorcinol-formaldehyde-latex solution.

[e] Drivers are exposed to CO from truck exhaust.

[f] Cutters, some bead workers, and machinists are exposed to oil mist, used to lubricate and/or cool parts they are working on.

[g] Curing press operators are exposed to curing press emissions.

[h] Mechanics and others in the maintenance department work wherever they are needed to repair machines that malfunction, and consequently encounter a wide variety of exposures to health hazards.

[i] A vapor degreaser in the machine shop occasionally exposed machinists to vapors of trichloroethylene.

[j] Welders encountered metal fumes and other emission from welding.

TABLE II. Personal Exposure to Respirable Particles

Department	Job	No. of samples	Respirable mass mg/m³ TWA	Respirable mass mg/m³ Max	Principal particulate exposure
Mill	Banbury operator	13	1.39	3.45	Carbon black
	Banbury helper	3	0.51	0.60	Carbon black
	Drop mill operator	10	0.69	1.33	Carbon black and talc
Cutting	Cutting	2	1.88	1.90	Silicone oil mist
Curing	Curing press operator	24	0.82	2.77	Curing press emissions
Cleaning	Buff	3	0.44	0.61	Cured rubber dust
Tube	Tuber operator	8	0.82	2.33	Talc*
	Curing press operator	5	1.16	1.75	Curing emissions
	Booker	3	1.36	2.61	Talc*
Maintenance	Carpenter shop (planer)	1	1.68		Sawdust
General air samples	Mill	3	0.42	0.57	
	Bead	1	0.04		
	Tire building	2	0.05	0.09	
	Curing	1	0.22		
	Ship and receive	2	0.13	0.13	

*Bulk talc samples analyzed by X-ray diffraction did not contain asbestos.

TABLE III. Personal Exposure to Solvent Vapor

Department	Job	No. of samples	Benzene (ppm) TWA	Benzene (ppm) Max	Toluene (ppm) TWA	Toluene (ppm) Max	n-Hexane (ppm) TWA	n-Hexane (ppm) Max	Total hydrocarbons (as hexane) ppm TWA	Total hydrocarbons (as hexane) ppm Max	Other (ppm)
Mill	Cement house attendant	5	2.1	5.0	8.1[a]	10.9	12.5	32.7	287.0	1372.0	77[1a]
	Cement house attendant	1[b]	0.8					1.7		112.0	
	Drop mill	1		0.1		0.2		0.2		1.0	
Bead	Bead preparer	8	0.6	2.4	2.4[c]	6.2	3.9	11.8	29.8	91.0	
Tread	Tuber operator	3	0.1	0.2	0.8[d]	1.2	0.7	0.8	6.6	8.0	
	Take-off[e]	5	1.8	12.0	8.4	26.6	12.1	93.2	89.6	571.0	
Tire building	Tire building	8	3.6	16.3	7.6[c]	26.5	8.3	32.7	74.4	322.0	
Curing	Curing preparer	25	1.7	14.6	6.0[f]	24.4	6.9	32.0	68.6	306.0	28[1b]
Tube	Curing press operator	3	0.3	0.4	1.8	3.8	1.1	2.1	15.8	21.0	
Maintenance	Machinist	1						4.1		139	168[2]

[a] Only two samples analyzed for toluene.
[b] General air sample.
[c] Only six samples analyzed for toluene.
[d] Only two samples analyzed for toluene.
[e] Combined job, two workers alternate.
[f] Only 19 samples analyzed for toluene.
[1a] Methyl alcohol = 77 ppm.
[1b] Methyl alcohol = 28 ppm.
[2] Trichloroethylene = 168 ppm.

TABLE IV. Personal Exposure to Noise

Department	Job	No. of samples	Sound level (dBA) TWA
Mill	Banbury operator	2	86.5
	Drop mill operator	2	88.5
	Warm-up mill operator	1	84.0
Tread	Mill operators	4	88.8
	Tread tuber operator	2	88.2
Curing	Curing press operator	8	83.9[a]
Cleaning	Buffing machine operator	4	89.4[b]

[a] Curing press operators are exposed to a wide variety of short-duration noise from escaping steam and other sources with bursts of less than 5 seconds peaking at sound levels from 98 to 105 dBA and have an approximate 12-minute break at about 75 dBA every 20–25 minutes.

[b] Buffing machine operators generally experience steady-state noise from the machine except when maintenance is needed when short-term exposure (5–15 minutes) was recorded as high as 105 dBA.

measurements for each sex and age decade. Those measurements that fell in the upper or lower tails (2½% in each tail) of the frequency distributed for each constituent were considered abnormally elevated or depressed.

A person was considered hypertensive if the lowest measurement of systolic blood pressure was over 140 mm Hg, if the lowest measurement of diastolic was over 90 mm Hg, or if the person was taking medication for hypertension at the time of the investigation.

The presence of chest symptoms and reports of other problems were determined by responses to the questionnaire. Cough or sputum was considered present if persons indicated they had either for at least 3 months of the year. Wheezing was considered present if persons reported ever wheezing. Shortness of breath was considered present if persons indicated such while walking up a slight hill. Shortness of breath on stairs was considered present if persons indicated such on one or two flights of stairs. Signs consistent with heart disease were taken to be present when persons answered a series of questions that indicated persistent shortness of breath and pressure, pain, or heaviness in the chest. Other complaints (nausea, abdominal pain, tingling or numbness in the extremities, pain while urinating, red or brown urine, and others) were inquired about within the year prior to this screening.

Evaluating Associations Between Positive Screens and Workplace Exposure

Workers were cross-classified by the department they nad worked in longest and by outcome on each screening test (usually positive or negative). This created a two-dimensional contingency table for each screening test. We determined the number of positive screens for each department and compared this number with that expected.

We computed expected values by the indirect method [Hill, 1977]. We identified potential confounding variables for each screening test as described in more detail below and stratified each contingency table by these variables. We then computed

stratum-specific prevalence rates for outcomes of each screening test and applied these rates to the number of workers in each department in that stratum. The adjusted expected number is the sum of these stratum-specific numbers taken over all strata.

The measure of association between work in a particular department and outcome for each screening test is the ratio of observed number of abnormals to the adjusted expected number. If this ratio is greater than 1.0, there is a positive association between work in the department and an abnormal test result; if it is less than or equal to 1.0, the association is negative.

Variables for which we adjusted the expected values include age (greater or less than 45 years), sex, race, smoking habits, and alcohol consumption. Persons were classified as never having smoked if they had smoked less than a carton of cigarettes in their entire life, as ex-smokers if they had ever smoked regularly but had quit smoking more than a year prior to the date of this study (February 1976), and as current smokers if they were regular smokers up to at least a year prior to February 1976. Persons were classified as nondrinkers if they reported not drinking at all, as light drinkers if they reported consuming fewer than two drinks per day, and as moderate to heavy drinkers if they reported consuming two or more drinks per day.

Alcohol consumption was considered a potential confounding variable in the evaluation of liver function tests and other constituents of blood sera; age and sex were considered in the evaluation of "other" symptoms; smoking was considered in the evaluation of ventilatory function; age and smoking habits were weighed in the evaluation of chest symptons; and age (by decade), sex, and race were considered in the evaluation of noise-induced hearing loss and hypertension. We adjusted for these variables as described above.

To determine whether exposure to workplace hazards that we measured (respirable particulates, solvent vapor, and noise) was associated with outcome on any of the screening tests, we compared the observed to expected ratios for departments classified by whether they included these exposures. We also noted the proportion of workers in each department that experienced the exposure in question.

To evaluate associations between increased time spent in each department and prevalence of abnormals, we analyzed O/E ratios for workers who had spent more than 10 years in the department in which they had worked longest.

Statistical evaluation on these associations was performed by pooling observed and expected values for workers in "exposed" and "unexposed" departments, which gave us a 2 × 2 table for each screening test. For each of these tables, a chi-square statistic was calculated by $\Sigma\ (O-E)^2/E$ with one degree of freedom [Mantel and Haenszel, 1959].

RESULTS

Participants, Nonparticipants, and Confounding Variables

Participants classified by the department in which they had worked longest (ie, in which they had worked longer than any other department) differed slightly with respect to average age, sex, race, smoking habits, and alcohol consumption. Therefore, where appropriate, we adjusted the expected number of positive screens by these potential confounding variables. There were no meaningful differences in the frequency of prior hazardous exposures or prior disease among workers classified by department worked in longest.

Participants and nonparticipants were similar with respect to age, sex, race, and department worked in longest. However, the proportion of very young and very old workers and of black women workers was slightly higher among nonparticipants than participants.

Patterns of Positive Screens Associated With Exposure to Respirable Particulates

Workers in departments that include exposure to higher concentrations of respirable particulates have more than the expected number of positive screens for respiratory symptoms (Table V). This is particularly true for workers in the curing department, who had an observed to expected ratio greater than 1.0 for eight out of nine of the screening tests considered. The association between employment in these departments and prevalence of abnormals on these screening tests was statistically significant ($p < 0.05$) for reports of chest tightness, wheeze, and cough and for reductions of FEV-1 and reduced FEV-1:FVC ratio (Table V).

Workers in these same departments also reported an excess of nausea and abdominal pain. This was particularly true for workers in the cutting department who were exposed to oil mist, and workers in the cleaning department who were exposed to rubber dust (Table VI). The association between exposure to respirable particulates and reports of abdominal pain was statistically significant ($p = 0.004$).

Other Findings

Elevated levels of serum creatinine were seen more often than expected among mill workers. They also reported pain or difficulty while urinating and red or brown urine more often than expected (Table VII). These findings were not statistically significant.

Chest tightness on return to work was reported by four workers in the mill and bead departments. At the time of the study, all four such workers operated machines that mixed (three) or extruded (one) hot, uncured rubber and that probably produced similar emissions in the process. Given that there were 42 workers with similar jobs among the participants, the probability that three out of four workers with chest tightness on return to work would also have such a job is approximately $(41/743)^3 = 0.0002$.

Workers in departments that were classified as noisy or exposed to solvent vapor had no significant differences between observed and expected number of positive screens for any of the screening tests. There were also no meaningful associations between employment in these departments and other biological parameters including CBC, serum constituents, or chest X-ray. None of the associations noted were strengthened or otherwise changed by confining analysis to workers with more than 10 years in the department in which they had worked longest.

DISCUSSION

Although differences between participants and nonparticipants were a minor problem in this study, for future similar programs it may be necessary to make special efforts to recruit people who tended not to participate in this study (black women, younger and older workers) in order to reduce this potential source of bias.

TABLE V. Associations Between Exposure to Respirable Particulates and Screening Tests for Respiratory Morbidity

			Reports of respiratory complaints										Depressed ventilatory function							
			SOB[2]		SOB/stairs[3]		Chest tightness		Wheeze		Cough		Sputum		FEV-1		FVC		FEV-1/FVC	
Departments[1]	No.[1]	%[1]	O[a]	O/E[b]	O	O/E	O	O/E	O	O/E	O	O/E	O	O/E	O	O/E	O	O/E	O	O/E
Mill[c,d]	76	47	3	0.6	14	0.9	14	1.5	26	1.3	25	1.4	15	1.7	15	1.3	11	1.0	14	1.0
Cutting[e]	41	72	1	0.5	5	0.7	3	0.7	11	1.2	8	1.4	2	0.6	5	0.9	4	0.7	4	0.7
Tread[c]	24	37	2	1.4	4	0.8	4	1.5	5	0.9	2	0.5	4	1.9	1	0.3	2	0.7	4	1.1
Curing[f]	67	49	6	1.3	14	1.0	14	1.8	23	1.4	17	1.2	9	1.2	12	1.3	10	1.1	16	1.5
Cleaning[g]	69	22	5	1.0	17	1.1	7	0.9	21	1.2	15	0.9	8	1.0	15	1.5	12	1.3	20	1.8
Tube[d,f]	21	63	3	2.3	5	1.2	5	2.3	3	0.7	4	1.1	1	0.6	4	1.7	2	0.8	3	1.1
Other	446	0	26	1.0	89	1.0	36	0.7	82	0.8	68	0.9	34	0.8	46	0.8	56	1.0	52	0.8
Chi-square[h]			0.06		0.18		9.49[j]		8.51[j]		3.99[i]		2.94		5.28[i]		0.04		7.69[j]	

[1] Departments with exposure to respirable particulates; No. of workers; % exposed.
[2] Shortness of breath.
[3] Shortness of breath on stairs.
[a] O is the number observed with positive outcome.
[b] O/E is the ratio of observed to expected with positive outcome.
[c] Carbon black and other additives.
[d] Talc.
[e] Oil mist.
[f] Curing press emissions.
[g] Rubber dust.

Other notes:

[h] Chi-square with one degree of freedom was calculated by pooling workers from the exposed departments to create a 2 × 2 contingency table. Adjusted expected values were used.
[i] $p < 0.05$.
[j] $p < 0.01$.

TABLE VI. Associations Between Exposure to Respirable Particulates and Screening Tests for Gastrointestinal Morbidity

	No. of workers	% Exposure	Reports of GI complaints: Abdominal pain O[a]	Abdominal pain O/E[b]	Nausea O	Nausea O/E
Mill[c,d]	76	47	21	1.6	22	0.9
Cutting[e]	41	72	15	1.9	21	1.5
Tread[c]	24	37	3	0.8	6	0.9
Curing[f]	67	49	9	0.8	21	1.1
Cleaning[g]	69	22	16	1.5	22	1.2
Tube[d,f]	21	63	2	0.5	7	1.1
Other	466	0	64	0.8	129	0.9
Chi-square[h]			9.53[j]		2.98	

[a] O is the number observed with positive outcome.
[b] O/E is the ratio of observed to expected with positive outcome.
[c] Carbon black and other additives.
[d] Talc.
[e] Oil mist.
[f] Curing press emissions.
[g] Rubber dust.

Other notes:
[h] Chi-square with one degree of freedom was calculated by pooling workers from the exposed departments to create a 2 × 2 contingency table. Adjusted expected values were used.
[i] $p < 0.05$.
[j] $p < 0.01$.

TABLE VII. Urinary Tract Problems Among Workers in the Mill Department (N = 76)

Parameter	Observed	Obs/Exp
Pain or difficulty while urinating	4	1.4
Red or brown urine	4	1.5
Elevated serum creatinine	7	1.6
Elevated BUN	3	1.1

Although this study design is attractive because of its relative simplicity and ease of interpretation, it has weaknesses. First, it is a search for associations between exposures and outcome (ie, it is a hypothesis-generating and not a hypothesis-testing study). By chance alone we will find some positive associations, and must keep this in mind when interpreting the results.

Second, it is a cross-sectional survey and thus cannot distinguish between new and old cases of disease. It is also insensitive to those processes of selection that could result in some workers leaving certain jobs because of adverse conditions or ill health. Longitudinal observation of workers and the work environment would be an obvious improvement. Even so, this study is a useful first approximation.

Third, workers were classified by the production department they had worked in longest as the fundamental index of exposure. This classification scheme is relatively crude because of the varieties of different exposures within and between depart-

ments. For example, workers in the tread department are exposed to talc dust on one job (take-off), emissions from uncured hot rubber on another (tread tuber operator), and solvent vapor in another (take-off). Mill operators are found in several departments: mill, tread, bead, and tube. Other departments had more homogeneous exposures. In order to compensate for this source of variability, we pooled these workers in order to achieve more reliable measures of association between exposure and outcome.

A fourth problem is that expected values were based on the entire population, including members from all departments. This procedure increases the likelihood of false-negative associations between individual departments and outcome and reduces the likelihood of false-positives. In either case, we do not consider it an important source of bias because no one department was so large or so heavily exposed that it distorted the standard rates. That we have observed positive associations suggests that it was not a serious problem.

The associations that we did observe more likely indicate causality if we could have shown a dose-response relationship—ie, if the strength of associations rose and fell with exposure. That we were unable to show such a relationship could be because either it does not exist or because the problems of selection, classification, or our method of computing expected values prevents us from measuring it. Some of these problems can be solved as shown in Part II of this study, and a dose-response relationship can be demonstrated among workers in the curing department.

Associations that we have observed, however, are noteworthy. It makes intuitive sense that workers who are exposed to respirable particulates should have respiratory symptoms. It is also consistent with other studies of workers exposed to curing press emissions, dust in the mill (or compounding, as it is called elsewhere) department, and talc [Fine and Peters, 1976a, b, c; Fine et al, 1976; McMichael et al, 1976b]. Inasmuch as inhaled particulates may be coughed up and swallowed, it is also possible that gastrointestinal complaints by such workers (in the mill and cutting departments) may be caused by such exposure.

The occurrence of possible urinary tract problems among workers in the mill department could be due to inhalation of toxic additives in the rubber mix.

We suggest further studies in other plants of workers exposed to oil mist and mill department dust in order to evaluate these hazards more fully. Chest tightness on return to work among workers exposed to emissions from heated, uncured rubber during mill mixing or extrusion suggests further studies of the time course of respiratory symptoms among workers with similar exposures.

CONCLUSION

We believe that multiphasic health testing combined with industrial hygiene measurements and determination of work histories can be a useful method for evaluating occupational health hazards. We have observed associations suggesting health hazards among rubber workers: Exposure to respirable particulates is associated with respiratory and gastrointestinal problems, exposure to dust in the mill or compounding area with urinary tract problems, and exposure to mill or extrusion emissions with chest tightness on return to work.

We suggest that this method be considered for evaluating workplace health hazards and, for programs of multiphasic health testing already in place, that measurements of workplace exposure be included in the analysis of results. The method we have employed could be improved as discussed above by examining workers longitudinally and by improving the classification of workers by exposure.

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