This paper is a follow-up on thirty-eight workers exposed from 1 to 24 years to average benzene concentrations generally between 5 and 50 ppm, but as high as 90 (peak of 140) in the case of one worker. One individual was diagnosed as suffering from mild benzene poisoning and a small number of workers in the group had blood changes considered abnormal, but blood dyscrasia or leukemia has not developed in 13 years after benzene use was terminated in 1964. The population studied was small, but the data, nevertheless, would appear to support the former ACGIH TLV of 25 ppm. One case of mild benzene poisoning reported from benzene exposures of the order of 40 ppm suggests, however, that the margin of safety may be small. The current ACGIH TLV of 10 ppm seems reasonable in the light of our findings.

Benzene exposure in the rubber coating industry – a follow-up

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introduction

A study of benzene exposure in the rubber coating industry was published in 1961.[1] This paper is a follow-up on 38 workers in one plant from that study who were exposed for 1 to 24 years to benzene in concentrations that were generally between 5 and 50 ppm, but as high as 90 ppm (peak of 140 ppm) in the case of one worker. The paper contains:

(a) Air analysis findings and phenol excretion studies performed between 1961 and 1973.

(b) The results of blood tests made in 1961 and 1963 during the benzene exposure period.

(c) The results of blood tests made in 1973 and 1977, eight and 13 years after the use of benzene-containing solvents was discontinued.

(d) The health or employment status of the workers in the original group.

materials and methods

Air samples for benzene were collected on silica gel contained in U tubes which was subsequently extracted with 2-propanol and analyzed by ultraviolet spectrophotometry, as previously described.[2,3] Ultraviolet spectrophotometry was preferred over gas chromatography for our study because most of the components of naphtha do not absorb in the ultraviolet region and therefore do not interfere with the analysis and a positive identification can be made from benzene's ultraviolet absorption spectrum. Toluene was the only other aromatic solvent found in the naphthas and when it interfered with the analysis benzene was separated from the sample by a special technique.[2] Sampling time for individual air tests ranged from 10 to 30 minutes.

Urine samples were obtained from workers at the end of their shift and analyzed for total phenol with diazotized p-nitroaniline.[4] The test was developed in our laboratory for this study. A paper describing the correlation between benzene exposure and phenol excretion was published in 1961 and can be referred to for details.[1] Sampling time for air tests ranged from 10 to 30 minutes, but additional tests were performed under different exposure conditions in order to develop a correlation with urine phenol. Spreader and saturator operators made good subjects because their solvent exposure did not usually fluctuate markedly during a work-

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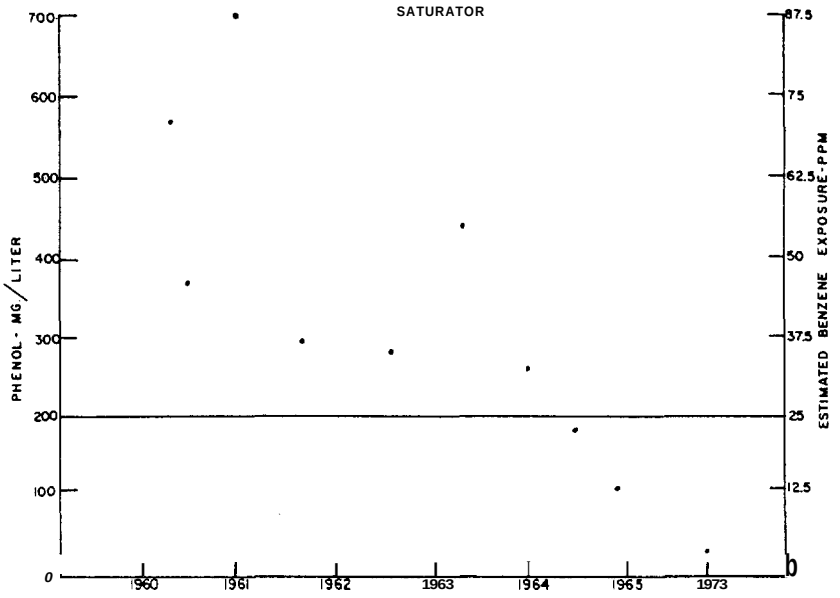

Figure 1 — Urine phenol and indicated benzene exposure of saturator.

run. It was found that urine phenol was a good index of benzene exposure. A phenol concentration of 200 mg per liter in end of shift samples corresponded to an average benzene exposure of 25 ppm, the threshold limit value at the time of the 1961 study.

Our findings were confirmed by **Buchwald**[5] who reported that environmental benzene concentrations of 25 ppm would result in 195-225 mg of phenol per liter of urine. Docter and Zielhuis[6] found people exposed to 25 ppm benzene produced 170-195 mg per liter of urinary phenol while those exposed to 10 ppm produced phenol concentrations of 70-80 mg per liter. Sherwood and Carter'" reported that **25** ppm of benzene caused a urinary phenol of 170-190. On the basis of this data, NIOSH selected a level of 75 mg per liter of phenol in urine collected at the end of a work shift to correlate with a time weight average exposure of 10 ppm of benzene.'"

Blood samples were taken in 1961, 1963,1973 and 1977 from workers in the original group. Blood analyses were all performed by the same clinical laboratory. The 1961and 1963tests were conducted by the following procedures:[9]

Red blood cells in Hayem's counting fluid
White cell counts in 1% acetic acid
Hemoglobin by the Sahli method
Blood smears and differential counts on glass slides (Wright's stain)
Platelets by the Fonio Method
Spin hematocrits

Hemoglobin, hematocrit, white blood cell and red blood cell counts were performed in 1973 and 1977 with the Coulter automated system. A phase contrast microscope was used for platelets and differential counts. The findings by the old and new methods are comparable. Significant differences are not usually due to methodology.

The male "norms" of the clinical laboratory performing the blood tests are as follows:

White blood cells $\times 10^3$:	7.8±3
Red blood cells $\times 10^6$:	5.4±0.7
Hemoglobin (gm):	16.0±2
Hematocrit (%):	47±5
Platelets $\times 10^5$:	2.59 (1.45 to 3.75)

Differentials

Eosinophiles:	2-5%
Stab(neutrophilic):	2-5%
Polymorphonuclear neutrophiles:	65-75%
Lymphocytes:	20-25%
Monocytes:	3-8%
Basophiles:	0.5%

TABLE I

Summary of Air Test Findings

Date	Location	Benzene (ppm)
May, 1960	Saturator	68
	Spreader	5-27
July, 1960	Churnroom	12-17
	Saturator	57
	Spreaders	7-25
1961	Saturator	90
	Spreaders	20-25
September, 1961	Churnroom	14-44
	Saturator	22-23
	Spreaders	19-36
August, 1962	Saturator	10-40
	Spreaders	3-20
April, 1963	Churnroom	6
	Saturator	33-43
	Spreaders	7-39
December, 1963	Saturator	38-140
	Spreader	17-35
July, 1964	Saturator	15-67
September, 1969	Spreaders	0
January, 1972	Spreaders	0
August, 1973	Saturator	0
	Spreaders	

rubber coating process

Rubber coated fabric is produced in this process. A rubber formulation is first prepared by churning rubber stock with solvents for several hours. The resulting homogeneous mixture is then added to fabric using saturator and spreader machines. On the saturator, the rubber is allowed to penetrate the fabric as it passes through a light rubber mix. The spreader, however, applies a coat of rubber to the surface of the fabric. The thickness of the coating is adjusted with a doctor blade. The solvents used in the plant during the 1961 study were naphthas containing 3% and 7.5% benzene.[11] Solvents introduced subsequent to 1964 and currently used are methyl ethyl ketone, mineral spirits and toluene which have been found to be benzene free.

results and discussion

Figure 1 shows urine phenol levels on the saturator operator (only one machine and operator on this job) between 1960 and 1973. He was on this job in 1957 and was still performing his task in 1977. From his urine phenol values, it was determined that his average benzene exposure was frequently above 25 ppm (the former ACGIH TLV) and as high as 90 pprn. The comparison of phenol levels with benzene exposure found on the left and right sides of Figure 1 was taken from the 1961 study.[11][12] Air tests on the saturator taken during 8 plant visits between 1960 and 1964 are reported on Table I. The air samples were of 10 to 30 minutes duration. Although they do not represent time

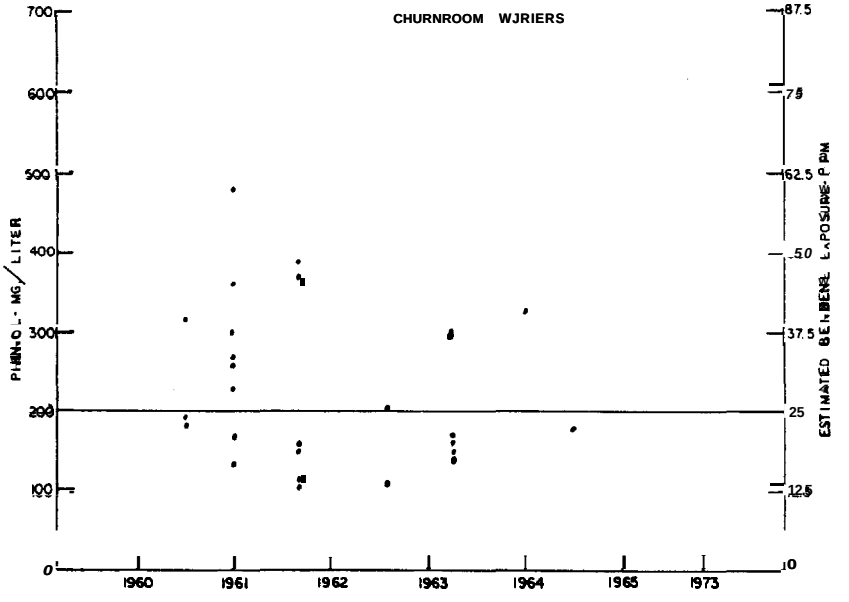

Figure 2 — Urine phenol and indicated benzene exposure of churnroom workers.

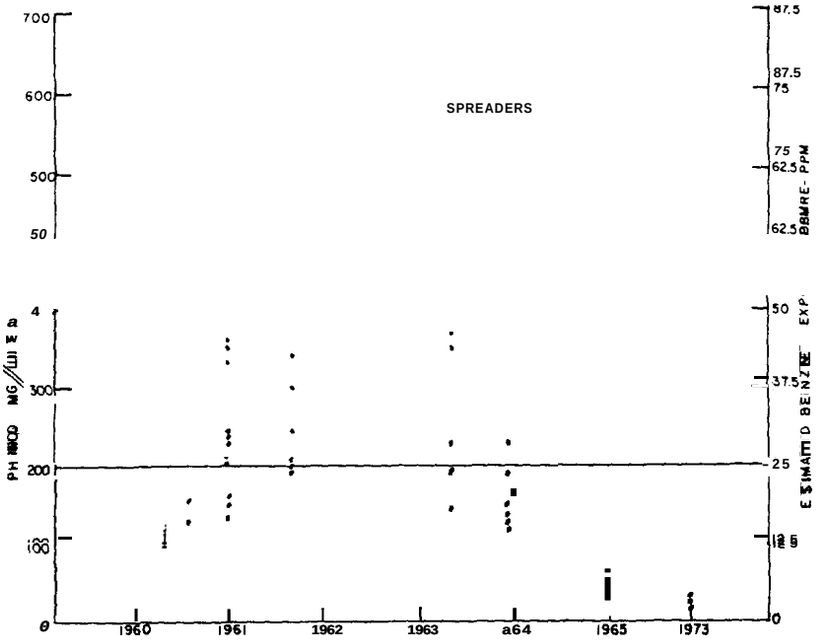

Figure 3 — Urine phenol and indicated benzene exposure of spreader operators.

weighted averages, it is clear that the worker experienced extremely high benzene exposures. This is confirmed by the phenol analyses which indicate his average benzene exposures.

Because of the variable nature of their work, air tests were not frequently performed on churnroom workers. Personal samplers were not in general use in the early 1960's when this phase of the study was performed. Urine phenols, therefore, were relied upon for measuring benzene exposure. These findings are reported on Figure 2. The spread of phenol values was somewhat less than that observed for the saturator. Benzene exposures as measured by this procedure ranged from 10 to 60 ppm.

Air tests taken on spreader operators (8 machines were nearly always in operation) showed that benzene exposures ranged from 5 to 39 ppm. See Table I. These samples were also of short duration, 10-30 minutes, but solvent exposures of spreaders did not vary too much. Air test findings agree with phenol results reported on Figure 3 which indicate average benzene exposures were usually below 40 ppm.

Tables II, III, and IV present complete blood findings on 38 workers in 1961 and 1963. They also include data on 17 workers from this group who were still on the job in 1973 and 12 of the 15 who were still employed by the plant in 1977.

Hemoglobin values of churnmen and spreaders are summarized on Table V. A number of these were below 13.5 grams in 1961 and 1963, but tests repeated in 1973 and 1977 showed no exposure related trend.

Two hemoglobin values in the 11.0 to 11.5 range on Table V belonged to churnroom worker C-14. All of his blood findings are listed on Table II. C-14 was employed for 6 years in the churnroom, 1958 to 1964. For a year between 1963 to 1964, he suffered many episodes of nose bleeds. An examination by a physician found him free of complaints, but he was described as appearing very pale. A diagnosis of mild benzene intoxication was made, and he was transferred to another job. His blood picture improved afterwards, and when seen in 1977 he did not complain of any health problems. From phenol levels reported on Table VI, on tests taken from 1/61 to 12/64, C-14's average benzene exposures ranged from 20 to 60 ppm.

In contrast to C-14, the saturator operator (SA) had much higher benzene exposures reaching 140 ppm as indicated by one air sample taken in 1963. See Table VII. His blood picture, except for the hemoglobin values, was considered normal. This worker was still on the job in 1977, operating the same saturator, and did not complain of any health problems when interviewed.

TABLE II

Blood Analysis Data on Churnmen

Date	Name	RBC (10^6)	WBC (10^3)	Hb (grams)	HCT (%)	Plate. (10^5)	E	S	P	L	M	E
3/61	C-1	5.33	10.0	15.0			2		70	25	3	
3/61	c-2	4.90	10.1	14.9			6	4	66	21	3	
10/63		4.17	12.6	13.8	41		5		65	25	5	
3/61	c-3	4.86	9.0	15.5			2	1	48	37	12	
10/63	c-3	4.73	8.4	15.3	44	2.38			58	41	1	
10/63	c-4	4.74	16.2	15.3	46	2.54	2	1	69	23	5	
8/73	c-4	5.12	6.9	15.1	45	3.08			53	42	4	1
8/77	c-4	4.79	8.4	13.8	41		6	3	50	31	9	1
3/61	c-5	5.23	8.3	16.8			1	2	51	42	4	
10/63	C-6	4.63	14.6	15.3	49	2.20			57	40	2	1
3/61	c-7	4.65	7.3	13.7			3	2	63	29	3	
10/63	C-8	4.32	11.2	14.3	44	1.52						
10/63	c-9	4.50	7.8	13.4	42	1.91			70	19	6	5
8/73	c-9	4.56	8.2	14.0	40	2.11	1		74	22		3
8/77	c-9	4.59	5.3	13.9	41		2	1	49	44	4	
3/61	c-10	4.97	9.4	14.9			4	3	75	15	3	
10/61	c-11	4.87	10.1	15.5			2	1	64	33		
8/73	C-11	5.33	9.5	16.2	47	3.34	8		49	41	2	
8/77	C-11	5.52	8.0	16.6	47		5		68	21	6	
10/63	c-12	4.87	6.7	13.8	45	2.30	3	1	46	46	4	
8/73	c-12	4.88	7.3	15.1	45	4.21	3		54	41	1	1
10/61	C-13	5.15	8.5	14.4								
8/73	C-13	4.92	4.4	11.9	37	2.65	2		56	41	1	
10/74	C-13	4.70	3.9	10.8	34	3.35	6		55	34	5	
10.77	C-13	5.00	5.1	14.4	41		2		54	36	7	1
3/61	C-14	3.95	7.2	11.3					50	50		
4/61	C-14	3.95	8.3	12.2					69	29	2	
10/61	C-14		6.5	11.9								
10/63	C-14	3.88	5.5	11.5	35	2.89						
8/64	C-14	4.47	6.0	12.2	39	4.10		2	40	55	2	1
11/71	C-14		8.3	13.6	41			1	57	38	4	
8/73	C-14	4.82	6.0	13.5	41	3.65			64	35	1	
8/77	C-14	4.76	6.8	13.1	39		1	2	47	47	3	
3/61	C-15	4.83	5.0	15.8								
10/63	C-15	4.74	11.3	16.4	48	1.42	2		85	12		1
8/73	C-15	4.70	5.1	14.7	43	2.36	1		66	24	8	1
3/61	C-16	4.48	7.9	12.8					67	31	2	
4/61	C-16	4.56	8.4	13.4			3	8	60	24	5	
10/63	C-16	4.29	8.1	13.8	42	2.19		4	56	34	5	1
7/73	C-16		7.3		41	4.50	3	2	74	19	2	
3/61	C-17	5.29	8.6	16.2			1	1	53	45		
3/61	C-18	4.50	8.6	15.5					56	42	2	
3/61	c-19	4.46	7.7	13.7			3	1	59	35	2	
10/63	c-19	4.65	4.7	13.4		2.09	5		45	44	6	
3/61	c-20	4.25	8.2	12.2			3	1	54	36	6	

E = Eosinophiles
S = Stab (neutrophilic)
P = Polymorphonuclear neutrophiles
L = Lymphocytes
M = Monocytes
8 = Basophiles

TABLE III
Blood Analysis Data on Spreader Workers

Date	Name	RBC (10^6)	WBC (10^3)	Hb (grams)	HCT (%)	Plate. (10^5)	E	S	P	L	M	B
3/61	S-1	4.93	8.4	12.7			1	8	59	24	8	
5/61	S-1	5.06	8.5	13.7			1	2	62	34	1	
10/63	S-1	4.64	6.6	15.8	48	2.19	3	2	42	49	3	
8/73	S-1	4.59	8.1	14.9	43	5.46			74	20	6	1
3/61	s-2	4.93	8.6	15.8								
10/63	s-2	4.60	11.6	15.3	46	3.41	4		55	37	4	
10/63	s-3	4.68	6.8	15.3	47	2.44	2		70	26	2	
8/77	S-3	4.86	7.1	14.9	44			7	51	34		
3/61	s-4	5.30	8.4	15.8			1	2	49	44	4	
10/63	s-5	4.44	9.9	14.8	44	1.31	3		64	31	1	
8/73	s-5	5.12	6.9	16.0	47	3.22	1		60	39		
8/77	s-5	4.66	7.0	14.8	43			1	60	36	3	
3/61	S-6	4.85	10.0	14.9				2	67	25	6	
10/63	S-6	4.34	8.9	14.8	46	2.76	1		55	43	1	
8/73	S-6	4.96	7.6	16.6	48	1.94	2		53	42	2	
3/61	s-7	5.11	8.3	15.8			4		65	29	2	1
10/61	S-8	4.80	5.9	14.2								
8/73	S-8	4.67	4.0	15.1	43	2.82	3	1	55	40	1	
3/61	s-9	5.01	10.2	15.5			2	1	64	33		
3/61	s-10	5.09	6.7	15.0					69	29	2	
10/63	s-10	5.42	7.8	14.8		1.99	4		65	30	1	
8/73	s-10	5.53	6.1	15.8	47	3.25			68	30	2	
8/77	5-10	5.07	6.4	14.3	43		2	2	52	40	4	
3/61	s-11	4.62	7.1	15.0			1		50	36	13	
10/63	S-11	4.53	6.1	14.3	42	2.49	1		59	36	2	
8/73	s-11	4.78	6.1	14.9	43	3.20	8	1	38	42	10	2
8/77	S-11	4.92	7.2	15.1	43		5	2	49	38	6	
3/61	S-12	4.43	8.0	14.6			2	2	56	36	4	
3/61	S-13	4.35	8.0	13.8				3	58	36	3	
8/73	S-13	4.72	12.7	15.1	44	2.00		5	74	20	1	
8/77	S-13	4.68	10.3	14.7	45		2	4	72	19	3	
3/61	S-14	4.62	7.2	14.0			1	3	57	37	2	
3/61	S-15	5.12	7.3	15.5			2	2	60	33	3	
3/61	S-16	4.66	5.1	12.5				2	53	42	3	
5/61	S-16	4.59	6.4	12.3			1	4	59	28	7	1
10/63	S-16	4.32	6.7	12.6	42	2.37	1		55	42	1	1
8/73	S-16	4.76	5.0	13.0	40	3.13	1		41	58		
8/77	S-16	4.63	5.2	12.5	38		1		58	36	4	1
3/61	S-17	4.43	8.4	14.3					68	32		
10/63	S-17	4.59	9.6	14.3		2.40			62	37	1	
8/73	S-17	5.06	8.1	15.5			1	1	60	34	4	
8/77	S-17	5.04	10.3	14.9	45		1	2	64	32	1	

E = Eosinophiles
S = Stab (neutrophilic)
P = Polymorphonuclear Neutrophiles
L = Lymphocytes
M = Monocytes
B = Basophiles

TABLE IV
Blood Analysis Data on the Saturator Operator

Date	Name	RBC (10^6)	WBC (10^3)	Hb (grams)	HCT (%)	Plate. (10^5)	E	S	P	L	M	B
3/61	SA	4.61	5.6	13.0			5		63	32		
9/63	SA	-	5.5	13.8	42	3.45	5		56	32	5	2
10/63	SA	4.51	6.8	13.8	42	1.62	2		66	28	4	
8/73	SA	4.67	10.7	14.9	44	4.44	1		79	17	3	
8/77	SA	4.89	8.5	15.1	46		4	2	49	36	8	1

TABLE V
Summary of Hemoglobin (grams) Findings

	1961		1963		1973		1977	
	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders
11.0-11.5	1	0	1	0	0	0	0	0
11.6-12.0	0	0	0	0	1	0	0	0
12.1-12.5	1	1	1	0	0	0	0	1
12.6-13.0	1	1	0	1	0	1	0	0
13.1-13.5	0	0	2	0	1	0	1	0
13.6-14.0	2	2	3	1	0	0	2	0
14.1-14.5	1	2	1	1	0	0	0	1
Over 14.5	9	9	3	6	4	8	3	4

TABLE VI
Benzene Exposure of Churnroom Employee C-14 as Measured by Phenol Excretion

Date	Phenol (mg/L)	Indicated Benzene Exposure (ppm)
1/61	480	60
9/61	390	50
8/62	206	25
5/63	300	35
12/63	325	40
7/64	180	20
12/64	15	0

TABLE VII
Benzene Exposure (measured) and Phenol Excretion (saturator operator)

Date	Benzene (ppm)	Phenol (mg/L)
5/60	68	570
7/60	57	
1/61	90	700
9/61	22-23	295
8/62	10-14	40
4/63	33-43	
5/63	-	440
12/63	38-140	260
7/64	15-67	185
8/73	0	40

TABLE VIII
Red Blood Cell Counts for All Workers Examined

Range × 10	1961		1963		1973		1977	
	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders
3.5 - 4.0	1	0	1	0	0	0	0	0
4.1 - 4.5	4	5	5	4	0	0	0	0
4.6 - 5.0	7	4	4	0	5	6	3	5
Over 5.0	3	8	1	0	2	3	1	2

TABLE IX
White Blood Cell Counts for All Workers Examined

Range × 10^3	1961		1963		1973		1977	
	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders	Churnmen	Spreaders
Below 5.0	0	0	1	0	1	1	0	0
5.0 - 10.0	13	16	5	8	7	7	4	5
Above 10.0	2	1	5	1	0	1	0	2

TABLE X
White Blood Count vs Benzene Exposure

Worker	Benzene (ppm)	1961 or 1963 WBC (10')	1973 WBC (10')	1977 WBC (10')	Employment Status
c-2	15-40	12.6	*n.d.	n.d.	Retired
c-4	25	16.2	6.9	8.4	Employed by plant
C-6	...	14.6	n.d.	n.d.	Employed elsewhere
c-8	30	11.2	n.d.	n.d.	Died, heart disease (1972)
C-11	15-20	10.2	9.5	8.0	Employed by plant
C-15	35	11.4	5.1	n.d.	Retired
s-2	15.33	11.6	n.d.	n.d.	Employed elsewhere
s-9	20-30	10.2	n.d.	n.d.	Retired
S-13	...	n.d.	12.7	10.3	Employed by plant
S-17	...	9.6	8.1	10.3	Employed by plant

*n.d. = not determined.

Table VIII summarizes the red blood cell counts on the workers. One count was below 4,100,000 and it was on C-14 mentioned earlier.

Table IX shows that 3 workers had white counts less than 5,000. From Table II and 111, it is seen that C-19's count was 4,700 in 1963, and two others, C-13 and S-8, had counts of 4,400 and 4,800 respectively. C-13's count was repeated in 1974 and found to be 3,900, but in 1977 it was 5,100. C-19 retired in 1969 reportedly in good health and was still alive in 1977, S-8 is retired because of poor eyesight, and C-13 is still employed in the spreader room.

Ten workers had white counts above 10,000, and this information along with available benzene exposure data and employment status are summarized on Table X. No exposure related trend was noted.

Table XI summarizes the benzene and health or employment information on the 38 workers in our study exposed to benzene up to 1964. Fifteen of the workers who have had up to 21 years of benzene exposure were still employed by the plant in 1977. When interviewed, they did not complain of any health problems. Five retired at 65 years of age reportedly in good health and were still alive in 1977. Four retired early because of disabilities and three others have died: one from lung cancer, another from heart disease and the third from coronary sclerosis. Eleven of the group left the company. With the exception of C-5 who is in his eighties, they are employed elsewhere and were said to be free of any serious health problems.

summary and conclusions

Rubber coating workers in this study were exposed for 1 to 24 years to benzene at concentrations generally between 5 and 50 ppm, but one worker's average exposure was as high as 90 ppm (peak 140 ppm). One case of mild benzene poisoning was reported, but the worker recovered rapidly when he was transferred to a benzene free job. Some of the other workers had blood pictures which were considered slightly abnormal. The hemoglobin of one worker (S-16) remained low (12.5 grams) and unchanged from 1961 to 1977. No blood dyscrasia or leukemia, however, has as yet been reported in the group 13 years after benzene exposures were terminated in 1964.

While it is true that the population studied was small, the data nevertheless would appear to substantiate the former ACGIH TLV of 25 ppm since no significant abnormal blood findings were associated with lower exposures. The margin of safety of the 25 limit, however, appears to be small because one case of apparent mald benzene poisoning developed in a worker exposed for only six years at concentrations of the order of 40 ppm. The recent reduction to the current ACGIH TLV of 10 pprn would seem reasonable in the light of our findings.

TABLE XI
Years Exposed to Benzene and Health or Employment Status

Worker	Age (1977)	Benzene Exposure (years)	Employment Status (1977)
SA	45	2	Still employed by plant
S-1	41	8	
s-3	38	4	
s-5	54	3	
s-10	41	6	
S-11	41	10	
S-12	42	9	
S-13	49	8	
S-16	51	21	
S-17	52	9	
C 4	45	2	
c-9	55	4	
C-11	49	6	"
C-13	51	10	"
C-14	42	7	"
s-9	78	9	Retired
c-2	69	18	
c-10	70	11	
C-15	65	9	
c-19	73	19	
S-6	65	24	Retired at 63, heart disease
S-8	59	6	Retired at 57, legally blind
C-12	58	4	Retired at 58, emphysema
C-16	46	12	Retired at 44, hip injury
S-4		17	Died, coronary sclerosis in 1972 at 72
S-15		14	Died, lung cancer in 1975 at 71
C-8		13	Died, heart attack in 1972 at 64
s-2	44	6	Left 1963, employed elsewhere
S-7	54	2	Left 1962
S-14	41	7	Left 1961
C-1	43	6	Left 1965
c-3	51	6	Left 1975
c-5	81	1	Left 1961 retired
C-6	58	2	Left 1965 employed elsewhere
c-7	37	2	Left 1962
C-17	37	6	Left 1961
c-18	37	2	Left 1961
c-20	67	9	Left 1977

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