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Vinyl Chloride Monomer and Other Contaminants in PVC Welding Fumes

J. WILLIAMSON and B. KAVANAGH
Water Authority of Western Australia

An investigation into the nature of fumes produced during thermal welding of plasticized PVC sheeting has been carried out with the objective of determining if the known carcinogen vinyl chloride monomer (VCM) is formed and to assess the level of exposure to the operator. The results show that the atmospheric concentrations of VCM are well below accepted occupational exposure limits. This finding is consistent with reports in the technical literature which suggest that VCM is produced during thermal degradation of PVC only at temperatures considerably higher than those encountered during plastic welding.

Introduction

Over the past ten years plasticized polyvinyl chloride (PVC) sheeting has been used extensively as an internal lining in sewers to protect against corrosion. During construction, PVC-lined pipes are laid and the overlapping ends of the sheeting in adjacent sections are joined by plastic welding. In this process, a hot air gun is used to heat fuse a strip of PVC over the joint in order to form a seal.

There has been concern expressed industrial unions that the fumes generated during plastic welding may contain vinyl chloride monomer (VCM); VCM is a confirmed carcinogen that causes tumors in humans and experimental animals. To date however, no specific studies have been carried out on fumes generated during plastic welding of PVC.

Pure PVC is a colorless rigid material with limited heat stability. Various other ingredients such as stablizers (*e.g.*, lead compounds) and plasticizers (*e.g.*, diethyl hexylphthalate DEPH and di-iso-octyl phthalate DIOP) are added to make more useful plastic materials. PVC is thermally stable below 225° C. Between 225° C and its ignition temperature of 475° C, thermal degradation results in the release of various chemicals.[1] Exposure of PVC to temperatures ranging from 225° C to 310° C results in quantitative dehydrochlorination of the PVC, making hydrogen chloride (HCl) the major low temperature thermal degradation product.

Some release of plasticizers — such as DEHP and DIOP — occurs from plasticized PVC in this temperature range. Small amounts of methane, benzene and toluene may be liberated also. At higher temperatures (*e.g.*, above 350° C) oxidative reactions occur; carbon monoxide (CO) and carbon dioxide (CO_2) are the major products formed.[2] Vinyl chloride monomer may be released from PVC at temperatures in excess of 300° C,[3] while above 600° C, small amounts of phosgene and chlorine are thought to be formed

A number of studies have been carried out that focus on possible hazards associated with the release of degradation products produced by thermal cutting of PVC film during meat-wrapping operations.[4] Two findings from these studies are relevant in the context of the current investigation First, it has been shown on several occasions that the principal contaminant of occupational health significance — at least as far as an acute response is involved — is hydrogen chloride.[5,6] Second, the concentrations of chemical products generated at conventional hot wire cutting temperature (≈225° C) have been found to be well below accepted occupational exposure levels.[4]

No concern has been expressed in any of these reports concerning possible hazards arising from release of vinyl chloride monomer.

The main objectives of the study reported in this paper were as follows:

1) to examine the possibility of VCM formation during routine PVC welding and to determine the level of exposure to the operator.

TABLE I
Sampling Periods and Detection Limits for Various Constitutents

Constitutent	Method of Analysis	Sampling Period (min)	Detection Limit (ppm)
VCM	GLC	30-100	0.05-0.10
HCl	Draeger tube	3	0.5
Benzene	Draeger tube	10	1.0
Formaldehyde	Draeger tube	2	1.0
Acetaldehyde	Draeger tube	3	50

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TABLE II
Sampling of Welding Fumes in Field Situations

Test Number	Sampling Environment	Weather Conditions	Sampling Position	Ventilation
1	600 mm Sewer No. 1	cool (20°C) and still	750 mm downstream from operator	Mechanically assisted
2	manhole on 600 mm Sewer No. 1	cool (20°C) and still	100 mm above operator's head	Mechanically assisted
3^A	2200 mm Sewer No. 2	cool (15°C) S to SW wind 1-2 m/sec	breathing zone	Mechanically assisted

^A Test 3 was carried out in an experimental section of a 2200 mm main sewer. At the time of the test, the cross section of the sewer temporarily was bricked off approximately 80 m downstream from the ventilation source, thus reducing the effectiveness of ventilation.

TABLE III
Sampling of Welding Fumes in Simulation Trials

Test Number	Location	Welding Period (min)	Sampling Period (min)	Sampling Position	Welding Conditions
4	Laboratory	30	30	50 mm above nozzle	severe heating
5	Workshop	15	75	A	normal heating
6	Workshop	15	75	A	severe heating
7	Workshop	10	30	A	normal heating
8	Workshop	30	30	A	severe heating
9	Workshop	30	5	200 mm above nozzle	normal heating

^A During Tests 5-8, samples were taken approximately 1 m below crouching operator.

2) to carry out checks for the presence of other potentially troublesome compounds, namely benzene, hydrogen chloride, formaldehyde and acetaldehyde — all of which are irritants to the respiratory tract and mucous membranes.[7,8]

The study involved a series of laboratory and workshop simulations as well as field trials.

Experimental

Fume Analysis

Time-weighted average samples for VCM analysis were collected and analyzed by using gas liquid chromatographic techniques described in Method Number P&CAM 178 of the NIOSH Manual of Analytical Methods.[9]

This sampling method involved drawing a known volume of air through a sorbent tube containing activated carbon, which absorbed any VCM present in the air. The collected VCM then was desorbed in carbon disulphide, and the solutions were analyzed by gas liquid chromatography (GLC) with flame ionization detection. The detection limit for VCM in air in this study varied from 0.10 to 0.05 ppm with sampling periods varying from 30 to 100 min.

The atmospheric concentrations of benzene, hydrogen chloride (HCl), formaldehyde (HCHO) and acetaldehyde (CH_3CHO) were measured using Draeger gas detection tubes. Details of sampling procedures and detection limits for the various constituents examined are given in Table I.

Two sorbent tubes samples also were collected for examination in which gas chromatography-mass spectroscopy (GC-MS) was used. The purpose of this work was to identify any unknown trace organic compounds present in the welding fumes.

Sampling

A series of field and simulation trials were carried out using a Leister Triac hot air gun as shown in Tables II and III.

The laboratory simulation involved severe heating of a piece of PVC sheeting with a hot jet until copious amounts of white fumes were generated. These fumes were sampled 50 mm above the nozzle of the welding gun for 30 min at a rate of 50 mL/min. The PVC sheeting was charred heavily at the completion of the test. The conditions of this test were extreme and chosen so as to be considerably more severe than conditions likely to be encountered in the field.

The workshop simulations (Tests 5-8) involved sampling during welding in a confined space and were conducted inside a length of concrete lined steel pipe (internal diameter 1400 mm, length 1000 mm) with the ends sealed with tarpaulin. As no ventilation was used, the operator wore a self-contained breathing apparatus during the trials.

In several of the tests, the PVC sheeting was overheated deliberately, which resulted in the formation of dense white fumes. This prevented welding being carried out for periods greater than 10 to 30 min. Sampling, however, sometimes was continued for longer periods to allow more representative data to be obtained.

Test 9 involved direct sampling of fumes generated in a trial welding exercise carried out in the open workshop area. Normal welding procedures were observed with only slight fume generation.

Welding Temperature Measurements

Since the nature of the fumes generated during welding of PVC depends on temperature, the surface temperature of the sheeting during normal welding was determined by using an infrared scanning technique.

Results

Gas Analyses

Results of the gas analyses from field and simulation trials are shown in Table IV. All gas concentrations are expressed in parts per million by volume (ppm) Also shown are the maximum exposure levels for the individual gases as recommended by the American Conference of Governmental Industrial Hygienists.[10] The values quoted are the Threshold Limit Values on a time-weighted average basis (TLV®-TWA). The values represent the average concentration of toxic gas to which a normal person can be exposed without injury for 8 hr/day, 5 days/week for an unlimited period.

Vinyl Chloride Monomer Analysis

1) Analysis of field samples taken during normal welding operations (Tests 1 and 2) showed that VCM was not present in concentrations above the detection limit of 0.05 ppm. A somewhat higher result (0.2 ppm) was obtained in Test 3 in a closed section of a 2200 mm main sewer when ventilation procedures failed to meet normal standards (See footnote in Table II).
2) Atmospheric VCM concentrations in workshop trials varied from less than 0.05 to 0.1 ppm, the latter value being obtained under conditions of severe heating and no ventilation; *i.e.*, conditions more severe than those likely to be encountered in the field.
3) Evidence of the presence of a low concentration (≈0.2 ppm) of VCM was obtained in the laboratory simulation. Quantification was not possible because of the presence of interfering compounds.

TABLE IV
Results of Welding Fume Analyses

Test Number	Type of Test	Conditions During Test	VCM (ppm)	HCl (ppm)	Benzene (ppm)	HCHO (ppm)	CH_3CHO (ppm)
1	Field	normal welding good ventilation	<0.05	< 0.5			
2	Field	normal welding good ventilation	<0.05	< 0.05	< 1		
3	Field	normal welding poor ventilation	0.2	1.0-3.5	< 2	<1	< 50
4	Laboratory Simulation	severe heating no ventilation	<0.2				
5	Workshop Simulation	normal welding no ventilation	<0.05				
6	Workshop Simulation	severe heating no ventilation	0.1				
7	Workshop Simulation	normal welding no ventilation		0.5			
8	Workshop Simulation	severe heating no ventilation		10		<1	< 50
9	Workshop Simulation	normal welding open ventilation		< 0.5	< 2	<2	< 50
Theshold Limit Value — Time-Weighted Average for Individual Components (ppm); C denotes ceiling limit			C5	5.0	10	C2	100

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Even the highest values obtained during the trials were significantly below the TLV-TWA value of 5 ppm. These results are consistent with the results of an earlier investigation in which VCM was found to be absent in fumes generated during laboratory simulations of PVC welding.[11]

Other Atmospheric Contaminants

1) Hydrogen Chloride (HCl)

HCl concentrations ranged from less than 0.5 ppm to 10 ppm depending on the severity of welding conditions and the adequacy of ventilation. (TLV-TWA for HCl is 5 ppm). Concentrations of less than 0.5 ppm were observed on four of the six test occasions — these all being situations where normal welding procedures were used (*i.e.*, no overheating of the plastic). Higher concentrations of 1.0 to 3.5 ppm were encountered in Test 3, a field welding situation where ventilation procedures were below normal standards. (See footnote in Table II). The highest concentration of 10 ppm was found in Test 8, a workshop simulation where severe overheating was carried out deliberately and no ventilation provided.

2) Benzene, Formaldehyde and Acetaldehyde

Spot tests for these constituents were performed on three occasions, including one field situation (Test 3) and two workshop simulations (Tests 8 and 9). All concentrations measured were less than the TLV-TWA values. It should be noted that the Draeger test for benzene is not specific to this compound and may yield positive responses to other aromatic hydrocarbons.

Benzene also was not detected in welding fume measurements carried out in an earlier investigation.[11]

3) Trace Components

The GC-MS analysis of samples collected during a simulation revealed the presence of several low molecular weight volatile organic compounds at trace levels. These included dichloroethane, cyclohexane, benzene and methylcyclopentane. No VCM or plasticizers were detected in these samples.

With the exception of benzene (considered earlier), the compounds identified all have relatively high TLV-TWA values (200 to 300 ppm). As they were present in the fumes only at trace levels, it can be concluded that they pose no risk in an occupational health context.

Welding Temperature Measurements

The results of infrared scanning measurements showed that the highest temperature to which the surface of the PVC sheeting was raised during welding was 196°C. This is about 30°C less than the temperature at which thermal degradation of the PVC can be expected to occur (≃225°C).

Summary and Conclusions

Vinyl Chloride Monomer Formation

The primary objective of this investigation was to examine the possibility of VCM formation during routine welding of PVC and to determine the level of exposure to the operator. Tests for VCM were carried out on six separate occasions under welding conditions ranging from moderate to very severe; these included several occasions when severe heating of PVC sheeting was carried out under confined conditions and the dense fumes sampled directly. On no occasion did the measured concentration of VCM exceed 0.2 ppm; this is less than one-twentieth of the TLV-TWA value of 5 ppm (the accepted occupational exposure limit).

The low concentrations of VCM detected in this investigation are in accord with the relatively low temperature (less than 200°C) at which thermal welding of PVC is carried out. The VCM concentrations observed probably reflect trace quantities of monomer encapsulated in the PVC during the polymerization stage of the manufacturing process.

Other Atmospheric Contaminants

The second objective of this investigation was to carry out checks for the presence of other irritant compounds that might be released during heating of PVC. Tests for benzene, formaldehyde and acetaldehyde all yielded results well below their respective TLV-TWA values. In the case of HCl, measured values were all below the TLV-TWA value of 5 ppm, with the exception of one workshop trial where severe heating of the PVC in an enclosed environment was carried out. As noted earlier, formation of HCl would be expected under such conditions, although the levels were not as high as anticipated.

Occupational Health Implications

It is clear both from the results of measurements carried out in this study and from a consideration of relevant technical literature that no significant hazard arises from release of vinyl chloride monomer during routine welding of plasticized PVC sheeting. It is worth noting in this context that the use of TLV-TWA figures for setting of an acceptable exposure level is in itself a conservative practice. Such figures assume a continuous 8-hr exposure period to a particular contaminant. In contrast, normal welding operations are intermittent; it is estimated that, for example, in a sewer application not more than 4 hr/day actually would be spent in carrying out welding operations. This would provide an additional safety factor to that already afforded by the low measured VCM concentrations.

The only other consititutent of interest would appear to be hydrogen chloride (HCl); HCl has a TLV-TWA value of 5 ppm and can be detected by most persons at atmospheric concentrations of 1 to 5 ppm. At slightly higher concentrations (5 to 10 ppm), it is immediately irritating and disagreeable. It is therefore unlikely that exposure to excessive levels of HCl would occur without an operator becoming aware of it. In practice exposure to irritant concentrations of HCl may be avoided as follows:

1) good welding practices; in particular, overheating of the PVC sheeting resulting in charring and evolution of white fumes should be avoided;
2) maintenance of good ventilation conditions during welding of PVC sheeting.

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Respiratory illness caused by overheating of polyvinyl chloride

BRIGITTE FRONEBERG, P L JOHNSON, AND P J LANDRIGAN

From the National Institute for Occupational Safety and Health, Robert A Taft Laboratories, Cincinnati OH 45226, USA

ABSTRACT On 9 August 1979, 62 (30·8%) of 201 workers and one of 60 management personnel in a polyvinul chloride (PVC) fabricating plant developed acute upper and lower respiratory irritation, headache, nausea, and fainting. All were taken to hospital; none died. Sixty of the patients were women. Interviews two weeks later with 57 affected and 14 unaffected workers disclosed that illness had followed exposure to fumes from an overheated (362°C) PVC extruding machine. Fumes were emitted from 1100 until 1150; cases occurred from 1100 until late afternoon. All workers who became ill worked west of the overheated extruder, and the affected manager had visited that area. The earliest cases occurred closest to the machine, and incidence decreased (from 53·3% to 15·4%) with distance westward. This pattern was consistent with plant ventilation. Incidence rates in men and women did not differ ($p > 0·1$). At two and 14 weeks, pulmonary function testing of workers with persistent pulmonary symptoms showed abnormalities in 13 of 16 and in 9 of 11 respectively; the group with persistent symptoms contained an excess of non-smokers and of those with previous respiratory illnesses. One kilogram of PVC heated to 300°C releases an estimated 12·9 g of hydrochloric acid (HCl) and 4·9 g of carbon monoxide (CO). We attributed the outbreak to exposure to toxic HCl and CO and rejected the hypothesis of mass psychogenic illness.

Polyvinyl chloride (PVC) is a plastic used widely as an insulating material, as a substitute for rubber, and for thousands of consumer products from car equipment to pipes, phonograph records, and baby pants. It is formed from vinyl chloride monomer by addition polymerisation. Since PVC resin is tough and brittle with poor heat stability, fabrication of PVC into commercial products usually entails the "compounding" of PVC with other chemicals (plasticisers, stabilisers, fillers, pigments, lubricants, and modifiers) to produce the desired properties; such additives may constitute up to 60% of total weight in some finished PVC plastics. These plastics are usually formed into products by milling, calendering and extrusion moulding.

PVC is thermally stable at temperatures below 225°C. Its ignition temperature is 475°C. Between 225°C and 475°C PVC will not burn but will degrade thermally, releasing first hydrochloric acid (HCl) and then, above 300°C, carbon monoxide (CO), carbon dioxide (CO_2), benzene, and vinylchloride monomer.[1 2] Above 600°C, small amounts of phosgene and chlorine are formed.[1] Many additional degradation products may be released from PVC additives.

Occupational exposure to thermal degradation products of PVC has been reported to produce acute and chronic illness. Carbon monoxide poisoning may occur in acute exposure. Acute exposure to corrosive HCl fume from PVC resins has been shown in firefighters to cause laryngitis, glottal oedema, bronchitis, pulmonary oedema, and death.[1-3] Prolonged exposure to HCl fume, phosgene, chlorine, and the degradation products of PVC additives is thought to contribute to the aetiology of "meat wrapper's asthma."[4-9]

We describe the epidemiological and clinical features of an outbreak of acute respiratory illness that followed a single exposure to fumes from overheated PVC.

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The outbreak

The outbreak occurred on 9 August 1979 in a PVC fabricating plant. The major products of the plant were automotive switches, horns, and windshield wipers. Production took place in one long rectangular workroom without partitions or exhaust ventilation; an office building was separate. At the time of the outbreak there were 201 dayshift workers and 60 management personnel at the plant. The plant operated in three shifts.

At 1100 am on 9 August an extruding machine in the centre of the plant overheated from 148°C to 338°C and started to release heavy irritant fumes into the workroom. Soon workers closest to the machine began to complain of burning eyes, sore throat, and difficulty in breathing.

Because of the lack of ventilation the fumes dispersed to the west side of the workroom and accumulated there. Workers were kept in production lines despite their complaints and were supplied with wet cloths to cover their faces. They were dismissed for lunch in two shifts from 1130 until 1220. During the lunch period, between 1150 and 1200, the overheated extruder was finally shut down. Two overhead doors along the western side of the workroom were, however, closed, and fans were set up in the far west corners of the building to blow the fumes back towards the centre of the plant.

After workers returned from lunch to the lines the situation worsened rapidly. The fumes had apparently been pushed by the fans to the area near the overheated extruding machine. At 1235 a worker collapsed; three or four others followed immediately, and all were sent to hospital. At 1300 the areas close to the extruder were evacuated. The workers, although they had been sent outside, continued to fall ill and to faint on the lawn and were taken to hospital. At 1400 all workers were sent home. The plant was thoroughly ventilated. During the next shift, which began at 1500, no workers fell ill or complained of symptoms. There was no further recurrence of illness.

Altogether, the extruder had emitted smoke from about 1100 to 1150, and workers were exposed for 1·5 to 2·5 hours, depending on lunchbreak schedules. A total of 62 workers and one manager fell ill. All were taken to a hospital for observation; all were discharged within hours. All but two cases occurred in women, three of whom were pregnant.

The managers of the plant regarded the event as mass hysteria. Workers and local union representatives thought, however, that more than fear and anxiety were involved and insisted on investigation. An evaluation of the episode was, therefore, conducted by the National Institute for Occupational Safety and Health (NIOSH).

Methods

MEDICAL

On 23/24 August 1979 one NIOSH investigator (BF) interviewed 57 (92%) of those taken to hospital from the plant, using a questionnaire to record age, sex, seniority, and marital and parental status, as well as information on time of onset of illness, work station at the time of onset, symptomatology, and duration of symptoms. In addition the questionnaire was specifically designed to elicit data on indicators of job dissatisfaction such as boredom, unwanted overtime, inadequate supervisory or peer support, and production pressure; several of these questions were taken from a NIOSH questionnaire developed for the evaluation of mass hysteria.[10] Fourteen exposed but unaffected workers were interviewed at the same time, as controls. Hospital records of all 62 workers sent to hospital were obtained and evaluated.

Pulmonary function tests (PFT) were performed at the initial evaluation on 16 workers with persistent respiratory complaints. Eleven with abnormal PFT results according to the criteria used[11] received a second test on 26 November 1979. These second test readings were compared with those of a group of matched controls from the same work areas; matching was on sex, race, and age (within ± three years). Both groups answered a shortened form of the American Thoracic Society questionnaire.

INDUSTRIAL HYGIENE

Air samples for measuring PVC decomposition products (HCl, CO, CO_2, phosgene, chlorine, and vinyl chloride monomer) were obtained on 23/24 August by means of detector tubes. There were no visible fumes in the workroom on those days.

Bulk pellets of PVC resin were collected at the plant on 23 August and were analysed at NIOSH laboratories for thermal degradation products at temperatures of 300-450°F (148-232°C) and 500-600°F (260-315°C). Analyses were performed by gas chromatography/mass spectroscopy techniques.

Results

EPIDEMIOLOGY

We interviewed 57 (90·5%) of the 63 people taken to hospital. The three who were pregnant were excluded from further analysis.

The principal symptoms were dry mouth (75%), headache (67%), dizziness (63%), and lightheadedness (58%) (table 1). Chest tightness was experienced by 56% of those interviewed, dyspnoea by 46%, and chest pain by 31%.

Onset of the outbreak was abrupt. No cases occurred before 1100, 24 occurred from 1100 to 1200 noon, 21 from noon until 1400 and nine had later onset at home. The onset of illness varied with distance from the overheated extruder: more

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Table 1 Incid
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depression
Severe headache (
Blurred vision (10)
Vertigo (63)
Lightheadedness (5
Weakness (62)
Numbness (50)
Sleepiness (37)
Convulsive laughter
Fainting (7)

Table 2 Distril
Location
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Table 3 Incidence r

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Women	148
Total	157

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Table 1 *Incidence of symptoms in affected workers. (Percentage of interviewed cases with symptom in parentheses)*

Central nervous system depression	*B Mucous membrane effects*	*C Respiratory tract irritation*	*D Miscellaneous*
Severe headache (67)	Burning eyes (42)	Sore throat (39)	Chills (39)
Blurred vision (10)	Lacrimation (12)	Hoarseness (12)	Bitter taste (46)
Vertigo (63)	Dry mouth (75)	Cough (37)	Difficulty swallowing (29)
Lightheadedness (58)		Dyspnoea (46)	Nausea (35)
Weakness (62)		Chest tightness (56)	Vomiting (6)
Numbness (50)		Chest pain (31)	Abdominal pain (8)
Sleepiness (37)		Feeling of suffocation (29)	Muscle soreness (6)
Convulsive laughter (2)			Racing heart (2)
Fainting (7)			

ble 2 *Distribution of cases by work area*

Location	*Mean distance (m) west of extruder*	*No of workers*	*No (%) cases*	*No (%) severe cases**
Subassembly	10	15	8 (53·3)	4 (26 7)
Area 700	25	5	3 (60 0)	3 (60 0)
Area 660	40	52	24 (46·1)	4 (7·7)
Areas 560, 580, 600	55	55	23 (41·8)	5 (9 1)
Areas 500, 520, lunchroom, noiseroom	80	26	4 (15 4)	0 (—)
Warehouse, moulding, paint room	East and north	48	0 (—)	0 (—)
Total	—	201	62† (30 8)	16 (7·9)

*Severe cases had persistent respiratory symptoms.
†An additional case occurred in a manager.

than half of the cases close to the extruder occurred between 1100 and 1200, whereas more than half of the cases further down the line occurred between 1200 and 1400 or even later ($p < 0·01$).

Sixty-two of the 63 cases occurred in workers whose work stations at onset of illness were in the western section of the plant (table 2). No cases occurred east of the overheated extruder. Attack rates were highest close to the extruder and decreased with distance westward (table 2). One case occurred in a manager employed in the warehouse, north of the main plant. During the outbreak he had visited his daughter, who worked in the western section of the plant.

Illness occurred in one out of five maintenance workers. Although their base was located in the eastern section of the plant, they were working west of the overheated extruder at the time of the outbreak.

Illness occurred much more frequently in women than in men, but the number of men employed was too small for this difference to reach statistical

Table 3 *Incidence rates among exposed workers by sex*

	No of workers	*No affected*	*Rate (%)*
Men	9	2	22·3
Women	148	60	40 5
Total	157	62*	39 5

$\chi^2 = 2·2237$.
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*An additional case occurred in a manager.

significance at the 5% level (table 3).

Comparison between affected and non-affected groups indicated that they were comparable in age, seniority, marital status, and number of dependants. The prevalence of current smoking was lower in those with symptoms than in those who developed no symptoms during the outbreak ($p < 0·001$). The affected group rated their state of general health lower than did the unaffected ($0·1 > p > 0·05$) and reported that they had suffered more often than the unaffected from nervousness, loneliness, upset stomach, headache, faint feelings, and fatigue before the outbreak ($p < 0·05$). The affected group did not, however, have a higher frequency of past absenteeism. Both groups worked 40 hours a week, none did overtime work, and only two had other paid employment. They showed no significant differences in their attitudes towards their jobs; most liked their jobs and colleagues and expressed satisfaction with the management/worker relationship and with their income. Both groups, however, expressed discontent with working conditions such as poor ventilation and the lack of a safety programme.

Examination of hospital records showed that the examining doctors had attributed workers' signs and symptoms largely to anxiety. All 41 radiographs obtained were normal or showed unrelated findings; three ECGs were also normal. One of two blood gas analyses was normal, the other showed respiratory alkalosis consistent with hyperventilation.

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PULMONARY FUNCTION TESTING

Most ill workers recovered within hours. Sixteen, however, had persistent respiratory symptoms that were still evident at the time of evaluation. Seven of those 16 clustered in the two plant areas closest to the over-heated extruder (table 2). Pulmonary function tests were administered to the 16 with persistent respiratory complaints by means of a dry wedge spirometer (Vitalograph).* Thirteen of the 16 showed pathological results (table 4). Only five (38%) of those with abnormal results smoked.

Repetition of ventilation tests in late November on 11 of the 13 workers who had abnormal lung function in the initial testing showed persistence of abnormal function in nine (3 obstructive, 6 restrictive). Overall, the indicators for obstructive and restrictive lung disease had, however, improved slightly. Compared with matched controls from the same work areas, cases evaluated in November had significantly poorer lung function ($p < 0{\cdot}05$). They also reported significantly more experience of respiratory illness (bronchitis, pneumonia, asthma) before their exposure to fumes in the present episode ($p < 0{\cdot}05$).

Table 4 *Results of pulmonary function testing (Vitalograph) of workers with respiratory symptoms*

	Smoker	*Non-smoker*	*Total*
Normal function	1	2	3
Obstructive defect	1	1	2
Restrictive defect	1	5	6
Combined obstructive/ restrictive defect	2	3	5
Total	5	11	16

A ventilation defect was considered obstructive when either FEV_1 was less than 80% of predicted or the ratio of FEV_1/FVC% was less than 70%, it was considered restrictive when FVC was less than 80% of predicted.[11]

INDUSTRIAL HYGIENE

Sampling at the plant on 23/24 August showed no detectable concentrations of CO, CO_2, HCl, phosgene, or chlorine. Vinyl chloride monomer was, however, detected in air at concentrations between 0·45 and 1·3 ppm.

Thermal degradation testing of two types of bulk PVC samples from the plant at temperatures of 300-450°F (148-232°C) showed release of long-chain aliphatic alcohols, toluene, benzene, various chlorinated species, and a major peak of HCl. Main components released at 500-600°F (260-315°C) were aromatic hydrocarbons such as benzene, phenol, and adipates along with various aliphatic alcohols, alkenes, anhydrides, few of them chlorinated. Carbon monoxide release could not be assessed by the method used.

*Mention of a company name or product is for information only and does not constitute endorsement by NIOSH.

Discussion

The major finding in this investigation was that a high proportion of workers exposed to fumes produced by the thermal degradation of PVC resin in an overheated extruder developed symptoms of respiratory irritation and of central nervous system dysfunction (table 1). Although no one died, symptoms were of sufficient severity to require transient hospital care for 63 workers.

Plant management believed initially that the outbreak was caused by psychogenic factors, a belief that was possibly reinforced by the high proportion of women among the affected workers. That hypothesis was, however, abandoned after examination of the spatiotemporal distribution of cases and with the realisation that attack rates did not differ significantly between men and women workers. This experience exemplifies the hazard of too ready acceptance of a psychogenic aetiology for outbreaks of mass industrial illness.

Acute illness similar to that encountered in the present outbreak has been reported in firefighters exposed to burning or smouldering plastic[1-3] and in workers exposed to fumes from burning PVC-coated wiring.[12] Also residual pulmonary injury was described in several of the latter group of workers.[12]

In the present investigation we observed a subset of exposed workers, consisting principally of nonsmokers, who exhibited persistence of cough, chest pain, and chest tightness for several weeks after the episode. Those symptoms were associated with persistent spirographic abnormalities, which improved only slightly in the three months following the outbreak. Although the persistent symptoms in those workers were related clearly in their onset to the acute exposure, it is difficult in the absence of previous baseline data to ascribe the spirographic abnormalities to that source. Again, we were surprised to find that many of this group with spirographic abnormalities had restrictive rather than the obstructive changes that have been reported in people, such as meat wrappers, exposed occupationally to the thermal degradation products of PVC.[6 8] A possible explanation for the finding is that the group with persistent abnormalities reported a higher prevalence of prior respiratory disease than controls, a finding that may suggest previous background of respiratory illness or a heightened susceptibility to respiratory insult in this subgroup.

Prior studies of thermal degradation of PVC at various temperatures[3 13 14] have indicated that the major toxic decomposition products released at the not be assessed by

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Table 5 *Quantities of substances emitted from 1 kg PVC at various temperatures*[13]

Temperatures (C)	*Quantities of substances (mg)*			
	Hydrogen chloride	*Phosgene*	*Carbon monoxide*	*Carbon dioxide*
300	12 900	0	4900	6600
600	15 300	1	6900	14 800
900	15 400	3	480	28 700

temperature range encountered in the overheated extruder in this outbreak (362°C) are HCl and CO. It has been estimated that at the temperatures encountered in the present episode maximum releases into air of HCl and CO from each kilogram of overheated PVC resin would have been 12 900 mg and 4900 mg respectively (table 5). The concentrations of HCl and CO actually achieved in workroom air are, however, not known, because the quantity of resin combusted and the rapidity of dilution cannot be ascertained. It appears likely that in the presence of inadequate ventilation HCl and CO could have accumulated to concentrations well above the normally accepted industrial threshold limit values and short-term exposure limits, and that those concentrations of HCl, CO, and possibly of other degradation products, accounted for the observed illness.

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