Plastic Pipe Installation:

Potential Health Hazards for Workers

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Plastic Pipe Installation:
Potential Health Hazards for Workers

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Kenneth W. Kizer, M.D., M.P.H., Director

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Copies of this report are available to the public. Inquiries should be directed to:

California Occupational Health Program
2151 Berkeley Way, Room 504
Berkeley, California 94704
(415) 540-2115

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SUMMARY

During August-November 1988, the California Occupational Health Program studied possible worker health hazards associated with the installation of plastic pipe. The state's Department of Housing and Community Development, anticipating a possible change in the State Plumbing Code that would allow increased use of plastic pipe, requested the study to assess whether the change would result in more-hazardous working conditions for plumbers installing the new materials, particularly chlorinated polyvinlychloride (CPVC) pipe. The cements used to join the pipes contain several organic solvents, including tetrahydrofuran (THF), methyl ethyl ketone (MEK), cyclohexanone (CHX), acetone (ACE), and dimethylformamide (DMF). Workers installing copper pipe and polybutylene (PB) pipe were also monitored for exposures to toxic substances. The study was limited to residential construction.

Exposure monitoring was conducted at 35 construction sites throughout California and in the state of Georgia. At each plastic pipe installation site, short-term and full-shift solvent exposures were assessed by collecting a variety of personal air samples. Urine samples were obtained from most workers monitored, and analyzed to determine whether significant concentrations of the solvents had been absorbed. Workers soldering copper pipes were monitored for exposures to metal fumes and flux decomposition products.

In 60 air samples representing full-shift exposures, the average concentrations were 47 ppm THF and 10 ppm MEK. The highest measured full-shift exposures were 158 ppm for THF (79% of the airborne exposure limit) and 45 ppm for MEK (23% of the exposure limit). Based on an index of combined exposure to THF, MEK, CHX, and ACE, one worker's exposure to these substances exceeded the exposure limit. Workers installing CPVC potable water pipe had average exposures 1.8 to 8.5 times higher than the average exposures of workers installing other types of plastic pipe, based on the combined exposure index. Workers who experienced the highest exposures were installing numerous fittings in highly enclosed areas—crawl spaces and an attic. Exposures to DMF were low: measurable DMF was detected in only three of 28 air samples at a maximum concentration of 0.4 ppm, and no evidence of DMF exposure was found in 26 urine samples.

Concentrations of THF and MEK in workers' urine samples were closely correlated with their airborne exposures. Workers who had extensive skin contact with plastic-pipe primers and cements had higher urine concentrations of THF—relative to their airborne exposures—than workers with light skin contact, suggesting that a significant portion of a worker's total THF dose may be absorbed through the skin. Four of 29 workers who had heavy skin contact with THF-containing products had urine THF concentrations up to seven times higher than the maximum among workers with little skin contact, even

though their airborne exposures were comparable. The total THF exposures (airborne plus dermal) of these workers were estimated to be equivalent to airborne exposures of 150-740 ppm (75-370% of the exposure limit). These estimated values incorporate considerable uncertainty, but they represent the best available interpretation of the urine concentrations.

Short-term exposures under some conditions were substantially higher than the full-shift exposures, up to 529 ppm for THF (210% of the short-term exposure limit) and 95 ppm for MEK (32% of the limit). Short-term exposures were highest at CPVC installation sites, especially during extended work in highly-enclosed spaces. The probability that the limit for combined short-term exposure to THF, MEK, CHX, and ACE would be exceeded, during installation of CPVC potable water pipe, was estimated to be 3.5% for any randomly-selected 15-minute period. This value indicates a 68% chance that the combined exposure limit would be exceeded during at least one 15-minute period over a typical 8-hour work day. Work-area ventilation rates were the strongest and most consistent determinant of exposure levels.

The potential health impacts of these full-shift and short-term exposures (especially THF) are not fully known. The occupational exposure limit for THF has been set to prevent eye, nose, and throat irritation, so workers exposed above the limit may experience irritation. Concurrent exposures to MEK, CHX, and ACE may exacerbate any sensory irritation. The effects of chronic exposure to THF have not been studied in humans or animals. THF absorbed through the skin is unlikely to contribute to sensory irritation but could amplify any systemic effects from ongoing exposure to THF and other solvents.

Exposures associated with installation of copper and polybutylene pipe were studied in less detail, but were found to be well below the established workplace exposure limits for all substances monitored. Workers in every type of pipe installation faced significant safety hazards, especially when working with chain saws in awkward positions and when working atop unsafe ladders. Most employees (90%) had received no health and safety training.

To reduce work-related health hazards, the following recommendations should be implemented consistently during all plastic-pipe installation. Employers should arrange installations such that no plastic-pipe cementing in completely enclosed areas is necessary and should provide forced ventilation when work in enclosed areas is unavoidable. Employers should establish work practices that prevent extensive skin contact with primers and cements, and primers should be supplied strongly tinted to discourage skin contact. Employers should provide comprehensive, effective health and safety training for all workers.

INTRODUCTION

Newly-built housing units currently have as many as six separate piping systems installed. The two systems common to every unit are potable water supply (pw) and drain, waste, and vent (DWV). Other plumbing systems may also be required by the developer or buyer, or by local ordinance; these systems are for: fire sprinklers, garden sprinklers, natural gas, and "condensate lines" for draining air conditioners and clothes-washer overflow.

In February, 1988, the California Occupational Health Program (COHP), a unit of the state Department of Health Services, was asked by the Department of Housing and Community Development to assess the health hazards associated with installation of three types of water-supply pipe: chlorinated polyvinylchloride (CPVC), polybutylene (PB), and copper. At the time of the study, only copper and galvanized steel pipe were approved by the State Plumbing Code for distribution of potable water within structures. Local city or county building departments could approve other plumbing materials, but few chose to do so. The Department of Housing and Community Development was considering an amendment to the State Plumbing Code which would grant statewide approval for use of CPVC and PB potable-water pipe, and sought to determine whether this regulatory change would ultimately impact the health of workers installing the pipe.

In keeping with the original request, the goal of this study was to evaluate the work-related health hazards that occur during installation of the three types of water-supply pipe: CPVC (designated CPVC-pw), PB, and copper. However, three other types of pipe were also included in the study: CPVC pipe used for fire sprinkler systems (CPVC-fire), DWV pipe made of polyvinylchloride (DWV-PVC), and DWV pipe made of acrylonitrile-butadiene-styrene copolymer (DWV-ABS). These pipes were included for two reasons. First, CPVC-fire was included because the fact that CPVC-pw was not approved statewide severely limited the number of CPVC-pw sites available for monitoring. CPVC-fire installation served as a surrogate in determining the patterns of exposure and the factors affecting exposure levels. Installation of CPVC-pw and CPVC-fire systems are similar in many respects, including: the size of the joints cemented, the primers and cements used, and the work practices and general worksite conditions. Second, DWV-PVC and DWV-ABS pipes were included because plumbers who install water-supply pipe are often assigned to install DWV lines during subsequent hours or days, so consideration must be given to cumulative exposures.

CPVC pipe joints are cemented together with fittings in a two-stage process. Parts to be cemented are prepared with a primer, then coated with cement, and finally the parts are held together for a few seconds while the bond is made. Both the primers and the cements have organic solvents as their major constituents. Five solvents are used in varying proportions: tetrahydrofuran (THF), methyl ethyl ketone (MEK), and cyclohexanone (CHX) are in most cements and primers; acetone (ACE) and dimethylformamide (DMF) are in a few. CPVC resin is added to the cements. DWV-PVC and DWV-ABS joints are made in a similar manner, but primer is usually not used. DWV joints are usually much larger (1 1/2 to 4 inches diameter) than the joints in CPVC-pw or CPVC-fire lines (1/2 to 1 1/2 inches). PB joints are not cemented; they are either made with mechanically-crimped fittings or by a thermal fusion process. Copper joints are soldered together using propane (or other gas) torches. Most copper-pipe solders are mainly tin, with small amounts (less than 10% in all) of copper, silver, or antimony added. Lead is prohibited for use in potable water systems.[1] A flux, usually organic acids in a greasy base, is applied before soldering to ensure good flow properties.

Exposures associated with installation of plastic pipe have been assessed in three previous studies.[2,3,4] In each of those studies, full-shift exposures to THF, MEK, CHX, ACE, and DMF were below the respective exposure limits. However, short-term exposures have been found to approach or exceed the short-term exposure limits for THF and MEK, especially during work in enclosed areas. The frequency of overexposures and the effects of various job factors on exposure levels have not been previously determined. In other industries, dermal absorption of DMF has been shown to add significantly to workers' total exposure;[5] plumbers sometimes have extensive skin contact with DMF-containing primers or cements, but dermal absorption of DMF during plastic pipe installation has not been adequately evaluated. The physical and chemical properties of THF, MEK, and CHX (especially their solubility in both water and non-polar solvents) suggest that they, too, might be well absorbed through the skin from primers and cements, but dermal absorption of these substances has not been studied.

In this study, a combination of air monitoring and biological (urine) monitoring were used to evaluate average exposures that occur during various types of pipe installation, to identify the highest exposures that are likely to occur and the conditions that produced them, and to assess the importance of dermal absorption. Measured exposure levels were used to assess the likelihood that workers installing CPVC, PB, and copper pipes would suffer adverse health effects. However, no assessment of health status was included in this study.

METHODS

General

Field monitoring was preceded by walk-through inspections of nine plastic and copper pipe installation sites. A detailed monitoring protocol was developed, and was followed closely throughout the study. Methods used for collection and analysis of air samples are summarized in Appendix A.

Monitoring of workers' exposures was conducted by one- to four-person study teams, each led by a qualified industrial hygienist. At each pipe installation site monitored, supervisors were interviewed to obtain basic information about the work being done at the site, particularly the activities of each worker. Individual workers were interviewed to obtain basic demographic information and to determine their job training, specific health and safety training, usual use of protective equipment, and any observations about unusual conditions on the day of monitoring. At the end of each work day, workers were asked to report any symptoms of ill health that they had experienced during the day.

With few exceptions, the exposures of all workers performing the installation of interest at each site were monitored. All workers were asked to participate in exposure monitoring if they met a single criterion: that they were assigned to work on the installation of interest for at least one-half of the workday monitored. At some sites, workers were split into several crews to install different types of plumbing in separate structures. If the study team was large enough, it was then split to follow the individual crews, otherwise a single installation was selected for monitoring. Detailed records were maintained of each workers' activities, including the number of joints completed, use of protective equipment, and uncommon work practices. At the end of each day, workers were asked to report whether they had experienced any of the following symptoms during the day: headaches, dizziness, skin rash, dried skin, gastrointestinal disturbances, or irritation of eyes, nose, or throat.

Site Selection

The primary goal of the site selection process was to identify representative CPVC-pw installation sites. An extensive but fruitless search was made in California and surrounding states. Ultimately CPVC-pw and DWV-PVC sites were identified and monitored in Georgia. Installations of other types of plastic pipe (CPVC-fire and DWV-ABS) were identified in California and a sample selected for monitoring. Installations of copper potable water and PB pipe were also identified. In all more than 1500 calls were completed in the effort to identify and select appropriate sites, and to arrange site visits.

The first task in site selection was to determine whether any California cities or counties permitted the use of CPVC for potable water distribution within residential units. The most up-to-date information available listed 44 cities and counties which had approved some or all of the expanded uses of plastic pipe as of 1985. Appropriate building or plumbing department officials were contacted in each of these jurisdictions—and 44 other California cities and counties—and were questioned about the use of CPVC-pw. Only four areas (South Lake Tahoe, Palm Springs, Marin County, and Nevada County) permitted CPVC-pw in their local plumbing code. Most plumbing inspectors from these areas reported that they "discouraged" the use of CPVC and that the contractors themselves chose not to use it. The site search process is described in detail in Appendix B.

When no CPVC-pw installation sites could be located in California, the U.S. manufacturer of CPVC resin suggested that Atlanta, Georgia was the area most likely area to provide an adequate number of CPVC-pw sites for monitoring. Under that recommendation, the CPVC-pw site selection process was then focussed on the Atlanta area. The regional CPVC sales representative contacted two of the largest plumbing contractors in the area and provided several other contractors' names. Other leads were provided by the Atlanta building department, referrals from individual contractors, referrals from local plumbing suppliers, and the telephone directory. The local plumbers union was contacted but could not provide additional leads. In all, approximately 30 Atlanta-area contractors were contacted. Most of these did not use CPVC or were not using it at the time monitoring was scheduled. Every contractor known to be using CPVC-pw in the Atlanta area during the monitoring period agreed to participate in the study. PVC was the main pipe material used for DWV at the Georgia sites monitored; all DWV-PVC monitoring was done in that state.

The search for CPVC-pw sites led to a realization that CPVC pipe was widely used in fire sprinkler systems in California. To identify potential monitoring sites, communities requiring fire sprinklers were identified, and individual sites were located by a process similar to that used for CPVC-pw sites. As monitoring of CPVC-pw and CPVC-fire sites progressed, sites were sought that had specific characteristics not yet included in the study: multiple-unit buildings, installations in enclosed spaces, use of DMF-containing glues, and high ambient air temperatures.

ABS is the pipe most widely used for DWV in California residences. Monitoring of DWV-ABS installation was conducted almost entirely in Northern California at sites of plumbing contractors whose names were provided by pipe trades unions.

All copper-installation monitoring was done in Northern California, primarily at sites suggested by the pipe trades unions. Using the same search methods designed for CPVC, no fusion-method PB potable water site was located in California. The only PB installation site monitored was a snow-melt system in Northern California, which was located with the assistance of a manufacturer's sales representative.

Cemented plastic pipe exposures

Dimethyl formamide

At each site of CPVC-pw, CPVC-fire, DWV-PVC, or DWV-ABS installation, the presence of DMF in all primers and cements to be used was established at the beginning of the work day by measuring DMF vapors in the headspace of the can with a colorimetric indicator tube (Draeger DMF 10/b). Products with bulk DMF concentrations of above 0.5% were expected to have headspace DMF concentrations detectable by this method. For workers using DMF-containing products, full-shift air samples were collected using silica-gel sorbent tubes. End-of-shift urine samples were also collected, and were analyzed for the DMF metabolite monomethyl formamide (MMF) by standard methods.[6] For each worker, extent of skin contact with primers and cements was classified by an industrial hygienist according to specified criteria into one of three categories: Light (skin contact less than 25 cm^2, 10 times or less); Heavy (contact repeated more than 10 times, or contact of more than 25 cm^2 at least once); and Gloves (cotton, leather, or rubber gloves worn during most cementing). Skin contact was rated separately for morning and afternoon work periods.

THF, MEK, CHX, and ACE

Full-shift exposures to airborne THF, MEK, and CHX were evaluated by collection of personal air samples with charcoal passive dosimeters (3-M #3500). For workers handling primers or cements labelled as ACE-containing, this substance was also determined in the passive dosimeter samples. End-of-shift urine samples were collected, and urine MEK was analyzed by an established method;[7] urine THF and CHX were analyzed similarly. The collection period for the passive dosimeters was the last four hours of the workshift. This period was selected to yield data comparable with previous studies of MEK exposure (in other industries), which have shown good correlation between end-of-shift urine concentrations and airborne MEK exposures measured by 4-hour charcoal passive monitors.[8,9,10] Based on previous walk-through inspections and worker interviews, no major difference were expected between morning and afternoon exposures, so exposure levels measured by the 4-hour passive monitors were provisionally assumed to be equivalent to full-shift exposures. Possible differences between morning and afternoon work patterns are discussed later. Skin contact was classified as described above. Work area temperature was measured during the mid-afternoon.

Short-term exposures were evaluated by collection of 15-min samples according to a stratified sampling scheme. The sampling scheme was developed to maximize the number of samples collected during each workers' highest exposure periods while maintaining a degree of randomness about the specific exposure periods to be monitored. The sampling strata were based on two easily-observable parameters of work activity: work in enclosed vs. unenclosed areas, and the number of joints cemented per 15-min period. Five distinct strata were defined:

I	no cementing
IIa	unenclosed area with 1-7 joints per 15 min
IIb	unenclosed area with 8 or more joints per 15 min
IIIa	enclosed area with 1-7 joints per 15 min
IIIb	enclosed area with 8 or more joints per 15 min

Each stratum had a specified sampling frequency for each worker-day (I, one sample per two site-days; IIa, one per worker-day; IIb, 50% of all periods; IIIa, 50% of all periods; IIIb, 100% of all periods). Individual sampling periods were selected systematically within each stratum. (For example: the first 15-min IIb period was sampled; the next 15-min IIb period was not sampled; the next was; the next was not; etc.) As members of the study team became familiar with the pipe installation process, they could generally anticipate the number of joints that would be cemented in an upcoming 15-min period, and plan their monitoring accordingly. For data analysis, samples were categorized according to the actual conditions during the monitoring period, even if these were different than anticipated. Each 15-min period throughout the workday was classified into one of the five sampling strata to form a complete record of the time each worker spent in the strata.

For each air sampling period, 15-min personal air samples were collected using sorbent tubes. In most cases, two samples were collected simultaneously—one on activated charcoal and one on ambersorb XE-347—because no single sorbent is normally recommended for THF, MEK, CHX, and ACE. Each charcoal tube was analyzed for THF, MEK, and CHX, and for ACE if products labelled as ACE-containing were used. Analysis of an initial batch of 22 samples showed good agreement between the paired charcoal and ambersorb tubes (weighted average deviation was less than 15% for each substance), so most ambersorb tubes were not analyzed. After all charcoal tubes had been analyzed, ambersorb tubes collected during 14 high-exposure periods were analyzed to confirm the charcoal-tube results. For 15-min exposures measured by both paired tubes, the higher result was used for subsequent data analysis.

For each 15-min monitoring period, the air-flow rate in the worker's breathing zone was measured with a hot-wire anemometer, the work space was classified as enclosed or unenclosed, and breathing-zone temperature was measured. Working conditions were recorded for each period, including: the number of joints cemented, spills, and the potential for secondary exposure (defined as other workers cementing within 10 feet or in the same enclosed area). A "joint cemented" was defined as cementing pipe in both ends of a two-opening fitting, or in two openings of separate fittings.

Real-time exposure profiles

An H-Nu 101 photoionization detector (PID) was used to qualitatively characterize exposure variability. Real-time measurements were made of workers' exposures during CPVC installations of potable water and fire sprinkler systems by placing the probe of the PID in the workers' breathing zones. Exposure levels were recorded continuously on a strip chart; average concentrations for each 12-sec interval were later estimated from the strip chart to summarize the data. Because CHX and DMF concentrations were low, and because the PID is almost equally sensitive to MEK and THF, the total organic vapor concentration indicated by the PID was considered to represent the sum of the MEK and THF concentrations. The PID's response was expected to be unaffected by variations in the relative proportions of these two solvents in the primers and cements used.

Although the PID provided interesting information about the variability of exposure levels within 15-min periods, it had some major limitations. The instrument was cumbersome, and keeping the probe in the workers' breathing zones sometimes became downright dangerous as they went up and down ladders and into tight spaces. MEK or THF calibration gases were unavailable (n-hexane and isobutylene were used instead, with appropriate sensitivity correction factors), making exact calibration impossible. For that reason, the PID data were used to provide qualitative, rather than quantitative, information about the variability of contaminant levels within 15-min periods. For periods in which exposures were assessed concurrently with the PID with 15-min sorbent-tube samples, the sorbent tube result was taken as the "true" 15-min exposure. The PID data was then adjusted by applying a correction factor, such that the average of all 12-sec concentrations in the monitoring period was equal to the 15-min average concentration of the concurrent sorbent tube sample.

CPVC/PVC dust

For the few workers who used high-speed power saws to cut plastic pipe, exposure to plastic dust was evaluated by collecting personal air samples on 37-mm membrane filters (0.8 µm pore size PVC or PTFE). The filters were analyzed gravimetrically. In one case, two samples were collected simultaneously: one of total particulates and one of the respirable fraction only, using a cyclone pre-selector. Workers who cut pipe with hand tools or with low-speed reciprocating saws were judged to have no significant exposure to plastic pipe dust.

Polybutylene pipe exposures

Samples of thermal decomposition products during one PB fusion operation were obtained. Sample collection included the day's entire exposure, and a background air sample was collected at the same time. The non-volatile and semi-volatile fraction of the sample was collected on a 37-mm filter (0.8 μm pore size, at 2 l/min). The volatile fraction was collected on a sorbent tube (400 mg pre-washed and desorbed Tenax in stainless steel) at 50 ml/min. The Tenax tube was preceded by a Teflon filter to prevent the non-volatile and semi-volatile fraction of the sample from reaching the sorbent. Formaldehyde, an expected thermal degradation product, was collected simultaneously on 2-(hydroxymethyl)piperidine sorbent tubes (Orbo-24) at 100 ml/min, and analyzed by gas chromatography.

The filters were desorbed in an ultrasonically-agitated solvent bath and analyzed by gas chromatography-mass spectrometry (GC-MS). The Tenax was thermally desorbed and analyzed by GC-MS. The GC-MS analysis consisted of: a) quantitation of 82 EPA priority pollutants (polyaromatic hydrocarbons, chlorinated hydrocarbons, phthalates, pesticides, PCBs, and chloro- and nitro-phenols) and b) a semi-quantitative identification of all other GC peaks.

Copper pipe exposures

Workers installing copper pipe were monitored for full-shift exposures to metal fumes and flux decomposition products. Breathing zone samples (13) were collected on 37 mm filters and analyzed by standard methods (plasma emission or atomic absorption spectroscopy). Concentrations of copper, tin, silver, antimony, and lead were determined. Bulk samples of several brands of solder were obtained and analyzed by plasma emission spectroscopy.

Samples of thermal decomposition products generated during copper pipe soldering operations were obtained for two workers at separate sites. Tenax, teflon filter, and Orbo-24 tube samples were collected and analyzed as described above. An additional Orbo-24 tube sample was collected for a second worker at one of the sites.

Quality assurance

Each air sample representing a full-shift exposure included all exposure periods for the work day, unless otherwise noted. Sorbent tubes, dosimeters, and urine samples were cooled on ice immediately after collection, and then kept frozen until analyzed. Flow rates for air-sampling pumps were checked regularly in the field with calibrated rotameters, and in the laboratory with bubble flowmeters. Any flow-rate changes between calibrations were assumed to have been linear during periods of pump operation. Field blanks were submitted for analysis along with air sampling media; the number of blanks was approximately 10% of the number of samples.

A laboratory quality assurance (QA) protocol was established for the THF, MEK, and CHX samples collected on charcoal and ambersorb, and for DMF samples collected on silica gel. The analytical laboratory spiked sorbent tubes with known quantities of the analytes (as a mixture for THF, MEK, and CHX). The tubes were shipped on ice to the study team, completely relabelled, and then returned to the laboratory mixed together with field samples such that the two could not be distinguished. The spiking levels were equivalent to the quantity obtained by sampling exposures of 20%, 50%, 100%, and 200% of the exposure limits. At each spiking level, three tubes were prepared. All charcoal and silica gel tubes were analyzed, along with one ambersorb tube at each spiking level.

Urine samples of two unexposed individuals were sent for analysis along with the field samples. In addition, four samples of urine from unexposed individuals were spiked with MMF (0.009 mg/ml) and sent for analysis along with field samples. Five field samples and two spiked samples were each analyzed for THF, MEK, and CHX on two or three separate days.

Evaluation criteria

The exposure limits used for evaluating exposures to the substances monitored are shown in Appendix C. These exposure limits were taken from U.S. OSHA standards, from NIOSH Recommended Exposure Limits, or from ACGIH TLVs and STELs.[11,12,13] Concentrations of MMF and MEK in urine were evaluated according to the Biological Exposure Indices (BEIs) established by ACGIH (40 $\mu g_{MMF}/g_{creat}$ and 2000 $\mu g_{MEK}/l$, respectively). Appendix C contains brief summaries of the toxicity of each substance, together with comments on the quality of information used to set the exposure limits.

For antimony, animal evidence—supported by limited epidemiologic data—suggests that it is carcinogenic, but it has not been evaluated by the International Agency for Research on Cancer. The exposure limit shown in Appendix C (0.5 $\mu g/m^3$) may not protect against carcinogenicity. Similarly, recent epidemiologic evidence has suggested that DMF may cause testicular cancers, but the carcinogenicity of DMF has not been fully evaluated. The DMF exposure limit listed in Appendix C (10 ppm) may not protect against carcinogenicity.

Data analysis

The purposes of the statistical analysis were to describe the exposure measurements and to explore the relationships between job factors and exposure levels. The methods used for data analysis closely followed a plan specified prior to data collection. For each substance and for each pipe installation type, arithmetic mean exposures and the associated geometric standard deviations (GSDs) were calculated. For all calculations, substances present in air samples at concentrations below the analytical limits of quantitation were assigned a value of 2/3 the quantitation limit, a value chosen to represent expected exposures at the low end of log-normally-distributed data. (This choice of assignment for concentrations not quantified had little bearing on the analysis of THF and MEK exposures, since most exposures were far above the detection limits). A confidence level of 95% was used for all statistical tests, unless otherwise noted. Most analysis was performed with a standard microcomputer software package.[14]

THF, MEK, CHX, and ACE all exert similar effects at low to moderate exposure levels, and workers were typically exposed to a mixture of the four. Therefore, a combined exposure index was calculated for each full-shift solvent sample, as:

$$\%FSEL = \Sigma(c_i/FSEL_i) \times 100\%$$

where %FSEL is the combined exposure index (sometimes referred to as dose), c_i is the airborne concentration of each substance, and $FSEL_i$ is the full-shift exposure limit for each substance, as shown in Appendix C. An analogous value was also calculated for short-term exposures, as

$$\%STEL = \Sigma(c_i/STEL_i) \times 100\%$$

where %STEL is the combined short-term exposure index and $STEL_i$ is the short-term exposure limit for each substance.

Estimates of average full-shift exposures to THF, MEK, CHX, ACE, and %FSEL were calculated two ways. First, the air samples collected by 4-hour passive dosimeters were assumed to adequately represent the entire work day. To check this assumption, the fraction of total on-site work time included in the afternoon dosimeter-sampling periods was compared to the fraction of the days' total joints that were cemented during those periods. Second, the average 15-min exposure levels in each sampling stratum, weighted by the fraction of total time worked in that stratum, were used to reconstruct average full-shift exposures. The estimates derived by these two methods were then compared.

As an additional comparison, the short-term exposure data were also used to estimate each individual's exposure during the 4-hour monitoring periods. For this calculation, measured exposure levels for each worker-day in each sampling stratum were weighted by the percentage of time (during 4-hour passive monitoring) worker in each sampling stratum. When no worker-specific exposure data were available for a stratum, the average for that stratum and installation was substituted. The estimates derived for each worker were then compared with the exposure levels measured by passive dosimeters.

Exposures in each particular category were expected to have an approximately log-normal distribution. After data collection, histograms of the log-transformed exposure levels were visually inspected and were observed to approximate a log-normal model for each type of exposure (goodness-of-fit not tested). Therefore, log-transformed exposure data were used when performing statistical tests that require normally-distributed data for validity. For each type of exposure (except as noted), the fraction of the entire exposure distribution which would be expected to exceed the relevant exposure limit was estimated using standard techniques,[15] based on the estimated geometric mean and GSD of the exposure distribution.

A standard analysis-of-variance procedure was used to determine whether average (log-transformed) exposure levels differed significantly among installation types and sampling strata. Several short-term exposure measurements were made for most workers, so analysis-of-variance techniques were used to assess the portion of overall exposure variability attributable to between-workers vs. within-worker variability, for each installation type and sampling stratum with multiple measurements.

Multiple regression modeling techniques were used to explore the relationships between various job factors and the resulting exposures. Exposures were hypothesized to be related to four factors—number of joints cemented, composition of bulk products, air flow rate, and temperature—according to the following model:

$$c_i = \frac{k_N N^{b_N} \times k_B B_i^{b_B} \times k_T T^{b_T}}{k_V V^{b_V}}$$

where c_i is the airborne concentration of substance *i*, N is the number of joints cemented, B_i is the concentration of substance *i* in the bulk products used (as a weight-weight fraction), T is the temperature, and V is the air flow rate. The exponents b_V and b_B were expected *a priori* to equal -1 and unity, respectively, while no particular values were expected for the exponents b_N or b_T, or for the coefficients k_N, k_B, k_T, or k_V. A logarithmic transformation was used to place this model in a form suitable for standard multiple linear regression analysis:

$$\ln(c_i) = b_N \ln(N) + b_B \ln(B_i) + b_T \ln(T) + b_V \ln(V) + \ln(k_N k_{Bi} k_T k_V).$$

Unfortunately, the coefficients k_N-k_V combine as a single constant term in this log-linear model.

The individual variables were entered stepwise into an overall model, in order of decreasing partial correlation. Variables that were significantly associated with exposure in the overall model were then interpreted to be determinants of exposure.

Several adjustments to the raw data were made to facilitate the regression analysis, as described below. To form a simple index for the concentration of each substance in all bulk products used at a given site, the primer and cement concentrations were averaged together. Where more than one primer or cement were used, their concentrations were also averaged. For full-shift exposures, day-long mean air flow rates were calculated by averaging all worker-specific air flow rates measured during the day. For the log-transformed model, values equal to zero (for example, zero joints cemented) could not be transformed, so they were replaced by values equal to one-half the lowest non-zero number recorded (in this example, 0.5 joints).

The effects of secondary exposure were assessed by analysis of variance, with sampling strata and presence or absence of secondary exposures as the grouping factors. The effects of spills on exposure levels were assessed similarly.

The relationships between airborne exposures and the resulting urine concentrations were evaluated with linear regression analysis (THF and MEK only). Possible differences in this relationship between Heavy and Light skin-contact groups were tested with standard analysis-of-covariance techniques (log-transformed data). For MEK, the regression results were compared with previously published values.

RESULTS

Study Group

Sites

Exposure monitoring was conducted at 35 pipe installation sites (CPVC-pw, 6; CPVC-fire, 9; DWV-PVC, 5; DWV-ABS, 5; PB, 1; and copper, 9). Where two types of pipe installation were monitored at a single construction site, these were counted as separate installation sites if they took place in different buildings and if individuals worked on only a single type of installation. At four sites, workers installed both CPVC-pw and DWV-PVC concurrently; these were classified as CPVC-pw sites, and all exposures measured at those sites were included among the CPVC-pw exposures. Follow-up monitoring was conducted at seven sites (1 day, 6 sites; 2 days , 1 site). In all, 43 site-days of exposure monitoring were completed (CPVC-pw, 8; CPVC-fire, 13; DWV-PVC, 7; DWV-ABS, 5; PB, 1; and copper, 9). Characteristics of the sites are described in Appendix D, including the type of installation, number of workers monitored, and the source from which the site was identified. At three sites, workers installed subassemblies that had been prefabricated off-site. Monitoring was conducted at each of the three prefabrication shops (sites 7, 9, and 35).

Several sites were selected for monitoring specifically because they featured working conditions that had not yet been monitored at an adequate number of sites. For example, sites with multiple-unit dwellings were sought, and five such sites were monitored. The special selection criteria are shown in Table 1. Conversely, some possible sites were rejected because their working conditions had already been monitored at several other sites, and the exposure levels were believed to be similar among sites.

Plumbing contractors generally were cooperative, often to the extent of scheduling their jobs to match the times that monitoring could be conducted. Three contractors refused several efforts to recruit them into the study; whether their workers installed CPVC pipe was not determined. General contractors were usually indifferent to the presence of the study team; only one general superintendent expressed hostility. All workers monitored were asked whether working conditions were normal on the day of the study. None reported that their employers had arranged their work to minimize exposures, or had encouraged workers to alter their work practices. In fact, a few contractors attempted to maximize the amount of plastic-pipe cementing to be done during the monitoring periods; others seemed content to let small details slow their workers' progress.

Workers

The exposures of 78 workers (1-4 per site) were monitored. For 15 workers, exposures were monitored again on subsequent work days, for a total of 95 worker-days of monitoring (CPVC-pw, 18; CPVC-fire, 34; DWV-PVC, 18; DWV-ABS, 9; PB, 1; and copper, 15). The workers ranged in age from 20 to 66 years (mean 32 years); all were men. Workers' experience in the pipe trades ranged from three months to 41 years. In this study group, the workers installing DWV-ABS pipe had the most experience (mean 18 years); workers installing CPVC-fire had the least (mean 1.7 years). Only 8 (10%) reported receiving specific health and safety training, which usually focused on worksite safety: ladders, hard hats, electrical wires. Only two workers (3%) said they had been informed about potential hazards of the substances in plastic pipe primers and cements, and most workers had read the warning labels on the products they used. Many workers considered the label warnings—such as "avoid contact with skin" and "use only in well-ventilated areas"—to be comically impractical.

A typical work day for these workers consisted of eight hours of work time, with a half-hour lunch and two 15-min breaks. Workers often reported first to the pipe contractor's shop for assignment and to pick up supplies, so actual time at the installation site was usually less than 8 hours. Work days were then broken up into various tasks, such as setting up, drilling and other preparation, running pipe, making joints, "blocking" the pipe to prevent movement, and cleaning up. Workers installing plastic pipe spent an average of 49% of each day's on-site time in stratum I (no cementing). The remaining time was distributed among the other sampling strata as follows: IIa, 30%; IIb, 7%; IIIa, 12%; and IIIb, 2%. The distribution of work time varied among the installation types: workers installing DWV-ABS spent the most time on non-gluing tasks, workers installing CPVC-fire spent the least. The amount of work time spent in various sampling strata also differed among workers within each installation type. For example, during CPVC-pw installation, the range of times spent in each stratum are as follows (expressed as 10%-90% percentiles): I, 19-59%; IIa, 12-70%; IIb, 0-28%; IIIa, 0-46%, IIIb, 0-1%. The average amount of work time in each installation type and sampling stratum is shown in Table 2.

Most workers were completely cooperative with the study and interested in its purpose. Five workers declined to give urine samples. At one site, three of five workers refused all monitoring. At two sites, plumbing contractors had arranged for installation to be done by subcontractors rather than hourly employees; these workers participated in the study but tended to be more rushed and less cooperative than regular wage-earners.

Work practices

Individual work practices were mainly the result of decisions made by workers and their employers, but were sometimes influenced by site characteristics. For example, workers did extensive cementing in crawl spaces at two sites (17 and 23) because their employer had not assigned them to the sites until after the house was framed, leaving no way that the under-floor plumbing could be installed without working in the crawl space. Remodeling, such as retrofitting of fire sprinklers in existing structures, inevitably requires some work in enclosed spaces. Most workers installing plastic pipe preferred well-ventilated areas whenever possible. Some people tended to work by themselves; others worked together in one area, depending on the wishes of both the contractors and the workers themselves.

At some sites, each worker drilled holes for the pipe that he would install. At others, one worker was assigned to drill holes all day while other workers laid pipe and cemented joints. The latter arrangement would tend to concentrate primer and cement exposures on a few workers.

Four workers (5%) wore cotton work gloves for most of their work, and two (3%) wore rubber gloves when handling glues and primers. Three workers (4%) wore protective eyewear during some part of the day, four (5%) wore kneepads, and two wore hard hats. None wore organic vapor respirators, but two wore dust masks when working in dusty areas.

Primer or cement spills were observed during 14 (5%) of the 15-min periods monitored; most were small (area<0.25 m^2). Some workers applied primers and cements liberally, such that their clothes, the pipes, and nearby surfaces were sprinkled with drips and small splashes. Four workers (5%) used primers, "primer/cleaners" or other solvents to remove cement from their hands at the end of the day, and one did so repeatedly throughout the day.

Usually, the amount of cement applied to the pipe and fittings was more than would fit in the joints; the excess ran down the pipe when the joint was assembled. Some workers wiped this excess from each joint, using a rag or—more commonly—their fingers. A common reason for application of excessive cement was that the daubers provided to apply cement to the joints were often too big, so that all the cement would be squeezed out each time the dauber was pushed into a fitting. Smaller daubers are provided with smaller primer and cement cans, but these small cans are typically more expensive. One worker trimmed new daubers to match the size of the joints to be glued, and one other worker transferred his favorite (small) dauber into each new can he used.

The experience and skill level of workers in this study varied tremendously. In general, workers with little experience were unsure of their tasks and proceeded slowly. They tended to cement few joints in any given period, and thus had fewer and briefer opportunities for exposure than workers who could move rapidly from joint to joint. Workers' caution in handling primers and cements was not determined by their skill level. For example, some experienced workers were quite adept at avoiding skin contact with primers and cements, while others had given up all hopes of keeping clean in favor of working quickly. Similar variation was observed among inexperienced workers. Because few workers had received health and safety training, and because few workers received specific guidance from their employers about such work practices as care in avoiding spills, use of protective equipment, and methods used to remove cement from hands, these factors were left largely to personal taste.

Installation of CPVC-pw pipe has important features, different from the other installation types, that could have a significant effect on exposures. Installation is relatively simple and fast, so workers cemented more joints per day doing CPVC than any other installation type (mean of 73 joints per day for CPVC-pw vs. 29-33 joints per day for the other installation types). CPVC-pw installation is usually done later in the overall construction process than is DWV installation, so the buildings tend to be more enclosed (but still not fully enclosed by walls, windows, and doors). In addition, CPVC-pw and DWV-PVC were being installed concurrently at three sites, creating the possibility that contaminants released by both installations could combine to yield higher exposures than each one singly. CPVC-fire and DWV-ABS were not installed concurrently with any other plastic pipe at any sites monitored.

Symptoms reported

Of the workers whose exposures were monitored, 28 (39%) reported experiencing one or more illness symptoms during the day. The most common of these were irritation of eyes, nose, and throat (10% of all worker-days), dizziness (9%), and dried skin (9%). The percentage of workers reporting other symptoms are listed in Table 3. These data were not designed for analysis of differences in self-reported symptoms among various exposure groups or of the factors related to symptom reporting, so no quantitative analysis is presented here. However, the most commonly reported symptoms are noteworthy in that they are consistent with the known (or suspected) acute effects of overexposure to THF, MEK, CHX, and ACE: irritation of mucous membranes and skin, and depression of central nervous system function.

Pipe installation materials

Contents of the bulk primer and cement samples are listed in Appendix E. Good agreement was found between the substances identified in the products and ingredients listed on their labels. In many products, the main solvent was THF, followed by MEK (average for all products: THF, 45%; MEK, 19%). DMF was present at concentrations above 1% in two products used at five sites (20% of all plastic-pipe cementing sites); these were a DWV-PVC cement and a CPVC-fire cement. The simple headspace test used to determine presence of DMF was accurate for all products. DWV-ABS cements had MEK as their primary ingredient. Bulk samples were not obtained for four products.

Concentrations of antimony, copper, lead, silver, tin and zinc in bulk samples of four copper solders are shown in Appendix F. Lead was not detected in any of the samples. Samples of two flux pastes were collected but not analyzed.

Laboratory quality assurance

In 57 blank sampling media submitted for analysis along with the field samples, no analytes of interest were present above the limits of quantitation. One of two blank urine samples contained 670 µg/l of MEK. The source of MEK in this urine sample is not known.

Twenty-eight spiked sorbent tubes (12 each of charcoal and silica gel, four of ambersorb) were analyzed along with the field samples; the analysts had no knowledge of which tubes had been spiked. Exceptional agreement between spiked and measured quantities was found for THF and MEK on both charcoal and ambersorb. For CHX, the average measured value was lower that the amount spiked (charcoal, 54% recovered; ambersorb, 87% recovered); the source of this error is not known. Measured DMF quantities were somewhat variable, but average values were in good agreement with the spiked value. Comparative results for all four substances are shown in Appendix G.

For 36 of the short-term air samples collected simultaneously on both charcoal and ambersorb, both tubes were analyzed for THF, MEK, and CHX. Twenty-two of these were collected at the beginning of the study and 14 matched charcoal-tube samples collected during high-exposure periods. Comparative results for THF and MEK are shown in Appendix G. Data derived from the two sorbent tubes were in good agreement, with no significant difference between two sorbents (paired t-test, p=.28 for THF; p=.77 for MEK). CHX was collected more efficiently on ambersorb than on charcoal.

An additional check on data quality was afforded by the comparison between 15-min solvent samples and corresponding 4-hour samples for individual workers. The general results of this comparison are presented later. However, one worker (site 14b, worker 34) was found to have an implausible disparity between the two sample types (for THF, 4-hour sample was 121 ppm; five 15-min samples, all in stratum IIIa, had a mean of 0.8 ppm). Another worker, working in the same enclosed area at the same time, had much higher 15-min samples, (mean 41 ppm) typical of the exposure category. Therefore, an equipment malfunction was suspected. All short-term sampling results for site 14b, worker 34 were excluded from further analysis. By chance, the pump was not used again for solvent sampling.

Replicate analyses of urine samples for THF, MEK, and CHX showed good reproducibility (average relative standard deviation, 11%). Among four urine samples spiked with MMF, the substance was detected in only one, but the quantity spiked (0.009 mg/ml) was slightly below the analytical limit of detection (0.01 mg/ml).

Dimethyl formamide

Airborne DMF was measured in full-shift samples collected on 28 worker-days. DMF was detected in three of the samples at concentrations of 0.1 to 0.4 ppm (mean 0.23 ppm), reflecting 8-hour TWA exposures of 0.1 to 0.3 ppm (mean 0.19 ppm). An additional three samples had DMF present, but below the analytical limit of quantitation (0.05 mg/sample), and no DMF was detected in the remaining 22 samples. The 8-hour TWA exposures represented by these samples were less than 0.01-0.03 ppm. For the days monitored, the average DMF exposure was 0.03 ppm (8-hour TWA), with two short-term samples (concentrations less than 1-7 ppm) were excluded. The probability that airborne DMF exposure would exceed the exposure limit on a randomly-selected work day was not estimated, because of the low concentrations and the small number of samples in which DMF was detected.

MMF was analyzed in 26 urine samples. In all samples, MMF concentrations were below the analytical detection limit (0.01 mg/l). Creatinine concentrations ranged from 0.8 to 3.4 mg/l (normal values are 0.5 to 3 mg/l). Thus, all urine MMF concentrations were less than 12.5 mg_{MMF}/g_{creat}, 31% of the established biological exposure index (40 mg_{MMF}/g_{creat}). DMF, not normally found unmetabolized in urine, was not detected in any urine samples, indicating that no samples had been significantly contaminated with DMF-containing products.

THF, MEK, CHX, and ACE

Short-term exposures

Concentrations of THF, MEK, CHX, and ACE were measured in 193 short-term (15-min) air samples (excluding five samples, as described in the quality assurance section). Table 4 shows the installations (CPVC-pw, etc.) and sampling strata (I-IIIb) in which the samples were collected, and Table 5 shows the percentage of total work time monitored for each category. The sampling frequency was close to the specified goals (50% of total time in strata IIb and IIIa; 100% of time in IIIb). Air flow in work areas during monitoring was 0-500 ft/min (median 30 ft/min); the distribution is shown in Figure 1. The temperature in work areas during monitoring was 13-39 C (56°-102° F, median 74° F), with the distribution shown in Figure 2. During the pipe installation periods monitored (excluding prefabrication operations), workers cemented 0-18 joints (median 4 joints). Workers were able to complete CPVC-pw joints the most rapidly, with a median of eight per 15-min period. In special prefabrication setups, workers completed up to 102 joints per 15 min. The distribution of the number of joints cemented in each monitoring period is shown in Figure 3.

The highest measured 15-min exposures were to THF, up to 529 ppm (211% of the exposure limit). Of these, six exceeded the short-term exposure limit of 250 ppm. Maximum concentrations of other solvents were: MEK, 95 ppm (32% of the exposure limit); CHX, 7 ppm (13% of the exposure limit); and ACE, 208 ppm (21% of the exposure limit). %STEL values, reflecting combined exposure to theses four solvents, ranged from 0.6% to 221%, and were often dominated by the THF concentration. The additive short-term exposure limit was exceeded (%STEL>100%) in six samples. CHX concentrations were below the analytical limit of quantitation in 275 samples (92%), and products labelled as ACE-containing were used by only 17 plastic pipe workers (28%) at eight sites, thus limiting the data analysis for CHX and ACE.

Average exposure levels for the four installations and five sampling strata are shown in Table 6. The highest mean THF exposures occurred at sites where CPVC-pw was installed in enclosed spaces (174 ppm in IIIa; 139 ppm in IIIb). These categories also produced the highest mean %STEL values (IIIa, 80%; IIIb, 71%). The highest mean MEK exposures occurred during installation of DWV-ABS or of CPVC-pw pipes in enclosed spaces (25 ppm in DWV-ABS/IIIb; 20 ppm in CPVC-pw/IIIb). Analysis of variance of (log-transformed) exposure levels indicated significant differences among installation types (THF, $p<.0001$; MEK, $p<.01$) and among sampling strata (THF, $p<.01$; MEK, $p<.05$). Within the strata, exposures were significantly higher (THF, $p<.05$) when workers had secondary exposure from other workers cementing nearby, but were not significantly affected by the presence or absence of spills (THF, $p>.2$).

Working conditions that led to the highest measured 15-min THF and MEK exposures are shown in Table 7. Many of the highest THF exposures occurred during extended work in three highly-enclosed areas: two low (1-2 meter) crawl spaces where CPVC-pw and DWV-PVC were being installed concurrently, and an enclosed attic where CPVC-fire sprinklers were being retrofitted. Of the six samples in which THF exposures exceeded the short-term exposure limit, three were for workers installing DWV-PVC pipe (at a site classified as CPVC-pw because both were installed concurrently); two were for workers installing CPVC-pw, and one was for a worker installing CPVC-fire. The highest MEK exposures occurred in these same areas, and in two DWV-ABS prefabrication shops.

For the highest-exposure sites (17a and 14c), the time sequence of exposures is shown in Figure 4. At both sites, during both the morning and the afternoon, exposures increased throughout the work period. These increases over time suggest that these enclosed areas functioned approximately as closed systems, with concentrations rising steadily as solvents evaporated from the joints cemented. In the area with the highest exposures (17a, morning), a spill (approximately 200 ml) occurred near the beginning of the work period and probably contributed to the high exposure levels. Analysis of variance among three workers in three crawl spaces (17a morning, 17a afternoon, 23 afternoon) indicated that exposures differed significantly between workers ($p<.05$) but did not differ with the type of pipe (CPVC-pw vs. DWV-PVC) being installed during monitoring ($p>.5$). The worker with the highest exposures consistently dripped more primer and cement on himself than did other workers.

Table 8 shows the estimated probability that the short-term exposure limits (for THF, MEK, and %STEL) would be exceeded in randomly-selected 15-min periods within each type of installation and sampling stratum, based on the calculated parameters of the exposure distribution. In general, these exceedance probabilities were highest in the categories that had the highest mean exposures. For THF, the exceedance probability was highest during installation of CPVC-pw pipe (IIIa, 20%; IIIb, 17%). For %STEL, the pattern was similar with slightly higher probabilities (CPVC-pw: IIIa, 25%; IIIb, 23%). The estimated probability of exceeding the MEK short-term exposure limit was 1% for CPVC-pw stratum IIIa, and much lower for all other categories. With the exceedance probabilities for each category weighted by the amount of time worked in that category, the exceedance probabilities for randomly-selected 15-min periods ranged from 0.001% for DWV-PVC to 3.5% for CPVC-pw, based on the combined exposure index %STEL.

For a hypothetical CPVC-pw installation worker, on a work day reflecting the average amounts of time spent in the various sampling strata by all CPVC-pw workers monitored (I, 42%; IIb, 10%; etc.), and whose exposures during each 15-min period were randomly drawn from the corresponding exposure distribution, the estimated probability that the short-term exposure limit would be exceeded at least once in an 8-hour day is 66% for THF, 5% for MEK, and 68% for %STEL. Similarly, the probability that two or more short-term overexposures (%STEL greater than 100%) will occur during the hypothetical work day is 31%. Of course, this estimated exceedance probability for an average workday (with samples randomly drawn from the exposure distribution) does not necessarily reflect the experience of individual workers; rather, it reflects the experience of the average worker. Analysis of variance among CPVC-pw samples indicated that exposures were not randomly distributed among workers but that there were significant differences between workers ($p=.02$ to $.04$ for various sampling strata). For the categories with adequate data, between-workers variability accounted for a substantial portion of total exposure variability (THF, 37-95%; MEK, 17-89%). Significant between-worker differences were found in all installations and sampling strata. This suggests that individual working conditions, tasks, or work practices differed substantially among the workers monitored.

Multiple regression modeling revealed significant associations between THF exposures during CPVC-pw installation and two job factors: air flow rate and ambient temperature. Two other factors (concentration of THF in the bulk products and number of joints cemented) were not significantly associated with exposure. For all installation types together, THF exposures were significantly associated with air flow rate and with bulk THF concentrations, but not the other factors tested. The coefficients and partial correlations for the four significant factors are shown in Table 9. Together, these factors accounted for a large portion of the variability among exposure levels (CPVC-pw, r^2=.57; all installation types, r^2=.59). The regression coefficients for the effects of air flow rate and bulk THF concentration were very close to the expected values (for all installations, b_V=-0.90; b_B=1.03). Figure 5 shows the conditions which produced the measured exposure levels for each factor individually. Similar associations between exposure levels and various job factors were also found for MEK, except that the number of joints cemented was significantly associated with exposure levels for both CPVC-pw and all installation types grouped. Coefficients and partial correlations for MEK are also shown in Table 9. For both CPVC-pw and all installation types, there was a strong association between THF and MEK exposures within individual periods (data not shown).

Real-time exposure profiles were obtained for 11 workers at six sites. This data provided a useful qualitative assessment of solvent exposure. Subjectively, the number of exposure peaks matched closely the number of fittings cemented, and peaks tended to be broadest (exposures dissipated slowest) in areas of low air movement. A representative detector trace is shown in Figure 6. For three 15-min periods, real-time exposure data could be directly associated with 15-min average values from a sorbent-tube sample. The real-time exposure data are summarized in Table 10. Although the 15-min averages were all less than 100 ppm (27-66 ppm), the top 5% of the 12-sec concentrations were much higher (130-235 ppm). Overall, the highest peaks (12-sec averages) were three to five times the 15-min average.

Full-shift exposures—air monitoring

Full-shift average exposures to THF, MEK, CHX, and ACE were assessed with passive monitors (mean duration 226 min) on 60 workdays. During the monitoring periods, workers cemented up to 232 joints (median 20). Daily high temperatures were 16-39° C (61-102° F, median 76° F). Air movement varied widely throughout the workdays with average air flow rates of 21 to 70 ft/min (median 46 ft/min).

Work activities during the 4-hour passive monitoring periods matched closely the entire days' work activities. For example, workers cemented an average of 0.18 joints per minute during the monitoring periods compared with 0.16 joints per minute for all on-site work time. Individual's work rates during monitoring periods and overall were strongly correlated (r^2 = .92), as shown in Figure 7. These data indicate that work activities during the 4-hour monitoring periods were representative and helps confirm the assumption that measured 4-hour TWA exposures represent closely workers' full-shift exposures.

Among the 4-hour solvent samples representing full-shift exposures, none exceeded the full-shift exposure limits for each substance. However, the index of combined exposure (%FSEL) exceeded the limit for one worker (mean for all workers 20%, maximum 107%). As with the short-term samples, the highest exposures were to THF (mean 26 ppm, maximum 158 ppm); these dominated the combined exposure index. MEK exposures were lower (mean 6 ppm, maximum 45 ppm). CHX and ACE exposures were still lower, and generally contributed little to the %FSEL. Exposure levels to THF and MEK were strongly correlated; workers with high THF exposures tended to also have high MEK exposures. Exposures varied significantly among the four types of pipe installation. Overall, average exposures during CPVC-pw installation (mean %FSEL, 36%), were 1.8-8.5 times the average exposures during other pipe installation. Mean exposures for each installation and each substance are shown in Table 11, along with the associated geometric standard deviations.

Working conditions that led to the highest exposures are shown in Table 12. The sites and workers with the highest TWA exposures were generally the same as those with the highest short-term exposures. Of these, all had substantial amounts of work in enclosed areas, especially crawl spaces and attics. In the crawl spaces where the highest exposures were documented, workers installed both CPVC-pw and DWV-PVC concurrently.

Although no full-shift overexposures to THF, MEK, CHX, or ACE were documented, and %FSEL exceeded 100% for only one worker, the calculated parameters of the exposure distribution can be used to estimate the probability that overexposures will occur during randomly-selected work days. These probabilities are shown in Table 13. The highest probabilities were for CPVC-pw installation (THF, 5.5%%; MEK, 2.2%; %FSEL, 10.0%). Day-to-day exceedance probabilities for individual workers would be higher or lower, depending on specific site characteristics and work practices.

Multiple regression modeling revealed significant associations between full-shift THF exposures (all installation types) and three job factors: air flow rate, concentration of THF in the bulk products, and ambient temperature. Regression coefficients and partial correlations are shown in Table 14. The association between job factors and exposure levels was weaker for the full-shift data than for the short term data (THF, r^2=.33). Figure 8 shows the working conditions (joints cemented and ambient temperature) that produced the measured THF exposures. Associations between full-shift MEK exposures and various job factors were similar, except that exposure levels were also significantly associated with the number of joints cemented, mirroring a similar result for the short-term data. Regression coefficients for the effects of air flow rate and bulk THF concentration closely matched the expected values (b_V=-1.27; b_B=1.17).

Average full-shift TWA exposures were also estimated from the average short-term exposures for each installation type and sampling stratum, weighted by the amount of time worked in the strata. The results are shown in Table 15. Average full-shift exposures estimated by this method were lower (by 8-60%) than the TWA exposures measured by passive dosimeters.

Figure 9 shows the 4-hour exposures of individual workers, as measured by passive monitors and as estimated from worker-specific 15-min exposure data for the same period. Again, the exposure levels measured by passive monitors were higher than the estimates based on short-term data. Detailed evaluation of the samples with the greatest discrepancies revealed that nearly all were collected in an enclosed attic (sites 14a, 14b), where the slow pace of work typically caused work activities to alternate between stratum I (no cementing) and stratum IIIa. Fifteen-min exposure levels were high during IIIa periods but no samples were collected during the stratum I periods. High exposures probably continued during the stratum I periods, which would be reflected in the passive-monitoring samples but would not have been included in the estimation process based on short-term samples.

Full-shift exposures-urine monitoring

End-of-shift urine samples were collected and analyzed for 61 worker-days; 53 of these were paired with passive-monitor air samples. Concentrations of THF in urine ranged from less than the detection limit to 6700 μg/l (mean 452 μg/l); no BEI has been established. MEK concentrations were up to 950 μg/l, (48% of the established BEI); the average concentration was 180 μg/l. Urine CHX concentrations were below the limit of quantitation (200 μg/l) in all samples. Urine THF and MEK concentrations were significantly different among the installation types (analysis of variance, $p<.001$ for both THF, MEK). CPVC-pw workers had the highest average urine concentrations of both THF and MEK; the averages for all groups are shown in Table 16. Working conditions for individuals with the highest urine THF and MEK concentrations are shown in Table 17, and are similar to those that produced the highest airborne exposures.

Among all samples, urine THF concentration was significantly and positively associated with airborne THF exposure (r^2=0.65). However, the relationship between urine and air THF concentrations was stronger when the samples were divided into groups according to the level of skin contact (Heavy/Light) during the last four hours before urine samples were provided (Heavy, r^2=.82; Light, r^2=.87). Figure 10 shows the relationship for each group. The slopes of the best-fit regression lines are significantly different (analysis of covariance, $p<.01$ for log-transformed data). Relative to their airborne exposure, workers in the Heavy skin-contact group had nearly four-fold higher urine THF concentrations than did workers in the Light skin-contact group. These data strongly suggest that dermal absorption contributed to higher total exposures and higher urine concentrations in the Heavy skin-contact group. The relationship between urine and air THF concentrations for six workers who wore gloves was not significantly different than that of the Heavy or Light groups.

Four workers (14%) in the Heavy skin-contact group had urine THF concentrations that were higher (1.4 to 6.7-fold) than any in the Light skin-contact group, even though their airborne exposures were comparable. The best-fit relationship between urine and air THF concentrations for the Light group would have to be extrapolated out to airborne exposures of 150-740 ppm before urine concentrations of that magnitude would be expected.

Urine MEK concentrations were also significantly correlated with airborne MEK exposures measured by passive dosimeters, although the association was weaker than that found for THF ($r^2=.54$). With the data split by level of skin contact, workers in the Heavy skin-contact group had higher urine MEK concentrations, relative to their airborne exposures, than workers in the Light group, but the slopes of the regression lines were not significantly different (Heavy, 24 µg/l/ppm; Light, 16 µ/l/ppm). Both are within the range of previously reported values (9.4 µg/l/ppm [8,9] to 26.3 µg/l/ppm[10]). Data for both groups are shown in Figure 11. Differences between the apparent dermal absorption of THF and MEK could be accounted for in two ways. First, THF may have greater skin permeability than does MEK, but this has not been independently tested. Second, the lower concentrations of MEK in the bulk products may have made skin contact with those products relatively unimportant for dermal absorption of MEK.

CPVC, PVC, and ABS dust

No workers used saws for CPVC-pw or CPVC-fire installation. One worker used a high-speed abrasive cut-off saw to cut short lengths of CPVC pipe for prefabrication into fire-sprinkler head assemblies. Two samples—one of total particulates and one of respirable particulates—were collected simultaneously, and included the entire exposure period. The worker's 8-hour TWA exposure—presumed to be mainly CPVC dust—was 0.1 mg/m^3, of which 30% (0.03 mg/m^3) was respirable. One worker sawing DWV-PVC and one sawing DWV-ABS had total respirable particulate exposures of 0.04 mg/m^3 and 0.06 mg/m^3, respectively.

Polybutylene and flux decomposition products

Results of the GC-MS analysis of the semi-volatile fraction obtained during one PB fusion and two copper soldering operations are shown in Table 18. The only one of the EPA's 82 priority pollutants present was 2-chlorophenol which was found at a level of 0.1 $\mu g/m^3$ (near the detection limit) in one copper soldering sample and the accompanying background air sample. Another sample, collected at the same time and on the same worker, showed no 2-chlorophenol. No other GC peaks were present in the samples that were not also present in one or more blanks at approximately the same level. Semi-quantitative identification of all other peaks included the following: aliphatic hydrocarbons (C_{11}-C_{13}); alicyclic hydrocarbons (C_{16}-C_{20}); BHT (an antioxidant); phenoxy-substituted organics, fatty amines (C_{20}-C_{30}), and possible fatty acids. All constituents found in the samples were also found in one or more blanks at approximately the same level, except for aliphatic hydrocarbons (25 $\mu g/m^3$) at copper soldering site 32.

GC-MS results of the volatile fraction obtained during PB fusion are shown in Table 19. Aromatic hydrocarbons, including styrene, xylenes, toluene, benzene, and ethylbenzene, were the principal constituents noted in the analysis of PB fusion decomposition products. On an 8-hour TWA basis, these constituents were present at levels approximately 200 to 85,000-fold less than accepted exposure limits for these chemical agents. Volatile fractions of both samples collected during copper pipe installation were destroyed by the laboratory during analysis.

All formaldehyde exposures (if present) were less than the analytical detection limit (0.02-0.05 ppm at copper sites, 0.17 ppm at the PB site). It is likely that the concentrations of other low molecular weight aldehydes, such as acetaldehyde and propanaldehyde, which could also be present during copper soldering and PB fusion operations, would be less than the formaldehyde concentrations.

Metal fumes

Metal fume monitoring of fifteen plumbers at nine sites was conducted during copper pipe installation. Sampling results are shown in Table 20. Average 8-hour TWA exposures for copper, tin, silver, antimony, and lead ranged from 0.2% to 4% of their exposure limits for these metals. Lead-free solder was used at all the sites. Compositions of four bulk solder samples are shown in Appendix F. Low—but detectable—lead exposures were measured for two plumbers at one site. A bulk solder sample collected at that site contained negligible lead, and there was no other apparent source. However, workers at several other sites had lead/tin solder in their trucks or tool boxes for occasional use. Animal-fat based fluxes were used at all sites except two, where zinc chloride flux was used.

Safety hazards

Numerous safety hazards were observed at all construction sites monitored. Workers frequently used chain saws and wood-boring "hole hogs" in awkward positions to cut holes for pipe to pass through and worked atop ladders that were inadequate for the task. The combination of these two types of hazards—such as a chain saw used at the top of a too-short ladder—produced a situation far more dangerous than either hazard alone. Plumbers and other trades workers on upper floors regularly dropped objects—both small and large—near workers below. Electric power supply arrangements were often haphazard. No workers had access to eye-washing facilities in case of chemical or hot flux splash, and the building's water supply generally is not functional while pipe is being installed. Most pipe installations are done with roofs already in place, but under-floor rough-in work is inevitably done in open sunlight; no workers who were monitored or interviewed wore sunscreen.

DISCUSSION

Comparison with previous studies

The principal findings of this study are generally consistent with three previous studies of plastic pipe installation.[2,3,4] Airborne DMF exposures averaged less than 1 ppm in each study, and no MMF was detected in workers' urine either in this study or in the one previous study that measured this parameter. The DMF exposures measured in this study are far below those that have been associated with acute toxicity in other industries.[16,17]

Previous studies, like this one, have found that exposures to THF, MEK, CHX, and ACE are generally low for plastic pipe installation, but that short-term overexposures occur during some tasks.[18] Work in enclosed areas has consistently been found to be most responsible for producing overexposures. The exposures reported here are in good agreement with previous findings, especially for full-shift exposures. Short-term overexposures to THF were higher and more numerous than previously reported, most likely because a greater number and range of sites were surveyed.

Few workers in this study were exposed to plastic dust, and their full-shift exposure levels were much lower than the average exposures that were associated with changes in lung function in a group of plastics-industry workers.[19]

The quality assurance samples and the paired samples collected on both charcoal and ambersorb indicate that MEK and THF are well-collected by both sorbents, and that they suffered little degradation during storage and handling. This differs from a previous finding that MEK rapidly degrades on charcoal.[20] The facts that samples were cooled immediately after collection, and then kept frozen until analyzed, probably account for the difference. The discrepancies between measured 4-hour exposures (based on passive-dosimeter samples) and estimates based on 15-min sorbent-tube samples are comparable to previously reported discrepancies, even for passive-monitor and sorbent-tube samples collected simultaneously.[21]

Study limitations

This study had several limitations which should be considered when interpreting its results. The most fundamental of these limitations was that the scope of the study was limited to residential installations. Most plumbers do many types of installations during their careers at a mix of residential, commercial, and industrial sites. Commercial and industrial installation, typified by larger pipe sizes and extensive piping systems, are likely to produce higher exposures than occur in residential work.

Conclusions about the possible hazards of installing residential plumbing do not directly apply to the hazards faced by these same workers at other sites.

Every reasonable effort was made to include a broad spectrum of installation sites, and to monitor enough sites that all common practices in the industry would likely be included. The resulting characterization of exposures is more comprehensive than is available for most industries. Still, the fact remains that the numbers of sites and contractors included in the study are small compared to the statewide totals. Some work practices or conditions that are usual in the industry may have been missed by the study. However, overall conditions were roughly similar at many sites, suggesting considerable uniformity among sites. Workers were asked about conditions at other residential installation sites but did not report any practices that were not observed at the sites monitored.

The sites selected for monitoring were not a truly random sample, in the manner that could be achieved if sites were selected from a large pool of suitable sites. The difficulty of locating sufficient appropriate sites, especially sites where uncommon materials were being installed, left little leeway for true randomization. Often, specific sites were selected to meet the scheduling needs of the study team; this selection method would not be expected to introduce any systematic bias to the exposure levels encountered. Other sites were selected according to defined criteria, possibly biasing the results. For example, several sites with DMF use were sought (to increase the amount of DMF exposure information available), so the mean DMF exposure measured in this study may be higher than the true mean exposure level for all installation sites.

Workers and their employers have the ability to affect exposure levels by altering their practices during monitoring. All workers monitored were asked whether any such interference had taken place, and none reported changes that significantly compromise the data. However, the possibility remains that intentional or unintentional actions could have produced unrepresentative exposure levels during monitoring.

Certain combinations of working conditions could, in principle, sometimes occur together to produce "worst-case" exposures higher than those found in this study. For example, the data presented above suggest that those might occur at a site with: no air movement, several workers in the same work space, many joints glued for a given period, heavy skin contact with primers and cements, and perhaps high ambient temperatures and a few spills of the bulk products. Two of the sites monitored (sites 14 and 17) had several of these factors, but not all of them. Sites with all the factors listed above could have higher exposures.

Applications of data

Many exposure parameters have been estimated in this study. In many cases, these parameters can be used to estimate the exposures likely to occur under conditions different than those found in this study. However, suitable caution must be exercised, as discussed below.

The average short-term solvent exposures for each installation type and sampling stratum, together with the average times worked in each category, were used to estimate average full-shift exposures. The same data could be used to calculated the expected exposure of a worker whose activities were not average. For example, a CPVC-pw worker who spent three times as much work-time as average under stratum IIIa and IIIb conditions would have an expected THF exposure of 64 ppm, compared to the 36 ppm expected for an average worker. This value is still considerably less than the highest TWA exposure measured in this study, 158 ppm THF. Using additional assumptions, expected full-shift exposures could be calculated for workers with any allotment of time in the various sampling strata, and whose exposures within each stratum corresponded to any desired percentile of the measured exposure distribution.

The statistical associations between exposure levels and various job factors help highlight patterns in the data. Overall, air flow rate (a measure of ventilation rate) was the strongest and most consistent determinant of exposure levels. Composition of bulk products was a significant determinant of exposures for all installation types grouped, but with the analysis restricted to CPVC-pw (in which bulk compositions that were relatively homogeneous), the association was no longer significant. Conversely, ambient temperature was significantly associated with exposure levels during CPVC-pw installation, but not significantly associated with all installations grouped. These data do not preclude the possibility that high ambient temperatures produce somewhat elevated exposures; rather they indicate that in this data set the temperature effect (if any) is minor compared to the effects of ventilation and bulk composition.

The observed associations between job factors and exposure levels cannot reliably be used to predict exposure levels expected under conditions not monitored in this study, particularly because several of the job factors were interrelated, decreasing the reliability of the resulting statistics. For example, the highest exposures, which dominated the exposure distribution, were collected in just two crawl spaces. Both had little ventilation, and both were partially underground and quite cool. Thus, if the overall exposure model controlled imperfectly for air flow rate (which is likely), then a misleading apparent (negative) association could appear between temperature and exposure level. This same phenomenon also applies to other job factors. Fortunately, there is little need to extrapolate the observed associations to hypothetical conditions, because the two factors which most strongly determined exposure levels—air flow rate and bulk composition—were each encountered at relatively extreme values during this study. Specifically, exposures were monitored in areas with no ventilation, where products containing 80-85% THF were in use, leaving little room for extrapolation.

Probabilities of exceeding the applicable short-term and full-shift exposure limits during CPVC-pw installation, presented above, apply specifically to the working conditions found in this study. These exceedance probabilities are the proportion of all exposures expected to exceed the exposure limit. The estimated exceedance probabilities are 68% for %STEL and 10% for %FSEL. These were fixed mainly by the amount of time worked in highly-enclosed areas, and by the relative severity of the exposures in those areas. For workers who rarely work in such areas, the chance of their exposures exceeding the established limits is very low. Conversely, workers who spend extended periods in highly-enclosed areas may experience frequent overexposures. Two workers did, in fact, have repeated overexposures while working for several hours in a crawl space. Because the amount of work in highly-enclosed areas may be over-represented or under-represented in this study (sites with enclosed areas were specifically sought for monitoring, but few were located), the calculated exceedance probabilities may not apply to the industry as a whole.

The average daily full-shift solvent exposures reported in this study are probably higher than workers' long-term average exposures during residential plastic pipe installation, because workers are unlikely to cement joints continuously day after day. At the sites monitored, installations were frequently interrupted by poor organization, lack of supplies, or building inspections: workers would then be assigned to test for leaks, drill holes, or other tasks. Exposures on such days were not monitored and thus are not included in the results. Workers who also install industrial plastic-pipe systems may have higher long-term exposures.

Four workers in the Heavy skin-contact group with the highest THF exposures (80-160 ppm) had urine THF concentrations of 1400-6700 µg/l. These values would be expected in the Light group only after airborne exposures of 150-740 ppm; and the difference was attributed to dermal absorption. Based on a model that the best-fit line for the Light skin-contact group represents the true relationship between airborne THF exposures and urine THF concentrations, these concentrations (150-740 ppm) can be considered estimates of equivalent airborne exposure. Calculation of these equivalent airborne exposures is based on extrapolating far beyond any measured values the relationship between airborne and urine THF concentrations found in the Light group. A conservative lower bound to the equivalent airborne exposures can be derived by extrapolating the upper 95% confidence limit (10.85 µg/l/ppm) of the best-fit slope for the Light group; this method suggests that the equivalent airborne exposure corresponding to the highest measured urine THF concentration was at least 610 ppm. These equivalent airborne exposure values should be regarded with caution, since they are based on interpretation rather than on direct measurement. The values cannot be lightly dismissed, however, because they so far exceed the established full-shift exposure limit for THF (up to 3.7-fold), and because they indicate that dermal absorption may be an important contributor to total exposure

Health significance

Although the health effects of workplace exposures were not studied, the ultimate goal of this exposure assessment was to evaluate the possibility that the exposures could lead to adverse health impact. No airborne exposures measured in this study reached levels known to cause long-term health damage, but the existing toxicity information is extremely limited for several substances, notably THF. For some substances monitored (especially the metal fumes), the measured exposures were sufficiently lower than the established exposure limits that toxicity seems unlikely, based on present information.

The short-term and full-shift exposures to THF and MEK were highest relative to their exposure limits, so their significance is of particular interest. For both substances, the established exposure limits were set to prevent eye, nose, and throat irritation, and are much less than the levels needed to induce acute central nervous system depression. The potential for these substances to cause other types of systemic effects—especially after chronic exposure—has not been comprehensively assessed.

A particular weakness in the existing toxicity information for THF and MEK regards their ability to cause chronic neurologic effects. Some organic solvents, especially aromatic hydrocarbons, have been associated with neurobehavioral impairments (in reaction time, memory, and related parameters) in workers with long-term exposure.[22,23,24] The potential for THF or MEK to cause similar impairments has not been assessed.

Because short-term THF exposures up to twice the exposure limit were documented, some workers may experience eye, nose, or throat irritation. The brief (12-sec) exposure peaks described earlier are unlikely to have substantial health impact but are noticeable (because of the strong odors of THF and MEK) to many workers and may contribute to perceptions of intense, intermittent exposures.

Although the full-shift airborne THF exposure levels measured in this study did not exceed the exposure limit, the estimated equivalent airborne exposures, based on urine THF concentrations for four workers in the Heavy skin-contact group, were up to 740 ppm, 3.7 times the full-shift exposure limit. The health effects of dermally-absorbed THF cannot be fully assessed with the available toxicity information, but substantial dermal absorption would be expected to increase the likelihood of systemic effects from chronic exposure to THF. Overall, the highest measured urine THF concentrations suggest that some workers have total exposures that are considerably higher than the airborne exposures reported in this study or previously. The magnitude of these estimated equivalent exposures highlights the need for better chronic toxicity data for THF.

Exposures to DMF and antimony were low in comparison with their respective exposure limits. Inconclusive evidence for each of these substances has suggested that they may cause cancer, but their exposure limits do not reflect possible carcinogenicity. If either proves to be a carcinogen, the exposures documented in this study would need reinterpretation. The possibility that carcinogenic flux decomposition products might be produced during copper soldering could not be adequately evaluated, because the volatile fraction was lost in analysis.

CONCLUSIONS

The following conclusions apply only to residential pipe installation under conditions similar to those observed in this study, which were believed to have been representative of the industry as a whole. Substantially different working conditions could produce exposures for which these conclusions are not valid. [This caveat must be included when citing any of the following conclusions.]

1. Short-term exposure limits for THF, and for the additive effects of THF, MEK, CHX, and ACE, are sometimes exceeded during routine residential plastic-pipe installation. The probability of exceeding the short-term exposure limits at least once in a work day is dependent on working conditions and is highest for workers installing CPVC potable water pipe; for these workers, this probability is estimated to be 68%.

2. Full-shift exposures to THF, MEK, CHX, and ACE did not exceed the respective exposure limits for any worker monitored in this study. However, the combined exposure limit (%FSEL) was exceeded (107%) for one worker, indicating that full-shift overexposures occur on some work days. Overexposures are most likely to occur during CPVC-pw installation, in which the probability of overexposure is estimated to be 10%.

3. Conditions most likely to produce the highest short-term and full-shift exposures include: extended work in highly enclosed areas such as attics and crawl spaces, several people working in the same enclosed area, many joints cemented in a short period, and excessive application of primers and cements, leading to spills and heavy skin contact.

4. Exposures to airborne THF, MEK, CHX, and ACE at the levels measured in this study may produce eye, nose, and throat irritation. They are not known to produce any long-term health effects, but for some of these substances (notably THF) the health effects of long-term exposure have not been studied.

5. Dermal absorption of THF probably contributes significantly to the total (airborne plus dermal) exposure of workers who have heavy skin contact with primers and cements. Based on their urine THF concentrations, four of these workers had estimated equivalent airborne exposures ranging from 150 to 740 ppm. Despite the uncertainty of these estimated values and the lack of chronic toxicity information, these data are of concern because they suggest that for some workers, total exposure may far exceed the airborne exposure limit.

6. DMF exposure, both airborne and total (airborne plus dermal, measured by urine MMF), is below the established exposure limits during cementing of plastic pipes.

7. Exposure to plastic dusts is uncommon during plastic pipe installation and is far below the concentrations that have previously been associated with changes in pulmonary function in other industries.

8. Metal fume exposures during copper pipe soldering (with lead-free solder) are far less than their established exposure limits.

9. Thermal fusion of small-diameter PB pipe joints produces low levels of several hydrocarbons and oxygenated hydrocarbons, but the concentrations were far below those shown to produce toxicity.

10. The potential toxicity of flux decomposition products produced during copper soldering was not evaluated, because samples were irretrievably damaged during analysis.

11. Pipe installation workers face a variety of safety hazards including: chain saws and wood-boring tools used in awkward positions, unsafe ladders, and objects falling from above.

12. Few workers have received adequate training in the spectrum of hazards that they routinely encounter on construction sites, or in safe work practices.

RECOMMENDATIONS

Data in this study indicate that workers cementing plastic-pipe joints are sometimes overexposed to substances contained in the primers and cements, and that overexposures are most likely to occur during work in highly-enclosed areas or when workers have heavy skin contact with primers and cements. To prevent such overexposures, the following recommendations should be implemented consistently throughout the construction industry. Each of the recommendations are technically feasible, and all have been adopted successfully in other industries.

1. Contractors and workers should attempt to arrange their work so that little plastic pipe cementing is required in highly enclosed areas such as crawl spaces and attics.

2. When cementing in highly-enclosed areas is necessary (for example, when repairing plumbing or remodeling), employers should provide portable fans to prevent short-term and full-shift overexposure to substances in the primers and cements.

3. Employers should establish and enforce work practices that minimize skin contact with primers and cements. Two practices should be specifically prohibited: cleaning hands with primer, and wiping excess cement from joints. Workers who cannot follow these practices should be provided with protective gloves and required to wear them.

4. Plumbing contractors should provide portable emergency eyewash facilities for all employees, because splashes of plastic pipe primers and cements or of hot flux could produce serious eye damage, and this damage could be reduced by immediate flushing. Portable eyewash stations could be installed on contractors' trucks, which are kept as close to the worksite as possible.

5. Plumbing contractors should provide health and safety training for all employees. This training should include: ladder safety, safe use of chain saws and wood-boring tools, hazards associated with other construction trades, and the potential hazards and safe use of plastic pipe primers and cements.

The following recommendations should be implemented by chemical manufacturers and formulators who supply products used in plastic-pipe installation.

6. All primers and primer/cleaners should be strongly tinted in bright colors, to discourage their use as hand cleaners.

7. Because of its greater toxicity, DMF should be replaced in primers and cements by THF, MEK, CHX, or ACE whenever practical, even though the DMF exposures measured in this study were below the established limits.

8. Information about the health effects of THF exposure should be improved by conducting appropriate tests on the acute and chronic toxicity of THF, including its potential to produce neurologic effects.

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TABLES

Table 1. Plastic pipe installation sites selected because they were believed to have specific workplace conditions that had not been encountered at previous sites.

Criterion	Sites selected
Apartments/Townhouses	11, 12, 13, 16, 17, 18, 31
High Temperatures	8, 9, 11, 12, 13
Use of DMF	14, 18, 22, 31
Enclosed	9, 11, 13,
Work in crawl spaces	14, 17
Cross-exposures (i.e. CPVC/PVC)	17, 23
Remodels	14
Unusually high number of workers	8
Repeat site visits	8b, 13b, 14b, 14c, 16b, 17b, 22b
Prefabs	7,9,35

Total chosen for specific criteria: 14

Table 2. Average proportion of total on-site work-time spent in each sampling stratum, for workers in each installation type. All values are percentages.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
I	42%	50%	56%	48%
IIa	34	28	40	12
IIb	10	1	1	31
IIIa	13	20	2	3
IIIb	1	2	1	7

Table 3. Prevalence of symptoms reported by workers for days monitored.

Symptom	Percent reporting
None	51%
Any symptom	31
irritation of eyes, nose, or throat	10
dizziness	9
dried skin	9
headache	8
skin rash	7
gastrointestinal disturbances	4
other	2
Not reporting	19

Table 4. Number of short-term solvent samples collected for each installation and sampling stratum.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
I	0	5	0	1
IIa	10	18	7	3
IIb	23	5	1	18
IIIa	20	57	0	3
IIIb	3	13	1	5

Table 5. Percentage of total work time monitored, for each installation and sampling stratum. Goals established prior to monitoring were 50% of total time in strata IIb and IIIa, and 100% in stratum IIIb.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
I	0%	1%	0%	1%
IIa	5	8	6	11
IIb	45	63	30	54
IIIa	42	50	0	44
IIIb	100	65	100	83

Table 6. Mean short-term exposures for each installation type and sampling stratum, for a) THF, b) MEK, c) CHX, d) ACE, and e) %STEL. Concentrations in ppm, and %STEL is shown as percentage of combined exposure limit.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
a) THF				
I	—[a]	5	—	0.2
IIa	27	25	5	0.3
IIb	16	72	18	0.2
IIIa	174	30	—	0.2
IIIb	139	27	66	0.2
b) MEK				
I	—	2	—	1
IIa	2	3	1	5
IIb	8	6	0.4	15
IIIa	13	7	—	11
IIIb	20	3	0.6	25
c) CHX				
I	—	0.2	—	0.3
IIa	0.4	0.4	0.3	0.4
IIb	0.3	0.5	0.3	0.3
IIIa	1	0.5	—	0.3
IIIb	1	0.3	0.4	0.3
d) ACE				
I	—	0.5	—	0.5
IIa	7	1	2	1
IIb	6	0.5	0.5	0.5
IIIa	43	0.5	—	0.5
IIIb	77	0.5	1	0.5
e) %STEL				
I	—	3%	—	1%
IIa	13%	11	3%	2
IIb	10	32	8	6
IIIa	80	15	—	4
IIIb	71	12	27	9

[a]no samples were collected in these categories.

Table 7. Working conditions during the highest measured short-term exposures to a) THF (>200 ppm), and b) MEK (>40 ppm).

Site	Installation	Location	Joints	Temp, F°	Notes	Exposure, ppm
a) THK						
17a	CPVC-pw	crawl space	2.5	70	DWV-PVC[a]	529
17a	CPVC-pw	crawl space	4.5	71		443
14c	CPVC-fire	attic	1	77		311
17a	CPVC-pw	crawl space	3	68	DWV-PVC[a] spill	307
17a	CPVC-pw	crawl space	8	71		304
17a	CPVC-pw	crawl space	4.5	70	DWV-PVC[a]	292
23	CPVC-pw	crawl space	2	68	DWV-PVC[a]	213
17a	CPVC-pw	crawl space	1.5	68	DWV-PVC[a]	209
b) MEK						
14c	CPVC-fire	attic	1	77		96
17a	CPVC-pw	crawl space	4.5	71		53
7	DWV-ABS	prefab shop	102	71		49
35	DWV-ABS	outdoor,prefab	32	59		45
16b	CPVC-pw	interior	16	76		42

[a]these workers also installed DWV-PVC during at least part of the monitoring period.

Table 8. Estimated probability (based on parameters of exposure distribution) that short-term exposure limits would be exceeded in randomly-selected 15-min periods, by installation and sampling strata. All values are percentages.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
a) THF				
I	0.3%	0.3%	—[a]	—
IIa	2	1	0.1	0[b]
IIb	0	4	—	0
IIIa	20	2	—	0
IIIb	17	0.8	—	0
b) MEK				
I	0	0	—	—
IIa	0	0	0	0
IIb	0	0	—	0.1
IIIa	1	0.02	—	0
IIIb	0	0	—	0
c) %STEL				
I	0	0	—	—
IIa	0.7	0.8	0	0
IIb	0.02	4	—	0
IIIa	25	1	—	0
IIIb	23	0.3	—	0

[a]not estimated, because of insufficient data.

[b]values less than 0.01% were rounded down to zero.

Table 9. Associations between various job factors and the resulting short-term exposure levels, in stepwise multiple regression modeling. Coefficients (slopes) and partial correlations are shown.

	CPVC-pw		All installations	
Job factor	slope	partial r^2	slope	partial r^2
a) THF				
Air flow, ft/min	-1.05	.44*	-0.90	.16*
THF in bulk products (wt/wt)	0.90	.02	1.03	.42*
Temperature, °F	-4.91	.10*	-1.31	.004
Joints cemented	-0.23	.01	0.22	.01
b) MEK				
Air flow, ft/min	-0.74	.24*	-0.57	.13*
MEK in bulk products (wt/wt)	-0.49	.01	0.46	.14*
Temperature, °F	-1.27	.004	-0.85	.004
Joints cemented	1.54	.17*	0.50	.13*

*significantly associated with exposure level ($p<.05$)

Table 10. Total photoionizable organics, measured in real time by photoionization detector, for three representative sampling periods.

ID/Installation	15-min charcoal TWA (ppm)	Estimated GSD	12-sec periods with ppm>250	95th %ile (ppm)
1 CPVC-pw	50	2.2	0	133
2 CPVC-pw	26.9	2.3	0	130
3 CPVC-fire	66.4	3.3	4	235

Table 11. Mean full-shift exposures to THF, MEK, CHX, and ACE (and %FSEL) for each plastic pipe installation type. Exposures were assessed with 4-hour passive dosimeter samples. Concentrations are in ppm, and values in parentheses are geometric standard deviations.

Exposure	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
THF	47	28	5	0.3
MEK	10	6	0.8	9
CHX	0.2	0.7	0.2	0.6
ACE	16	0.6	1	0.6
%FSEL	36%(3.5)	20%(2.6)	4%(2.1)	7%(1.6)

Table 12. Working conditions during the highest measured full-shift exposures to a) THF (>75 ppm) and b) MEK (>25 ppm).

Site	Installation	Enclosed Space	Skin Contact	Experience (Years)	Temp	Notes	Exposure ppm
a) THK							
17a	CPVC-pw	Yes	Heavy	5	72	DWV-PVC[a]	158
14b	CPVC-fire	Yes	Heavy	6	80		121
14a	CPVC-fire	Yes	Light	8	88	DWV-PVC[a]	110
17a	CPVC-pw	Yes	Heavy	4	72	DWV-PVC[a]	97
17a	CPVC-pw	Yes	Heavy	10	72		96
23	CPVC-pw	Yes	Heavy	4	78	DWV-PVC[a]	84
31	CPVC-fire	No	Gloves	0	75		83
14b	CPVC-fire	Yes	Heavy	1	80		77
b) MEK							
14b	CPVC-fire	Yes	Heavy	6	80		45
23	CPVC-pw	Yes	Heavy	4	78	DWV-PVC[a]	33
14a	CPCV-fire	Yes	Light	8	88		30
14b	CPVC-fire	Yes	Heavy	1	80		27
31	CPVC-fire	No	Gloves	0	75		27

[a]these workers also installed DWV-PVC during part of the monitoring period.

Table 13. Estimated probability (based on parameters of exposure distribution) that full-shift exposure limits would be exceeded in randomly-selected work days. All values are percentages.

Substance	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
THF	5.5%	1.9%	0.02%	0[a]
MEK	2.2	0.4	0	0.09
%FSEL	10.0	1.4	0	0

[a]values less than 0.01% were rounded down to zero.

Table 14. Associations between various job factors and resulting full-shift exposure levels, in stepwise multiple regression modeling. Coefficient (slopes) and partial correlations are shown.

	THF		MEK	
Job factor	slope	partial r^2	slope	partial r^2
Air flow, ft/min	-1.27	.07*	-1.18	.03*
THF in bulk products (wt/wt)	1.17	.19*	0.70	.09*
Temperature, °F	4.74	.06*	—	<.001
Joints cemented	0.17	.01	0.45	.09*

*significantly associated with exposure (p<.05)

Table 15. Mean full-shift exposures estimated from short-term exposure monitoring, weighted by percentage of work time spent in each sampling stratum for each installation type. Concentrations are in ppm. Values in parentheses are percentages of comparable values derived from 4-hour passive dosimeters.

Substance	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
THF	36 (76%)	16 (59%)	3 (50%)	0.2 (59%)
MEK	4 (40%)	3 (48%)	0.4 (54%)	8 (92%)

Table 16. Mean urine THF and MEK concentrations for each plastic pipe installation type, and number of air samples collected. All concentrations are in µg/l.

Substance	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS	Overall
THF	1260	269	137	33	452
MEK	365	123	119	169	180
n	14	29	15	3	61

Table 17. Working conditions and airborne exposures of workers with highest concentrations of THF (>700 µg/l) and MEK (>500 µg/l) in urine.

Site	Installation	Location	Skin contact	Airborne exposure, ppm	Urine concentration, µg/l
a) THF					
17a	CPVC-pw	crawl space	heavy	158	6700
17a	CPVC-pw	crawl space	heavy	97	4200
23	CPVC-pw	under floor	heavy	84	2500
17a	CPVC-pw	crawl space	heavy	96	1400
14a	CPVC-fire	crawl space	light	110	1000
14b	CPVC-fire	crawl space	heavy	69	860
23	CPVC-pw	under floor	heavy	55	820
14c	CPVC-fire	attic	light	49	750
17b	CPVC-pw	interior	heavy	48	710
b) MEK					
23	CPVC-pw	under floor	heavy	33	960
17a	CPVC-pw	crawl space	heavy	23	950
	unexposed control			none	670
14a	CPVC-fire	attic	light	30	540
17a	CPVC-pw	crawl space	heavy	25	540
17a	CPVC-pw	crawl space	heavy	11	520

Table 18. Substances identified by GC-MS analysis of semi-volatile fraction of copper flux and PB fusion thermal decomposition products.

Installation/ Site	Constituent	Quantity detected, ng/filter	Concentration, µg/m^3
Copper Installation: site #33, sample #549 high flow (same sampling period as #548)	Aliphatic HCs.[a](C_{11}-C_{30})	1	0.006
Copper Installation: site #33, sample #548 low flow (same sampling period as #549)	Aliphatic HCs.(C_{11}-C_{30})	3	0.723
	2-chlorophenol[b]	0.4	0.096
Copper Installation site #32	Aliphatic HCs. (>C_{15})	4000	24.7
PB Fusion site #34, sample #498 high flow	Aliphatic amines(C_{11}-C_{30})	50	0.926
	Alicyclic HCs.(C_{16-18})	3	0.037
	BHT (antioxidant)	2	0.019
	Phenoxy substituted organic	1	0.019
	Fatty amines	3	0.056
	Possible fatty acids	3	0.037
Background: site #33, sample #550	Aliphatic HCs.	3	0.598
	2-chlorophenol[b]	0.4	0.080
Blank: site #33, sample #902	Aliphatic HCs.(C_{11}-C_{30})	40	NA
	Alicyclic HCs.(C_{11}-C_{30})	3	NA
	BHT (antioxidant)	1	NA
	Fatty amines(C_{20}-C_{30})	3	NA
Blank: site #34, sample #504	Aliphatic HCs.(C_{11}-C_{30})	60	NA
	BHT (antioxidant)	1	NA
	Phenoxy substituted organic	1	NA
	Fatty amines (C_{20}-C_{30})	2	NA
	Possible fatty acids	1	NA

[a]HCs=hydrocarbons [b]EPA Priority Pollutant NA-not applicable

Table 19. Substances identified by GC-MS analysis of volatile fraction of PB fusion thermal decomposition products.

Installation/ Site No.	Component	Approx. level (ppbv)
PB fusion site #34	Benzene	4.8
	Carbon tetrachloride	0.06
	Chlorobenzene	0.3
	Ethylbenzene	9.4
	Styrene	30.0
	Tetrachoroethane	0.2
	Toluene	6.0
	1,1,1-trichoroethane	2.1
	Trichloroethene	0.2
	Xylenes	19.0
Blank	—	
Background	Carbon tetrachloride	0.09
	Ethylbenzene	5.8
	Styrene	15.0
	Tetrachloroethene	0.2
	Toluene	1.7
	Trichloroethene	0.1
	Xylenes	5.2

Table 20. Average concentrations of metal fumes measured in personal air samples.

	8-hr TWA mg/m^3	GSD	Exposure Limit (mg/m3)	% of Exposure Limit
Silver	0.0004	1.94	0.01	4.4
Antimony	0.0014	1.89	0.5	0.3
Tin	0.0038	3	2	0.2
Copper	0.0018	3.2	0.2	0.9
Lead	0.0017	2.1	0.05	3.4

FIGURES

Figure 1. Air flow rate in work areas during short-term monitoring periods.

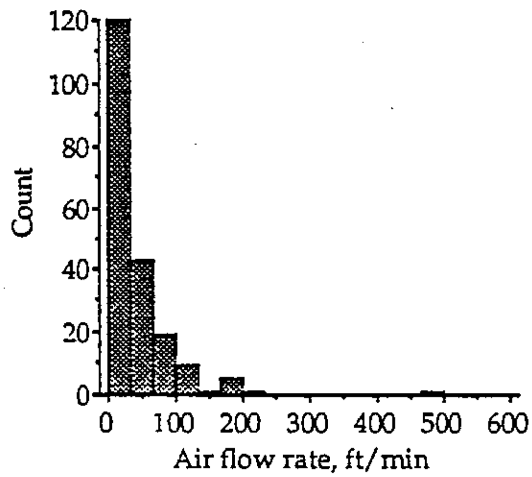


Figure 2. Temperature in work areas during short-term monitoring periods.

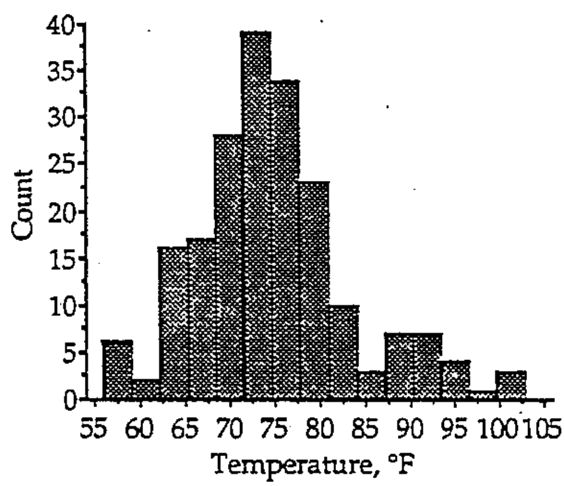


Figure 3. Number of joints cemented per 15-min period during all short-term monitoring periods.

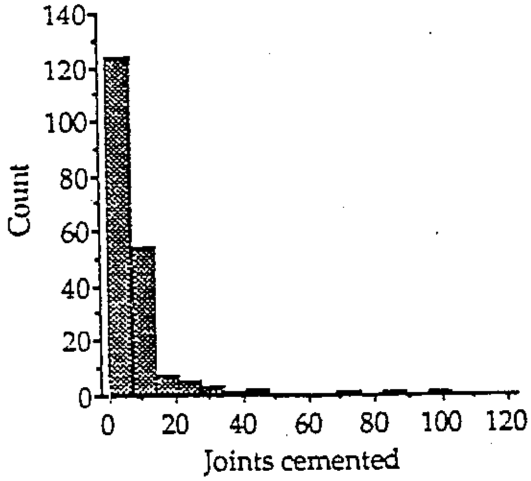


Figure 4. Time sequence of exposure levels measured in three highest exposure sites: a) site 17a, morning, b) site 17a, afternoon, c) site 14c, morning, and d) site 14a, afternoon.

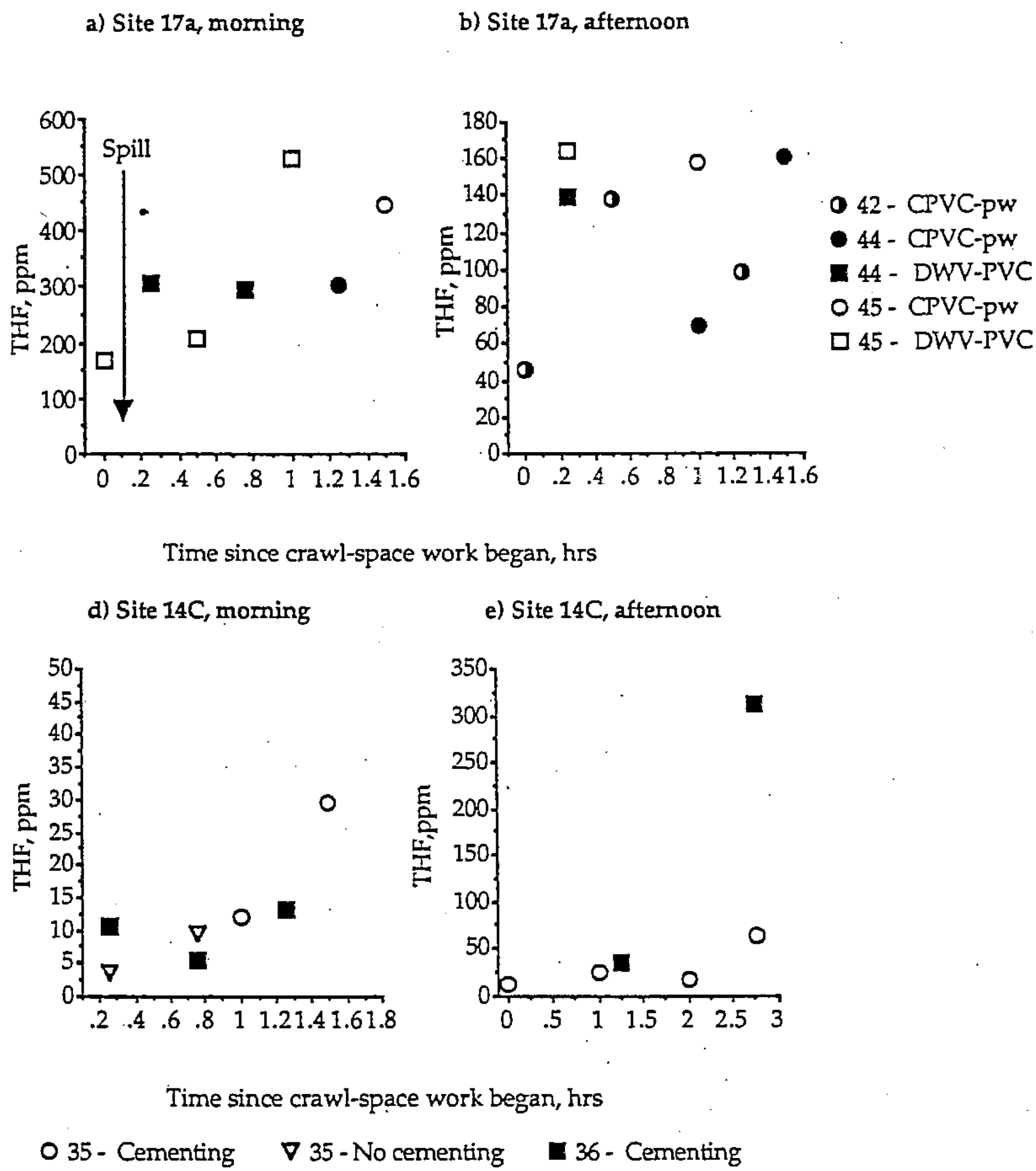


Figure 5. Relationship between short-term THF exposure during CPVC-pw installation and three job factors: a) air flow rate, b) temperature, and c) number of joints cemented in the 15-min period.

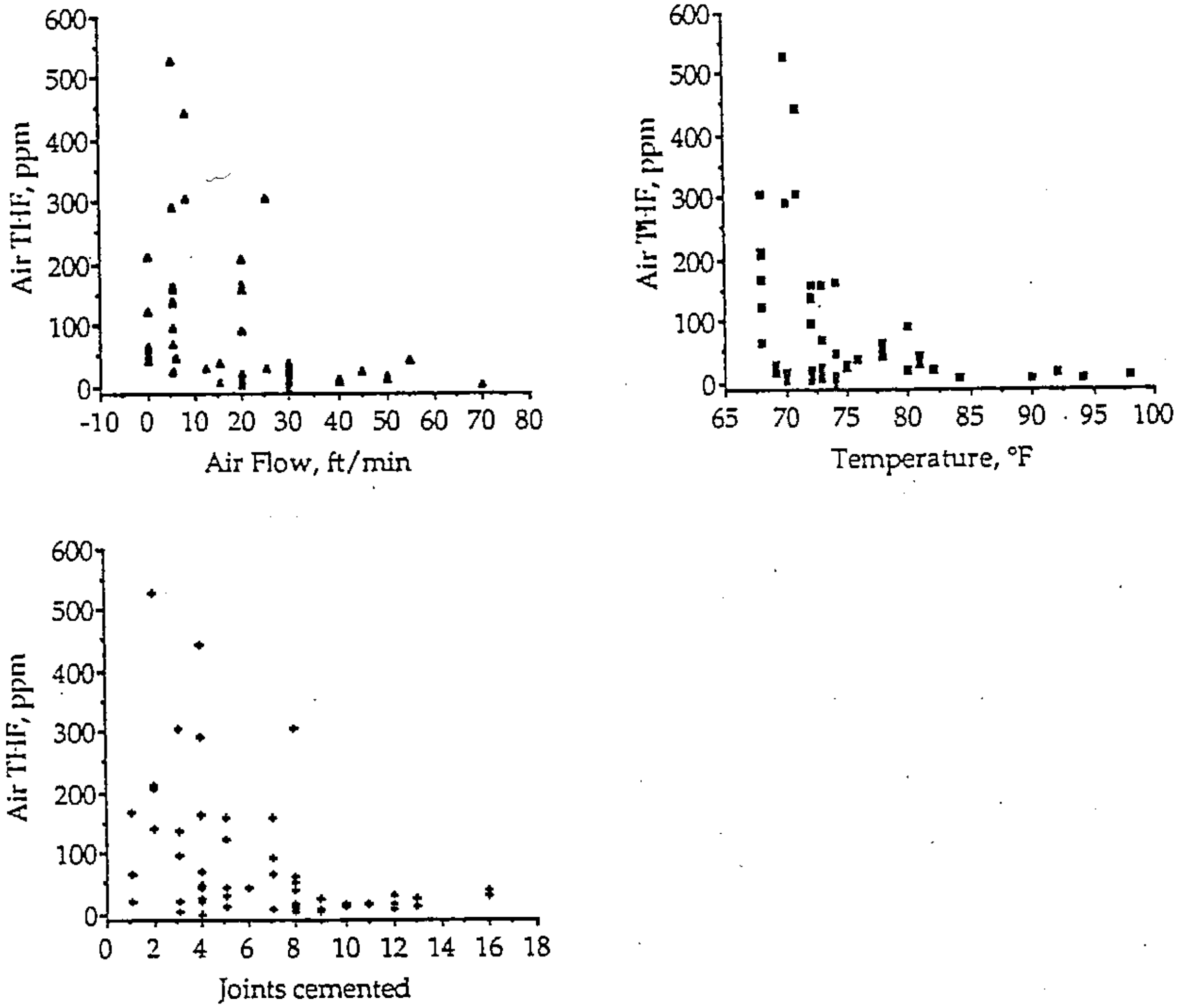


Figure 6. Real-time exposure variability during a representative 15-min monitoring period, as shown by photoionization detector trace.

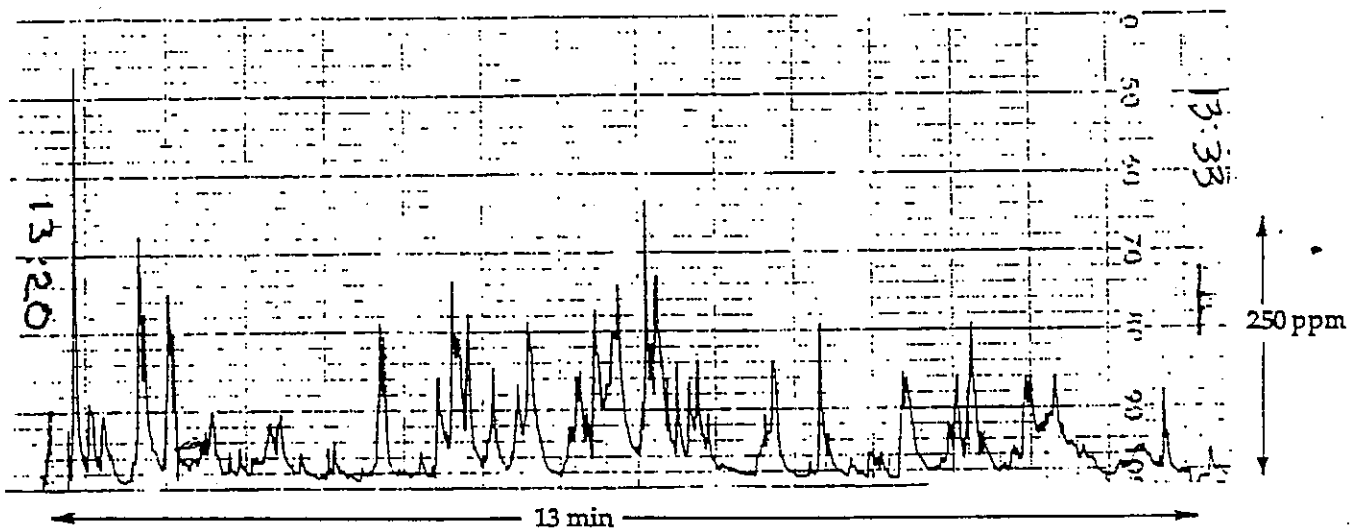


Figure 7. Individual work rates (as joints per minute) during 4-hour monitoring periods and for entire work days.

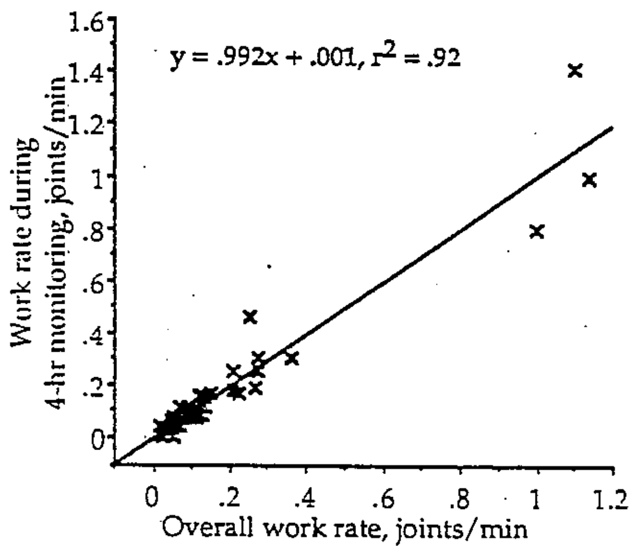


Figure 8. Working conditions associated with full-shift THF exposures: a) number of joints cemented during the monitoring period, and b) temperature.

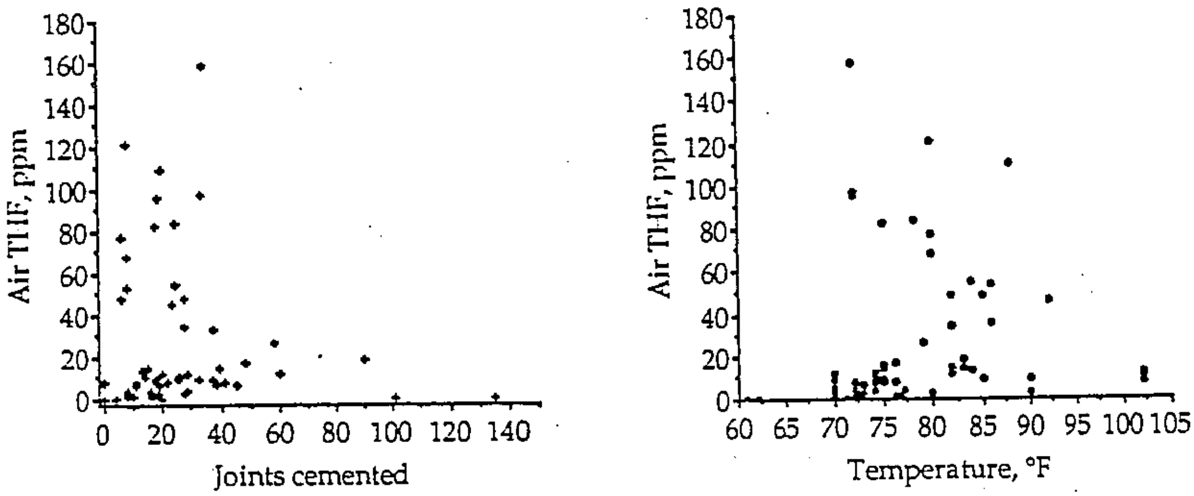


Figure 9. Four-hour exposures to a) THF and b) MEK, as estimated from time-weighted short-term exposure data and as measured by passive dosimeters. All exposures in ppm.

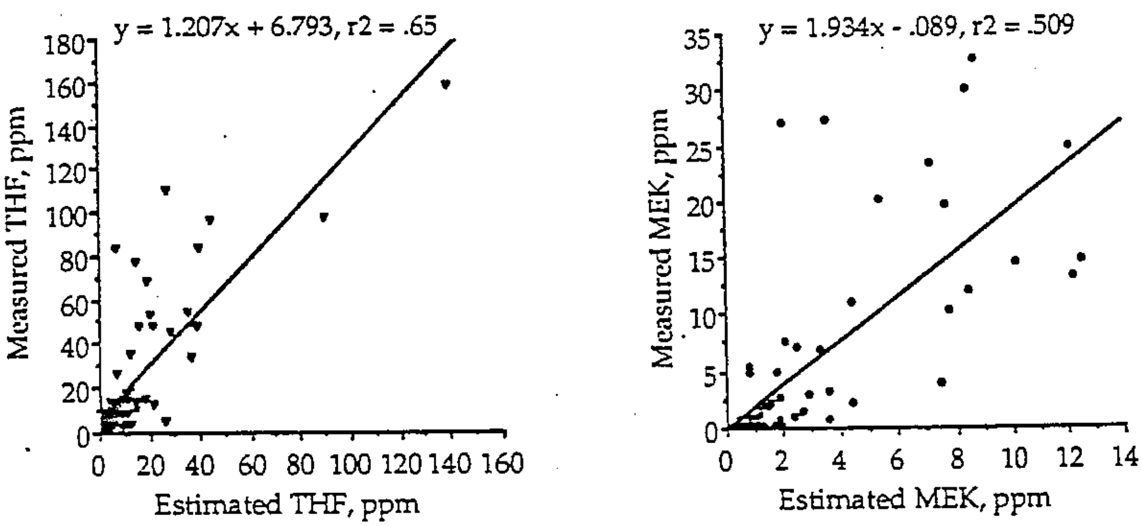


Figure 10. Relationship between urine THF concentrations and airborne THF exposures, by level of skin contact: a) Heavy, and b) Light. Best-fit regression lines are shown.

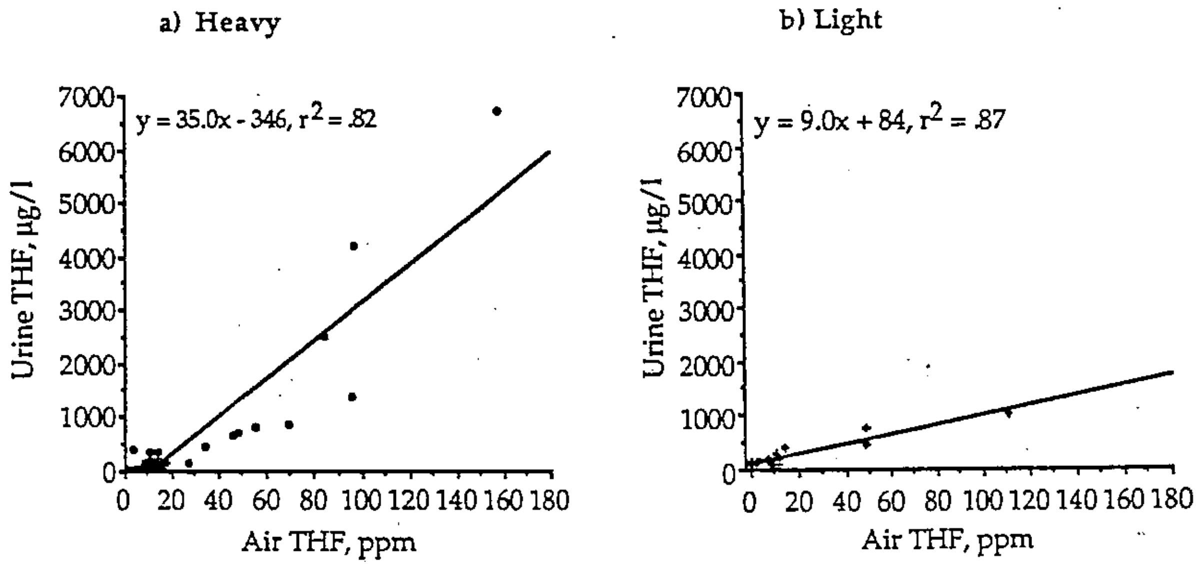
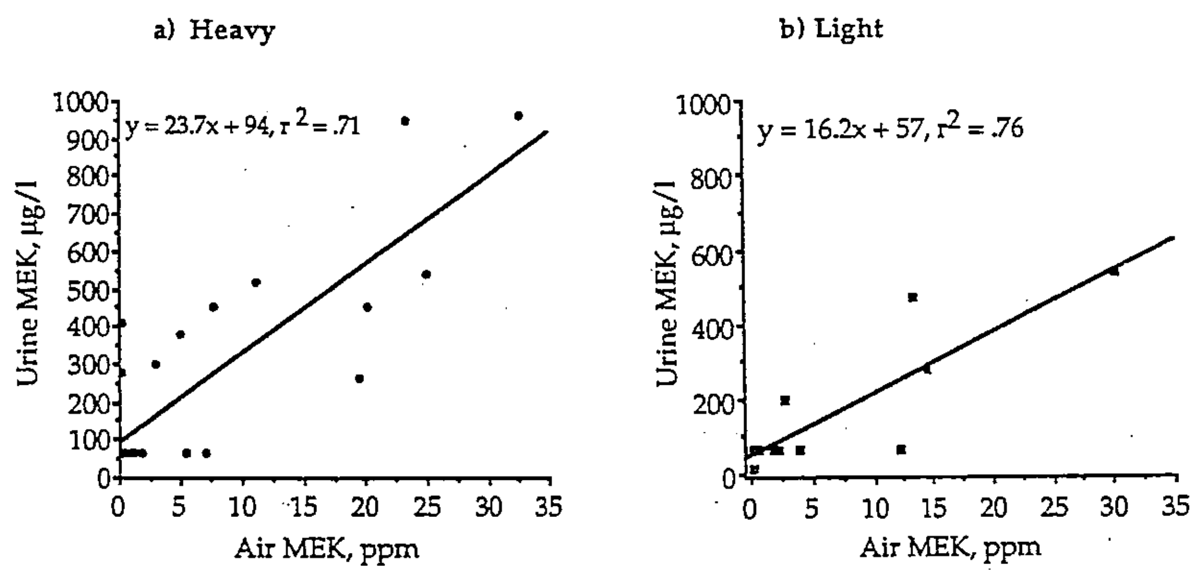


Figure 11. Relationship between urine MEK concentrations and airborne MEK exposures, by level of skin contact: a) Heavy, and b) Light. Best-fit regression lines are shown.



APPENDIX A

Air sampling and analysis methods, and typical detection limits.

Analytes	Collection media	Sampling time	Analysis	Minimum detectable exposure[a]
THF, MEK, CHX, ACE				
full-shift	passive dosimeter	4 hr	GC-FID[b]	0.2 ppm THF,MEK,CHX
short-term	charcoal	15 min	GC-FID	0.7 ppm
	ambersorb XE-347	15 min	GC-FID	0.7 ppm
DMF	silica gel	full shift	GC	0.05 ppm
Plastic Dust				
total	membrane filter	full shift	gravimetric	0.01 mg/m^3
respirable	filter + cyclone	full shift	gravimetric	0.01 mg/m^3
Metals (antimony, copper, lead, silver, and tin)	membrane filter	full shift	plasma emission	0.01 mg/m^3
PB-fusion and flux decomposition products				
semi-volatile	teflon filter	full shift	GC-MS[c]	various
volatile	tenax tube	full shift	GC-MS	various
formaldehyde	Orbo-24 tube	full shift	GC-NPD[d]	0.05 ppm

[a]value shown is detection limit for sample of typical volume; for full-shift samples, this is expressed as the indicated 8-hour TWA exposure, based on typical sampling times.
[b]gas chromatography with flame ionization detector.
[c]gas chromatography/mass spectrometry.
[d]gas chromatography with nitrogen-phosphorus detector.

APPENDIX B

Methods used to identify suitable monitoring sites.

Site Search Process

The overall strategy in searching for CPVC-pw installation sites was to establish contacts at all levels of the plastic-pipe distribution system, shown below:

Resin manufacturer
↓
Extruders
↓
Distributors
↓
Local suppliers
↓
Plumbing contractors
↓
Workers

To identify contractors using CPVC pipe, contacts were made with the U.S. manufacturer of CPVC resin, most CPVC pipe manufacturers, many regional distributors, and dozens of local suppliers. The resulting chain of referrals ultimately led to a small number of firms familiar with CPVC installation. The network of referrals is described below. Plumbing inspectors also proved to be a rich source of information about local plastic pipe installation practices. Several other sources were also consulted to generate new leads: telephone directories, trade associations, and local union business agents, whose names were provided by pipe trades unions. Tables A-1 and A-2 show a partial listing of the organizations contacted.

Only one contractor was identified (in Nevada County) who used CPVC-pw occasionally in custom homes. Where permitted, CPVC-pw was used primarily by do-it-yourselfers. A number of prefabricated-home and mobile-home distributors and manufacturers were contacted but they did no CPVC-pw installation in California.

When it became clear that the search for needed sites would have to extend beyond California, leads to CPVC-pw installations in Nevada, Oregon, Washington, and later Arizona were investigated. Using the above methods, no suitable CPVC-pw installation sites were located. A slightly less rigorous search technique was also used for Orlando, Florida, with no CPVC-pw sites located.

All contacts questioned about CPVC-pw were also asked about the use of PVC in California. PVC was generally permitted and frequently used for water service outside residences and for garden sprinkler systems, and was occasionally used for air-conditioner condensate lines inside homes. No PVC condensate installation sites were monitored, because contractors reported that this work was usually done in brief periods between other job tasks. No garden-sprinkler sites were monitored because the outdoor conditions were judged to be substantially different than indoor CPVC installation. According to these sources, PVC is rarely used for DWV in California.

Many referrals, no sites

The following paragraphs illustrate the numerous leads that were followed, and how these ultimately led to very few contractors installing CPVC-pw pipe.

Eight manufacturers supply most CPVC pipe used in North America. They are:

Company Name	Headquarters
Bow	Montreal, Canada
CGF	Ardmore, AL
Cresline	Evansville,IN
Genova	Davison, MI
Nibco	Elkhart, IN
R&G Sloane	Sun Valley, CA
Thompson	Huntsville, AL
U-Brand	Ashland, OH

Described below are the referrals provided by these manufacturers. These are provided to illustrate that various referrals ultimately led to a small number of appropriate suppliers and contractors for the purpose of this study.

Bow, CGF, Cresline, Genova, and Thompson do not service the West Coast or Nevada.

Nibco manufactures only industrial plastics and made referrals to various industries such as Chevron and Dow Chemical, etc. that use CPVC, but none of these companies used CPVC in a fashion comparable to pw distribution. Nibco also made a referral to Spears, manufacturer of Blazemaster glues, in Sylmar, California.

R&G Sloane made a referral to: 1) Western States Sales (Washington agent) who made a referral to Famillion N.W. and Perry (retailers in Oregon). Both Famillion and Perry sold only small quantities for do-it-yourselfers. Famillion made a referral to their Las Vegas branch who made a referral to a local contractor who did not use CPVC, and to Turf Supplies who made referrals to contractors who weren't using CPVC; 2) New Horizon Sales (Arizona agent) made a referral to Buffington & Associates (services Northern California and Northern Nevada) who in turn made a referral to PE O'Hair in Pittsburg, California who made a referral to a contractor who used CPVC for hot tubs and Western Nevada Supply in Sparks, Nevada (no CPVC); 3) their product manager for sprinkler products made a referral to the American Fire Sprinkler Association and three fire sprinkler companies, all in Southern California.

U-Brand made a referral to 10 wholesalers in Arizona: no contractor referrals were received from them. Sales of CPVC were only made to do-it-yourselfers. One wholesaler made a referral to Nibco, another to Spears.

Spears, manufacturer of Blazemaster, had already been contacted by B.F.G. and made a referral to Grinnell Supply, a Southern California fire sprinkler contractor, PE O'Hair in San Francisco (who made a referral to their Pittsburg branch), and to Harrington Plastics who made a referral to A.M.K., a company already referred by Nibco. Harrington also made referrals to three retailers and two contractors, none of whom sold or used CPVC in residences. These contacts made referrals of their own which were equally fruitless.

U-Brand also made referrals to 27 wholesalers in California and one in Oregon. None of these was able to supply us with contacts of retailers or contractors involved with CPVC for pw.

Names of other plastic pipe manufacturers and suppliers were obtained via various organizations and associations. Following is an illustration of some of the referrals made from these groups.

J.M. manufacturers in California only produced PVC. Pacific Western in Oregon made a referral to three distributors: Ewing in California (no CPVC); United Plastics in Oregon who made a referral to Famillion in Oregon (sold to do-it yourselfers only); and H.D. Fowler in Washington who made a referral to Jim Flag who made a referral to AMFAC who made a referral back to H.D. Fowler who than made a referral to Keller Supply who didn't sell CPVC and made a referral to three Seattle plumbers who did not use it. Also contacted were Tyler Pipe Manufacturer and Bay Plastics, both of Texas, neither of whom currently manufacture CPVC.

Table B-1. Building departments, distributors, and suppliers contacted for assistance in locating suitable sampling sites.

City/County Bldg.& Plumbing Depts.:		
	CA:	88
	NV, OR, WA, AZ, FL, GA:	37
Mobile and Pre-Fab Home manufacturers & distributors:		16
Plumbing Distributors and Suppliers:		
	CA:	45+
	Other:	35+
Plumbing Contractors:		
	CA:	75+
	NV:	65+
	GA:	30+
	Other:	10
California Fire Marshalls:		11
Fire Sprinkler Contractors:		50+

Table B-2. Trade associations contacted for assistance in locating suitable sampling sites.

Associated Builders and Contractors (CA)
Associated General Contractors (CA)
Association of General Contractors of California
Association of Builders and Contractors (NV)
Association of General Contractors (NV)
Associated Plumbing & Mechanical Contractors of Sacramento, Inc. (CA)
AFSA-American Fire Sprinkler Association
ASA-American Supply Association
AIM/R-Association of Industrial Manufacturers Representatives
Association of Builders and Contractors (NV)
CBIA-California Building Industry Association
CALBO-California Building Officials
Coalition For Home Fire Sprinklers
Dallas Trade Association (TX)
Home Builders Association of Portland (OR)
Home Builders Association (NV)
ICBO-Industrial Conference of Building Officials
International Association of Fire Chiefs
IAPMO-International Association of Plumbing & Mechanical Officials
IRC-Industrial Relations Council for the Plumbing & Pipefitting Industry
Lobby Group Plumbing & Heating Contractors (OR)
Mechanical Contractors Association of California
Mechanical Contractors Association of America
NAPD-National Association of Plastics Distributors
National Association of Remodeling Industry (FL)
National Fire Sprinkler Association
NSPC-National Standard Plumbing Code Committee
National Sanitation Foundation
Oregon State Home Builders Association (OR)
Oregon Home Builders Association (OR)
Plastic Pipe Technical Center (OH)
PPFA-Plastic Pipe Fitters Association
PHCC-Plumbing, Heating & Cooling Contractors of California
Plumbing & Mechanical Suppliers of Washington (WA)
PDI-Plumbing & Drainage Institute
PMI-Plumbing Manufacturers Institute
PPIC-Plastic Pipe Industry Council
Southern Nevada Plumbing Association (NV)
Unibell Pipe Association (TX)

APPENDIX C

Exposure limits used for evaluation of worker exposures.

Substance	Exposure Limit 8-Hour TWA	15-Minute	Source 8-Hour	15-Minute
MEK	200 ppm	300 ppm	N,A,O	A,O
THF	200 ppm	250 ppm	A,O	A,O
CHX	25 ppm	75 ppm	N,A,O	A[a]
ACE	250 ppm	1000 ppm	N	A,O
DMF	10 ppm[b]	none	A,O	--
antimony	0.5 mg/m^3[b]	none	N,A,O	--
copper	0.2 mg/m^3	none	A	--
lead	0.05 mg/m^3	none	O	--
silver	0.01 mg/m^3	none	O	--
tin	2 mg/m^3	none	A,O	--
formaldehyde	1 ppm	2 ppm	O	O

[a]According to ACGIH guidelines, this value should be exceeded (as a 15-min average) no more than twice per day.

[b]Does not address potential carcinogenicity.

Sources:

N = NIOSH Recommended Exposure Limits, as listed in Morbidity and Mortality Weekly Report 1986;35(1s):1s-33s.

A = American Conference of Governmental Industrial Hygienists. Threshold Limit Values and Biological Exposure Indices for 1987-1988.

O = US OSHA Regulations; 29 CFR 1910.

Tetrahydrofuran

CAS# 109-99-9 ACGIH TLV-TWA: 200 ppm OSHA PEL: 200 ppm

TLV-STEL: 250 ppm OSHA STEL: 250 ppm

HUMAN TOXICOLOGY: Tetrahydrofuran is capable of irritating the eyes and upper respiratory tract. It is also a CNS depressant. Symptoms of overexposure in workers include headache, dizziness and nausea. These symptoms are readily reversible. It is also a defatting agent and prolonged skin contact may cause dermatitis.There are few reports of chronic toxicity in the literature. There is a case report of IgA glomerulonephritis developing in a worker exposed to high levels of THF (389-757 ppm) while working in a confined area. The odor threshold is 25 ppm.

ANIMAL TOXICOLOGY: THF is an irritant of the eyes and upper respiratory tract in test animals. It is also a CNS depressant at high air levels. No chronic toxicity studies (reproductive, carcinogenicity, neurotoxicity) have been reported.

Dose Response of Adverse Effects of THF on Test Animals.

400 ppm	12 weeks	No histopathological effects (dogs)
2000 ppm	18 weeks	Decreased hepatic alcohol and formaldehyde dehydrogenase activity (rats).
3,000 ppm	20 days	Upper respiratory tract irritation Technical grade may cause liver and kidney damage from peroxide contamination.
17,000 ppm	30 days	No liver or kidney injury (rabbits, cats)
25,000 ppm		Anesthesia (dogs, mice)
20% solution on skin		Inconsistent reports of irritation.

TLV DOCUMENTATION: The existing toxicity information for THF is extremely limited. In particular,the health effects of ongoing exposure cannot be fully assessed, because no chronic toxicity studies have been reported. However, the few germane reports available were addressed in setting the TLV and PEL for this substance. No published information would warrant setting a different exposure limit for this investigation.

Methyl ethyl ketone

2-Butanone CAS# 78-93-3	ACGIH TLV-TWA: 200 ppm	OSHA PEL: 200 ppm
	ACGIH TLV-STEL: 300 ppm	OSHA STEL: 300 ppm

HUMAN TOXICOLOGY: MEK vapors are irritating to the eyes and upper respiratory tract. It is also a CNS depressant. Methyl ethyl ketone also potentiates the neurotoxicity of n-hexane and methyl butyl ketone. Combined workplace exposure to both MEK and n-hexane has caused outbreaks of peripheral neuropathy in a number of workplaces. There have been a few case reports of chronic MEK exposure, in combination with chronic exposure to other solvents such as THF or toluene, causing peripheral neuropathy. In one such report, the levels of MEK involved were below the TLV.

Effect of Air Concentrations on MEK's Acute Toxicity:

5-10 ppm	Odor threshold (100% response)
100 ppm	Slight nose and throat irritation
200 ppm	Mild eye irritation Estimated satisfactory concentration 50% response for eye and nose irritation.
350 ppm	Objectionable concentration
300-500 ppm	Headache, irritation, nausea
300-600 ppm	Numbness of the fingers and arms reported in one incident.
3300 ppm	Moderately irritation to eyes and throat. (momentary exposure).
33,000 ppm	Intolerable irritation of the eyes, nose, and throat (momentary exposure).

MEK is a defatting agent and may cause dermatitis upon prolonged skin contact. The liquid is absorbed through the skin.

ANIMAL TOXICOLOGY: The LC(50) for 4 hours exposure is 12,000 ppm for the rat. 6000 ppm caused fatal delayed bronchopneumonia in 100% of treated rats at seven weeks. In teratogenicity tests conducted in the rat, 3,000 ppm caused slight fetotoxicity (but no signs of embryotoxic or teratogenic effects); 1000 ppm and lower doses were without effect. In several studies, subchronic exposures up to 2500 ppm have been found to produce only slight effects on test animals (slight increase in SGPT at 2500 ppm in one study). MEK potentiates the neurotoxicity (peripheral nerve injury) of n-hexane in animal tests. An MEK air level of 200 ppm potentiated this effect of n-hexane in one rat study. The ability of lower levels of MEK to potentiate n-hexane's neurotoxicity has not been tested. In a number of animal studies, high doses of MEK (up to 6000 ppm) alone did not cause peripheral neuropathy. MEK has been reported to potentiate the hepatotoxicity of chloroform in the rat as well. No cancer bioassays have been conducted using MEK.

TLV DOCUMENTATION: The TLV documentation did not address animal studies describing the slight fetotoxicity of MEK at very high doses, the ability of MEK to potentiate the neurotoxicity of n-hexane and methyl butyl ketone in both test animals and overexposed workers, or the ability of MEK to increase the hepatotoxicity of chloroform in test animals. It is not known whether or not MEK at levels near or below the TLV would potentiate the toxicities of these agents in workers; for this reason, combined exposures to these agents should be avoided. The TLV documentation does not address the case reports which describe neuropathies developing in instances of combined exposure to MEK and other solvents (acetone, THF, toluene). In every instance, except one in which the combined exposures included acetone and toluene, these reports involved situations of likely gross overexposure. Excepting these case reports, the literature and use experience strongly indicate that exposure to MEK does not cause peripheral neuropathies.

It is uncertain as to whether or not the current TLV protects against MEK potentiation of the neurotoxicity of other solvents. The present TLV is adequate as an evaluation criteria for MEK exposure in the absence of combined exposures to n-hexane or methyl butyl ketone. With respect to combined exposure to THF and MEK, there is very little information on which to judge the existence or magnitude of hazard. In the one report involving THF and MEK, excessive skin and inhalation exposure (the worker used bare hands to handle THF adhesive-based, used MEK as a solvent and to clean hands; and used both solvents in a trench) was likely. No other reports of an interaction between THF and MEK exist. In the absence of confirmation of this effect, of reliable dose-response information, and of consistent animal toxicity findings, there is no basis for setting an evaluation criteria for this investigation which would be different from the current TLV-TWA for MEK.

Cyclohexanone

CAS# 108-94-1 ACGIH TLV-TWA: 25 ppm, S OSHA PEL: 25 ppm

NIOSH Recommended PEL: 25 ppm

HUMAN TOXICOLOGY: Vapors irritate the eyes, throat and upper respiratory tract. In one study, a majority of exposed subjects found 75 ppm to cause objectionable irritation of the eyes, nose, and throat; 50 ppm was found to cause some throat irritation; and 25 ppm was judged to be an acceptable working atmosphere by the majority of subjects. Cyclohexanone is a defatting agent causing dermatitis upon prolonged contact.

ANIMAL TOXICOLOGY: Cyclohexanone is a central nervous system depressant at high doses. The liquid caused moderate irritation and some corneal injury when placed in the eye of a rabbit. Chronic subcutaneous or cutaneous administration of cyclohexanone caused cataracts in guinea pigs. Subchronic exposure of rabbits and monkeys to 190 ppm caused slight kidney and liver injury. There are negative NTP drinking water bioassays on cyclohexanone conducted in both sexes of rats and mice. At very high doses of about 1 g/kg/day no significant histopathology was found in the subchronic phase of these NTP bioassays. In a reproductive toxicity study, exposure to 1,000 ppm for one generation and exposure to 250 ppm or 500 ppm for two generations were without adverse effects on reproductive performance or outcome, including behavioral neurotoxicologic endpoints. Continued exposure of the high-dose second generation to 1,400 ppm resulted in adverse effects such as lethargy, body weight depressions, reduced male fertility, reduced progeny survival, and reduced progeny body weight.

TLV DOCUMENTATION: The major reports covering irritation, hepatotoxicity, acute lethality, and renal toxicity in test animals, and reports of acute irritation in humans were addressed in setting the TLV for this compound. The documentation is sufficiently comprehensive to justify the use of the TLV-TWA as the evaluation criteria in this investigation.

Acetone

(CAS# 67-64-1)

ACGIH TLV-TWA: 750 ppm OSHA PEL: 750 ppm

ACGIH TLV-STEL: 1000 ppm OSHA STEL: 1000 ppm

NIOSH REL: 250 ppm

HUMAN TOXICOLOGY: Vapors irritate the eyes, throat, and upper respiratory tract. Acetone may cause this irritation at air levels below current TLV-TWA and PEL values (see table 1). Tolerance to this irritation may develop with continued exposure. At very high air levels, acetone is a CNS depressant. Complaints of CNS depression (light-headedness, weakness, dizziness, and headache) have occurred in workers grossly overexposed to acetone vapors. One controlled study examined the effect of airborne exposure to 250 ppm of acetone on performance in six neurobehavioral tests. This study found slight, but statistically significant, performance decrements on several measures (two measures of auditory tone discrimination, and on the anger hostility scale of a Profile on Mood States tests for the male subjects only) out of the many neurobehavioral parameters assessed. These results suggest that acetone exposures of 250 ppm can cause a mild CNS depression.

Acetone is well absorbed by inhalation and ingestion. About one-half of an inhaled dose is absorbed. The major route of excretion is via expired air. Acetone is a defatting agent causing dermatitis upon prolonged contact with the skin. Acetone is a product of human metabolism and is also a metabolite of isopropanol.

ANIMAL TOXICOLOGY: Acetone causes narcosis and irritation in test animals. In a number of studies, acetone has been found to potentiate the toxicity of other solvents including halogenated hydrocarbons. In one such study, acetone at the lowest tested dose (40 mg/kg, roughly equivalent to 250 ppm) potentiated the hepatotoxicity of compounds such as carbon tetrachloride and trichloroethylene in the rat. Acetone also potentiates the toxic effects of chloroform on the liver and kidney. Acetone has also been found to potentiate the toxicity of acrylonitrile by altering the rate at which it is metabolized to cyanide. It may also potentiate the neurotoxicity of n-hexane and methyl n-butyl ketone by altering the toxicokinetics of the 2,4-hexanedione metabolite of these compounds.

No studies of the reproductive toxicity or carcinogenicity of acetone were available.

Human Health Effects Resulting from Exposures to Acetone Below or Near Exposure Guidelines.

Acetone Level	Effect	Study
250 ppm	slight neurobehavioral effects	Dick, *et al.*
300 ppm	slight irritation	Nelson, *et al.*
500 ppm	tolerable irritation	" "
100 ppm	transient irritation	Matsushita, *et al.*
250 ppm	transient irritation	" "
500 ppm	transient irritation	" "
1000 ppm	transient irritation	" "
300-900 ppm	eye, throat irritation in exposed workers	Parmeggianni, *et al*
700 ppm	irritation of the respiratory tract, giddiness	Vigliani, *et al.*
100 - 500 ppm	no irritation	Divencenzo, *et al.*

TLV DOCUMENTATION: Four studies have reported acetone to cause mild irritation of the eyes or mucous membranes at air levels below or near the PEL and TLV values for this compound. One study failed to find an effect at exposures below the current TLV. Short-term irritation is a material impairment to health. The several studies finding irritation at levels below the TLV require the use of the NIOSH REL as the evaluation criteria in this investigation. Use of the NIOSH REL will also help protect against any adverse interactions in the event of exposure to mixtures of solvents.

Dimethylformamide

CAS# 68-12-2 ACGIH TLV-TWA: 10 ppm, S OSHA PEL: 10 ppm, S

HUMAN TOXICOLOGY: Hepatotoxicity (hepatomegaly, altered liver function tests, jaundice) has been observed in overexposed workers. In one workplace, a high proportion of heavily overexposed workers were found to have been affected. Well absorbed dermally; skin absorption is usually a factor in systemic toxicity. May cause an ANTABUSE-like reaction with alcohol at levels near the PEL. A defatting agent causing dermatitis. Symptoms of overexposure include nausea, vomiting, abdominal pain, dizziness, and facial flushing. Epidemiological investigations have suggested an association of DMF with an increased incidence of testicular cancer in heavily exposed men. However, the lack of exposure measurements prevents quantitatively assessing the possible cancer risk to workers exposed at the PEL. In addition, the association with DMF may not be specific as the possibility that cadmium exposures occurred in the three studied workplaces has been raised.

ANIMAL TOXICOLOGY: To date, animal studies are inadequate to reliably assess the carcinogenic potential of DMF. The National Toxicology Program is preparing to test DMF under its cancer bioassay protocols. Those results may not be available for several years. Monomethylformamide, a major metabolite of DMF, is highly teratogenic in rodents. However, a review of the majority of studies with DMF suggested that it is not teratogenic, but may be embryolethal at high doses. Levels of DMF at or above 100 ppm have been found to cause liver and kidney injury in rats.

TLV DOCUMENTATION: The major reports covering hepatotoxicity, acute lethality, renal toxicity, carcinogenicity, and reproductive effects in test animals, and reports of acute illness and liver injury in humans were addressed in setting the TLV for this compound. The documentation is sufficiently comprehensive to justify the use of the TLV-TWA as the evaluation criteria in this investigation.

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APPENDIX D

Characteristics of sites monitored.

Table D-1. Counties and states in which monitoring sites were located, and the number of sites and site days per area.[a]

County/State	Sites monitored	Site-days of monitoring
Georgia[b]	7	15
Alameda	4	4
San Bernadino	2	4
Santa Clara	2	4
Contra Costa	2	3
Riverside	2	3
Solano	2	3
Los Angeles	2	2
Sacramento	2	2
Napa	1	1
Shasta	1	1
Sonoma	1	1
Totals	28	43

[a]The site selection search was initially focused on the California counties with the most new construction: Los Angeles, San Diego, San Bernadino, Orange, Riverside, Contra Costa, Sacramento, Alameda, Santa Clara, and Ventura. No suitable sites were identified in Orange, San Diego, or Ventura counties.

[b]all CPVC-pw and DWV-PVC sampling was done in Georgia.

Table D-2. Selected characteristics of each site.

Site	Workers	Installation	Referral Sources[a]
1	2	copper	Union
2	3	copper	Bldg. Dept
3	1	DWV-ABS	Union
4	1	copper	Union
5	2	DWV-ABS	Union
6	3	CPVC-fire	Fire Marshall
7	1	DWV-ABS	Union
8A	4	CPVC-fire	Fire Marshall
8B	4	CPVC-fire	Fire Marshall
9	2	CPVC-fire	Fire Marshall
10	1	copper fire	Fire Marshall
11	4	CPVC-fire	Fire Marshall
12	1	CPVC-fire	Fire Marshall
13A	2	CPVC-fire	Fire Marshall
13B	2	CPVC-fire	Fire Marshall
14A	3	CPVC-fire	Fire Marshall
14B	3	CPVC-fire	Fire Marshall
14C	2	CPVC-fire	Fire Marshall
15	3	DWV-PVC	Resin Manufacturer
16A	2	CPVC-pw	Resin Manufacturer
16B	2	CPVC-pw	Resin Manufacturer
17A	3	CPVC-pw[b]	Resin Manufacturer
17B	3	CPVC-pw[b]	Resin Manufacturer
18A	4	DWV-PVC	Resin Manufacturer
18B	2	DWV-PVC	Resin Manufacturer
19	3	CPVC-pw	Resin Manufacturer
20	1	DWV-PVC	Resin Manufacturer
21	1	CPVC-pw[b]	Resin Manufacturer
22A	3	DWV-PVC	Resin Manufacturer
22B	3	DWV-PVC	Resin Manufacturer
23	2	CPVC-pw[b]	Resin Manufacturer
24	2	DWV-PVC	Resin Manufacturer
25	2	CPVC-pw	Resin Manufacturer
26	2	copper	Union
27	2	DWV-ABS	Union
28	1	copper	Union
29	2	CPVC-fire	Union
30	2	copper	Union
31	2	CPVC-fire	Union
32	2	copper	Union
33	1	copper	Union
34	1	PB fusion (snow melt)	Manufacturer
35	3	DWV-ABS	Union

[a] Contractors were sometimes referred from more than one source. Only the more direct or timely source is given.

[b] also had DWV-PVC

APPENDIX E

Contents of bulk primer and cement samples.

Product	Use	Ingredients listed on label	%THF	%MEK	%CHX	%ACE	%DMF
	CPVC-pw Products						
20	primer	MEK,ACE,THF	28.0%	12.0%	0.7%	55.0%	0.0%
24	primer	MEK,THF,CHX,DMF	(45.0)[a]	(37.5)	(10.0)	(0.0)	(7.5)
28	primer	THF	(80.0)	(0.0)	(0.0)	(0.0)	(0.0)
5	cleaner	MEK,ACE	0.0	6.9	0.0	77.7	0.0
1	cement	THF,MEK.CHX	65.9	10.5	7.3	0.0	0.0
2	cement	THF,MEK.CHX	68.4	14.1	6.7	0.0	0.0
7	cement	THF,CHX	85.4	0.0	10.6	0.0	0.0
8	cement	THF,CHX	77.7	0.0	12.3	0.0	0.0
	CPVC-fire Products						
11	primer	THF	79.0	1.0	0.0	0.0	0.0
14	primer	DMF,MEK,CHX,THF	29.5	25.0	7.7	0.0	0.0
12	cement	THF,MEK,CHX	67.9	14.6	5.6	0.0	0.0
15	cement	MEK,CHX,THF	60.4	12.2	11.6	0.0	0.0
	DWV-PVC Products						
3	cement	THF,DMF	59.4	0.1	0.1	0.0	30.5
4	cement	MEK,THF,CHX	7.2	6.2	0.8	0.0	0.0
6	cement	THF,CHX	77.7	0.2	13.4	0.0	0.0
9	cement	THF,CHX	26.0	0.5	18.6	0.0	0.0
27	cement	THF,MEK,CHX	(40.0)	(37.5)	(7.5)	(0.0)	(0.0)
	DWV-ABS Products						
10	cement	MEK	0.8	62.7	0.1	0.0	0.0
16	cement	MEK	0.0	68.2	0.2	0.0	0.0
19	cement	MEK	(0.0)	(75.0)	(0.0)	(0.0)	(0.0)

[a]values in parentheses were supplied by manufacturers; no bulk samples of these products were analyzed.

Appendix F

Alloy composition of copper solders collected at 4 work sites. All values are percentages of bulk material.

Sample No	Silver(%)	Copper(%)	Antimony(%)	Tin(%)	Lead(%)
315	0.7	4.3	0.2	91.7	0.12
530	0.3	0.2	0.2	94.3	0.19
553	1.0	4.7	0.2	85.6	0.22
136	0.3	2.5	2.6	61.0	0.26

APPENDIX G

Results of laboratory quality assurance program.

Figure G-1. Concentrations measured in paired air samples collected on charcoal and ambersorb sorbent tubes: a) THF, and b) MEK. Concentrations are in ppm.

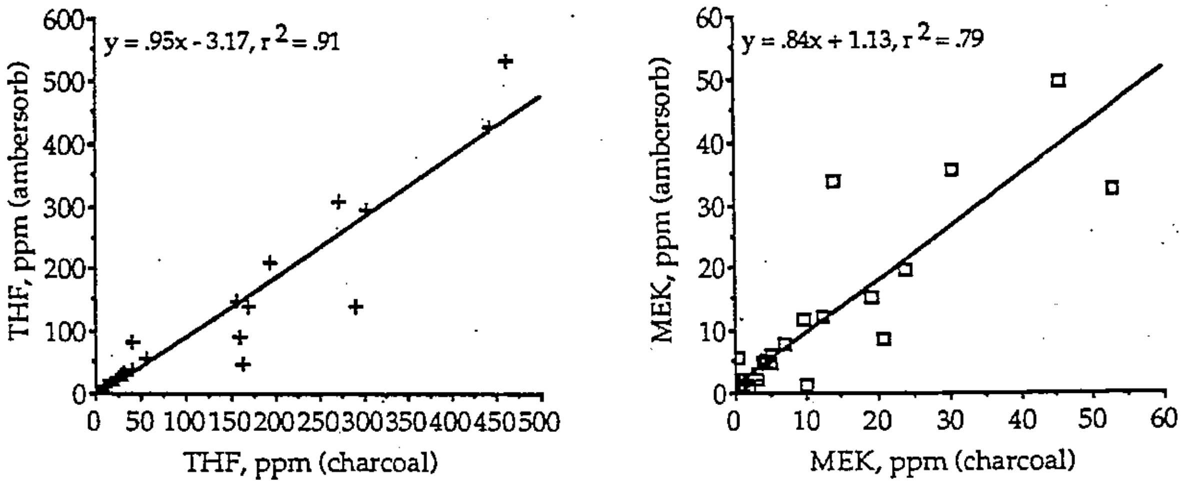

Figure G-2. Laboratory quality assurance: quantities of THF that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

a) charcoal b) ambersorb

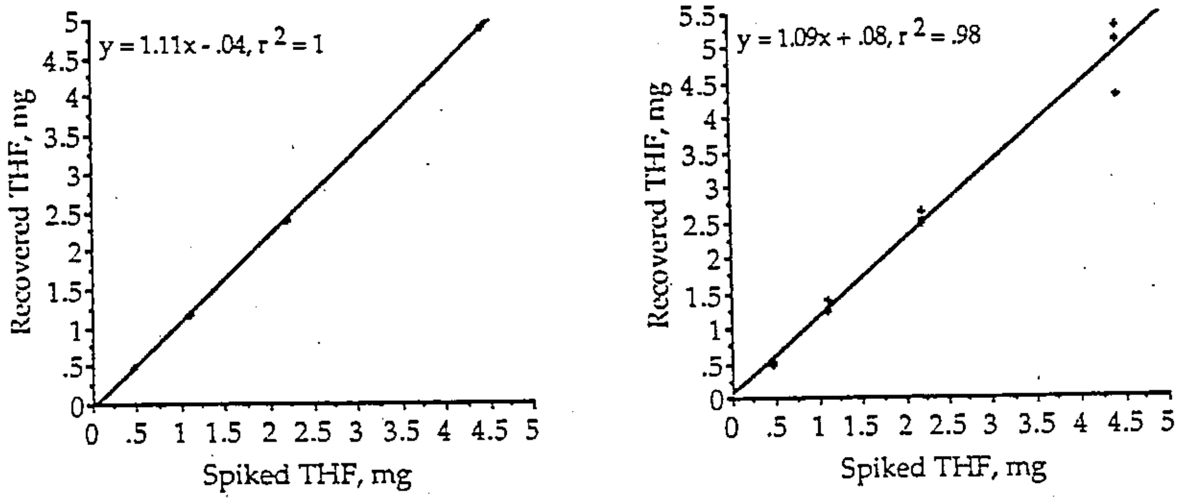

Figure G-3. Laboratory quality assurance: quantities of MEK that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

a) charcoal b) ambersorb

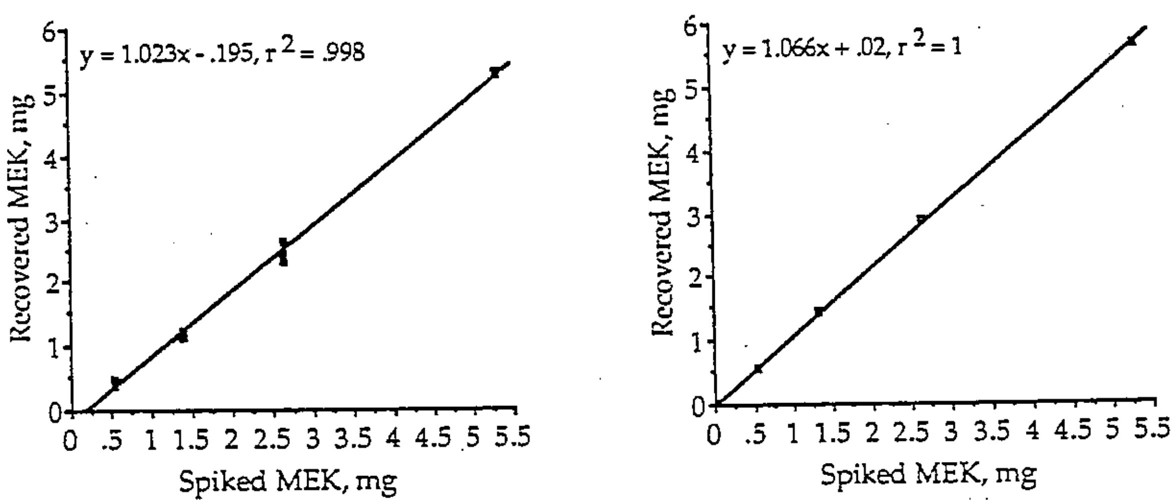

Figure G-4. Laboratory quality assurance: quantities of CHX that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

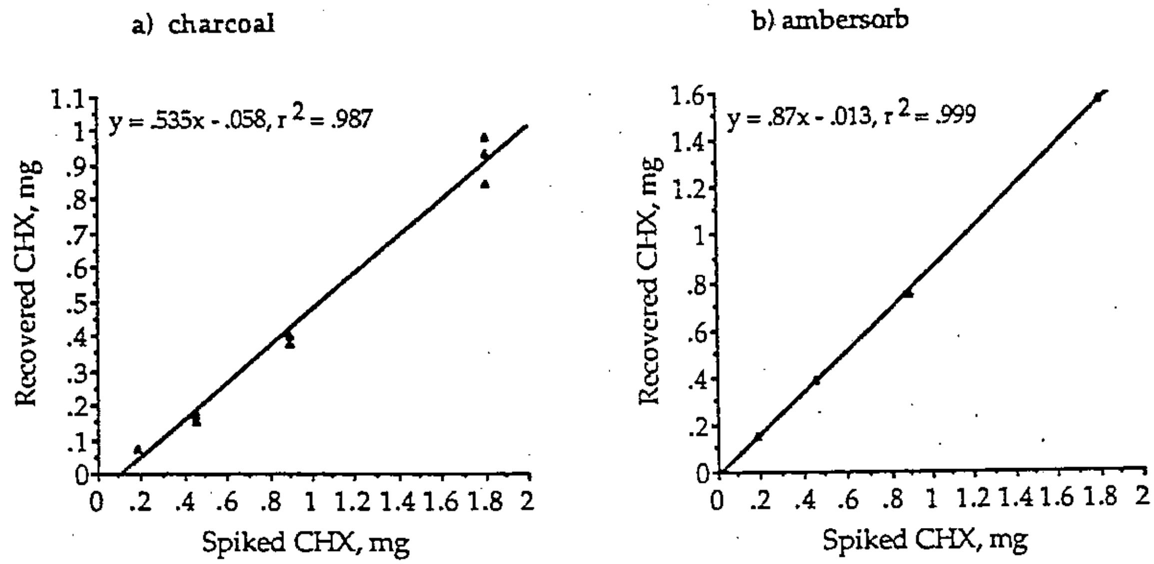

Figure G-5. Laboratory quality assurance: quantities of DMF that were spiked and later determined (blind) for 12 silica gel tubes.