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Plastic Pipe Installation:

Potential Health Hazards for Workers

Field Investigation FI-88-

California Occupational Health Program
2151 Berkeley Way, Room 504
Berkeley, California 94704

February, 1989

California Department of Health Services
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This report was prepared by Jim Bellows, M.P.H., Joan Sprinson, M.P.H., C.I.H., and Jon Rosenberg, M.D. The study would not have been possible without major contributions from Kathy Hunninen, Ph.D., Scott McAllister, M.P.H., C.I.H., and Linda Rudolph, M.D., M.P.H., Chief, California Occupational Health Program. The authors gratefully acknowledge the efforts of Donna Canali, R.N., and Robin Levinson, B.A., for their dogged pursuit of monitoring sites and assistance with field operations; and those of Ben Davis, who compiled much of the data and produced this report. Stephen Rappaport, Ph. D. and Mark Nicas, M.S., M.P.H. provided consultation on the sampling strategy and data analysis. The study was done under the supervision of the California Occupational Health Program, California Department of Health Services.

This study was funded in part by a contract between the Society of the Plastics Industry, Inc., and the California Public Health Foundation.

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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 Building 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 dimethyl formamide (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, solvent exposures were assessed by collecting a variety of short-term and full-shift 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). Workers installing CPVC potable water pipe had average exposures 1.7 to 7.8 times higher than the average exposures of workers installing other types of plastic pipe, based on an index of combined exposure to THF, MEK, CHX, and ACE. Workers who experienced the highest exposures were installing numerous fittings in highly enclosed areas—crawl spaces and an attic. 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 and MEK—relative to their airborne exposures—than workers with light skin contact, suggesting that a significant portion of a worker's total dose may be absorbed through the skin. Four workers who had heavy skin contact with THF-containing products had urine THF concentrations up to seven times higher than 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 165-850 ppm (83-425% of the exposure limit). These estimated values incorporate considerable uncertainty, and the health effects of exposures at these levels are not known. Exposures to DMF were low: measureable

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.

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 68% chance that the combined exposure limit would be exceeded during at least one 15-minute period over a typical 8-hour work day. Exposure levels were significantly related to air flow rate and to the number of fittings cemented during the monitoring period.

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, 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 required. Employers should also establish work practices that prevent extensive skin contact with primers and cements, and should provide effective health and safety training.

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 Building 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 Building 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 has not received statewide approval severely limits the number of CPVC-pw sites available for monitoring, so 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 to be 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, antimony, or zinc 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 well 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 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 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, 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 different 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 (Marin County, South Lake Tahoe, Palm Springs, and Nevada County) permitted CPVC-pw according to their adopted 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. 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. The local plumbers union was contacted but could not provide additional leads. 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 1% or more 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 one or more times); 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] Based on previous walk-through inspections and worker interview, no major difference were expected between morning and afternoon exposures, so exposure levels measured by the 4-hour passive monitors were assumed to be equivalent to full-shift exposures. Skin contact was classified as described above. Work area temperature was measured during the mid-afternoon.

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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 which specific exposure periods were 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 gluing
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 worker-days; IIa, one per worker-day; IIb, 50% of all such 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—regardless of whether exposures were monitored—to form a complete record of the time each worker spent in the strata.

For each 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 19 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 the charcoal tubes were analyzed, ambersorb tubes collected during the 14 highest 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, other workers cementing nearby.

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, measure by the PID, was considered to represent the sum of the MEK and THF concentrations. Thus, the PID's response was expected to be unaffected by variations in the relative proportions of these solvents in the primers and cements used. Although the PID provided invaluable information about the distribution of exposures within 15-min periods, it had some important limitations. The instrument was cumbersome, and keeping the probe in the worker's breathing zone sometimes became downright dangerous as he 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. The concurrent sorbent tube sample result was taken as the "true" average value. The PID data was then adjusted by applying a correction factor, ranging from 2 to 7, 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. A background air sample was also collected. The non-volatile and semi-volatile fraction of the sample was collected on a 37 mm filter with pore size of 0.8 microns at 2 l/min. The filters were desorbed in an ultrasonically-agitated solvent bath and analyzed by gas chromatography-mass spectrometry (GC-MS). 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. Sample collection included the day's entire exposure period. The Tenax was thermally desorbed and analyzed by GC-MS. The analysis included quantitation of 82 EPA priority pollutants (polyaromatic hydrocarbons, chlorinated hydrocarbons, phthalates, pesticides, PCBs, and chloro- and nitro-phenols) and a semi-quantitative identification of all other GC peaks. Formaldehyde, an expected thermal degradation product, was collected simultaneously on 2-(hydroxymethyl)piperidine sorbent tubes (Orbo-24) at 100 ml/min.

Copper pipe expoaures

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. 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 on 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 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 sampling by 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 mixed together and sent for analysis along with the field samples. In addition, 2 samples of urine from unexposed individuals were spiked with MMF and sent for analysis along with field samples.

Evaluation criteria

The exposure limits used for evaluating exposures to the substances monitored are shown in Appendix C These exposure limits are taken from U.S. OSHA comprehensive standards whenever possible, from NIOSH Recommended Exposure Limits, or from ACGIH TLVs and STELs for substances that have no applicable OSHA comprehensive standard or NIOSH recommended limit.[9,10,11] Concentrations of MMF and MEK in urine were evaluated according to the Biological Exposure Indices (BEIs) established by ACGIH. 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 listed in Appendix C 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 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 exposures and 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 lognormally-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.[12]

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, an additive exposure index was calculated for each worker, as:

$$\%TLV = \Sigma(c_i/TLV_i)$$

where %TLV is the additive exposure index (sometimes referred to as dose), c_i is the airborne concentration of each substance, and TLV_i is the exposure limit for each substance, as shown in Appendix C. An analogous value, %STEL, was also calculated for short-term exposures.

Estimates of average full-shift exposures to THF, MEK, CHX, ACE, and %TLV were calculated two ways. First, the air samples collected by 4-hour passive dosimeters were assumed to adequately represent the entire work day. 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 an average full-shift exposure. The estimates derived by these two methods were then compared.

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,[13] 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.

Standard multiple linear regression modelling techniques were used to explore the relationships between various job factors and the resulting (log-transformed) exposures. Variables with the highest partial correlations were entered stepwise into an overall model. Variables that were significantly associated with exposure in that overall model were then interpreted to be possible determinants of exposure. Two variables, air flow rate and the number of joints cemented during the monitoring period, were significantly associated (in a physically-meaningful direction) with exposure levels in most—but not all—subsets of the data. Therefore, these variables were forced into the regression models.

The relationships between airborne THF and MEK exposures and the resulting urine concentrations were evaluated with linear regression analysis. 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. In addition, a multiple regression model was used to determine whether the concentration of MEK in the bulk products used by each worker was associated with urine MEK concentration, independent of airborne MEK exposure. Such an association would be expected if dermal absorption were responsible for a substantial portion of total exposure.

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 4 sites, workers installed both CPVC-pw and DWV-PVC concurrently; these were classified as CPVC-pw sites. Follow-up monitoring was conducted at 7 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 piping 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, several contractors attempted to maximize the amount of plastic-pipe cementing to be done during the monitoring periods.

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 3 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 8 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 hr. 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 49.5% 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, 33%; IIb, 5.4%; IIIa, 10.4%; and IIIb, 1.7%. The distribution of work time varied among the installation types: workers installing CPVC-fire spent the most time on non-gluing tasks, workers installing DWV-ABS spent the least. Tasks performed in the morning were generally comparable to those in the afternoon. 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 because their employer had not assigned them to the sites until after the house was framed; there was no way that the under-floor plumbing could be installed without working in the crawl space. Remodelling, 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. Four workers wore protective eyewear during some part of the day, six (8%) wore kneepads, and 3 (4%) wore hard hats. None wore organic vapor respirators, but four wore dust masks when working in dusty areas.

Primer or cement spills were observed during 8 (3%) of the 15-min periods monitored; usually these were small (area<0.25 m^2), and workers often simply moved on to a different work area. 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 from joint to joint rapidly. 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 some 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. 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.

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 further analysis is presented here.

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. DMF was present at concentrations above 1% in 2 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, including one cement (used at one site) that was found to contain 0.3% DMF. 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 under investigation.

Twenty-eight spiked sorbent tubes (12 each of charcoal and silica gel, 4 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 33 of the short-term air samples collected simultaneously on both charcoal and ambersorb, both tubes were analyzed for THF, MEK, and CHX. Nineteen of these were collected at the beginning of the study and 14 matched charcoal-tube samples collected during the highest 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.

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 198 short-term (15-min) air samples. 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 (mean 43 ft/min); the distribution is shown in Figure 1. The temperature in work areas during monitoring was 13-39 C (56°-102° F, mean 75° F), with the distribution shown in Figure 2. During the pipe installation periods monitored, workers cemented 0-18 joints (mean 4.9 joints). Workers were able to complete CPVC-pw joints the most rapidly, with an average of 6.7 per 15-min period. In special pre-fabrication 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, 6 exceeded the short-term exposure limit of 250 ppm. Maximum concentrations of other solvents were: MEK, 95 ppm (32% of the exposure limit); CHX, 10 ppm (13% of the exposure limit); and ACE, 167 ppm (16% of the exposure limit). %STEL values, reflecting combined exposure to theses four solvents, ranged from 0.8% to 224%, and were often dominated by the THF concentration. The additive short-term exposure limit was exceeded (%STEL>100%) in 6 samples. CHX concentrations were below the analytical limit of quantitation in 275 samples (92%), and products labelled as ACE-containing were used by only 5 plastic pipe workers (4%), so the data analysis for CHX and ACE was limited.

Working conditions that led to the highest measured 15-min THF and MEK exposures are shown in Table 6. Many of the highest THF exposures occurred during extended work in two highly-enclosed areas: a low (1-1.5 meter) crawl space where CPVC-pw and DWV-PVC were being installed concurrently by two workers, and an enclosed attic where CPVC-fire pipes were being retrofitted. The highest MEK exposures occurred in these same areas, and in two DWV-ABS prefabrication shops.

Average exposure levels for the four installations and five sampling strata are shown in Table 7. The highest mean THF exposures occurred during installation of CPVC-pw in enclosed spaces (167 ppm in IIIa; 139 ppm in IIIb). These categories also produced the highest mean %STEL values (IIIa, 77%;

IIIb, 70%). The highest mean MEK exposures occurred during installation of DWV-ABS and 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, $p=.004$) and among sampling strata for THF only (THF, $p=.04$; MEK, $p=.08$).

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 measured parameters of the 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, 24%; 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 0.05% for DWV-ABS to 3.5% for CPVC-pw, based on the additive 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, 40%; 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-hr day is 69% for THF, 3% for MEK, and 68% for %STEL. 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.

Stepwise multiple regression modeling revealed significant associations between solvent exposures during CPVC-pw installation and four job factors. Exposures were positively associated with the concentration of THF (but not MEK) in the bulk cement and with the number of fittings cemented per 15-min period, and were negatively associated with air flow rate and temperature. Two other factors (presence or absence of spills, concentration of THF/MEK in the bulk primer) were not significantly associated. The coefficients and significance probabilities for the four significant factors are shown in Table 9. The relationships between short-term THF exposure and each factor individually are shown in Figure 4; only air flow rate was significantly associated in univariate analysis. Together, these factors accounted for a large portion of the variability in this subset of the data (THF, r^2=.61; MEK, r^2=.55). Similar associations between exposure levels and job factors were found for samples collected during CPVC-fire installation, except that temperature was not significantly associated with exposure levels in this large subset of the data. Coefficients and significance probabilities for CPVC-fire are also shown in Table 9. For both CPVC-pw and CPVC-fire installations, 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 correlated closely with 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 5 (missing). 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 3 to 5 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 (mean 29.3). Daily high temperatures were 16-39 C (61-102° F, mean 78° F). Air movement varied widely throughout the workdays; no suitable single index was recorded.

Of the TWA exposures measured, none exceeded the full-shift exposure limits. As with the short-term samples, the highest exposures were to THF (mean 26 ppm, maximum 158 ppm); these dominated the additive exposure index, %TLV (mean 18%, maximum 98%). MEK exposures were lower (mean 6 ppm, maximum 45 ppm). CHX and ACE exposures were still lower, and contributed little to the %TLV. 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 %TLV, 31%), were 1.7—7.8 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 GSD values.

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.

Although no full shift overexposures to THF, MEK, CHX, or ACE were documented, 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%; %TLV, 8.2%). Day-to-day exceedance probabilities for individual workers would be higher or lower, depending on specific site characteristics and work practices.

Stepwise multiple regression modeling revealed significant positive associations between full-shift solvent exposures during CPVC-pw and CPVC-fire installation and two job factors: the number of fittings cemented during the monitoring period, and the concentration of THF or MEK in the bulk primer. In CPVC-fire installation only, THF exposures were also associated (positively) with temperature and with concentration of THF in bulk cement. However, the association between job factors and exposure levels was weaker for the full-shift data than for the short term data (for CPVC-pw: THF, r^2=.21; MEK, r^2=.31). Figure 6 shows the relationships between THF exposure and two factors: joints cemented and ambient temperature. Other factors, such as composition of bulk cements and presence or absence of spills, were not significantly associated.

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 14. Average full-shift exposures estimated by this method were lower (by 25-50%) than the TWA exposures measured by passive dosimeters.

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 15. Working conditions for individuals with the highest urine THF and MEK concentrations are shown in Table 16, 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=0.64). 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=.60). Figure 7 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 approximately three-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. Urine and air THF concentrations for 6 workers who wore gloves did not fit any discernable pattern.

Four workers (14%) in the Heavy skin-contact group had urine THF concentrations that were higher (2.5 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 165-850 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=.51). With the data split by level of skin contact, the regression lines for the Heavy and Light groups were not significantly different (analysis of covariance, $p>.5$) for log-transformed data. Data for both groups are shown in Figure 8. The slope of the best-fit line for the Light skin-contact group (14 µg/l/ppm, 90% C.I. 9, 20) was higher than a previously published comparable value for a group with no contact (9.4 µg/l/ppm), but the difference between these was not significant.[14] However, the best-fit line for the Heavy skin contact group (24 µg/l/ppm, 95% C.I. 18, 30) was significantly higher. Stepwise multiple regression analysis indicated that urine MEK was positively associated ($p<.05$) with the bulk cement MEK concentration, in addition to its association with airborne MEK. Together, these data suggest that dermal absorption contributed to total MEK exposure and to urine MEK concentrations.

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

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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-hr 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 Appendix H. The only one of the EPA's 82 priority pollutants present was 2-chlorophenol which was found at a level of 0.08 $\mu g/m^3$ (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 (C11-C13); alicyclic hydrocarbons (C16-C20); BHT (an antioxidant); phenoxy-substituted organics, fatty amines (C20-C30), and possible fatty acids. All constituents found in the samples were also found in one or more blanks at approximately the same level.

GC-MS results of the volatile fraction obtained during PB fusion are shown in Table 17. Tenax samples collected during copper pipe installation were destroyed by the laboratory during analysis. 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-hr TWA basis, these constituents were noted at levels approximately 1000 to 10,000 fold less than accepted exposure limits for these chemical agents.

All formaldehyde exposures 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 formaldehyde.

Metal fumes

Metal fume monitoring of fifteen plumbers at nine sites was conducted during copper pipe installation. Sampling results are shown in Table 18. 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.[15,16,17] 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 exposures measured in this study are far below those that have been associated with acute toxicity in other industries.[18,19]

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.[20] 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.[21]

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.[22] The facts that samples were cooled immediately after collection, and then kept frozen until analyzed, probably account for the difference.

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 asked about conditions at other residential installation sites 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 that 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 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.

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 8.2% for %TLV. 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. 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 full-shift solvent exposures measured in this study probably do not reflect workers long-term average exposures, 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 are not included in the monitoring results.

The 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 165-850 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 (165-850 ppm) can be considered estimates of equivalent airborne exposure. However, 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. Therefore, the equivalent airborne exposure values should be considered speculative. The values cannot be lightly dismissed, however, because they so far exceed the established full-shift exposure limit for THF (up to 4.25-fold).

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 inadequate 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 are intended to prevent eye, nose, and throat irritation, and are much less than the levels needed to induce acute central nervous system depression. However, other systemic effects—such as chronic neurologic effects—have not been well studied and were not considered in establishing the exposure limits.

Because short-term THF exposures up to twice the exposure limit were documented, eye, nose, or throat irritation must be considered likely. 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 workers in the Heavy skin-contact group, were up to 850 ppm, 4.3 times the full-shift exposure limit. The health effects of ongoing exposure to 850 ppm THF cannot be adequately assessed with the available toxicity information. Overall, the highest measured urine THF concentrations raise considerable uncertainties about the total absorbed doses and their possible health effects.

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 their individual or additive exposure limits for any worker monitored in this study. However, the fact that the additive exposure limit (%TLV) was approached (up to 98%) suggests that overexposure is likely to occur on some work days. Overexposures are most likely to occur during CPVC-pw installation, when the probability of overexposure is estimated to be 8.2%.

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 are not known to produce any long-term health effects, but the existing toxicity information is incomplete.

5. Dermal absorption of THF and MEK probably contributes significantly to the total (airborne plus dermal) exposure of workers who have heavy skin contact with primers and cements. Based on the urine THF concentrations of these workers, the estimated equivalent airborne exposures were up to 850 ppm. However, the estimated values incorporate substantial uncertainties, and the possible health effects of such exposures are not known.

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

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

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 industry.

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 remodelling), 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. 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. (?)

5. 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.

6. 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.

REFERENCES

References for this report will be provided with the next draft.

TABLES

Table 1.CPVC-pw, CPVC-fire and DWV-PVC 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, 16B, 17, 18, 31
Wrapped(enclosed)	9, 11, 13,
Remodels	14
High Temperatures	8, 9, 11, 12, 13
Use of DMF	14, 18, 22, 31
Cross-exposures (i.e.CPVC/PVC)	17, 23
Repeat site visits	8b, 13b, 14b, 14c, 16b, 17b, 22b
Unusually high number of workers	8
Work in crawl spaces	14, 17
Total Number of sites chosen for specific criteria:	17

Table 2. Proportion of total on-site work-time spent in each sampling stratum, by installation type. All values are percentages

.Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
I	40%	53%	56%	51%
IIa	40	28	40	18
IIb	10	1	1	22
IIIa	9	16	2	5
IIIb.	1	2	0.3	4

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	62	0	3
IIIb	3	13	1	5

Table 5. Percentage of total work time monitored, for each installation and sampling stratum. Goal 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

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Table 6. Working conditions during the highest measured short-term exposures to a) THF (>160 ppm), and b) MEK (>25 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
17A	CPVC-pw	crawl space	1.5	68	DWV-PVC[a]	209
17A	CPVC-pw	crawl space	1	68	DWV-PVC[a]	168
17A	CPVC-pw	crawl space	4	74	DWV-PVC[a]	164
17A	CPVC-pw	interior	5	73	DWV-PVC[a]	161
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		44
16B	CPVC-pw	interior	16	76		42
35	DWV-ABS	prefab shop	27	62		40
7	DWV-ABS	prefab shop	72	67		35
35	DWV-ABS	prefab shop	15	65	spill	33
35	DWV-ABS	outdoor,prefab	30.5	60		29
35	DWV-ABS	prefab	13	63		27

[a]installed concurrently

Table 7. 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.

Sampling stratum	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
a) THF				
I	—[a]	5	—	0.2
IIa	41	25	5	0.3
IIb	16	72	18	0.2
IIIa	167	27	—	0.2
IIIb	139	27	66	0.2
b) MEK				
I	—	2	—	1
IIa	4	2	1	5
IIb	8	6	0.4	15
IIIa	12	6	—	11
IIIb	20	3	0.6	25
c) CHX				
I	—	0.3	—	0.4
IIa	1	1	0.4	1
IIb	0.4	1	0.4	0.4
IIIa	2	1	—	0.4
IIIb	1	0.4	1	0.4
d) ACE				
I	—	0.4	—	0.4
IIa	9	1	1	1
IIb	4	0.4	0.4	0.4
IIIa	32	0.4	—	0.4
IIIb	62	0.4	1	0.4
e) % STEL				
I	—	3	—	1
IIa	19	11	3	3
IIb	10	32	8	6
IIIa	77	14	—	4
IIIb	70	12	27	9

a no samples were collected in these categories.

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Table 8. Estimated probability (based on measured 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	0.4	—[a]	—
IIa	4	0.7	0.1	0[b]
IIb	0	0.01	—	0
IIIa	20	3	—	0
IIIb	17	0.8	—	0
b) MEK				
I	0	0	—	—
IIa	0.01	0	0	0
IIb	0.01	0.01	—	0.2
IIIa	1	0.01	—	0
IIIb	0	0	—	0.01
c) %STEL				
I	0			
IIa	3			
IIb	0.01			
IIIa	24			
IIIIb	23			

a not estimated, because of insufficient data.
b values less than 0.01% were rounded down to zero.

Table 9. Job factors found to be significantly associated with short-term exposure levels in stepwise multiple regression modeling. Relationship coefficients (slopes) and significance probilities are shown.

	CPVC-pw		CPVC-fire	
Job factor	slope	p value	slope	p value
a) THF				
Joints cemented	0.11	0.01	0.17	0.0006
Air flow, ft/min	-0.061	0.0001	-0.006	0.08
Temperature, °F	-0.057	0.005	—[a]	—
%THF in cement	0.04	0.009	—	—
b) MEK				
Joints cemented	0.20	0.0001	0.13	0.0009
Air flow, ft/min	-0.062	0.0001	-0.007	0.006
Temperature, °F	-0.064	0.005	—	—
%MEK in cement	—	—	0.047	0.0001

[a]not significantly associated

Table 10.Total ionizable 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 %TLV) for each plastic pipe installation type. Exposures were assessed with 4-hr 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	26	5	0.4
MEK	10	6	0.8	9
CHX	0.2	0.3	0.2	0.2
ACE	16	0.6	1	0.6
%TLV	31%(3.4)	18%(3.3)	4%(2.2)	5%(2.3)

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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		84
31	CPVC-Fire	No	Gloves	0	75	DWV-PVC[a]	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		33
14A	CPCV-Fire	Yes	Light	8	88	DWV-PVC[a]	30
14B	CPVC-Fire	Yes	Heavy	1	80	DWV-PVC[a]	27
31	CPVC-Fire	No	Gloves	0	75		27

[a]DWV-PVC installed concurrently in same area.

Table 13 Estimated probability (based on measured parameters of exposure distribution) that full-shift exposure limits would be exceeded in randomly-selected work days, for THF, MEK, and %TLV.All values are percentages.

Substance	CPVC-pw	CPVC-fire	DWV-PVC	DWV-ABS
THF	5.5%	2.8%	0[a] %	0.01%
MEK	2.2	0.3	0	0.09
%TLV	8.2	2	0	0.01

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

Table 14.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 (77%)	15 (58%)	3 (47%)	0.2 (60%)
MEK	5 (44%)	3 (43%)	0.4 (53%)	7 (75%)

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Table 15. 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 16. Working conditions and airborne exposures of workers with highest concentrations of THF and MEK 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	2	1000
14b	CPVC-fire	crawl space	heavy	69	860
23	CPVC-pw	under floor	heavy	55	820
14c	CPVC-fire	attic	light	8	750
17b	CPVC-pw	interior	heavy	48	710
29	CPVC-fire	interior	heavy[a]	46	680
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	0.12	540
17a	CPVC-pw	crawl space	heavy	25	540
17a	CPVC-pw	crawl space	heavy	11	520
14c	CPVC-fire	attic	light	4	470
17b	CPVC-pw	interior	heavy	8	450
14b	CPVC-fire	attic	heavy	20	450
19	CPVC-pw	interior	gloves (rubber)	0.15	430

[a]cotton gloves worn in the first half-day but not in the latter half-day.

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Table 17 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 18. 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.

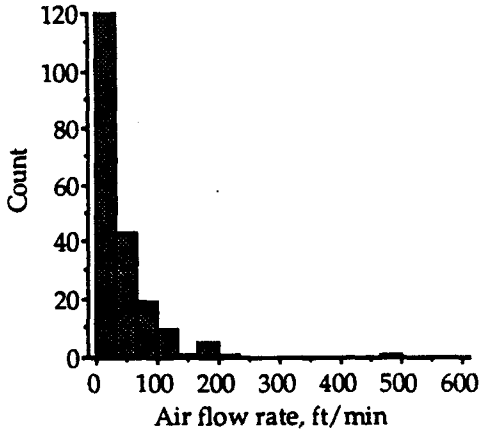

Figure 2. Temperature in work areas during short-term monitoring periods.

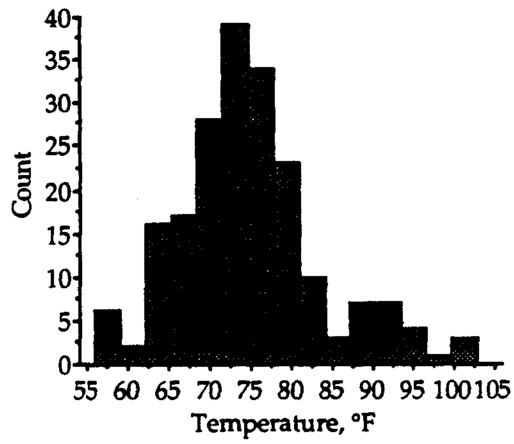

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Figure 3. Number of joints cemented per 15-min period during all short-term monitoring periods.

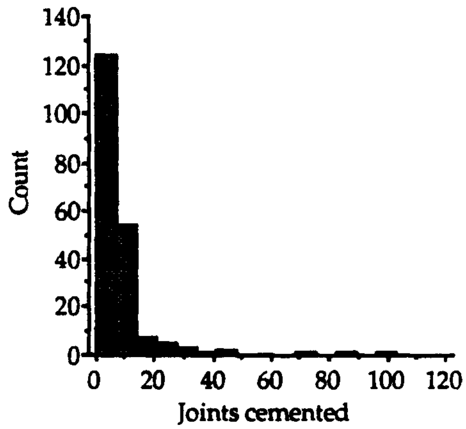

Figure 4. Relationship between short-term THF exposure during CPVC-pw installation and three job factors: a) air flow rate, b) temperature, and c) number of joints glued in the 15-min period.

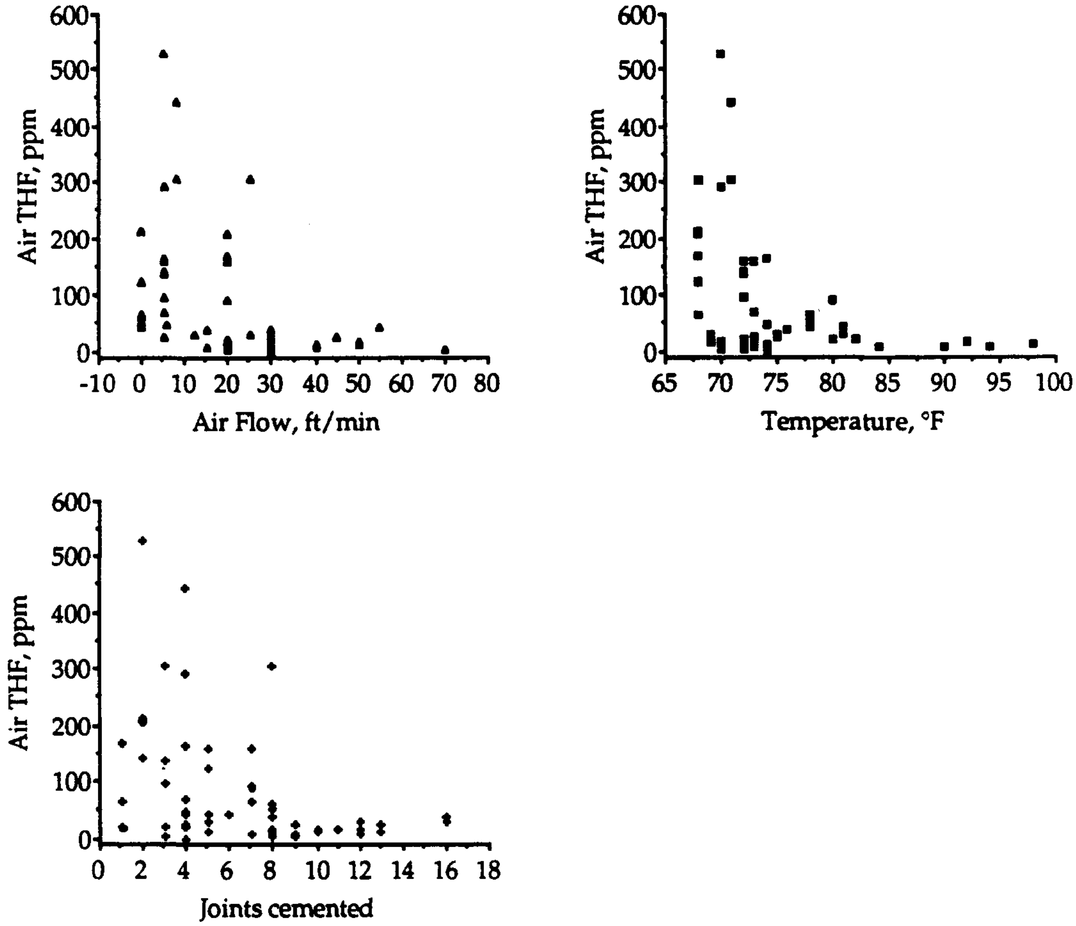

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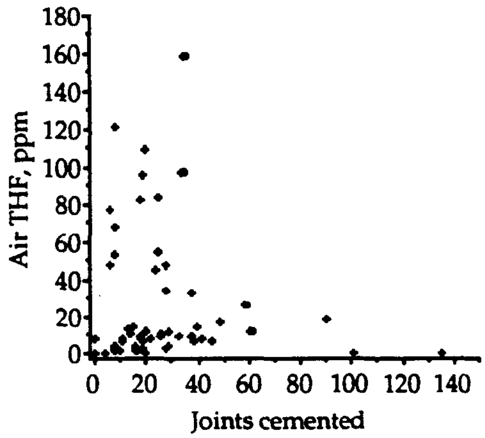
Figure 5. Real-time exposure variability during a representative 15-min monitoring period, as shown by photo-ionization detector trace.

Figure 6. Relationship between full-shift THF exposure and two job factors: a) number of joints cemented during the monitoring period, and b) temperature.



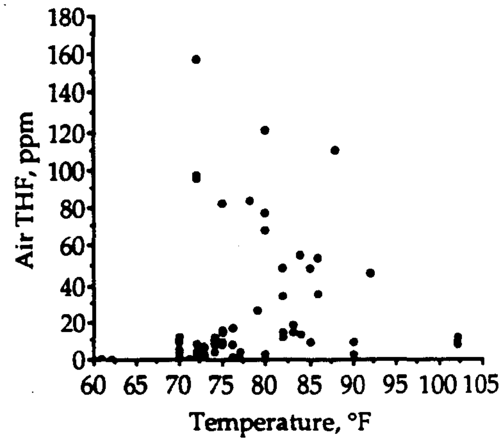
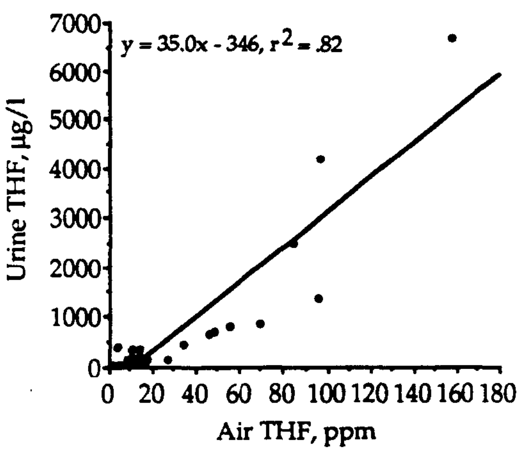


Figure 7. Relationship between urine THF concentrations and airborne THF exposures, by level of skin contact: a) Heavy, and b) Light. Best-fit regression lines are shown.

a) Heavy



b) Light

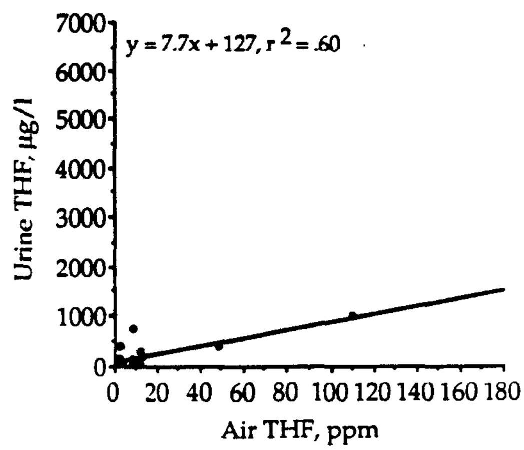


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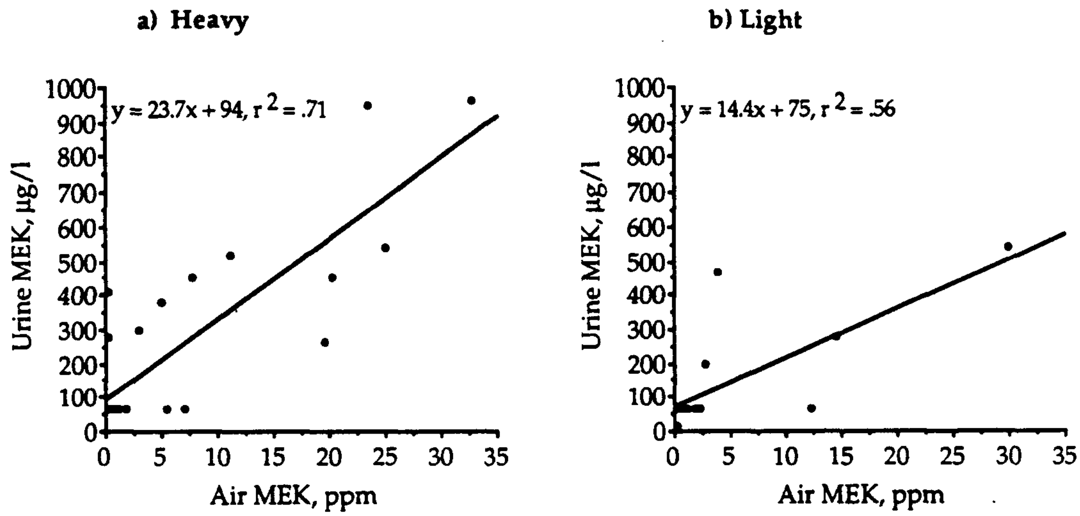
Figure 8. Relationship between urine MEK concentrations and airborne MEK exposures, by level of skin contact: a) Heavy, and b) Light. Best-fit regression lines are shown.



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	0.2 ppmTHF,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	various
volatile	tenax tube	full shift	GC-MS	various
formaldehyde	Orbo-24 tube	full shift	GC-NPD	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-hr TWA exposure, based on typical sampling times.

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 viable 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. PVC was rarely used for DWV in California, according to these sources.

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, 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, CA.

R&G Sloan 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 Turf Supplies who made referrals to contractors who weren't

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using CPVC; 2. New Horizon Sales (Arizona agent) made a referral to Buffington & Associates (services No. Calif. and No. Nevada) who in turn made a referral to Pe o'Hair in Pitsburg, CA who made a referral to a contractor who used CPVC for hot tubs - and Western Nevada Supply in Sparks, NV (no CPVC); 3. their product manager for sprinkler products made a referral to the Am. Fire Spr. Assoc., and 3 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 and a southern Ca. fire sprinkler contractor, and Pe O'Hair in San Francisco who made a referral to their Pitsburg 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 as fruitless.

U-Brand also made referrals to 27 wholesalers in California and 1 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 (Appendix DC-2). Following is an illustration of some of the referrals made from these groups.

J.M. manufacturers in CA only produced PVC. Pacific Western in OR made a referral to 3 distributors: Ewing in CA (no CPVC); United Plastics OR who made a referral to Famillian OR (sold to do-it yourselfers only); and H.D. Fowler WA. 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 3 Seatle plumbers who didn't use it. Also contacted were Tyler Pipe Manufacturer and Bay Plastics, both of TX, neither of whom currently manufactured CPVC.

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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 manf. & distributors:	16
Plumbing Distributors and Suppliers:	
CA:	45+
Other:	35+
Plumbing Contractors:	
CA:	75+
NV:	65+
GA:	30+
Other:	10
CA 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 Assoc.
ASA American Supply Assoc.
AIM/R Association of Industrial Manufacturers Representatives
Association of Builders and Contractors (NV)
CBIA California Building Industry Assc.
CALBO California Building Officials
Coalition For Home Fire Sprinklers
Dallas Trade Association (TX)
Home Builders Assc. of Portland (OR)
Home Builders Assc. (NV)
ICBO Industrial Conference of Building Officials
International Assc. of Fire Chiefs
IAPMO International Association of Plumbing & Mechanical Officials
IRC Industrial Relations Council for the Plumbing & Pipefitting Ind.
Lobby Group Plumbing & Heating Contractors (OR)
Mechanical Contractors Assc. of California
Mechanical Contractors Assc. of America
NAPD National Assc. of Plastics Distributors
National Assoc. of Remodeling Industry (FL)
National Fire Sprinkler Assc.
NSPC National Standard Plumbing Code Committee
National Sanitation Foundation
Oregon State Home Builders Assc. (OR)
Oregon Home Builders Assc. (0R)
Plastic Pipe Technical Center (OH)
PPFA Plastic Pipe Fitters Assc.
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
So. Nevada Plumbing Assc. (NV)
Unibell Pipe Assc. (TX)

APPENDIX C

Exposure limits used for evaluation of worker exposures.

	Exposure Limit		Source	
Substance	8-Hour TWA	15-Minute	8-Hour	15-Minute
MEK	200 ppm	300 ppm	N,A,O	A
THF	200 ppm	250 ppm	A,O	A
CHX	25 ppm	75 ppm	N,A	A[a]
ACE	750 ppm	1000 ppm	A	A
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.

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%)	(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%
13	cement	--	61.0%	2.6%	2.5%	0.3%	0.26%
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						
y10	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%)

APPENDIX F

Alloy composition of copper solders collected at 4 worksites. 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.

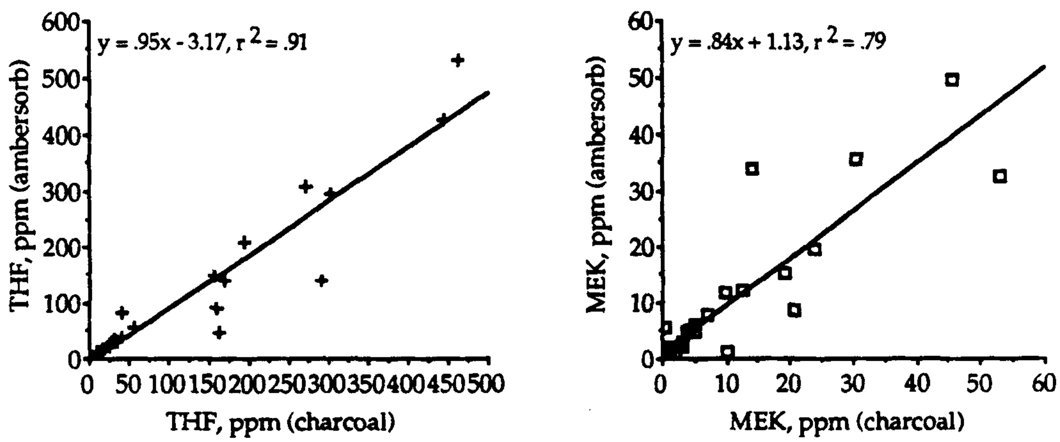

Figure G-2. Laboratory quality assurance: quantities of THF that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

a) charcoal **b) ambersorb**

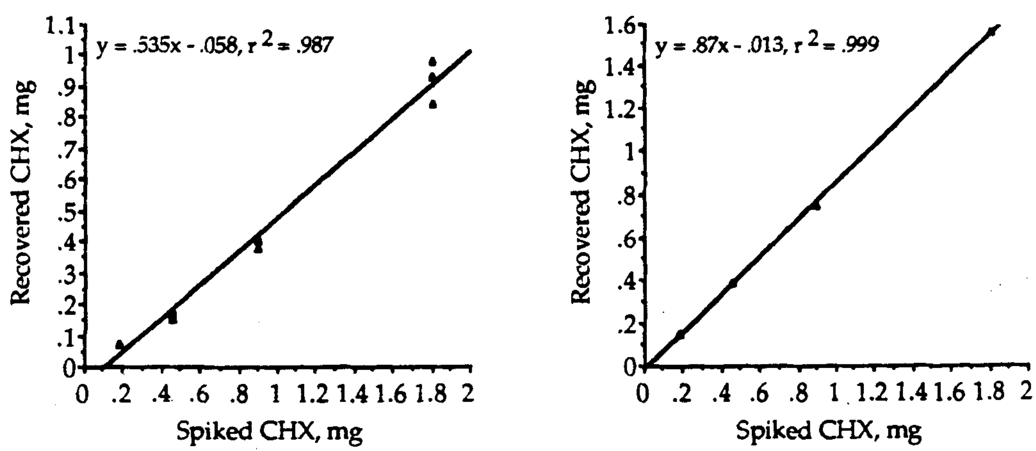

Figure G-3. Laboratory quality assurance: quantities of MEK that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

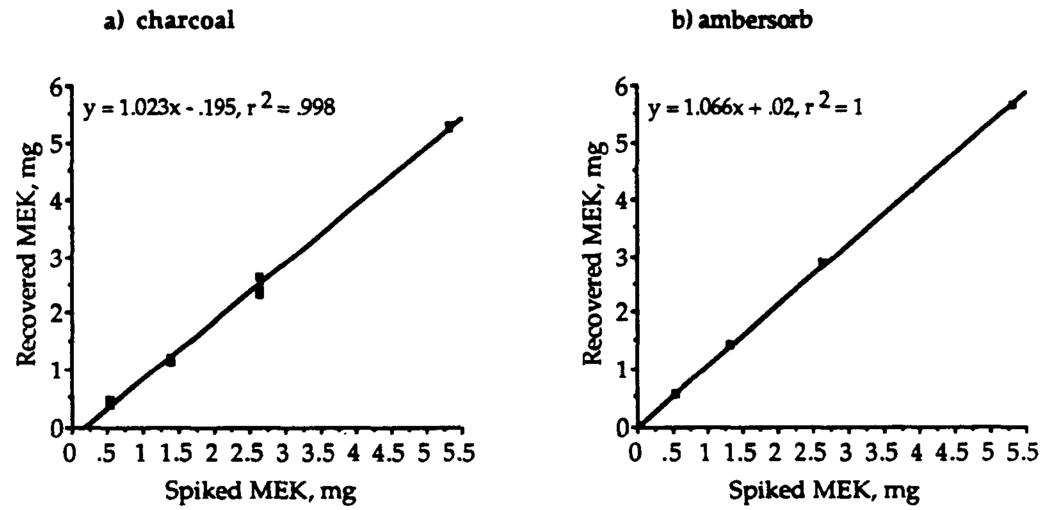

Figure G-4. Laboratory quality assurance: quantities of CHX that were spiked and later determined (blind) for 12 charcoal and 4 ambersorb tubes.

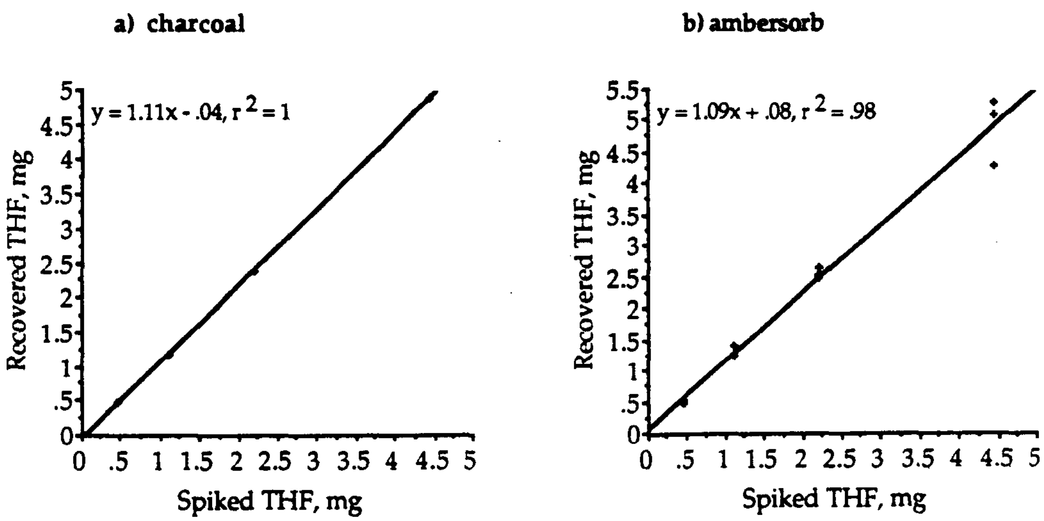

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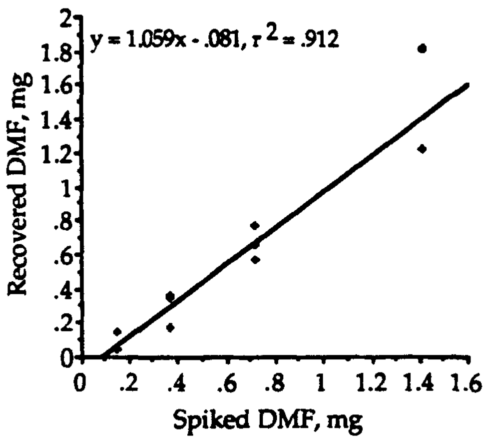
Figure G-5. Laboratory quality assurance: quantities of DMF that were spiked and later determined (blind) for 12 silica gel tubes.



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

Installation/ Site	Constituent	Concentration, ng/filter	Detection limit, ng/filter
Copper Installation: site #33 worker #	Aliphatic hydrocarbons (C11-C30)	1	NA
Copper Installation: site #33	Aliphatic hydrocarbons (C11-C30)	3	NA
	2-chlorophenol	0.4	0.2a
Copper Installation: site #32	Aliphatic hydrocarbons (C13-H28)	10	NA
	Aliphatic hydrocarbons (C16-H34)	25	NA
	Aliphatic hydrocarbons (C17-H34)	53	NA
	Aliphatic hydrocarbons (C18-H38)	57	NA
	Aliphatic hydrocarbons (C20-H42)	63	NA
	Aliphatic hydrocarbons (C16-H35)	27	NA
PB Fusion site #34	Aliphatic amines (C11-C30)	50	NA
	Alicyclic hydrocarbon (C16-18)	3	NA
	BHT (antioxidant)	2	NA
	Phenoxysubstituted organic	1	NA
	Fatty amines	3	NA
	Possible fatty acids	3	NA
Background: site #33	Aliphatic hydrocarbons	3	0
	2-chlorophenol	0.4	0.2a
Blank: site #33	Aliphatic hydrocarbons (C11-C30)	40	NA
	Alicyclic hydrocarbons (C11-C30)	3	NA
	BHT (antioxidant)	1	NA
	Fatty amines(C20-C30)	3	NA
Blank: site #34	Aliphatic hydrocarbons (C11-C30)	60	NA
	BHT (antioxidant)	1	NA
	Phenoxysubstituted organic	1	NA
	Fatty amines (C20-C30)	2	NA
	Possible fatty acids	1	NA

NA not applicable (semi-quantitative analysis) [a]EPA Priority Pollutant

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DOCUMENT NUMBER: 22066001

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DOCUMENT NUMBER: 22067001

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DOCUMENT NUMBER: 22068001

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