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FIGURE IV-9 JOINING COPPER PIPE IN A SOLVENT SYSTEM

Source: McGuiness, 1980

Table IV-32

POTENTIAL FOR SUBSTANTIAL EXPOSURE IN PLUMBING

Pipe	Operation Layout	 Cutting	 Prefab	 Installation
Galvanized	no	yes	no?	no?
Cast Iron	no	no	rarely?	rarely?
Copper	no	no	yes	yes
Plastic (excluding PB and PE)	no	no	yes	yes
PB and PE	no	no	no	no

Note: The nature of the potential exposures varies from type to type; the operations for which a yes or ? answer was given are discussed in the text.

b. Installing Galvanized Steel Pipe

There may be some residual oil on the pipe--the exposure will be minimal, except to pipe dope used for thread sealing or to Teflon tape.

c. Installing Cast Iron

The older type of pipe ("bell and spigot") was productive of extraordinarily high exposures to lead on occasion; the joint in such pipe is formed by packing the bell with oakum and then pouring molten lead into it. Excessive exposures to freshly formed lead fume were common. It is now extremely rare for such work to be done, except in restoration or in work commissioned by a very few older architects. Even when it is necessary to replace such pipe, and for some reason the newer "no-hub" pipe cannot be used, the usual practice is to pack the joint with lead wool, which is time-consuming but produces no inhalation exposures. There may be some exposure during the removal of the old pipe, which is accomplished by melting the old lead out with a torch, and then chiselling out the softened remainder. It is conceivable that there may be exposure to welding fumes, but that would be extremely rare in current residential construction.

d. Installing Copper

The major exposures of concern are those to solder and flux fumes and vapors. Lead, tin, antimony, zinc, and cadmium would be the elements of concern; the flux might be productive of HCl, inorganic flourides, and possibly other Cl and F compounds (depending on the flux used). Substantial skin and eye hazards exist from the molten solder and flux; it is the latter that is most dangerous because of its tendency to stick to the skin, thus producing a severe burn. The solder drops can be easily "flicked" off (usually).

e. Installing Plastic (Except Polybutylene and Polyethylene)

The major exposure here will be to the vapors from the solvents used in the cement; dermal exposure will also be extensive. If the plumber is under time pressure, the application of cement will be more extensive than usual, and it is likely that his clothing may be coated with the cement. This would lead to inhalation of the vaporizing solvents even during periods when cement is not being actively used, and to dermal exposure of unknown magnitude.

f. Polybutylene and Polyethylene

These are special cases. The olefins (flexible black tubing) are usually fitted with barbed "hose nipples" and clamped. No cement is used in these installations; there is thus no chemical exposure.

The actual extent of exposure in these various activities for the entire group of plumbers potentially exposed will depend on the total population of plumbers, and on the fractions engaged in the several activities. The total number of plumbers in California is uncertain, although about 30,000 Californians reported their work as plumbing or pipe fitting in the 1970 Census (Census, 1973). Perhaps the best estimate is that of Dolan (1980), who concluded (in a study sponsored by the California Pipe Trades Council) that "there are currently between 16 and 17 thousand union workers who work as plumbers or pipe fitters in a relevant part of the pipe trades..." If it is assumed that there may be an additional 25% nonunion workers, then a reasonable estimate of the occupationally exposed population would be approximately 20,000. Mr. Tom Hunter, Business Manager for Local 467 (San Mateo County), has estimated that the long-term distribution of assignments for members of his local would be as shown in Table IV-33.

Table IV-33

APPROXIMATE DISTRIBUTION OF JOB ASSIGNMENTS FOR PLUMBERS IN LOCAL 467
(Estimated Average Percentages Over Several Years
of Time Spent by Typical Plumbers)

Service and Repair	15%
Residential	50
Commercial	35
<u>Within the New Construction Segment</u>	
Prefabrication	30%*
Installation	70
<u>By Type of Service</u>	
DWV	60%
Water	40

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*Almost entirely for DWV--i.e., approximately 50% of work with DWV pipe is prefabrication.

Source: Personal communication from Mr. T. Hunter, Business Manager for Local 467, through Mr. T. Adams, attorney for Local 467.

8. Occupational Exposures to Chemicals in Plumbing

As noted above, our major concern in this document is with the occupational exposure to chemicals in plumbing. Such exposure may arise during any of the aspects of installation detailed above that involve use of chemicals. In particular, our concern is with the soldering of copper pipe and the cementing of plastic pipe. There are two ways in which exposures usually arise. The first of these--inhalation--is applicable to both soldering and cementing, while the second--dermal contact--is of potential importance only in the cementing of plastic pipe.

The safety hazards in plumbing--defined as the risk of traumatic injury--are of no less concern than the chemical exposure hazards, but it is difficult to come to a quantitative understanding of the extent of the risk involved. Therefore, in this document this topic will be most often dealt with qualitatively, with quantification when possible.

Very little information is available on the occupational exposures of plumbers to chemicals. What little there is has been directed at the exposures to airborne contaminants, with little attention paid to potential dermal exposures. NIOSH is currently preparing a study of the exposures of California plumbers to solvent vapors; it was scheduled for publication at the end of February 1983. In the absence of such industry-wide studies, the few data compiled by the California Department of Health Services and Cal/OSHA during their studies of the health risks associated with plastic pipe in 1979-1980 represent the major body of information available. In addition to the Cal/OSHA-CDHS studies, a recent NIOSH health-hazard evaluation of the exposures of plumbers in the Boston area to solvents has been performed under contract by Harvard University (NIOSH, 1983).

One of the areas in which valid information appears to be completely lacking is the exposure of plumbers to soldering fumes (including lead fumes) and airborne contaminants arising from heating or combustion of flux. Limited field observations during the preparation of this document indicate that exposures may occasionally be severe.

Another area in which quantitative information is lacking (as indicated earlier) is the extent of dermal exposure to either cements or fluxes. The field observations confirm CDHS and Cal/OSHA reports that dermal contact is frequent, and that plumbers rarely use gloves with adequate protective qualities against the solvents used in cements.

Tables IV-34 to IV-37 show the levels of exposure found by NIOSH, CDHS, and Cal/OSHA in their studies. In addition to these studies, NIOSH performed a Health Hazard Evaluation (NIOSH, 1976) on the employees of several water well drilling companies in Western Tennessee who were cementing PVC pipe.

Although several different exposure situations are represented in these studies, it seems reasonable to discuss them together to see if recognizable patterns of exposure appear. There are only two types of plastic pipe that use solvent-based cements--PVC (and CPVC) and ABS. These two types of pipe require different solvent mixtures, and the potential exposures are thus different.

a. Exposures in The Installation/Prefabrication of ABS Pipe

It will be recalled from Section III and Table III-3 that the principal solvent expected in ABS cements is MEK; minor components/contaminants expected are MIBK, xylene, toluene, THF, and cyclohexanone. The only organized body of measurements of occupational exposures available is that compiled by the California Department of Health Services (CDHS, 1980a). They analyzed the cements in use on several job sites and found only MEK, THF, and cyclohexanone. The exposures to airborne chemicals found during their environmental monitoring were as shown in Table IV-34 and IV-36. The only solvent for which substantial exposures were measured was MEK, and that only during the finishing operations studied, where the average exposure was approximately 1/10 of the 8-hour permissible exposure limit (PEL) TWA of Cal/OSHA (59.6 mg/m^3 vs. the PEL of 590 mg/m^3). The maximum 8-hour TWA found was 448.1 mg/m^3--roughly 75% of the PEL. Short-term exposures

Table IV-34

ABS PLASTIC PIPE SOLVENT EXPOSURE MEASUREMENTS

Solvent:	MEK		THF		Cyclo	
Cal/OSHA 8-hr. PEL	200 ppm		200 ppm		75 ppm	
Short-term Exposure Limit	300 ppm		300 ppm		50 ppm	
	8-hr. TWA Exposures (ppm)	Short-term Exposures (ppm)	8-hr. TWA Exposures (ppm)	Short-term Exposures (ppm)	8-hr TWA Exposures (ppm)	Short-term Exposures (ppm)
Prefabrication (2 sites)						
Average (N)	7.5 (3)	16.8 (4)	0.0046 (3)	0.12 (3)		
Maximum	12.7	28.3	0.10	0.28	0.05	0.089
Roughing (1 site)						
Average (N)	0.1 (2)	0.44(2)	0.01 (2)	0.04 (2)	0.01 (2)	0.04 (2)
Maximum	0.13	0.55	0.01	0.04	0.01	0.04
Topping (1 site)						
Average (N)	0.62(2)	2.54(2)	0.01 (2)	0.04 (2)	0.01 (2)	0.04 (2)
Maximum	0.80	3.42	0.01	0.04	0.01	0.04
Finishing (5 sites)						
Average (N)	20.2 (9)	94.2 (9)	0.023 (5)	0.68 (8)	0.018(5)	0.26 (9)
Maximum	151.9	351.0	0.06	3.01	0.055	0.98

Source: CPHS (1980a)

Table IV-35

PVC--PLASTIC PIPE
(Field Observation: Roughing Only)

Solvent	8-hour TWA (ppm)	Short-Term (ppm)
MEK		
Average (2)	4.0	12.5
Maximum	6.4	22.4
THF		
Average (2)	5.4	16.4
Maximum	7.2	17.7
Cyclo		
Average (2)	1.6	5.6
Maximum	3.1	11.3
DMF (skin)		
Maximum	0.008	0.011

Source: CDHS, 1980a

Table IV-36

SHORT-TERM LEVELS FOUND, ALL SAMPLES (PVC PIPE INSTALLATION)
(In PPM)

Location/Sample ID		VC	ACN	THF	MEK	Benzene	Hexane	Heptane	Toluene	Cyclo- hexanone	Dimethyl- Formamide
		Chemicals									
Finishing	Plumbing										
OB2	GW1	NR		79	34	NR	NR	NR	NR		0.5
Area	GWA	NR		41	18	NR	NR	NR	NR		0.5
1' Trench											
OBZs	VC1	0	0		ND		NR	NR	NR	NR	NR
	VC2	0	0		ND	1.4	NR	NR	NR	NR	NR
	VC3	0	0	10.3	ND		NR	NR	NR	NR	NR
	VC4	0	0	12.6	ND	1.4	NR	NR	NR	NR	NR
	VC5	0	0		NR		NR	NR	NR	NR	NR
OBZ Badge	4251	NR	NR	6.5		NR	NR	NR	NR	NR	NR
Area 1 Badge	4293	NR	NR			NR		NR	NR	NR	NR
Area 2 Badge	4255	NR	NR			NR		NR	NR	NR	NR
3' Trench											
OBZ	GD1	NR	NR	10	10	NR	NR	NR	NR	Z	NR
OBZ	GD2	NR	NR	93	13	NR	NR	NR	NR	Z	NR
Area	Area	NR	NR	10	10	NR	NR	NR	NR	Z	NR

OZB: Operatory's breathing zone
VC: Vinyl Chloride
ND: None detected per lab report
ACN: Acrylonitrile
NR: None reported. Except for vinyl chloride, if any of these materials had been present, it would have been reported.
THF: Tetrahydrofuran
MEK: Methyl Ethyl Ketone
: Trace amount may be present but is below detection limits of method used.

Source: CDHS (1980b).

Table IV-37

MAXIMUM EXPOSURES FOUND (PVC PIPE INSTALLATIONS)
(In PPM)

Condition	VC	ACN	THF	MEK	Benzene	Hexane	Heptane	Toluene	Cyclo-Hexanone	Dimethyl-Formamide
	Chemicals									
Outside, 1 ft. Trench	ND	ND	12.6±	ND	1.4	ND	ND	ND	ND	ND
Inside, Finishing Plumbing	NR		79	34	ND	ND	ND	ND		
Outside, 3 ft. Trench	NR	ND	43	13	ND	ND	ND	ND		ND

VC: Vinyl Chloride
ACN: Acrylonitrile
THF: Tetrahydrofuran
MEK: Methyl Ethyl Ketone
ND: Not detected
NR: Not reported
: Trace amount may be present but is below detection limits of method used.

Source: CDHS (1980b).

(assumed to be for 15-minute periods) were relatively higher in comparison to the standard. The average short-term exposure in the finishing operations was 277.9 mg/m^3--roughly 1/3 of the short-term exposure limit (STEL). The maximum short-term exposure found was 1035.5 mg/m^3, which was approximately 20% above the short-term exposure limit. Evaluation of the exposures to acrylonitrile monomer indicated exposures of less than 1 part per billion (ppb) as 8-hour averages, and less than 2 ppb as short-term exposures. Although ABS dust exposures were measurable (0.13 mg/m^3), they were far below the relevant standard of 10 mg/m^3 for inert dusts.

b. Exposures in the Installation/Prefabrication of PVC Pipe

More data are available for exposures to PVC pipe components/ solvents than for ABS. One of the first studies done of these exposures was that reported by NIOSH in the well-drilling industry (NIOSH, 1976). Several well-drilling operations in which PVC pipe was being used as either well casing or water delivery pipe were studied.

In the two sets of California data (CDHS 1980a and 1980b), similar results were found. In the first investigation (see Tables IV-31, IV-34, and IV-35) it was found that the cements contained measurable amounts of the four expected solvents--MEK, THF, cyclohexanone, and DMF. Average and maximum 8-hour TWA exposures to the solvents were less than 10% of the relevant standards, while the short-term standards were more closely approached--to a maximum of 15% for the highest short-term exposure to cyclohexanone. Exposures to vinyl chloride monomer were measured only during roughing operations, and were found to be less than 10 parts per billion (1/100 of the TWA standard of 1 ppm) and less than 50 ppb for the short-term exposures measured. No measurements were made of exposures to PVC dust.

The second set of California data (Tables IV-36 and IV-37 from CDHS, 1980b) requires some interpretation. It must be recognized that all the measurements made were for less than 8-hour periods, and that the exposures measured in these periods constitute the bulk of the exposures of the plumbers during the workday evaluated. The maximum THF concentration found (233 mg/m^3, or 79 ppm) was approximately one-fourth (26%) of the relevant short-term exposure limit. As in the study of ABS operations, this maximum was found in a finishing operation.

The study by Harvard investigators for NIOSH (NIOSH, 1982) was also an evaluation of the exposures of plumbers to the solvents from PVC pipe installation and prefabrication. The solvents found in the cement were MEK, THF, and cyclohexanone. DMF was sought but not found. As shown in Table IV-38, the exposures to individual solvents were all below the relevant exposure limits. The exposure limits used for comparison in this study were the NIOSH Recommended Limits--which were somewhat different in the allowable short-term exposures than the Cal/OSHA limits used by the California investigators.

The highest TWA exposure found (again to THF) was 400 mg/m^3, approximately 2/3 of the standard of 590 mg/m^3. The highest peak exposure (similar to the short-term exposures above--and assumed to be for 15-minute periods) was 280 mg/m^3 for THF, about 40% of the peak exposure limit. The Harvard investigators also calculated the fractions of the exposure limits for the mixed exposures seen ("Calculated Vapor Mixture Fraction"). The method is the conventional one, in which the fractions of the exposure limits for the individual components of the vapor mixture are summed, and a total over unity indicates excessive exposure to the mixture. In the sample for plumber #3 in the D Street Housing Project, for instance, the measured exposure is divided by the exposure limit for each solvent (400/590; 170/590; 36/100), and the results (0.678; 0.288; 0.36) are summed to yield 1.33--an excessive exposure if additive effects of the individual solvents are assumed.

Table IV-38

ABS PLASTIC PIPE SOLVENT EXPOSURE MEASUREMENTS

Solvent:	MEK		THF		Cyclo	
Cal/OSHA 8-hr. PEL	200 ppm		200 ppm		75 ppm	
Short-term Exposure Limit	300 ppm		300 ppm		50 ppm	
	8-hr. TWA Exposures (ppm)	Short-term Exposures (ppm)	8-hr. TWA Exposures (ppm)	Short-term Exposures (ppm)	8-hr TWA Exposures (ppm)	Short-term Exposures (ppm)
Prefabrication (2 sites)						
Average (N)	7.5 (3)	16.8 (4)	0.0046 (3)	0.12 (3)		
Maximum	12.7	28.3	0.10	0.28	0.05	0.089
Roughing (1 site)						
Average (N)	0.1 (2)	0.44(2)	0.01 (2)	0.04 (2)	0.01 (2)	0.04 (2)
Maximum	0.13	0.55	0.01	0.04	0.01	0.04
Topping (1 site)						
Average (N)	0.62(2)	2.54(2)	0.01 (2)	0.04 (2)	0.01 (2)	0.04 (2)
Maximum	0.80	3.42	0.01	0.04	0.01	0.04
Finishing (5 sites)						
Average (N)	20.2 (9)	94.2 (9)	0.023 (5)	0.68 (8)	0.018(5)	0.26 (9)
Maximum	151.9	351.0	0.06	3.01	0.055	0.98

Source: CDHS (1980a)

c. Summary of Vapor Exposure Data

The general pattern of exposures revealed in these samples is instructive. Roughing in (with the exception of work in trenches) appears to be the lowest exposure operation. Topping is the next lowest, with prefabrication and work in the trenches appearing to be somewhat higher. The highest exposures appear to occur in finishing work. This pattern is in accordance with expectations from the previous discussion--finishing work will always be performed in somewhat enclosed spaces.

There appears to be insignificant exposure to the platic monomers VC and ACN--the measured exposures are in the range of parts per billion. Dust exposures similarly appear to be slight, although the potential for substantial dust exposure during fabrication--if power saws are used--certainly exists. The major area of concern is the potential for exposure to excessive mixed vapors of the solvents used in cements, and the potential for excessive dermal exposures to those solvents.

The question of dermal exposure remains to be considered. As indicated earlier, field observations indicated that plumbers do not ordinarily use effective protective gloves during the application of cements. Illustrations in the CDHS Interim Report (1982b) show that instructions for the application of cements do not indicate the need for such protection--the manufacturers' literature in one case is particularly striking in that a worker is shown applying cement without hand protection. Anecdotal information relayed to us during this study by plumbers and by health professionals familiar with construction work have been uniform in confirming that, first, plumbers rarely wear gloves and second, that their dermal contact with the cements is frequently extensive. It is probable that there is substantial systemic absorption of those solvents able to penetrate the skin--DMF is such a solvent that is found in many of the cements.

Although there is also significant skin contact with the flux used in soldering, this is likely to have less systemic significance because of the low systemic toxicity of the materials reported to be present in the flux (see Table III-13 for examples).

9. Toxicity of Plumbing Materials

The chemicals that appear to pose the greatest potential health hazard to plumbers are the following:

- Components of primers and cements for plastic piping
- Components of cutting oils for metal piping
- Components of solders for metal piping
- Components of fluxes for metal piping
- Components of pipe joint compounds for metal piping.

In addition to these chemicals, unreacted monomer in plastic pipe (acrylonitrile or vinyl chloride) and dusts from the cutting of both plastic and metal pipe (e.g., PVC dust, ABS dust, and iron, copper, or steel dust) might pose some hazard. However, monitoring, although inadequate for a comprehensive assessment, indicates that exposures to these chemicals are so low as to be relatively insignificant when compared to allowable workplace concentrations.

a. Cements for Plastic Piping

Cements for plastic piping are usually composed of a small quantity of resin and one or more solvents. Plumbers are potentially exposed to resins by skin contact and to solvents by both skin contact and inhalation. Resins are not expected to present any toxicological hazard.

b. Solvents

The toxicity of the four major solvents used in plastic piping adhesives--tetrahydrofuran, methyl ethyl ketone, cyclohexanone, and dimethylformamide--is described in detail in Section IV.B and Appendix D of this report. Tetrahydrofuran and methyl ethyl ketone can cause central nervous system depression in high concentrations, but no chronic effects have been attributed to exposure to these compounds. Cyclohexanone is a more toxic compound, but again, no chronic effects have been attributed to repeated exposure. The solvent of greatest concern is DMF, which though relatively nonvolatile, is readily absorbed through the intact skin. Reports available to date indicate that DMF is neither mutagenic nor carcinogenic, but human exposures have resulted in liver damage, pancreatitis, skin sensitization, and alcohol intolerance. DMF is metabolized to two compounds that have been teratogenic in animal tests: formamide and N-methyl formamide. There is also concern that these compounds might affect male fertility, although adequate testing has not yet been conducted.

The current OSHA permissible exposure limit and ACGIH recommended workplace levels for the four solvents of greatest interest are listed in Table IV-39. The maximum concentrations found by the Department of Health Services and Cal/OSHA in their surveys are also listed. With the exception of one measurement for methyl ethyl ketone, the concentrations found were well below the short-term exposure limits set by Cal/OSHA (CDHS 1980). The 351 ppm concentration of MEK found might affect alertness and, therefore, safety; however, it would not appear to pose any other health hazard. The exposures in all other cases were so low that additive effects would not appear to be significant. However, all of these comments are based on an extremely small number of observations. A comprehensive assessment of the situation would require a much larger body of data, including typical and unusual concentrations in a wide variety of installations.

Four additional solvents--hexane, heptane, methyl cyclohexane, and toluene--were detected in one glue used by a plumber in the HALTS/Cal/OSHA

Table IV-39

EXPOSURE LIMITS AND CONCENTRATIONS FOUND IN PLUMBING SURVEYS

	OSHA Cal/OSHA PEL	Cal/OSHA STEL	ACGIH TVL	ACGIH STEL	PVC Roughing Short-term*	ABS Operations Short-term*	All Operations+
THF	200	300	200	250	17.7	3.01	79
MEK	200	300	200	300	22.4	351	34
Cyclo	50	75	25	100	11.3	0.98	ND
DMF	10		10	20	0.011		0.5

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[*] California Department of Health Services, April 29, 1980.

[+] California Department of Health Services, October 17, 1980.

survey, and presumably may also be found in other formulations. These compounds were not detected in air samples collected at the site (CDHS, 1980).

All four compounds are highly volatile central nervous system depressants in high concentrations (about 600 ppm) and irritants of the eyes, skin, and mucous membranes. Toluene has caused severe but reversible liver damage in habitual glue sniffers; workers exposed to concentrations ranging from 80-300 ppm for many years have not exhibited signs of altered liver function (Proctor and Hughes, 1978). Hexane caused peripheral neuropathies (nerve damage in the extremities) in workers exposed for 2-4 months to concentrations of 650-1,300 ppm in air, and similar conditions have been reported among workers exposed to plastic cements (Korobkin et al., 1975). Methyl ethyl ketone potentiates the neurotoxicity of hexane (Altenkirch et al., 1979). All of the above effects, however, have occurred at exposures far in excess of those expected for plumbers working with plastic adhesives.

c. Pigments and Stabilizers

No information on pigments or stabilizers was available for review and analysis.

d. Toxicity of Cement Mixtures in Humans and Animals

In a health hazard evaluation conducted among Tennessee water well drillers, NIOSH concluded that exposures to PVC cement under existing conditions did not constitute a health hazard. Environmental samples showed only low levels of tetrahydrofuran and no detectable levels of cyclohexanone. Responses to medical questionnaires indicated no symptoms associated with exposure to the chemicals in PVC cements (Gilles, 1976).

Plastic pipe adhesives coded as PVC #710 and ABS #194 were tested for eye irritation effects in a modified Draize test (Applied Biological Sciences Laboratory, 1969). Scores for the adhesives indicated slight or slight to moderate damage, respectively. However, in the absence of any protocol used and information on the composition of the compounds, it is difficult to interpret the significance of reported results. Dermal LD50s (median lethal doses) were also determined for PVC adhesives #205 and ABS #194. The values obtained were 4.09 and 7.5 ml/kg, respectively (Applied Biological Sciences Laboratory, 1968). The respective lowest lethal doses were 6.0 and 9.4 ml/kg. Both compounds were irritating to the skin, although the PVC adhesive was more toxic and more easily permeated the skin. Because the doses are reported in mililiters per kilogram rather than miligrams per kilogram, some conversion is necessary to fit the results to a miligrams per kilogram scale. Most of the compounds likely to be found in either of the cements have a density close to 1 g/ml. Therefore, converting the lethal doses results in LD50s of 4,000 and 7,500 mg/kg. According to the testing laboratory and a modified Gosselin et al. toxicity rating system (Gosselin et al., 1976), the adhesives tested may be considered relatively nontoxic or slightly toxic.

e. Cutting Oils

The cutting of galvanized steel pipe may result in potentially serious exposures to cutting oils, depending on the composition of the oils in question. Dermatitis and bronchitis due to repeated contact with cutting oils are common industrial health problems (Jarvholm, 1982; Adams, 1981; NIOSH, 1979; Goldberg and Herszenson, 1982). Some oils appear to be innocuous, while others may be carcinogenic to humans, possibly as a consequence of the presence of polycyclic aromatic hydrocarbons (Eyres, 1981), nitrosodiethanolamine, or other carcinogenic nitrosamines (Lijinski et al., 1980). Increases in polycyclic aromatic hydrocarbons during use can occur through heating; chemicals used as coolants, lubricants, solvents, bacteriocides, and antirust compounds in these oils may be important determinants of their carcinogenic properties (Roush et al., 1980).

Several epidemiologic studies have associated exposure to cutting oils or cutting oil mists with cancer of the lung, gastrointestinal tract, scrotum, or skin (Scott, 1982; Kipling, 1969; Kipling, 1974; Waterhouse, 1971; Cruickshank and Squire, 1950).

Recently, Roush et al. (1980) reported an increased risk of cancer of the nasal sinus in Connecticut males employed in positions where cutting oils are used. This report is discussed more fully in Section IV-C-10.

NIOSH is currently conducting a prospective cohort mortality study of 24,000 men exposued to cutting oil mist for at least 1 year. Emphasis is being placed on cancer and specific respiratory diseases (Decoutle, 1980). Results have not yet been reported.

No studies of plumbers exposed to cutting oils have been reported. In view of the lack of exposure data and information on the constituents of the cutting and threading oils used by California plumbers, it is impossible to assess the risk attendant upon the use of such oils, but it is probably safe to assume that some risk exists.

f. Solders

Solders are a potential source of metal fumes. The compounds most commonly used in solders are lead, tin, and antimony. Silver solder is used less frequently. It contains silver, copper, and zinc; cadmium has also occurred as an impurity. Of the compounds present in solder, several are known to cause metal fume fever: antimony, cadmium*, copper*, iron*, lead, tin, and zinc* (Peterson, 1978). Flu-like symptoms result when small particles of condensed metal or metal oxide are inhaled. Although the exact mechanism is unknown, the immune systems is believed to be involved;

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* Trace amounts.

tolerance typically develops over the course of a workweek and then disappears after 2 or more days of nonexposure. Metal fume fever is most often associated with welding operations in which very high temperatures are achieved and relatively large quantities of metals are vaporized. Exposure to solder fumes may also produce symptoms of metal fume fever, as well as respiratory tract irritation (Gunter and Thoburn, 1980) and allergic rhinitis (Niordson, 1981). The exposures of plumbers to soldering fumes have not been characterized; in the absence of such determination, it is not possible at this time to define the extent of the health hazard associated with inhaling fumes. However, injuries resulting from eye and skin contact with molten solder and soldering irons have been well documented (Lassiter, 1983).

The toxicity of the major components of solder, as listed in Table III-14, is discussed briefly below; unless otherwise indicated, information was obtained from Hammond et al. (1980). The toxicity of several of the heavy metals is discussed in greater detail in Section IV-B of this report.

Lead--Lead comprises approximately 50-60% of lead-tin solder. Lead is readily absorbed from the respiratory and gastrointestinal tracts. GI absorption is greater in children and in fasting persons. It is absorbed more effectively from water than from food; absorption is also influenced by dietary intake of calcium, iron, fat, protein, and phosphates. Lead is rapidly transferred to bone (9% of the body burden is in bone) and is excreted at a progressively decreasing rate. Lead is also found in the blood, the liver, and the kidney. It is excreted in bile, urine, exfoliated epithelial tissue, and sweat. Infants excrete more through the GI tract than do adults.

Lead affects the CNS and causes functional disturbances and neurobehavioral manifestations at very low levels of exposure. Lead also causes peripheral neuropathy (signaled by numbness or tingling in the hands and feet) by demyelination and axonal degeneration. Nerve conduction velocities, and therefore response times, are slowed. Lead can damage the kidney. After low levels of exposure, effects may be reversible; high levels can lead to irreversible effects.

Lead may cause anemia by reducing the integrity of red blod cell membranes so that destruction occurs. It also interferes with the uptake of iron and in this manner may prevent synthesis of hemoglobin (which carries oxygen in the blood) and of essential enzymes based on the heme structure. Lead also causes chromosomal aberrations and appears to produce abnormal sperm morphology.

Tin--Tin is present in high concentrations (usually 40-50%) in lead-tin solder and very high concentrations (95%) in tin-antimony solder. Oral ingestion of soluble tin salts results in 90% excretion in the feces. The average daily tin intake from all sources is about 17 mg; 500 mg/kg are required to produce toxicity. Chronic inhalation of tin dust or fume causes a benign pneumoconiosis. The majority of the dose remains in the lung--most extracelluarly, and some in macrophages as tin oxide. Tin concentrates in the blood, liver, muscle, spleen, heart, and brain. Organic tin is more toxic than inorganic tin and produces headache, visual disturbances, and changes in EEG. In animals, CNS depression and cerebral edema occur. Triphenyltin is an immunodepressent.

Antimony--Antimony is a component of tin-antimony solder. Antimony has been used therapeutically as an emetic and parasiticide. GI absorption is slow and ingestion causes vomiting. Toxic effects are similar to those of arsenic. Antimony compounds may generate stibine (antimony anhydride), which causes hemolytic anemia, kidney dysfunction, headache, vomiting, nausea, and gastrointestinal disorders. Industrial exposures may produce upper respiratory tract symptoms, pneumonitis, dizziness, diarrhea, and dermatitis.

Cadmium--Cadmium occurs in nature with lead and zinc, and frequently workers are occupationally exposed to all three metals. Cd is found in only one valence state (++) and does not form stable organometallic compounds of toxicologic significance. It has a high vapor pressure and its biologic salts, sulfate, and nitrate are soluble in water; the oxide, hydroxide, and carbonate are not water soluble.

The toxicity of Cd and its compounds is a function of solubility, route, and size of aerosol particles, among other factors. Aerosol may be absorbed into the bloodstream, cleared by the lung, or transported up the trachea by the mucouciliary escalator and then swallowed. GI tract absorption is poor--only 5-7% in man. Calcium deficiency increases Cd absorption in the small intestine because of the increased production of CaBP, a calcium and cadmium binding protein. The young absorb more Cd than the old, and the body burden increases until age 50, when kidney concentrations also peak. Blood concentrations reach a steady state within 1 year; therefore, blood samples cannot be used to monitor exposure to the metal. In chronic exposure, 90% of Cd is partially bound to metallothionein or bone. The Cd in plasma is bound to high molecular weight proteins. The biologic half life of Cd in man is 19-38 years. Cd is excreted in the urine. Excretion is constant except under heavy exposure conditions, when binding sites are apparently saturated. A sudden rise in urinary output, probably due to the breakup of metallothionein complexes in the kidney, indicates damage to the kidney.

The LD50s of Cd and its compounds range from 350-8,900 mg/kg in man. The lowest toxic dose is probably 10 mg; at this level, GI irritation and some liver damage are seen. Acute exposures produce respiratory and kidney symptoms. Chronic exposures produce hypertension, itai itai (ouch ouch) disease, kidney damage, and respiratory tract problems, including emphysema.

Overexposure to Cd is difficult to detect by clinical chemical methods, but yellow teeth and anosmia (the inability to detect odors) have occurred in heavily exposed industrial populations. Therapeutic measures are largely futile. Administration of vitamin D for itai itai (possibly a result of calcium deficiency?) has been successful, but the chelating compounds usually used to treat heavy metal toxicity are not effective.

g. Fluxes

Fluxes are commonly used in the soldering of copper pipes. Components vary, but the most common are resins, waxes, zinc chloride, and ammonium chloride; organic amine hydrochlorides may also be added, and carcinogens such as nitrosamines may be present. Both zinc chloride and ammonium chloride are irritants of the eyes, skin, and respiratory tract that liberate hydrogen chloride when heated to decomposition. Zinc chloride has been reported to cause ulceration of the fingers, hand, and forearms of persons using it as a soldering flux (Sax, 1979).

Natural or synthetic resins may be used in soldering fluxes. Information on health effects has been located for natural resins only; none of these studies has focused on plumbers. Occupational asthma and rhinitis have been reported in workers exposed to soldering fume in the electronics industry (Burge et al., 1979). Reactions were attributed to exposure to colophony fume. Employees in a factory manufacturing flux-cored solder were also affected (Burge et al., 1981). Several constituents of flux were found to be allergens in tests designed to detect immunologic responses in guinea pigs. A pine resin concentrate was classified as a Grade I allergen, abietic acid was a Grade III allergen, and colophony was a Grade IV allergen (Karlberg et al., 1980).

The exposures of plumbers to soldering fluxes have not been well characterized. It is probable, however, that exposure is intermittent and less intense than is common in the electronics industry.

h. Pipe Joint Compounds

The majority of the constituents of pipe joint compounds are of little toxicological significance. These include chalk, kaolin, blackstrap molasses, amorphous graphite, vermiculite, bentonite, and linseed oil. The potential components of concern include lead, lithopone, turpentine, and sodium pentachlorophenate (Gosselin et al., 1976). The toxicity of lead has been reviewed in connection with solders. Both sodium pentachlorophenate and turpentine are irritants of the eyes and skin and can cause allergic skin and respiratory tract reactions. Lithopone is a mixture of zinc sulfide, barium sulfate, and zinc oxide. The compound does not appear to be very toxic through dermal contact, but zinc sulfide can irritate the skin and in this way facilitate absorption of lead and other more toxic components.

10. Outcome of Exposures--Reported Health Effects

There have been two major epidemiological studies of plumbers and pipe fitters as an occupational group. One of these (Dolan, 1980) has been adequately discussed elsewhere (CDHS, 1980b) and may be dismissed as an example of poor study design from which no valid conclusions may be drawn. The other deserves more attention.

An investigation of the proportional mortality experience during 1971 of U.S. members (including some retirees) of the United Association of Journeymen and Apprentices of the Plumbing and Pipefitting Industry has been published (Kaminski et al., 1980). The authors intended this as a pilot study to be followed by more specific investigations if warranted. They recognized most of the limitations of such studies. While one would not agree with all their decisions on study design, those decisions do not affect the data very much and therefore should not affect the conclusions given below.

Within the limitations of their methodology, the authors rightly emphasized the need for caution in interpretation, particularly for cases with increased risk. However, the proportional mortality for one cause, cancer of the esophagus, in the plumbers is so much higher than any other cause, including the causes of death most likely to be biased by the weaknesses in this study design, that it is very likely to be real. The increased risk for cancer of the esophagus appears to be confined to those identified as plumbers, but it is not clear that exposures unique to plumbers among the union members are responsible. According to information in the paper that was obtained from union officials, pipe fitters and steam fitters were first defined as a trade between 1960 and 1965, which would probably not allow a sufficient interval by 1971 for any latent period for cancer of the esophagus to have elapsed. To complicate matters further, the authors state that union members commonly crossed trade lines. Additional analyses could have ruled out nonoccupational causes, such as excessive alcohol intake, as an explanation for the increased risk; because such analyses are not reported, we cannot do so with certainty. Union officials told the authors that plastic pipe did not come into widespread use until the 1960s; therefore, the authors felt that none of their findings were related to the use of plastic pipe because of the short latency. However, because the authors did not collect any job history or exposure information for the specific individuals included in their study, we cannot tell whether their findings are related to exposure to metal pipe either.

The findings of the study can be summarized as follow:

- There appears to be an increased risk of cancer of the esophagus in these union members. This increased risk seems to be confined to those identified as plumbers and appears to be real.
- Nonoccupational causes of this increased risk cannot be ruled out on the basis of this paper.
- It is impossible to tell from this study whether the risk has anything to do with exposures to plastic or metal pipe, although the reported history of plastic pipe use makes it unlikely that the finding is related to plastic pipe exposure.

It will be recalled from the earlier section that cutting oil used for thread cutting on steel pipe may be a significant occupational exposure. A report (Roush et al., 1980) of a case control study of cancer of the nasal sinus and occupation is potentially of interest because of the findings reported for cutting oils. Cases were indentified from the Connecticut Tumor Registry but were limited to male Connecticut residents who had died between 1935 and 1975 but had lived to at least the age of 35; controls represented a random sample of male Connecticut deaths at ages 35 and over during that same perod. Information on the subjects' job title and industry of employment was taken from death certificates and city directories that covered most of the state, at 1, 10, 20, 25, 30, 40, and 50 years prior to death, except for years in which the subject was under the age of 20. Nearly half the subjects had two or more jobs. For those individuals, the job that was held closest in time to 25 years before death was the job assigned to that subject based on the authors' consideration of latency.

Jobs involving exposure to cutting oil were defined by the authors as specific occupations listed in reports showing increased risk of skin and lung cancer from these exposures. (Deaths from lung cancer were excluded from the control group.) With the use of this definition, the authors reported a relative risk of nearly three for cutting oil exposure using both death certificate and city directory occupational information (available for 85% of the cases and 84% of the controls). For the 73% of the subjects for whom this information was available from the city directories, the relative risk for cutting oil exposure as defined was still more than two. When job titles such as machinist and machine operator were included as involving cutting oil exposure, the increased risk nearly disappeared. The authors noted that all but one of these other job titles and industries did not work with cutting oils that had been reported to be carcinogenic. Machines using cutting oils that had been reported to be carcinogenic constituted less than 15% of all machines in use in the United Kingdom (presumably the only location for which such data were available). The authors believed this statistic justified their exclusion of machine operating from jobs with cutting oil exposure.

The risk for cutting oil exposure as defined in the paper was not uniform with the age and calendar time; it was much stronger for deaths before 1959 and for deaths at ages over 68. The relative risk for exposed individuals who died before 1959, after their 69th birthday, is over 25. The excess risk essentially disappeared for individuals who died before their 69th birthday after 1958. The authors attributed these findings to improvements in industrial hygiene instituted by the state over time and to their belief that risk may be increasing with duration of employment. A trend of increasing risk with increasing duration of exposure to cutting oils for a subset of their subjects would have been excellent evidence that the risk was directly related to these exposures.

In the absence of such convincing information, one must be concerned about potential problems in methodology. While the mean and median age at death and year of death are essentially identical for cases and controls, the distributuion could still be different through greater variance of one or the other. For this reason, it would have been helpful if the authors had explicitly stated that date of birth was specifically controlled for in their multivariate analysis; we do not know whether age-related variables were controlled or not. In addition, the authors do not state that the identification of whether or not an individual worked with cutting oils was made in the absence of knowledge of whether he was a case or a control. If this identification was not blind, bias could have resulted. It is not hard to imagine one or both of these potential problems accounting for the overall findings in the absence of a true association. However, it appears unlikely that these problems could account for the great difference in risk found with age at and date of death. The authors themselves recognized the need for their findings to be corroborated by more specific studies.

The relevance of this paper to the risk of plumbers and pipe fitters is equivocal. Previous work on oil and oil mist exposures has shown that certain types of oils appear innocuous, while others appear to be carcinogenic in humans. People in the petroleum industry believe that mixtures obtained from fractional distillation of petroleum or coal are carcinogenic only at certain boiling point ranges; this would imply that the specific hydrocarbon mixture used is the crucial determinant of whether a particular oil is carcinogenic. Roush and his colleagues speculate that other chemicals used as coolants, lubricants, solvents, bacteriocides, and antirust compounds, particularly when heated, may also be important determinants of whether a particular cutting oil is carcinogenic. In any event, only one steam fitter was reported among the subjects, and he was a control; none were reported to be plumbers. (The other occupations reported among the subjects with cutting oil exposure were tool makers, tool setters, set-up men, tool hardeners, hardeners, turners, and polishers.)

In summary, this paper reported an increased risk of cancer of the nasal sinus in Connecticut males who had worked in jobs where cutting oils that have been found to be carcinogenic have been reported to be used, according to death certificate and city directory occupational information. One wishes that the authors had either done the study a little more carefully or reported it a little more thoroughly, which would have made their caution that the findings need to be confirmed by other studies less needed. In any event, it is not clear that the cutting oils that have been shown in a number of previous investigations to be carcinogenic are the same ones used by plumbers; a number of other investigations have found other types of cutting oils to be innocuous.

In addition to these studies, Lassiter (1983) recently completed a study of the reported injuries and illnesses among plumbers, pipe fitters, and steam fitters in California in 1979, using data from the U.S. Bureau of Labor Statistics. Among his conclusions were:

> Tables 8 and 9 have been prepared to focus on those occupational injuries and illnesses which were associated with metal or plastic pipe. This association is determined from the source codes (Table 4). Hence, instead of source code 4140 for plastic pipe, the larger, encompassing source category code, 4800, must be used. This latter code may not, in fact, include any plastic pipe or, on the other hand, all the cases listed with 4800 as the source category may involve plastic pipe. In any case, the difference is academic since the number of cases associated with metal pipe is striking: 312, compared to 6 for plastic pipe.
>
> Both Tables 8 and 9 provide a detailed analysis of the available SDS data with respect to (1) nature of injury or illness by (2) type of accident or exposure by (3) part of body affected. This multi-level presentation provides a detailed picture of injuries and illness involving metal and plastic pipe. For cases involving metal pipe (total--312) over half (51%) involved a strain or sprain. Of these 160 cases, 76 (47.5%) involved overexertion by lifting an object and, of these 76 cases, 58 (76%) involved the back. Hence, approximately 19%

> of all LWD* cases of strains and sprains occurring among plumbers and pipe fitters in 1979 (California) involved back injuries resulting from overexertion while lifting metal pipe. Other types of injuries are fairly uniformly distributed among contusion (48 cases), cuts (34), and fractures (26). A significant number of contusions occurred when metal pipe fell onto workers, particularly the foot (40% of such cases). Similarly, 54% (14 of 26) of the fractures occurred when workers were struck by falling metal pipe. In fact, of the 144 total fractures which occurred among plumbers and pipe fitters, 18% (26) involved metal pipe as the source.
>
> In Table 9, of the six cases which were associated with a plastic item (presuming, plastic pipe), two involved a burn to the hand from contact with hot pipe, two involved a scratch or abrasion of the eye from a plastic item (which may have been plastic particles etc.), and the other two involved a back strain/sprain from overexertion by lifting a "plastic pipe."
>
> Of special interest, with respect to the comparison under consideration, is the incidence of 26 cases of welder's flash (code 295--Table 1) associated with 1% of all LWD cases. It would appear likely that most of these cases, at least, involved the welding of metal pipe, since metal pipe represents most of the metal items which would be expected to be associated with welding operations involving plumbers and pipe fitters.

Lassiter also included a brief summary of a previous study in which he had reviewed the cancer incidence in the San Francisco Bay Area for NIOSH. One relevant table from this study (Table IV-40) is included here. Lassiter concluded:

> From this table, it can be observed that the standard incidence ratio (SIR) for cancers at all sites in the study cohort of plumbers and pipe fitters (total of 1592) was 65 ($p < 0.05$) for the period 1972 through 1977.
>
> A SIR of 320 was observed for cancers of the larynx for this cohort, although the probability ($p < 0.10$) was less than the commonly accepted value of statistical significance of 0.05. Certainly, the most significant finding from this study, with respect to plumbers and pipe fitters, was the extremely low incidence of cancers at all sites.

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* LWD = lost work days.

Table IV-40

OBSERVED (O) AND EXPECTED (E) INCIDENCE AND SIR FOR SELECTED PRIMARY SITES, 1972 THROUGH 1977

	Occupational Group								
	Plasterers			Plumbers			Roofers		
Site	O	E	SIR	O	E	SIR	O	E	SIR
All sites	00	23.50	47[+]	30	46.02	65[**]	22	20.29	003
TBL&P[*]	2	4.89	40	5	00.06	49	3	4.70	64
Colon	2	2.48	80	0	4.30	23			
Prostate	3	4.44	68	4	6.82	59	2	3.34	60
Stomach									
Leukemia									
Bladder				3	2.80	007			
Rectum & Anus							3	0.00	272
Larynx				4	0.25	320[++]			

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[*] Trachea. bronchus, lung, and pleura.
[+] $p < 0.10$.
[**] $p < 0.05$.
[++] $p < 0.01$.

Source: Lassiter (1983)

Although Lassiter's choice of modifiers (extremely low incidence) appears to overstate the findings, at the least there does not appear to be a significant excess of cancers among plumbers. The Division of Labor Statistics and Research of the California Department of Industrial Relations has completed a review of their data for the period 1960-1981--a period roughly coinciding with the period of introduction of plastic pipe in California. As noted above, significant fractions of the injuries associated with metal pipe are due to bruises and crushing injuries. It has been alleged that plastic pipe installation will be accompanied by occupational disease. Thus, it seemed reasonable to compare the fractions of these specific injuries/illnesses with reported totals. Tables IV-41 and IV-42 and Figure IV-10 make those comparisons. As can be seen especially clearly in Figure IV-10, there does appear to be a downward trend in the contusion/crushing injury fraction, and a less clear upward trend for occupational illnesses. It cannot be emphasized too strongly that such comparisons must be regarded skeptically. Detailed evaluation of the reported illnesses would be needed before allegations of cause could be entertained, much less supported.

Finally, the NIOSH study performed by Harvard investigators mentioned in the section on occupational exposures included a medical evaluation of the health of the members of a Boston area plumbers local union. This evaluation was carried out by mail questionnaires, and by examination of nine plumbers whose exposures to solvents were measured in the field. The summary of this study states:

> Of the 740 plumbers surveyed by mail questionnaire, 353 (48%) responded. Most had worked with plastic pipe, almost half for 10 or more years, but only 78 has worked with it for more than 13 weeks in the preceeding years. Dizziness (54%), headache (41%), eye irritation (36%), irritation of the skin of the hands (36%), and tingling or numbness in the fingers (33%) were frequently reported and were attributed by the plumbers to working with PVC pipe. However, the low response rate for the survey and the tendency for responders to report more symptoms than non-responders indicates that the prevalence of reported symptoms may be overestimated.
>
> The nine plumbers participating in the medical survey reported a prevalence of symptoms similar to that found in the mail questionnaire survey. Physical examinations and laboratory testing showed no

Table IV-41

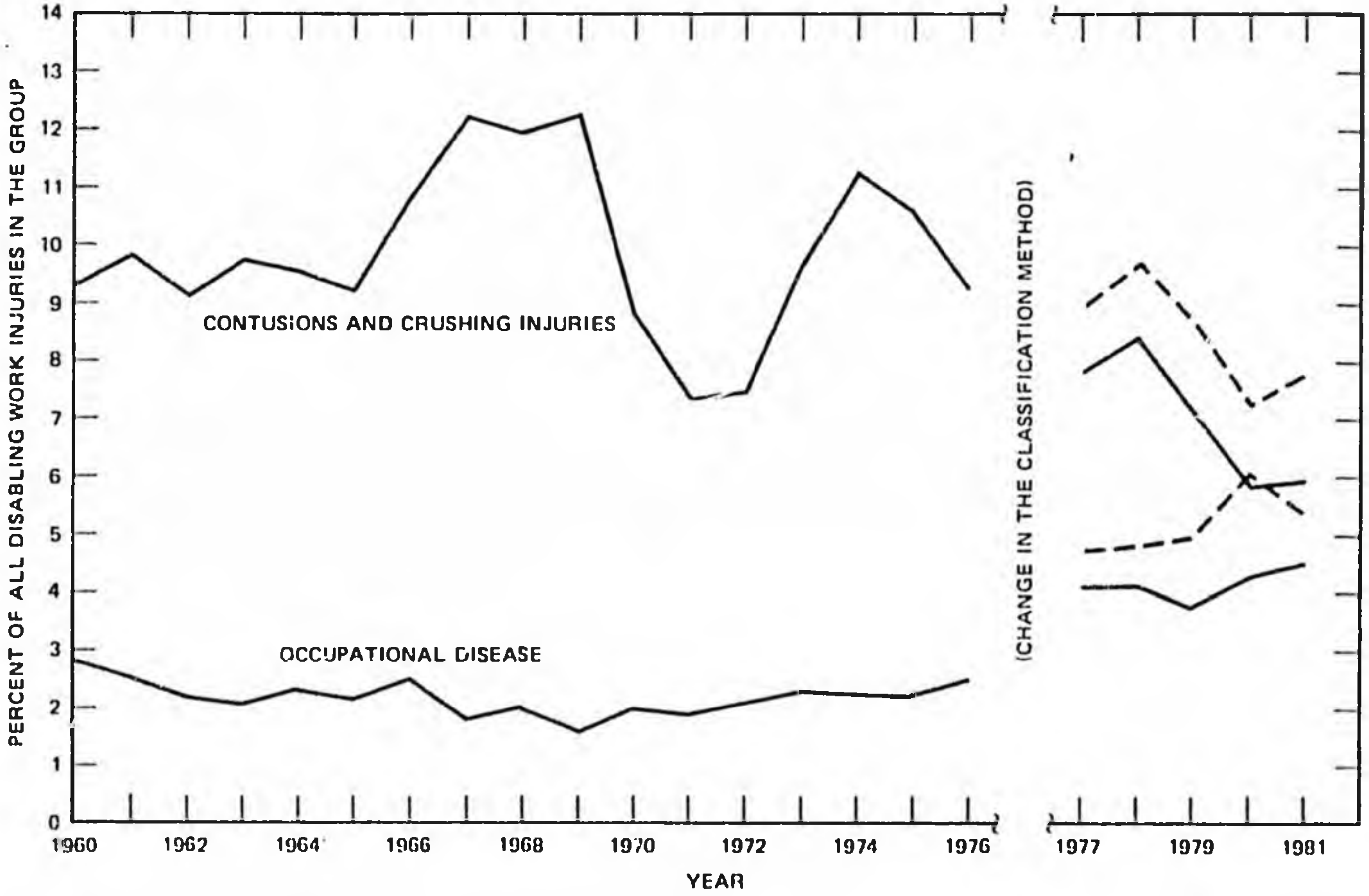
CONTUSIONS AND CRUSHING INJURIES AS FRACTIONS OF ALL DISABLING WORK INJURIES AND ILLNESSES IN CALIFORNIA--1960 to 1981*

		Plumbing, Heating, and Air Conditioning Contractors				Plumbers and Pipe Fitters		
Year	Total	Crush	Contus.	Total	C.C.I.%	Total	C.C.I.	C.C.I.%
1960	2,311	(62	154)	216	9.34%			
1961	2,385	(68	164)	232	9.73			
1962	2,626	(56	184)	240	9.14		Not reported	
1963	2,870	(80	200)	280	9.76		before 1977.	
1964	3,186	(85	219)	304	9.54			
1965	2,605	(84	156)	240	9.21			
1966	2,353	(59	196)	255	10.84			
1967	2,131	(55	206)	261	12.25			
1968	2,318	(53	225)	278	11.99			
1969	2,358	(38	250)	288	12.21			
1970	2,460	(38	178)	216	8.78			
1971	2,188	(21	140)	161	7.36			
1972	2,536	(40	151)	191	7.53			
1973	2,861	(32	243)	275	9.61			
1974	2,748	(44	266)	310	11.28			
1975	2,269	(28	213)	241	10.62			
1976	2,395	(33	189)	222	9.27			
1977	2,881			226	7.84	1,994	178	8.93
1978	3,466	Not Reported		292	8.42	2,266	220	9.71
1979	4,223	After 1977.		302	7.15	2,687	234	8.71
1980	3,694			228	5.86	2,668	194	7.27
1981	3,825			228	5.96	2,798	216	7.72

Table IV-42

OCCUPATIONAL DISEASES AS FRACTIONS OF ALL DISABLING WORK INJURIES AND ILLNESSES IN CALIFORNIA--1960 to 1981*

	Plumbing, Heating, and Air Conditioning Contractors			Plumbers and Pipe Fitters		
Year	Total	O.D.	O.D.%	Total	O.D.	O.D.%
1960	2,311	65	2.81%			
1961	2,385	61	2.56			
1962	2,626	58	2.21	Not Reported before 1977.		
1963	2,870	60	2.09			
1964	3,186	74	2.32			
1965	2,605	56	2.15			
1966	2,353	59	2.51			
1967	2,131	39	1.83			
1968	2,318	48	2.07			
1969	2,358	38	1.61			
1970	2,460	50	2.03			
1971	2,188	42	1.92			
1972	2,536	54	2.13			
1973	2,861	67	2.34			
1974	2,748	61	2.22			
1975	2,269	51	2.25			
1976	2,395	60	2.51			
1977	2,881	119	4.13	1,994	94	4.71
1978	3,466	144	4.15	2,266	109	4.81
1979	4,223	159	3.77	2,687	134	4.99
1980	3,894	167	4.29	2,668	162	6.07
1981	3,825	174	4.55	2,798	150	5.36



SOURCE: California Department of Industrial Relations – see Appendix E.

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FIGURE IV-10 COMPARISON OF DISABLING INJURIES DUE TO CONTUSIONS AND CRUSHING INJURIES AND THOSE DUE TO OCCUPATIONAL DISEASES AMONG CALIFORNIA PLUMBING, HEATING AND AIR CONDITIONING CONTRACTORS (——) AND PLUMBERS AND PIPEFITTERS (— — —), 1960-1981 abnormal findings attributable to solvent exposure. As a group, the participants had no appreciable decrement over the workday in any of the neuropsychological tests.

The environmental data did not indicate excessive solvent exposures. None exceeded survey criteria or OSHA standards, and only one of nine combined solvent expsoure fractions exceed evaluation criteria. The medical study of a limited number of plumbers documented no impairment of brain function and no work-related chronic disease, but the questionnaire survey revealed a high reported prevalence of acute symptoms associated with working with PVC pipe. However, because of the nature of this study, a definite link between the solvent exposures and reported health effects was not established.

11. Potential for Exposure Reduction

The two areas of concern regarding plastic pipe are the dermal and inhalation exposures to the solvents in the cements. The ideal solution to the exposure problem would be the elimination of solvents from these products. This, of course, is impossible--volatile solvents are needed to make the cements practically useful. Threaded fittings--already available for connections to galvanized steel piping--would also be a possible ultimate solution. However, based on observations of work practices, it is probable that the excessive time required to make threaded connections in the field would eliminate any advantage of the plastic pipe over competing systems and would not be acceptable to contractors. In the case of polybutylene pipe, the clamped fittings are already in use. However, for those pipes that are rigid, such fittings are impractical.

Given that complete elimination of solvents is impossible, it might be suggested that provision of local exhaust ventilation on the job site and requiring the use of impermeable gloves might be appropriate measures to reduce the exposures of workers. This matter has been given serious consideration. Our field observations and conversations with knowledgeable construction personnel indicate that provision of portable local exhaust ventilation systems is frequently thought necessary by plumbers but that (especially in commercial or large tract residential work) they frequently either do not ask for this protection, or are refused by representatives of some general contractors. The reasons for such reluctance to make this request, or for the refusals, are the pressures of time and cost on these closely scheduled jobs.

In the case of requiring the use of gloves, it is not clear that there is any one glove material that might be relied upon for protection against the variety of solvents found in the cements in common use. Table IV-43 shows results of a recent laboratory investigation of the permeability of some of the solvents of interest through common glove materials. From that table, it can be concluded that the materials that are most protective against DMF (neoprene and natural rubber) are poorly protective against THF and MEK. Similarly, the material most suitable for MEK and THF is polyvinyl alcohol (PVA), which is not suitable for DMF. Further, PVA tends to disintegrate in water, making it useless for construction work. Finally, it is not clear that plumbers would actually use such impermeable gloves, even if they were available. Plumbing requires a reasonable sense of touch for the installation of piping, especially in finishing work, where some of the work may be done "blind" inside cabinets and the like.

Thus, a compromise is needed. One such compromise that might be considered is to make much closer control over the constituents of cements mandatory for the manufacturers of such cements. There appears to be no technical reason, for example, for the inclusion of such solvents as DMF, n-hexane, and (possibly) benezene in the cements. Indeed, it may be possible to reformulate the currently used cements to reduce the concentrations of the most toxic components. At a minimum, those solvents with significant skin toxicity (such as DMF) should be eliminated. This might be accompanied by a requirement that each supplier of cements must identify specific gloves that can be relied upon to give adequate skin protection to the users. The feasibility of such measures is unknown; given the lack of quantitative data regarding exposures and outcomes of exposures, their need is not clear.

The inhalation of solvent vapors can also be controlled by use of respiratory protective devices. These are readily available, and could be

Table IV-43

EXTENT OF SOLVENT PENETRATION THROUGH GLOVE MATERIALS AFTER 0.5 HOURS

	Glove Material					
Solvent	Natural Rubber (0.4 mm)	Neoprene (0.4 mm)	Neoprene-Natural Rubber (0.5 mm)	Nitrile (0.4 mm)	PVC (0.2 mm)	PVA (0.4 mm)
Carbon Tetrachloride	D	D	D	A	D	A
Chloroform	D	D	D	D	D	A
Methylene Chloride	D	D	D	D	D	A
Methyl Iodide	D	D	D	D	D	A
1,1,2,2-Tetra-Chloroethane	D	D	D	C	D	A
1,1,2-Trichloroethane	D	D	D	D	D	A
Perchloroethylene	D	D	D	A	D	A
Methanol	A	A	A	A	B	D
Ethanol	A	A	A	A	B	C
2-Propanol	A	A	A	A	B	B
n-Butanol	A	A	B	A	B	A
Benzene	D	D	D	C	D	A
Toluene	D	D	D	C	D	A
Aniline	A	A	A		D	A
Phenol (10% Water)	B	A	B		B	C
Acetone	B	C	B		D	A
Methyl Ethyl Ketone	C	D	C	D	D	A
Tetrahydrofuran	D	D	D	D	D	A
Dimethyl Sulfoxide	A	A	A	A	B	D
Dimethyl Formamide	B	A	A	C	D	D
Pyridine	C	C	C	D	D	D
Dioxane	B	B	B	A	D	A
n-Hexane	C	A	C	A	D	A
Water (H_2O)	A	A	A	A	A	D

Key: A = 0.1%, B = 0.1-1%, C = 1-10%, D = 10%.

Source: Sansone and Tewari, 1978.

purchased by any contractor. While undesirable (they are uncomfortable and may pose an intolerable breathing burden on older workers and those who have pre-existing respiratory or cardiac disease), they can be effectively used to reduce the inhalation of solvent vapors to acceptable limits, if the workers are properly educated in their use. The education could be most effectively done as part of the apprenticeship training process, in conjuction with training on the need for and proper use of gloves.

12. Summary and Conclusions

There can be no doubt that the widespread introduction of plastic pipe in California will affect occupational health and safety. Unfortunately, for the purposes of this environmental review, a reasonable judgment of the net impact of that introduction cannot be made at this time. Insufficient information is available to evaluate the impact on any of the occupational groups that might be affected. This is true even for the group with the greatest potential for exposure--the plumbers.

The most pressing need is for definition of the occupational exposures of the plumbers and pipe fitters who will be most affected by the decision. An organized survey of exposures to chemical contaminants arising from the use of both metal and plastic pipe is desirable before a rational decision can be made. It seems likely, in the absence of such data, that increasing use of plastic pipe may be accompanied by a decrease in accidental injury (due to sprains, etc., from handling the heavier metal pipe) and a possible increase in occupational illness due to solvent exposure. The net impact of these tradeoffs (if indeed they do exist) cannot be calculated.

The definition of exposures would require both environmental monitoring and biological monitoring of plumbers in a wide variety of settings to evaluate both airborne and dermal exposures. The potential impact on safety should also be evaluated by observation of the use of the competing materials by trained safety engineers during the surveys. A suggested survey protocol is given in Appendix E.

In the absence of these desired data, it can be concluded that there does appear to be at least the potential for excessive exposures to the effluvia from either metal pipe work ("solder fumes") or plastic pipe work (solvent vapors). Based on the limited human data and the available records, neither of these appears to be extraordinarily dangerous. There has been no "epidemic" of solvent-related illness among plumbers in California during the recent past, when plastic pipe was broadly introduced into residential and commercial construction. The generalized increase in reported occupational disease has been accompanied by a decrease in reported accidental injuries (both as fractions of the total lost workday injuries/illnesses).

Although the potential for control of exposures to plastic pipe-related chemicals is limited because of constraints imposed by the construction worksite, it is likely that significant reductions in exposure can be effected by certain rational measures. First, the member manufacturers could expend more effort than is currently apparent to exercise close quality control of the contents of their products. There appears to be no reason, for example, for the inclusion of such contaminants as n-hexane and (possibly) benzene in these materials. Second, the labels of the cements should be more reflective of the actual contents of the containers, and should be required to display reasonable precautions--including specific types of gloves that will be both suitable for the conditions of use in the workplace and protective against the solvents in the cements. Third, a significant effort should be put forth to reduce the number of solvents in use in each cement, so that gloves suitable for use in a wide variety of plastic pipe installations could be made comerically available. (In the absence of such an effort, a "sandwich" composite material of neoprene/PVA/neoprene appears to be the most reasonable compromise. It is not known whether such a material is commercially feasible.) Fourth, an effort to educate both the general contractors and their foremen (who effectively control construction worksite conditions) and plumbers as to the potential for exposures to solvents could reduce exposures substantially.

Finally, it does appear that the increased use of plastic pipe in California may lead to increased exposure to solvents among the plumbers installing that pipe. The increased exposure will be accompanied by a decreased exposure to lead, and by a (probably) decreased risk of accidental injury. The extent (and effect on occupational health) of such changes cannot be quantitatively stated because of deficiencies in the available data. Additional exposure measurements are needed; in their absence, it does appear that control measures not now used that could be relatively easily encouraged would effectively reduce solvent exposures.

No evidence has been presented that would lead to the conclusion that either metal or plastic pipe ought to be banned--no immediate and obvious threat to the health of workers in California is apparent. Plastic pipe has been widely used without apparent major ill effects for many years; the deficiencies in controls that lead to excessive exposures appear to be remediable.

D. Fire Safety

1. Introduction

a. Statement of Problems

All materials of construction have some properties that keep them from being ideal in all respects. If they are to be used, techniques must be found to mitigate these deficiencies to an acceptable level of performance. The acceptable level is to a large extent* established by performance tests. Actual construction methods and materials must then pass the performance tests.

The plastic pipe materials proposed for expanded use in plumbing have two properties that are of concern as fire hazards. First, all four of the proposed materials are combustible when exposed to a sufficiently hostile thermal environment; second, although most of the products of pyrolysis and combustion from burning pipe are toxic, a few such products may be unusually toxic. This section of the report focuses on these two properties and the impact on life and property losses if the use of plastic pipe is authorized for the proposed additional services shown in Table II-1. The proposed DWV applications in fire-rated construction are the principal concern because (1) they are the major departure from existing practice, and (2) the disagreements about the proposed expanded uses center on this application.

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* Building construction standards and safety requirements, as provided by the relevant model codes, may be partly prescriptive and partly performance based; the prescriptive contents of codes are either derived from performance tests or based on trade or other experience or information. (See "Background" below.)

b. Background

The concerns of this environmental review are not isolated technical issues; they must be addressed within the technical framework governing all the issues of building construction. The Uniform Building Code, Uniform Plumbing Code, and other building standards and regulations are "dedicated to the development of better building construction and greater safety to the public by uniformity in building law (1)."

The Uniform Building Code (UBC 1982) states that "the code is founded on broad-based performance principles that make possible the use of new materials and new construction systems." This basic idea or premise of the code is further described in Section 105, Alternate Materials and Method of Construction:

> The provisions of this code are not intended to prevent the use of any material or method of construction not specifically prescribed by this code, provided any alternate has been approved and its use authorized by the building official.
>
> The building official may approve any such alternate, provided he finds that the proposed design is satisfactory and complies with the provisions of this code and that the material, method, or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in suitability, strength, effectiveness, fire resistance, durability, safety, and sanitation. The building official shall require that sufficient evidence or proof be submitted to substantiate any claims that may be made regarding its use. The details of any action granting approval of an alternate shall be recorded and entered in the files of the code enforcement agency.

The questions of approval for an alternate rests on tests, the subject of Section 107:

> Whenever there is insufficient evidence of compliance with any of the provisions of this code or evidence that any material or construction does not conform to the requirements of this code, the building official may require tests as proof of compliance to be made at no expense to this jurisdiction.

> Test methods shall be specified by this code or by other recognized test standards. If there are no recognized and accepted test methods for the proposed alternate, the building official shall determine test procedures.
>
> All tests shall be made by an approved agency. Reports of such tests shall be retained by the building official for the period required for the retention of public records.

Traditionally, technically complex or controversial changes in building materials or methods of construction have not been left to the individual building official to grapple with because the individual official typically does not have the resources or training to resolve the issue. Moreover, it has long been recognized that such a fragmented approach to issues concerning human safety and protection of property is not in the interest of society. It is one of the fundamental purposes of, for example, the International Conference of Building Officials (ICBO) to investigate the merits of new construction or material proposals and to develop and adopt into code the appropriate UBC provisions to specify safe construction methods and installation conditions. Changes to the Uniform Building Code, produced by ICBO, are processed each year. The changes to the code are carefully reviewed in public hearings by professional experts in the field of building construction and fire and life safety.

Following such a review procedure in the case of proposed expanded use of plastic pipe is essential for the following reasons:

(1) Special and as yet undeveloped or unproven construction measures involving additional cost and care are needed to satisfy code performance standards (primarily for fire-resistive construction).

(2) Significant amounts of combustible material are at issue, notably in the case of ABS DWV piping, and there is a potential health hazard from smoke generation, particularly from PVC and CPVC.

(3) Code enforcement is likely to be a significant problem with plastic pipes, and the resources for enforcement must be carefully weighed in developing code provisions.

(4) The Uniform Building Code (1982 Edition) is deficient in specific provisions, standards or recommendations for installation of plastic pipe in fire-resistive construction*. The Uniform Plumbing Code (1982 Edition) does not address the issue at all.

The Uniform Plumbing Code (1982 Edition) contains three major parts: Installation Requirements, Appendices, and IAPMO Installation Standards. The State of California adopts the Installation Requirements and the IAPMO Installation Standards, but not the Appendices.

The Installation Requirements, the main body of the Uniform Plumbing Code, do not address, or even mention, "fire," "fire-related," or "fire-resistive;" in fact, the index to the main body of the code does not even contain the word "fire" or any other term related to it. Chapter 3, General Regulations, has several sections in which the omission of references to fire is particularly noteworthy: Section 309, Workmanship; Section 315, Protection of Piping, Materials, and Structures; Section 318, Inspection and Testing; and Section 319, Maintenance.

The only references to fire occur in two Installation Standards: IAPMO IS 5-81, ABS Building Drain, Waste, and Vent Pipe and Fittings, and IAPMO IS 9-81, PVC Building Drain, Waste, and Vent Pipe and Fittings. These two Installation Standards apply to ABS and PVC DWV systems primarily+ in

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* The UBC (1982) defines "fire-resistive construction" as follows: "Fire-resistive construction is construction to resist the spread of fire, details of which are specified in this code" (emphasis added).

\+ IAPMO IS 9-81 pertains also to certain limited PVC industrial waste applications, where permitted by the Administrative Authority.

"residential occupancies of not more than two (2) stories in height." These two standards contain an identical section--Section 315.6, Piping Installed in Fire Resistive Construction--which reads:

> Where piping is installed and penetrates required fire resistive construction the fire resistant integrity of the construction shall be as required by the Administrative Authority, or when not established by the building code, by qualified testing methods approved by the Administrative Authority. Approval shall be obtained prior to installing any such piping.*

c. Objectives

Our goal is to provide answers to the following questions and, when suitable answers are not forthcoming from the existing pool of information, to recommend how to remedy the deficiency.

- Are adequate performance specifications for fire-rated construction available to govern all aspects of the plastic pipe fire spread hazard?
- Have techniques been developed to mitigate the problems arising from the combustibility of plastic pipe?
- Should fire-resistive construction containing plastic pipe have a more demanding fire rating and/or fire performance standard?
- What peripheral fire protection elements would be affected by the proposed plastic pipe approvals?
- Is there an adequate method for evaluating the potential toxic smoke hazard from burning plastic pipe?
- Are the unique toxic smoke hazards of plastic pipe (if any exist) sufficient to merit special regulatory concern?

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* Administrative Authority is defined in Section 102: "The Administrative Authority is the individual official, board, department, or agency established and authorized by a state, county, city, or other political subdivision created by law to administer and enforce <u>the provisions of the plumbing code</u> as adopted or amended."

d. Approach

We have divided the plastic pipe fire hazard question into the previously mentioned two parts, namely: (1) fire spread, which seeks to answer the first four objective questions, and (2) smoke toxicity, which deals with the fifth and the sixth, and which appears in Section IV-E below. Both fire spread and toxic smoke threat are sensitive to the characteristics of the fire; therefore, performance must be judged with respect to the features of the fire involved. Two general groups of scenarios are used here: (1) fires that start in a room so that the thermal insult to the pipes comes through a fire-rated wall, and (2) fires that start in a utility space, shaft, or raceway where the pipes themselves are among the combustible materials involved. Pertinent evidence was collected from building codes, entries into the Administrative Record concerning expanded use of plastic pipe in California, technical reports, and results from standard fire tests on plastic pipes.

Our approach to the evaluation has been essentially technical, i.e., evaluating the basic technical nature of the issues and what they mean in the broader context of the building process in California. Our investigation into the historical-statistical data related to the plastic pipe issue has been limited; a significant effort may be required to derive an adequately accurate experiential analysis. Some of the reasons are suggested below.

DWV pipes currently installed in residential non-fire-rated construction in California are ABS in 95% of cases. In other states, particularly on the east coast, the use for DWV systems is more balanced between ABS and PVC. It would therefore be hard to compare geographic fire data, if any are relevant. Moreover, if expanded use of plastic pipe is permitted in California fire-rated construction in the future, it is unclear what the distribution will be between ABS, PVC, and CPVC in DWV systems.

Actual statistics on fires in buildings with plastic pipes and on any actual involvement of plastic pipes are not available. Fire data collection methods and their computer encoding do not recognize plastic pipes, and it is not possible to come up with such information through a computer search of fire data. There is at present also no differentiation in the encoding method between different types of plastic compounds (i.e., ABS versus PVC etc.). The California Fire Incidence Reporting System (CFIRS) and the National Fire Incidence Reporting System (NFIRS)* utilize the data encoding method used by the National Fire Protection Association (NFPA) for the NFPA data base.

2. Fire Spread Hazards

a. Fire Spread Within Fire-Rated Construction

1) Fires Originating in a Room Surrounded by Fire-Resistive Construction

In the Uniform Building Code (UBC, 1982), fire-resistive construction is defined by a performance standard, namely UBC Standard No. 43-1, which is equivalent to the ASTM E119-80 tests. This standard requires that walls, ceilings, or floors, with all their penetrations, endure the thermal insult from the E119 test fire for the rated exposure time. Typical construction materials, such as wood studs and steel structural members, cannot survive this test environment unless protected from the heat by adequate thermal insulation (e.g., Type X gypsum board). Penetrations through this insulating layer (wallboard), such as those required for plumbing and electrical service, create weak points that must be protected from the thermal insult if the integrity of the wall is to be preserved. Fire stops of various types have been developed to perform this function.

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* This system is managed by the National Fire Data Center of the U.S. Fire Administration (USFA); USFA is a part of the Federal Emergency Management Agency (FEMA).

Much of the concern for the fire safety of plastic pipes focuses on the penetrations and the search for effective fire stops, particularly for the DWV systems. A fire test conducted in late 1982 (Warnock-Hersey, 1982) illustrated quite effectively that plastic DWV systems can drastically reduce the fire resistance of a wall when the penetrations are not protected. In this test, metal plumbing was replaced with plastic counterparts, including the pipes that penetrated the gypsum-board wall to support plastic traps directly exposed to the test fires. Although the report makes no mention of sealing the penetration, this detail is probably of little consequence because the large amount of exposed plastic soon caught fire and carried the flames into and through the wall. Plastic pipe cannot be installed in such a fashion without destroying the fire endurance of the wall.

In fact, considerable care and attention are required to fire-stop the penetrations for plastic plumbing systems sufficiently to maintain the fire rating (see OSU, 1973). Various protective schemes and devices have been employed in tests, as, for example, sheet metal plates (Draemel & Williams, 1976), sleeves (see, for example, Attwood, 1980), and combinations of metal pipe and plastic pipe. However, the details of the successful fire stops are not essential to our line of reasoning. The important conclusion regarding the fire spread hazard is that, with certain fire stops, plastic plumbing systems do not degrade the fire endurance of a wall; therefore, based on the performance standard for fire-rated systems, these systems may be viewed as acceptable as the other combustible or thermally weak members in the wall. Under such a performance standard, it becomes the responsibility of the pipe manufacturers and builders to develop, and to have certified by test, the necessary fire-stop materials and techniques. Obviously, such certification should occur before any systems are installed.

However, it should be noted that some additional burden falls on the regulatory agency, particularly the building inspectors who enforce the code. A combustible, thermoplastic plumbing system is not as forgiving as a noncombustible metal system; consequently, all parts--particularly the fire stops--must be installed properly if fire protection integrity is to be ensured. For this reason, both the builder and the building inspector must exercise diligence in monitoring the installation.

So far, this discussion has made no distinction between the various types of pipe proposed for acceptance in the plumbing code. Some difference in burning behavior has been observed for the various types; however, from a fire safety standpoint, the performance of the finished installation should determine acceptability, in any case. Differences in pipe composition, however, will profoundly affect the composition of smoke from the pipe in a fire, and this topic will be discussed separately (see Section IV.E).

2) Fire Burning in the Utility Shaft or Raceway

This scenario is of principal concern in tall buildings involving many floors, where the natural pressure differences due to wind, stack effect, and buoyancy of the hot combustion gases provide a driving force for fire spread in the vertical direction. Utilities, such as plumbing, electrical power, and communications cables frequently share a utility chase that extends the height of the building. Without fire stops, such shafts provide a ready path for flames and smoke to propagate. Even before plastic plumbing is considered, the amount of combustible material present as thermal and electrical insulation is frequently sufficient to maintain a substantial fire. Options to prevent fire spread include fire stops at each floor and active suppression systems, such as installed spinklers. In considering plastic plumbing, the emphasis has been on fire stops and various arrangements have been tested (F.R.O.S.I. #9116; McGuire, 1973; Attwood, 1980; Brown & Martin, 1979). These fire tests require the appropriate orientation and configuration of the test specimen and provisions to apply an appropriate air flow or pressure differential. Unfortunately, no performance test is generally accepted to certify such fire stops. Several test arrangement have been used in research and development, but the state regulatory agency would have to specify a performance test method to certify fire stops for plastic plumbing in utility-chase installations. Such a test method would be based on the ASTM

E-119 modeled fire thermal conditions but would differ in test configuration (sample orientation), air flow, and pressure.

3) Findings of Relevant Tests

Hornsby (1982) states:

> [Our] results . . . indicate that with further development of formulations, enclosing ducts, sleeves, seals, and branch configurations, there is a reasonable chance that the present problems associated with the use of plastic pipe where fire and smoke integrity is required, will be resolved. Also, when using construction . . . deemed to satisfy the criteria for a particular fire-resistance rating, it is implicit that there should be no breaching of the construction, but this, too, can occur in practice.

Brown (1979)* reviewed actual and simulated fires. He found that:

> The most meaningful method of testing plastic plumbing installations is to install them in fire resistance-rated wall or floor elements and test the assembly to check if the resistance is maintained. Past full-scale simulations have demonstrated that it is possible to install UPVC plumbing within certain fire-rated enclosures (wall cavities, ducts, etc.) without impairing their fire resistance.

Standard ASTM E-119 Tests--There are four fire laboratories in the United States that have conducted tests with the ASTM E-119 test protocol on plastic pipes installed in wood-frame or steel-frame, fire-resistive walls. These tests, all conducted during the last decade, were done in the following laboratories:

(1) National Bureau of Standards.

(2) University of California, Berkeley, Structural Research Laboratories.

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* Taken from Hornsby (1982)

(3) Ohio State University, Building Research Laboratory.

(4) The Warnock-Hersey fire testing laboratory, Antioch, California.

The Center for Fire Research, National Bureau of Standards, has conducted a research and test program on the effect that plastic and metallic DWV plumbing systems have on the fire endurance of gypsum-board walls and chases (see Parker et al., 1975). The program comprised 10 full-scale fire tests involving 39 piping assemblies within wall cavities and pipe chases. Iron*, copper, ABS, and PVC DWV pipe systems "typical of installations serving one or two-story buildings" were tested. The report stresses:

> This investigation covered only the fire performance of plastic (and metallic) pipe in one-hour fire-rated chases and walls. It did not address the fire performance of DWV in "high-rise" buildings nor DWV penetrating floor-ceiling assemblies. Further studies may be needed to determine whether pressure differences due to the stack effect in high-rise buildings will contribute to rapid fire and smoke spread. Also, there is a need for developing a procedure for quantitative measurements of smoke and gas accumulation in adjacent dwelling areas.

The standard ASTME E-119 time-temperature curve was used in the test program, with the following performance criteria used to judge the extent to which the wall assembly met the 1-hour endurance requirements (the report emphasizes that the tests were research tests rather than rating tests):

1. There should be no passage of flame through the wall as a result of the DWV installation.
2. The temperature rise on the unexposed surface of the wall should not be affected by the DWV installation and should not exceed 181 °C (325 °F) at any measured point. This corresponds to the highest temperature allowed at any point on the surface according to the ASTM test standard. The temperatures recorded on the laterals are not regarded as wall surface temperatures.

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* This included a "no-hub" cast iron installation.

3. Large quantities of smoke should not pass through the unexposed face. This last criterion is not defined in quantitative terms but was based on observations during the test which indicated when heavy smoke was seen to be issuing from the construction.

Their key findings and observations are as follows (emphasis added):

5.1. The PVC DWV systems with 4-inch stacks and 1-1/2-inch laterals in 20-inch by 20-inch chases met the criteria for 60 minutes fire endurance . . . The annular openings around the laterals were sealed for these tests. Although not tested, it appears likely that a similar ABS installation would also meet the criteria.

5.2. The one-hour fire-rated walls containing ABS and PVC pipe with back-to-back laterals in line with the stack met the 60-minute criteria <u>when all of the following conditions were satisfied</u>:

1. The annular openings around the laterals were scaled.
2. The wall cavity depth was 5-1/2 in. or more.
3. The stack was limited to 2- or 3-in. diameter. A 4-in. diameter PVC stack in a 9-1/2-in. deep wall cavity also met the criteria when the annular opening around the lateral was sealed.

5.3. The fire endurance of the wall containing PVC or ABS pipe with back-to-back laterals in line with the stack <u>was reduced when any of the following conditions existed</u>:

1. The plumbing fittings (e.g., tees, wyes) penetrated the gypsum board.
2. The annular hole around the PVC or ABS lateral was not sealed.
3. The PVC or ABS pipe was used in a 3-1/2-in. deep wall cavity with either wood or steel studs.

5.4. Offsetting the lateral from the stack in the same stud space for a 2 x 6 wood-stud wall increased the time to flame passage. However, when the annular openings around the lateral were not sealed, a considerable quantity of smoke was released into the room at 34 minutes and the ABS and PVC systems failed this criterion . . . When the lateral was offset from the stack in an adjacent stud space, the heavy smoke criterion was reached at 5 minutes and failure by flame-through occurred at 21 minutes . . . The effect of offsetting the laterals in 2 x 4 wood- or steel-stud walls was not examined in these tests.

5.5. The performance of the PVC system was superior to the ABS type, both in time to flame-through and in time to heavy smoke development in almost all the tests where a direct comparison was possible . . . These tests covered a variety of wall-cavity depths and stack sizes.

> However, in each of the above cases, the comparison is based on the condition where the annular hole around the lateral was completely sealed off with plaster spackling. When the annular hole was not sealed, the performance was difficult to compare since the times to failure were short in both cases.
>
> 5.6. All copper, galvanized iron and cast iron systems installed in wall cavities, a total of seven constructions, met the criteria for 60 minutes in every case. In six tests, the openings around the lateral were sealed . . . and in one test the opening around the lateral was not sealed . . . The wall cavities in these tests were of three depths, 3-1/2 in., 5-1/2 in., and 9-1/2-in. While the wall-surface temperature-rise did not exceed 181 °C (325 °F) the temperature of the copper lateral reached 500 °C (932 °F) just outside of the wall.
>
> 5.7. Based on the results from this series of tests, plastic DWV Systems with lateral sizes of 2 inches or less would not be expected to reduce the 1-hour fire endurance rating of wood-stud-and-gypsum board walls and chases in one- and two-story buildings provided that:
>
> 1. the annular hole in the wall around the lateral is sealed (an adequate inspection system may be required), and
>
> 2. the stud space depth is sufficient to obviate the need for the hubs of any tees or wyes in the vertical stack to penetrate the wall.
>
> 5.8. There was a quantitative difference in the fire performance of ABS and PVC DWV systems. However, neither system degraded the one-hour fire rating of wood-stud-and-gypsum board walls where the above conditions were followed.

The tests conducted by the University of California, Structural Research Laboratory (see Draemel and Williamson, 1976), were conducted at the University of California's Richmond Field Station. Two tests were conducted according to the ASTM E-119-73 protocol "to determine the effect on fire resistance of plastic pipe DWV plumbing assemblies with back to back sink penetrations when included in a 2" x 6" wood stud one-hour fire rated wall." Both ABS and PVC installations were tested.

The report states:

> A primary goal in these tests was to examine the effectiveness of 24 ga. sheet metal, 18" x 24", at each wall surface penetration (as described in Section 3.2) in preventing excessive heat and flame penetration through the assembly.

Some details from Section 3.2, titled "Special Fire Protective Elements," are as follows:

> Each plumbing assembly had 18" high by 24" wide 24 gauge galvanized steel sheets surrounding the pipe at each wall surface penetration.
>
> A 2-1/4" hole was punched 4" up from the bottom of the metal sheets, 12" in from the vertical edges. The pipe fitting hubs which penetrated the wall surfaces fit snugly through this hole. The metal sheets were nailed to the face of the wood studs with three 8d nails on each stud.
>
> Apart from these metal sheets, all of the plumbing assembly details were considered consistent with those found in field installations.

In both tests the wall assemblies withstood the standard ASTM E-119 exposure without showing failure under any of the ASTM E-119 criteria. The report concludes:

> The two tests under discussion showed that the specimen tested, with the sheet metal plate at each wall surface penetration, succeeded in preventing any significant fire spread within the specimen beyond the fire floor or through the unexposed face of the specimen. In brief, the inclusion of plastic pipe DWV systems within the wall tested did not measurably reduce the fire resistance of the wall.

A series of five ASTM E-119 standard tests on 1- and 2-hour walls was conducted at Ohio State University in 1973 and 1974 for the Plastic Pipe Institute. The results are described in five separate reports [see OSU 1973 (a,b) and OSU 1974(a,b,c)]. Both ABS and PVC DWV installations were used in each test. The DWV configurations in test walls were typical of back-to-back lavatory installations. Pipe diameters ranged from 1-1/2 inches to 4 inches. Walls using both 2 x 4-inch and 2 x 6-inch studs were tested.

All five wall assemblies tested retained their expected fire resistance according to the ASTM E-119 test criteria. The 2-hour assemblies retained their load-bearing capabilities during the test. From the description of the installation details, it is noteworthy that wall penetrations by the pipes were "completely sealed with asbestos furnace cement."

The fire testing laboratory of Warnock Hersey International, Inc., located in Antioch, California, conducted a single test on October 8, 1982, under the sponsorship of the Plumbers' and Steamfitters' Union, Local 467 (see Warnock-Hersey, 1982). The test was conducted on a non-load-bearing wood stud and gypsum-board wall assembly, which contained four ABS plastic plumbing runs in separate stud cavities. The fire test protocol was the standard ASTM E-119 (UBC-43-1). The report concludes:

> ABS plastic pipe, when installed in a one-hour wood stud fire wall as described in this report, greatly reduces the fire resistance of the wall. All four of the cavities with ABS plumbing systems failed the ASTM and UBC standards in 24 to 36 minutes.

Under the ASTM and UBC standards, two of the cavities with pipes were said to have failed by flaming on the unexposed face (at 24.5 and 32.5 minutes) and two by criterion of temperature rise on the unexposed face (at 36 and 32 minutes). The test of the 1-hour wall assembly was terminated at 45 minutes. A videotape made of the test illustrates these observations and otherwise documents the test. The report does not offer an explanation for the failure to complete the test. The purpose of the test is presented in another document (Adams, 1983):

> The purpose of the W-H [Warnock-Hersey] fire test was to simulate "real-world" construction practices to assess the basic performance of DWV plastic pipe.
>
> The construction was not designed to achieve laboratory perfection, it was intended to represent standard building practice.
>
> There was essentially no fire stopping of penetrations in this test.

Brown & Martin (1979)--These reduced-scale tests subjected overhead pipe penetrations through a concrete slab (30 x 30 inches with an exposed area of 21 x 21 inches) to a thermal insult that followed the standard ASTM E-119 time-temperature curve. The effects of various vertical-penetration protection techniques, such as insulated pipe coatings, sleeve protectors, gap sealants, and pipe collars, were examined for UPVC* pipes up to 4 inches in diameter. Their conclusions were:

> Significant improvements in the fire integrity of vertical UPVC SWV+ pipes penetrating a 100 mm thick horizontal concrete slab can be obtained by
>
> (a) penetrating with small diameter pipes (British regulations permit pipe with inside diameters of 38 mm and less to penetrate fire rated elements without any protection).
>
> (b) preventing fire (furnace) gases venting along the pipe (i.e., providing a cap on the "upward" side).
>
> (c) providing insulation to the pipe with a vermiculite-cement coating (this effect is somewhat similar to installing the pipe within a protective, fire-resistant enclosure).
>
> Some installation modifications provide only minor improvement or reduce the fire resistance of the penetration, e.g., metal sleeves may fail by a lack of thermal insulation and pipe collapse was erratic and in some cases caused early breach of fire integrity.
>
> The physical properties of pipes were also found to influence fire integrity. Pipes with high reversion characteristics shrank out of the slab with early loss of integrity. Pipe distortion on softening also caused early loss of integrity in some cases (an effect likely to need particular attention with horizontal pipes).

Although these tests indicated that significant improvements in vertical penetrations could be achieved, the work did not culminate in a satisfactory 1-hour fire stop.

McGuire (1973)--This study used an 18 x 18 x 4-inch test wall penetrated by either 3-inch or 4-inch pipe samples exposed, under a controlled gas pressure differential, to the standard E-119 thermal insult.

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[*] UPVC means "unplasticized PVC."

[+] SWV means "sewer, waste, and vent."

PVC, ABS, and polyethylene pipes were tested in both horizontal and vertical orientations to simulate wall, floor, and ceiling penetrations. An examination of various fire-stopping techniques leads to the following conclusions:

> The penetration of floors and walls by plastic DWV pipe of the sizes and types examined presents risk of fire propagation under various conditions. The hazard exists for almost all penetrations of floors; and in the case of walls, it arises when adverse pressure differentials prevail and when the pipe on the unexposed side of the wall leads to a vented system. By careful consideration of the pattern of pressure differentials likely to prevail within a building, it is possible to devise largely plastic DWV pipe systems for buildings that will not give rise to undue hazard of fire propagation across fire partitions. Such DWV pipe systems might well involve combinations of metal and plastic pipe.
>
> It should be borne in mind that the scope of this paper has been confined to propagation of fire across partitions. Other factors could enter into fire protection considerations, among them being the smoke generating and corrosive potentialities of certain plastics.
>
> Another aspect to be noted concerning the test work reported is that not all metal DWV systems would react favorablly if subjected to the test conditions described. If penetration of the pipe occurred in the fire region, a positive pressure differential and a vented system could give rise to a high metal temperature beyond the penetrated partition as occurred with the PVC pipes penetrating the floors (Tests 30, 36, and 38.) With certain modern jointing concepts, penetration of a metal pipe would be quite likely in the event of fire.

With appropriate protection by sleeves the times to penetration were extended to 1 and 2 hours, respectively, for the vertical and horizontal orientation of the pipe.

F.R.O.S.I. No. 9116--Full-scale plumbing installations three stories tall were tested in a four-story utility shaft equipped with a suction fan to serve the ventilation stacks. PVC and ABS stacks up to 12-inch diameter were exposed to the thermal insult from wood crib fires on the first floor. They concluded:

> Full-scale fire tests on ten different installations of plastics services, manufactured from polyvinyl chloride or ABS have shown that, provided adequate attention is directed to correct fitting, the danger of fire spread via these systems to other compartments in a

> multi-storey building is no more serious than with non-combustible systems.
>
> Two systems of fire protection have been investigated, viz. the use of floor stops at compartment floor levels without a fire resisting protected shaft or the use of a fire resisting protected shaft undivided by floor stops. With the plastics installations tested, both methods have been shown to be effective in preventing fire spread from one compartment to another with the size of combustible pipes used, (upto 150 mm (6 in.) in diameter).
>
> Rigid fixing of the stacks is essential to prevent excessive damage to the installation, particularly in the case of a protected shaft without floor stops.
>
> Stacks using cemented joints require a steel bracket just below each expansion joint and those with flexible pipe connections need all brackets to be of steel and well fitting. In sizes of pipes upto 150 mm (6 in.) diameter it was not found necessary to provide fire dampers.
>
> Passage of smoke from the fire to another compartment depended upon the design of the system. With the soil system there was no smoke hazard. With ventilation systems, erected in a protected shaft wthout any floor stopping, negligible passage of smoke occurred with shunt connections and only slight quantities with straight connections, even when the fan was not in operation. When floor stopping was employed, with an unprotected shaft, smoke collected in the shaft enclosure above the seat of fire. If the shaft were not properly sealed, smoke would enter the compartment. With straight connections slight amounts of smoke would also be able to enter this or other compartments through the ventilation duct, particularly on failure of the extraction fan.

Attwood (1980)--Horizontal and vertical fire-stopping techniques were tested using small-scale wall (23 x 18-inch) and overhead (39 x 39-inch) assemblies exposed to the E-119 thermal insult. The results with PVC and ABS pipes up to 3 inches in diameter lead to the following conclusions:

> Under conditions of positive pressure, it is evident that some means of creating a seal is required to prevent flame or hot gases from escaping the involved compartment.
>
> In the case of lateral penetrations of vertical walls, the tests indicate two solutions, those being the use of a sleeve mounted at an angle of 45° from the vertical and the use of a mechanical shutoff device. ...With a standard two-hour wall, a seal can be maintained for the full two-hour period. In the reverse situation, where the sleeve penetrates the wall upwards at a 45° angle, the integrity of the partition is maintained as long as the unexposed side in nonvented. This has only been demonstrated for 1-1/2-in. (38-mm) pipe.

Mechanical devices provided added protection. Single and double shutoff devices were both studied. The principal difficulty encountered with single shutoff devices lay in the reliability of a single metal-to-metal seal. Under positive pressure conditions, leakage of furnace gases occurred and caused ignition of the pipe on the unexposed side of the shutoff. The double flapper device...allows protection of the system for two hours for both PVC and ABS pipe. In this assembly, as in all lateral assemblies, the fit of the sleeve through the wall was snug, and the joint was carefully cemented. The assembly was also supported so that it did not rely on the pipe to hold it in place.

For vertical pipe, there also appear to be some solutions, notably the use of mechanical devices. The chase tests indicate that construction of a sealed chase offers protection against fire spread; however, it seems improbable that it would be possible to assure such a construction in normal building practice.

Both double and single shutoff devices created effective seals. The leakage problems encountered with single shutoff devices for horizontal pipe were not encountered with the slide plate assembly. This is probably a result of the orientation of the device and of its weight. The same explanation can be offered as the cause of warping in the double shutoff device for vertical pipe. Careful design and selection of materials could undoubtedly eliminate this problem.

...All these proposed solutions with the exception of the 45° sleeve, rely on the fact that thermoplastic drain waste, and vent pipes soften at temperatures well below the ignition temperature of the materials. This softening allows some weighted or otherwise driven device to crimp the pipe and initiate a seal. As the material heats further, the slide or flapper completes its travel, leaving a metal barrier between the exposed compartment and the adjacent compartment. In the moments before a seal is created, hot combustion products are vented through the plumbing system. This produces two effects:

- Warpage because of the high coefficient of expansion for plastics; and

- Possible bursts of flame at the end of the vent system.

The warpage of the pipe in the vertical applications can cause mechanical devices to be displaced unless they are firmly anchored. The solution for the slide plate assembly was to leave a small space between the base plate and the pipe, thus allowing the pipe to deflect without interfering with the device. After a seal was created with all mechanical devices, the pipe cooled and contracted. Because a permanent deflection was established in the pipe, this contraction caused the pipe to retract from the device resulting in no contact between metal and plastic.

The speed of operation of the device seemed significant. With the weights mentioned for the slide valve assembly, a couple of bursts of flame occurred above the top of the stack where furnace gases mixed with the air. When less weight was used, the pipe became very soft and sagged badly. If insufficient force is used, the stack is left unprotected and ignition would be probable.

These test results reveal that even under the most adverse conditions, plastic pipe can penetrate fire separations without propagating fire beyond the separation. The devices tested here would require refinement before they could be considered practical."

Curtis (1977)--This series of horizontal penetration tests employed PVC, CPVC, ABS, and polypropylene pipes in a 39 x 39-inch wall test section exposed to the British standard time-temperature curve. Various pipe sizes, 1-inch to 6-inch, and fire stops led to the following conclusions:

1. Plastics pipework passing through walls will, in most instances, lead to loss of integrity of the wall under fire test conditions quicker than would be the case with most non-combustible pipework. Loss of integrity will be rapid if:

   (a) the pipework is open to the atmosphere (as in the case of drainage pipework)

   (b) the wall is thin

   (c) the pipe diameter is large.

   (Limited quantitative data is given in Table 4 and in Part 1.)

2. Plastics materials which do not melt and drip under fire conditions and which decompose to leave a carbonaceous residue are better for the maintenance of the integrity of a pipe/wall combination. PVC was the best of the materials investigated.

3. It is practicable to lay down design criteria if, for the domestic situation, failure is deemed to have occurred only when the fire penetrates from one compartment to another.

4. The production of smoke and noxious gases should be the major cause for concern when considering the performance of plastics piping systems in fire. Rigid checks should be applied to ensure that no easy paths for the passage of smoke exist between compartments.

5. Flaming was not a problem in the tests and if occurring in practice would probably be satisfactorily contained within an

installation comprising a structural wall and casing having a reduced fire resistance requirement.

6. Casings for enclosures should be required to have a minimum thickness and a specified degree of resistance to fire from either side.

Hornsby (1982)--This limited literature survey examined 17 references concerned with hazard assessment and fire tests for plastic pipe. The summary of the survey states:

> 2.02 The results indicate that with further development of formulations, enclosing ducts, sleeves, seals and branch configurations there is a reasonable chance that the present problems associated with the use of plastics pipe where fire and smoke integrity is required will be resolved.
>
> 2.03 In the penetration of fire-resisting construction by pipes and conduits attention should be given to the potential breaching of the integrity of such construction by other elements such as chases, recesses and joints, and the use of unprotected lintels and ventilators. In many cases the inclusion of such elements in fire-resisting members is contrary to the provisions of AMUBC Part 20 which requires the construction of a member to match in all respects the tested prototype. Also, when using construction described in Table 20.10 as being deemed to satisfy the criteria for a particular fire-resistance rating, it is implicit that there should be no breaching of the construction, but this, too, can occur in practice.
>
> 2.04 Research should therefore be directed to the identification of all situations and practices that result in the erosion of fire-resistance ratings and to the identification of failures in specific instances to meet the criteria which, when tested according to AS 1530, define the performance of the specimen.
>
> 2.05 This research would include a study of the performance of construction penetrated by various types of pipe, conduit, duct and so on. Some experimentation may be necessary to determine the performance of particular components in a range of applications. When completed the objective would be to determine suitable performances for building regulatory purposes (where the performance of the unperforated or unmodified prototype cannot be met) and a range of solutions whose performance can be deemed to satisfy the nominated performances.

As stated in our conclusions below, it is technically possible to achieve an acceptable level of fire safety using plastic pipe or a combination of plastic pipe and noncombustible fittings in fire-rated construction. Suitable fire-stopping systems have not been demonstrated for all pipe materials, sizes, and orientations; particularly of concern are large pipes and vertical penetrations. The development of satisfactory fire-stopping systems should remain the responsibility of the interested industries. However, the regulatory agencies have the responsibility to select a suitable test to evaluate vertical penetrations, particularly in utility shafts.

b. Fire Spread in Non-Fire-Rated Construction

Upon reviewing the Administrative Record and other sources pertaining to fire spread and plastic pipes (see "Findings of Relevant Tests" above), it is apparent that any concern for an aggravated fire spread hazard with the expanded uses of plastic pipe in non-fire-rated buildings is very much outweighed by such concern for the possible hazard from fire spread in fire-rated buildings with plastic pipes. There are also positive statements by experts on the lack of any special hazard related to plastic pipe (particularly DWV) in non-fire-rated construction.

The State Fire Marshal (1980) concluded that "The use of plastic pipe in non-fire-rated construction, whether in residential, commercial, or industrial occupancies, does not present an unusual fire risk."

Williamson (1979) stated "for the record" that "there is no fire problem associated with plastic DWV systems in one- and two-family housing."

There are typically two reasons given to support statements such as those above:

(1) Even though installation of plastic DWV systems has been widespread and has been done for up to 20 years in some parts of the United States, there is no extensively documented fire hazard directly involving or stemming from the plastic plumbing systems.

(2) In view of the lack of regulation of furnishings or building materials in non-fire-rated construction, it is considered unfair to single out plastic plumbing pipes, even though these do add to

> the total combustible fuel load per residential unit. In other words, they present no unusual hazard relative to the hazard already posed by the furnishings.

Although there are inadequate statistics to support argument 1, at least it can be put into perspective. At present, 90,000 single-family dwelling units are built annually in California; all are non-fire-rated. Moreover, there are 60,000 new multifamily dwelling units built per year; it is assumed that 75% of these are non-fire-rated construction. The number of non-fire-rated dwelling units built now in California per year is therefore about 135,000. About 95% of the DWV systems installed in new, non-fire-rated (one- or two-story) residential housing in California are already ABS. By these estimates about 128,000--or certainly over 100,000--new dwellings units have ABS DWV installed annually. Although these numbers were probably smaller in the past, they lend perspective to argument No. 1 in what follows. Based on reviewing the administrative record, it appears that there are only singular cases of fires in non-fire-rated residences that have noticeably involved plastic DWV pipes; in other words, the handful of cases over several years appear insignificant with the perhaps 1 million ABS DWV systems in non-fire-rated construction installed in the last decade in California. Moreover, no extraordinary hazard can readily be surmised from the rough technical description of the cases given or referred to in the Administrative Record.

The extent of the proposed expanded uses relative to the existing uses is a major factor governing the net impact of the changes.

For DWV systems in non-fire-rated buildings, ABS and PVC are already allowed; and, as mentioned above, 95% of DWV systems installed in new non-fire-rated residential housing are already ABS. The expanded use would introduce CPVC as a potential pipe material for DWV uses. The intrduction of CPVC should not, itself, increase the usage of plastic DWV pipe because PVC has already been allowed for such use and CPVC presents no proven superiority to PVC. To whatever extent changes coming from allowing CPVC occur, they would primarily involve displacing ABS to some extent from the market. From the considerations of fire spread, this displacement of ABS by CPVC introduces no negative impact.

Another issue concerning expanded uses of plastic pipe involves the proposed use of polybutylene (PB) and CPVC for cold and hot water supply. Because there has previously been no plastic pipe allowed for cold and hot water supply, there is a potential impact. From our evaluation, we conclude that this impact is likely not to be significant for the following reasons.

First, it is estimated that of the total of about 200 to 300 pounds of plastic plumbing per dwelling unit, the water pipes account for only about 20 pounds, or less than 10%. For those residences (95% of total) where ABS DWV pipes are being installed, the additional 20 pounds of PB or CPVC do not significantly aggravate the fire spread hazard. The ABS DWV system is also more vulnerable than the PW piping and consequently may fail first in a fire or fail more extensively in the case where fire spread is aggravated by plastic plumbing; in other words, it may not matter, in the case of fire spread, what the water pipes do. The plastic DWV system is more vulnerable than the water pipes since (1) the pipe is larger in diameter, (2) there is no water in it for cooling or spraying if penetrated, and (3) the openings in the wall are larger. (The above arguments leave out the potential contribution of CPVC pipes to smoke toxicity, which is dealt with in another section.) In the 5% of new residential units that do not have ABS DWV systems, the possible use of PB or CPVC pipe would not create a significant hazard, based on argument 1 above, combined with the fact that 5% represents only about 6,000 new units in California each year.

In summary, the expanded use of plastic pipe in non-fire-rated construction is expected to add no significant or unusual hazard to that inherent in the present, allowed uses.

c. Fire Hazards from Plastic Water Supply Pipe

The conclusions given here are based on the following considerations:

- The amount of fuel present in the water supply pipes is a small fraction of that present in the DWV system.
- The small diameter of the water supply pipes will minimize the penetration problem in fire-rated construction.
- The presence of water will prolong the survival of the pipe in a fire; if a burnthrough occurs, the escaping water will suppress the fire near the hole (Palo Alto, 1972).

We conclude that:

- In non-fire-rated construction containing ABS or PVC DWV systems as currently permitted, the addition of PB or CPVC water supply systems will not increase the fire spread problem. Furthermore, because of the water cooling, the contribution to toxic products will be less than for the same amount of DWV pipe.
- In fire-rated construction, fire stops and other construction details permit the DWV system to pass the fire rating tests; similar procedures can adequately protect the water supply system. Here, also, the toxic pyrolysis and combustion products will be less than for the DWV system. We have assumed that the economics of construction would not lead to a plastic pipe water supply combined with a metal DWV system, but if it did, the water supply system should demonstrate acceptability by passing the appropriate performance test (E119).

d. Related Fire Protection Factors

1) Fire Fighting

This section covers several aspects of fire suppression where plastic pipes are involved. First, there is the question of fire intensity and how much the additional fuel contributed by the pipe will enhance the fire. Obviously, the answer is intimately connected to the building construction and occupancy. If we assume the extreme that is most disadvantageous to plastic pipe--i.e., a fire-resistive building where the only contribution to the fuel loading comes from the contents, finished flooring, interior finish and trim, coupled with a low-fuel occupancy--the amount of combustibles will generally exceed an average of 5 lb per ft^2. If the plastic pipe and fittings for a typical bathroom and kitchen installation weigh 200 lb, a small occupancy of 1,000 ft^2 would have about 4% by weight of combustible plastic to add to the fire. Where the heat of combustion is low, as in PVC or CPVC, the increase in fire intensity would not exceed 4%. With a higher heat of combustion, such as for ABS, the increase in intensity would remain below 10%. Such changes in the fuel loading will have a negligible impact on the fire-fighting effort because, if the pipes burn, generally it will be after the contents of the rooms have been consumed, thereby generating enough heat and toxic smoke to require protective gear for the firemen. The State Fire Marshal's report (1980) concludes:

> With regard to the protection of fire fighters and the need for additional and/or more specialized fire fighting tools, it would appear that sufficient protection is afforded through the use of self-contained breathing apparatus. This equipment, available to the fire service, does in fact moderate the question of the hazard of the products of combustion to a low toxic risk, since self-contained breathing apparatus is a totally enclosed environment. What is of concern is the hesitancy among some within the fire community to recognize and accept the value of this equipment as a significant and appropriate vocational tool. All too often in their zeal to protect property and to rescue citizens from the effects of unfriendly fire, fire fighters may not exercise the prudence and diligence of donning self-contained breathing equipment to protect themselves from the effects of toxic conditions. In doing so, they not only do a disservice to themselves, but to their fellow fire fighters, as well as those persons who may be threatened by the fire.

Futhermore, the fire fighter should be wearing a breathing apparatus to avoid injury from toxic products generated by the burning concents of the occupancy.

2) Quality of Fire Stopping

Finally, there is the question of nullifying the protective countermeasures by sloppy workmanship or intentional circumvention of the code. Smith (1973) has commented as follows:

> Resistance to fire propagation is no better than the most poorly constructed seal or sleeve. A forgotten cementing job around the outside of a conduit penetrating a wall, or an inadequate fire stop between floors in a pipe chase can negate the value of good design. Note that good fire stops and seals are more important in plastic systems than metal. With poor seals, heat and flame will be forced to flow around the pipe due to the positive pressure on the fire side.

This could quickly melt or burn the plastic conduit or pipe, exposing a much larger opening for flame penetration and transport of smoke and toxic gas. Even with steel pipe in rated construction, fire penetration has occurred. The chance for fire penetration, and the hazard resulting from such a failure, is greater for plastic pipe.

In view of the more stringent design and inspection requirements that are needed to achieve an equivalent level of fire safety, the difference in cost of plastic, compared to metal, systems may be less than some believe.

Such considerations should be considered in the design, testing, and approval of fire stops. Some designs may require too much skill and diligence in installation and inspection to be practical, but all stops should not be forbidden because some are weak. The pastic pipe manufacturers should take responsibility to develop fire stops that can function satisfactorily under average to poor installation conditions. Presumably, some installations will fail, as in the case in all areas of human endeavor, but the plastic pipes should not be required to perform better than other materials and systems allowed in construction.

3. Conclusions

(1) Plastic pipes are more of a fire hazard than their metal counterparts; however, the question is not which type is superior but which systems can be made acceptably fire safe. Besides the extremes of all-metal or all-plastic systems, we can envision a variety of hybrid combinations that use the desirable properties of both metals and plastics; e.g., the commonly used no-hub construction joins cast iron pipes together with plastic sleeves and hose clamps. Our criterion for establishing an acceptable level of fire safety should be applicable to all of these potential systems.

(2) The two potential fire problems, (a) fire spread and growth, and (b) toxic pyrolysis or combustion products, are amenable to countermeasures and mitigation techniques that can reduce the fire hazard to levels currently accepted for other building elements. In fire-rated construction, fire spread is essentially a problem of

(a) penetrations where pipes pass through walls, floors, and ceilings or (b) utility shafts that provide a passage between compartments. Fire spread can be controlled by a variety of fire stops, e.g., noncombustible fittings, sealants, and fixtures that prevent pipe failure or seal the opening if the pipe does fail. Fire stops are not unique to plumbing but apply to all systems that penetrate the fire barriers; in fact, the fire-stop industry has been concerned primarily with electrical cables and their fire-spread problem. Fire stopping is a developing area of the construction industry, and numerous new materials and techniques are becoming available.* Because the plumbing and building codes do not specify fire-stop construction details, it is essential to have a performance test to ensure that the building code criterion is satisfied, namely, that the penetration does not degrade the fire rating of the barrier.

(3) The ASTM E-119 test is adequate to certify the wall and floor penetration fire-stop techniques; however, a modification of the ASTM E-119 test, with the appropriate orientation pressure, and air flow will be required to certify penetration protection in utility shafts.

(4) There are at least four facets to the question about toxic pyrolysis and combustion products from plastic pipes and their contribution to fire deaths. First, the tremendous difference in type and yield of toxicants from the various formulations prevents blanket characterization of the problem, i.e., each formulation requires individual attention. Second, most fire deaths are caused by inhalation of toxic products; however, there are no statistics that specifically implicate plastic pipe. This lack of evidence does not necessarily exonerate plastic pipe. Usually it means that other combustibles, many of which are plastic, were the first to burn.

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* Furthermore, the codes should be written so as to stimulate ingenuity and the development of new and better fire stops.

Without regulating the entire plastic fuel load--e.g., floor, wall, and ceiling coverings; foam insulation; plastic fixtures such as showers, tubs, lavatories, counter tops; electric cables; and furniture--restrictions on plastic pipe will have a negligible effect on the number of fire deaths. Third, most fire deaths occur in non-fire-rated structures,* i.e., where plastic pipe is already allowed. Fourth, in fire-rated construction with adequate fire-stopping systems, toxic product control would appear not to require additional mitigation measures; however, in view of the uncertainties regarding the escape of toxic products, the presence of such gases should be monitored during the fire spread certification tests. Animal tests might be necessary to ensure that a highly toxic combustion product was not overlooked in any nonbiological monitoring.

(5) Economic pressures and competition generally drive performance to the minimum allowable level; therefore, the regulatory agencies, including building inspectors and certification testers, will have to exert extreme diligence to ensure that the acceptable level of fire safety is maintained. During the certification of fire-stopping systems, thought should be given to the potential for and consequences of poor workmanship (such as the negligent installation of the fire stop). This is the time to weed out the marginal systems.

4. Resolving Uncertainties about Fire Spread

As indicated above, plastic pipe could be acceptable from the standpoint of fire safety as long as it passed performance tests for fire rating. The major uncertainties are thus: 1) Are there designs for plastic

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* Deaths in one- and two-family dwellings account for about 77% of total residential fire deaths. Moreover, many of the fire deaths in apartments--which account for about another 19% of residential fire deaths--occur in non-fire-rated structures (Karter, 1981).

installations that will pass existing fire rating tests? 2) Can tests be developed for fire safety of designs not adequately tested by current methods?

Testing of designs for maintaining the ratings while using plastic pipe would normally--or should--be done by plastic pipe manufacturers and/or builders to satisfy building officials collectively (i.e., in connection with building standards) or individually. The questions to be resolved center on instances not at present covered by the UBC:

- Unlike for walls and floor assemblies, there is at present no recognized performance standard for:
  (a) ceilings with pipe penetrations
  (b) other vertical-shaft partitions; i.e., horizontal partitions in vertical shafts or raceways, with pipes penetrating the partition vertically.

Development of official test methods is essential since our general recommendations honor the spirit of performance standards. (Note that (a) and (b) may require different testing methods.)

- As a subitem in the development of a performance standard for vertical partitions, it would be useful to investigate the following:
  (a) How does the performance differ with various ABS compositions? Does composition therefore need to be specified when referring to an accredited ABS prior to permission for use?
  (b) When investigating PVC or CPVC, measure total weight loss ahead of and after partition (possibly weight loss rate or smoke evolution rate), and measure how "leaky" the partition is to smoke. The smoke generation rate is not well known in relation to even the basic structural systems and scenarios as captured, for example, by the ASTM E-119 test.

In general, we insist that safety can be assured only after specific materials and their particular installation methods--in the case of plastic pipes, this includes special protective measures--are tested in the standard performance test, such as the ASTM E-119 test for walls and floors. This has not yet been done officially (in an accredited way), and we leave it up to the state to decide whether this should be done before the EIR process is completed or should be only mandated.

E. Smoke and Combustion Product Toxicity

This part of the environmental review addresses the potential for harm resulting from exposure of people (and corrosion-sensitive materials or appliances) to the products of combustion when plastic pipes and fittings are exposed to a fire environment. As a practical matter, this potential for harm should be viewed in a context of whether significant increase in threat is likely to result when plastic pipe--having replaced pipes of conventional materials in applications where plastic is currently not allowed--accidentally becomes exposed to a fire. Since such questions cannot be answered with much confidence because of uncertainties in the technical state of art, an important goal of this effort will be the identification of information gaps and other sources of uncertainty that may influence the decision whether to allow expanded use of plastic pipe in California.

Our starting premise is that toxic products of pyrolysis and combustion are generated when plastic pipes are exposed to a sufficiently threatening thermal insult. Furthermore, the specific products and their yields will depend on the specific plastic formulation. For example PVC (and possibly CPVC) can generate copious amounts of hydrochloric acid (HCl) whereas ABS, PB, and PE do not. These products can be identified and their yields measured under controlled conditions of thermal insult, but the state of the art does not allow us to relate this information to hazard to life in real fires with much confidence. Hazards to life are usually expressed in terms of a toxicant concentration, a practice that not only oversimplifies the physiology but also fails to account for the influence of the fire scenario. Conditions of the scenario can significantly influence the yield of toxic products from the plastic pipe, introduce complications due to the products from other combustibles, modify the air available for dilution, and affect survival in many complex ways.

1. Expected Toxicants

a. Effects of Pipe Composition and Formulations

All types of plastic materials burn or are decomposed by fire exposure and can produce life-threatening products in a fire environment. Plastic plumbing is no exception. Besides the possible contribution of plastics to the "growth" of the fire, their specific threat to life stems from: (1) specific decomposition and/or combustion products, (2) decreased oxygen concentrations, and (3) impaired visibility. The potential hazards to humans are best evaluated from epidemiological data, when available, supplemented with animal data as necessary. Except for carbon monoxide inhalation, information on clinical toxicity in humans is meager. Thus, it is necessary to resort to animal data, usually determined either with samples of the polymers or with individual combustion product gases, from which combined effects can by synthesized analytically. Although it is reasonable to contemplate animal tests or experiments in realistic fire/smoke environments (National Academy of Sciences, 1977), such tests have not been fully developed as yet. A discussion of epidemiologic and animal evidence on smoke toxicity appears in Section IV-E-4 and in more detail in Appendix F.

Any real fire situation includes a continuously changing environment made up of a variety of hazards combining at least heat, oxygen depletion, and carbon monoxide generation. Other toxicants may also be present in various degrees. These hazards will vary with time and with changes in heating by the fire and either natural or mechanically driven ventilation.

The presence and amounts of the many possible smoke toxicants depend on the presence or absence of specific elements in the polymeric components subject to the thermal insult, the chemical structures involved, and any chemically reactive additives in the original polymer. For example, sulfur compounds--among the most hazardous toxicants in some situations (NASA, 1977)--will clearly not be present in the smoke unless sulfur-containing compounds are affected by the fire. Because nitrogen (N_2) is always present as the main component of air, no analogous exclusion can be made for the also very hazardous nitrogenous compounds. Nevertheless, the possible toxicants are very much limited and predetermined by which polymers are burning and pyrolyzing* (see Table IV-44). All of the pipe compounds can burn to produce carbon monoxide and consume oxygen in the process.

ABS contains nitrogen in its acrylonitrile copolymer, and acrylonitrile is known to produce hydrogen cyanide (HCN) and a variety of volatile nitriles when heated in either pure N_2 or air (Tsuchiya, 1977). Cyanides can also evolve from other household items, for example burning proteinaceous materials like sheep wool. The styrene copolymer may offer no unique hazards; however, styrene polymers do produce dense smoke, and few quantitative data are yet available on either yields or physiological effects of exposure to the combined products from pyrolysis and combustion of styrene-based polymers.

PVC decomposes at relatively low temperatures, producing mainly HCl (in addition to the oxides of carbon when heated in air) but with significant amounts of benzene and toluene (Boettner, 1969). Vinyl chloride is present among the products of pyrolysis. Phosgene has been reported but is not regarded as a serious toxic risk at the levels seen. Although few data are available on CPVC, its products are thought to be qualitatively similar to PVC's but with lower yields of HCl.

Very few data specific to combustion of polybutylene have been found in the literature; but it (like polyethylene) is a polyolefin, and all members of the class are expected to have qualitatively (even semiquantitatively) similar products of pyrolysis and combustion. The combustion of polyolefins has been extensively studied (see, for example, Callis, 1971), and no special physiological threat is evident. Combustion of these polymers has a

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*Pyrolysis is thermal decomposition not accompanied by an overt flame; it often occurs in an oxygen-poor environment.

Table IV-44

EFFECTS OF OXYGEN SUPPLY, TEMPERATURE, AND HEATING RATE ON VARYING COMBUSTION PRODUCTS OF PVC
(Milligrams Per Gram of Product)

Compound	Variation with Oxygen Supply			Variation with Temperature					Variation with Heating Rate	
	Air (30 cm^3/min)	Air (60 cm^3/min)	Air (25 cm^3/min) + O_2 (21 cm^3/min)	25°C to 280°C	280°C to 350°C	350°C to 430°C	430°C to 510°C	510°C to 580°C	(3°C/min)	50°C/min)
Carbon dioxide	861	619	814		9.7	181	244	237	619	397
Carbon monoxide					20	46	151	181		
Methane	6.7	4.7	3.8		0.20	1.3	1.8	0.31	4.7	8.7
Ethylene	0.76	0.53	0.28	0.04	0.33	0.39			0.53	2.3
Ethane	2.6	2.1	1.7		0.12	0.94	0.41		2.1	3.5
Propylene	0.80	0.53	0.28	0.06	0.11	0.31			0.53	1.5
Propane	1.3	1.0	0.66		0.08	0.44	0.11		1.0	1.3
Vinyl chloride	0.51	0.59	0.66	0.04	0.25	0.17	0.02		0.59	0.64
1-Butene	0.25	0.18	0.06	0.02	0.04	0.08			0.18	0.67
Butane	0.53	0.31	0.15		0.03	0.20	0.02		0.31	0.69
Isopentane	0.02	0.02	0.01			0.005	0.001		0.02	0.02
1-Pentene	0.10	0.08	0.04		0.01	0.03			0.08	0.18
Pentane	0.26	0.20	0.11		0.01	0.08	0.01		0.20	0.29
Cyclopentene	0.07	0.05	0.03		0.02	0.01			0.05	0.19
1-Hexene	0.07	0.06	0.03		0.01	0.02			0.06	0.13
Hexane	0.16	0.14	0.09		0.01	0.05	0.01		0.14	0.20
Methylcyclopentane	0.06	0.05	0.03			0.02			0.05	0.08
Benzene	35	31	32	24	6.6	0.35	0.16		31	43
Toluene	1.5	1.1	0.68	0.12	0.18	0.55	0.03	0.01	1.1	3.5

Source: Terrill et al. (1978).

definite potential to produce incompletely oxidized hydrocarbon fragments, such as acrolein, but their yields appear negligibly small when a flame is present (but see Michal, 1976). Even under conditions of local oxygen deprivation, the smoke components are probably not unlike the smoke from a candle after its flame is snuffed out.

b. Effects of Fire Conditions

In any fire involving mixed fuels, toxic combustion products will exist as a complex, heterogeneous mixture of gases, liquid droplets, and solid particulates. From any individual burning material or any materials being merely decomposed by the heat of the fire, the composition as well as the rate of smoke and gases evolved will depend on the rate of heating of the surface and on the local atmospheric oxygen concentration. In composite materials, the character of the smoke is apt to be further complicated by the chemical interactions among its constituents. Numerous examples can be cited where the measured composition of a mixture has deviated greatly from that predicted from the simple addition of the expected products of the individual source components.

The effect of the heat from the fire is to raise the temperatures in the exposed plastics until the surface temperature reaches a point where significant amounts of gases evolve (i.e., pyrolysis occurs); after that point, additional heat may continue to consume the material by gasification (pyrolysis) or further raise the material temperature--or both. Although a popular concept of "pyrolysis temperature" exists and test methods often include exposure of materials to a fixed or a specified rate of temperature rise, the concept is fundamentally flawed. Because of their relatively poor heat conduction properties, plastics generally experience a complex history of temperature change, with different portions of the same material experiencing different temperatures at any one time. Because of their tendency to soak up heat in the process of volatilization, plastics experience a rather limited range of temperatures while pyrolyzing in the fire; in other words, temperatures do not continue to rise indefinitely.

Once the heated surface reaches a critical temperature--which depends on the material's energy of activation for rapid pyrolytic breakdown and, to a lesser degree, on the rate of external heating--the temperature levels off or increases only slowly, depending on whether a char or other nonvolatile residue develops at the heated surface. From this point on, while heating continues, the rate of evolution of volatile pyrolysis products becomes roughly steady and the composition tends to remain roughly fixed until the reservoir of undecomposed polymer begins to be depleted. Thus, the driving force of smoke production is heat flux, and the rate of smoke production is more nearly proportional to the area of material exposed to this heating than to the total mass present in the fire.

The more heat needed to activate pyrolysis or to volatilize the constituents, the more slowly will smoke evolve under a given fire exposure. Char-forming materials also slow the evolution of smoke by somewhat different means. All such heat-resistant materials may offset any special toxicity with a much reduced tendency to generate volatiles (smoke), often combined with improved performance with respect to ease of ignition, flame spread, heat release rates, and so on. Conversely, easily pyrolyzed polymers, even if their smoke is relatively less toxic, may actually represent the more serious hazard potential because they generate smoke at such large rates, ignite so readily, and burn with such vigor.

As a reasonable first approximation, we will assume that smoke composition (but not rate of generation) is independent of heat flux, within the rather limited range of interest to fire exposure problems, but strongly dependent on (1) local concentrations of oxygen--i.e., is the fire in a room that is oxygen starved or is it causing oxygen depletion elsewhere--and (2) whether or not flaming occurs. Thus, in the selection of data, we have favored experiments using pyrolysis in air over pyrolysis in nitrogen; second, we have favored results from any experiments in which an attempt was made to simulate fire conditions--and attention paid to whether flames resulted--over those from classical laboratory techniques such as tube-furnace heating.

c. Toxicants from Fires Involving Plastics

The following list summarizes acute* toxicants to expect when plastic pipes are exposed to a fire:

- ABS: CO, HCN, and volatile nitriles
- PVC and CPVC: CO, HCl
- PB and PE: CO.

In all cases, carbon dioxide (CO_2) is produced and may contribute significantly to the acute toxicity load; one or more sulfur compounds, such as sulfur dioxide, carbonyl sulfide, and hydrogen sulfide, are likely to be present whenever sulfur compounds are incorporated in the pipe resin (as, for example, thioglycol-based stabilizers and antioxidants).

2. Toxicant Yield

a. ABS Toxicants

Gross et al. (1969) have reported yields of the major toxicants produced by burning aircraft materials, including some ABS formulations. Conditions were those of the NBS/Aminco smoke chamber, with 2.5 watt/cm^2 of applied radiant intensity to flat specimens with an exposed area of 42.4 cm^2; exposure resulted in flaming ignition. They used Draeger tubes to analyze the resultant smoke mixture. Runs lasted up to 15 minutes, and concentrations of carbon monoxide were typically a few hundred parts per million at the peak; HCN concentrations were much lower (tens of ppm). In

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*"Acute" is defined as highly toxic when only a small amount is present but not cumulative from one exposure to the next.

one case, oxides of nitrogen were observed at concentrations comparable to HCN. Spurgeon (1975) criticized the use of Draeger tubes for the analysis of HCl, HCN, and NO_2, finding that they grossly underestimate the concentration levels of these gases, especially when aerosols are abundantly present in the smoke. He showed HCN concentrations as indicated by Draeger tubes to be too low by factors of 4 to 5.

We have been unable to find fully suitable data for yields of toxicants from ABS. Perhaps the best, but still not closely germane, data are those reported by Tsuchiya and Sumi (Tsuchiya, 1977) for polyacrylonitrile decomposed in air. They report yields (i.e., fraction of polymer weight loss) of over 10% HCN at representative "test temperatures" and substantial yields of a variety of volatile nitriles, notably acetonitrile, acrylonitrile, methacrylonitrile, and glutaronitrile. Pending better data, we will assume a yield of HCN of 0.1 based on the polyacrylonitrile portion (only) of the ABS formulation in question, along with 1:1 volume ratio of combined volatile nitriles to HCN. Neglect of any oxides of nitrogen may be justifiable on the basis that they probably are formed at the expense of HCN and nitrile yields, and their potencies are comparable. A value of 0.3 (weight basis) for CO yield is an appropriate approximation for all ABS pipe resins unless contradictory evidence exists.

Although large variations are noted in fire-relevant data for fuels of various composition, a value of 30% CO yield is a high-side estimate for many organic fuels. For ABS and many other examples, this yield corresponds to a situation in which one carbon atom in six, converted by the burning process, appears as CO in the final mixture of airborne products. Accordingly, if the bulk of the carbon is, at the same time, converted to CO_2, the molar CO/CO_2 ratio would be about 0.2, which is consistent with many reported measurements in test fires.

b. PVC and CPVC Toxicants

Boettner et al. (1973) report that nearly all of the chlorine in PVC appears as HCl in combustion, "independent of air conditions." They also note that (1) production of benzene roughly parallels in time that of HCl and (2) heating rate has no significant effect on the amount of HCl produced. Yields of carbon monoxide from PVC under laboratory conditions of oxidative pyrolysis are often reported to be in excess of 400 mg/g of polymer weight loss, and comparable on a molar basis to carbon dioxide (see, e.g., Boettner et al., 1973). However, Boettner's data also show reduced CO yields under conditions of reduced air flow as well as under conditions of increased heating rates, both of which may be more representative of fires. Tewarson's data (1979a) from his 80-cm^2-cross-section burning rate apparatus (with PVC burning in an air supply) indicate CO yields of only about 6% of the stoichiometric limit, while CO_2 yields were over 30%. It should be noted, in addition, that such comparisons are not always valid because combustion product yields are also dependent on PVC formulations, which are subject to substantial variation. Nevertheless, 40% yields of CO are viewed as unrealistically high for fire conditions. We will take the yield values 0.58 by weight for HCl, 0.3 by weight for CO, and 0.03 by weight for benzene as representative of both PVC and CPVC combustion, recognizing that the lack of data on CPVC is a major uncertainty at present.

c. Polyolefin Toxicants

As previously noted, CO is the only toxicant considered in this preliminary overview, and its yield has been assumed, universally, to be 0.3 by weight.

3. Toxicant Concentrations in Fires

Translating toxicant yield to toxicant concentrations in real fires, and then to expected effects on people, is hampered by lack of data and the extreme complexity of the processes involved. Potential hazards must be inferred from model studies, with limited experimental confirmation.

a. Role of Fire Scenario

In attempting to estimate the toxic effects of plastic pipes in fires, many scenario variables are involved, and the result of any estimate is highly dependent on the set of circumstances assumed. For example, concentrations will vary with both time and location relative to the point of generation (source) of the toxicant vapors. Moreover, the characteristics of the source will vary greatly among different sets of fire exposure conditions (or circumstances), such as between the two quite different cases when the fire starts in a room adjacent to the enclosed pipe chase or starts within the chase. Nevertheless, it is possible, in principle, to estimate concentrations (in space and time) given sufficient information.

Highly sophisticated computer models have been developed in the past few years for carrying out numerical computations of smoke movement and dispersion mechanics within buildings (Zukowski, 1978) or to establish design criteria based on such life-safety concepts as safe egress times (Cooper, 1981). These are best applied to specific buildings and expected events, but they are not very (if at all) amenable to generalization and are therefore of limited usefulness in a study such as this environmental review. Models of fire conditions in the areas where fires start ("compartment or fire origin") are better suited to generalization as well as being more highly developed theoretically. Since these models can serve as "source" elements for detailed smoke movement calculations, their development is of considerable interest. A very recent treatment (Cooper, 1982) provides a relatively simple model of hazard dynamics in the compartment of fire origin. In the course of this study, we have further simplified this "source element" part of the problem to provide "ballpark" estimates of toxicant concentrations in the compartment of origin.

Still, the combustion product information needed to answer questions of environmental impact potential does ultimately entail estimates of toxicant concentrations and time histories <u>outside</u> the compartment of origin as well. These estimates are needed because the conditions in (or very near to) the compartment of fire origin so quickly exceed human tolerance, in several respects nearly at once, that any contribution of toxic combustion products to the immediate hazard is usually inconsequential. Therefore, although the character of the smoke source determines the character of the threat in the more remote locations, any attempt to quantify the threat level requires a resort to scenario selection and, to a substantial extent, to specific case-by-case analysis.

The following three scenario types were chosen as representative of the proposed expanded use of plastic pipe:

(1) Fire in a room, with plumbing within fire-resistive separations (walls or other fire-resistive construction).

(2) Fire in a room with some plumbing exposed or concealed by non-fire-resistive construction.

(3) Fire within a concealed space (e.g., utility chase) containing plastic plumbing.

b. Fire in Room, with Plumbing Within Fire-Resistive Separation

A major potential change in the application of plastic pipe would be its use, in place of metal, in concealed locations (e.g., utility chases) in buildings of fire-rated construction. Clearly, a fire can start on either side of the fire-rated separation, but the odds favor a fire starting in the room rather than in the concealed space where the pipe is located (California State Fire Marshal, 1980). To become an actual toxic-product threat to the occupant of the building, the pipe must burn or decompose to generate airborne toxicants as a result of heat coming through the wall from the fire in the room. The discussion below centers on how significantly the pipe in the fire-resistive wall may be involved with the fire in the room.