Comments of

COALITION FOR SAFE BUILDING MATERIALS

(California Pipe Trades Council, California Firefighters Association, Consumer Federation of California, Planning and Conservation League, Center for Environmental Health, Sierra Club of California and Communities for a Better Environment)

on the

ADDENDUM TO ADOPTED MITIGATED NEGATIVE DECLARATION
STATE CLEARINGHOUSE NO. 2000091089
FOR
CHLORINATED POLYVINYL CHLORIDE (CPVC) PIPE
USE FOR POTABLE WATER PIPING IN RESIDENTIAL BUILDINGS

VOLUME VII

APPENDICES TO THE COMMENTS OF
ADAMS BROADWELL JOSEPH & CARDOZO:
(1983 SRI International Environmental Review of Proposed Expanded Uses of Plastic Plumbing Pipe)

April 22, 2005

ENVIRONMENTAL REVIEW OF PROPOSED EXPANDED USES OF PLASTIC PLUMBING PIPE

March 1983

Prepared for:

State of California
Department of Housing and Community Development
P.O. Box 1407
Sacramento, CA 95801

Attention:

Michael C. McMillan, Project Coordinator

SRI Project Number HSH-4910
Contract 82-8-013

Submitted by:

Stephen L. Brown, Project Manager
SRI International
333 Ravenswood Avenue
Menlo Park, CA 94025

002765A

SRI International

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PREFACE

This document reports an environmental review of a proposed action by the California Department of Housing and Community Development (DHCD) to adopt regulations allowing selected new applications of plastic plumbing pipe. The review was conducted by SRI International of Menlo Park, California.

Although cast in a format similar to that of an Environmental Impact Report (EIR), it is not yet even a draft EIR. This environmental review provides an overview of existing information about the environmental implications of the new applications of plastic pipe, and identifies areas where better information is needed.

The review contains SRI's recommendations for testing that can be completed in reasonable time and that would be useful in making a more confident assessment of the environmental impacts of increased use of plastic plumbing pipe. DHCD, with advice from the Plastic Plumbing Pipe EIR Task Force, will decide which tests to carry out. After test results are available, SRI will update and modify this environmental review; DHCD will then issue a Draft EIR for public review and, after considering the comments received, will issue the final EIR.

Both DHCD and SRI encourage comments on this document and later on the Draft EIR. The purpose of the entire EIR process is to provide information useful for the state's decision on the proposed expanded uses of plastic plumbing pipe, and it is important for the Final EIR to be as accurate and complete as possible.

However, it is also important for readers to recognize two significant aspects of this or any EIR. First, the EIR itself does not make the

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ultimate decision on the proposed action. It presents the facts, as far as they are known, about the environmental impacts of the proposed action, but the state will combine that information with other considerations to determine whether to permit additional applications of plastic plumbing pipe and, if so, which ones. Second, an EIR, even in final form, can never be entirely definitive about the impacts of a proposed action. The nature of decisionmaking about such actions requires a balancing of evidence, much of which is uncertain. Nevertheless, the EIR attempts to clarify all uncertainties that are critical to the decision.

Therefore, we have attempted in this document to explain both the nature of the impact issues that have been raised and the meaning of the uncertainties about them. Furthermore, because this proposed action is unusually complicated and controversial, we explore the subtleties of the action more than is usual so that the state can make a better and more defensible decision and the public can make a more informed response.

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SUMMARY

The California Department of Housing and Community Development (DHCD) is proposing to allow certain expanded uses of plastic plumbing pipe in residential construction. The principal changes are to allow polybutylene (PB) and chlorinated polyvinyl chloride (CPVC) pipe in hot and cold potable water supply systems inside dwellings and to allow acrylonitrile-butadiene-styrene (ABS), polyvinyl chloride (PVC), and CPVC pipe in drain, waste, and vent (DWV) applications in fire-rated construction. Currently, only PVC and polyethylene (PE) are allowed for water supply, and only outside of residences; ABS and PVC are allowed for DWV, but only in non-fire-rated structures.

If adopted, this state-level action would stimulate similar changes in the plumbing codes of most local jurisdictions in California, and substantial use of the newly approved materials, especially PB for potable water and ABS for DWV in fire-rated buildings, would be expected. These materials would replace copper potable water pipe, cast iron DWV pipe, smaller quantities of galvanized steel water and vent pipe, and/or copper drain pipe, and minor quantities of the plastics currently allowed.

DHCD is currently assessing the environmental impacts that might stem from the proposed expanded uses for plastic pipe, and will be preparing an Environmental Impact Report to document the impacts of the proposed actions. This environmental review is a summary and evaluation of current knowledge about those impacts. The principal areas of concern about plastic and metal piping systems are:

- Possible impacts on public health of chemicals entering drinking water from pipe, pipe-joining materials, or surrounding contaminated soils.

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- Possible illness or injuries in plumbers as a result of installing pipe.
- Extent of danger from fires, as a result of either fire spread or smoke toxicity.
- Possible fiscal impacts on the price of housing and the employment of plumbers and pipe manufacturers.
- Other impacts such as energy consumption in pipe manufacture and use, or noise in plastic drain pipe.

Preliminary analysis indicates that, although there is little evidence to suggest clearly unacceptable environmental effects from adopting the proposed new code, neither is there a sufficient body of laboratory and field investigations to alleviate all concern. Important gaps in knowledge--not unusual in the EIR process--will have to be considered in making the final decision, even after the results of proposed testing are available. Our tentative conclusions and recommendations are summarized below.

Scores of chemicals have been reported as leaching from plastic pipe and solvent cements into drinking water, but substantial disagreement exists about both the validity of the findings and the interpretation of the concentrations found. Existing data are adequate to establish substantial leaching for only a few chemicals. Of these, carbon tetrachloride, perchloroethylene, and trichloroethylene appear to have sufficient toxicity to be of possible cumulative concern at the levels suspected. However, we recommend additional water quality testing to clarify both the levels of those substances and those of other suspected and as yet unknown ones. For metal pipe, lead from solder joints in copper piping is a leachate of potentially serious concern, but its significance cannot be fully assessed without better data on leaching from new copper water piping. We are somewhat more concerned about the chlorinated leachates from CPVC than about any leachates from PB, but at this point we cannot predict whether either will cause significant public health impacts. Our information on permeation of water pipe by soil contaminants is too sparse to draw any conclusions

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except that impacts from the expanded uses must be considered in the context of any impacts already incurred from existing plastic distribution and external water supply lines.

The effects of plastic versus metal pipe on worker safety and health are also in substantial doubt, principally because of an almost complete lack of information about worker exposures, and we are recommending testing to determine those exposures more accurately. Current evidence makes it relatively clear that plastic pipe is preferable to metal pipe in terms of worker safety because strains and contusions from heavy metal pipe, as well as burns from soldering copper pipe, would be more frequent than injuries from working with plastic. Health implications are much less certain: both respiratory and skin exposures to solvent cements and respiratory exposures to soldering fumes could be, but have not been proved to be, unhealthful. Here the only clear findings are, first, that PB is preferable because it is mechanically, not adhesively joined, and, second, that cast iron would cause very little health impact unless the antiquated bell-and-spigot/lead-packing technique is used.

Plastic pipe is more susceptible to fire damage than is metal pipe, although cast iron drain pipe is often joined by a "no-hub" gasket connection that can fail in fires. If installed as a direct substitute for metal DWV pipe, plastic will allow faster fire spread by burning or slumping at wall penetrations. On the other hand, the proposed code calls for fire rating to be preserved in so-called "fire-resistive construction"; if techniques for preserving the rating are implemented--such as the use of metal sleeves or fire closures at wall penetrations--then the plastic will by definition be acceptable in this regard. We recommend that manufacturers and distributors of plastic pipe demonstrate specific systems for preserving fire integrity and that these systems be the basis for passing fire safety inspections. We believe that water supply pipe represents such small quantities of plastic in a system and is so naturally cooled by the water

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inside that it is not a significant part of the fire spread problem. Furthermore, on the DWV side, PVC and CPCV are likely to be slightly more fire-resistant than ABS.

With respect to smoke toxicity, the situation reverses. The combustion products from ABS, although containing cyanide and some other hazardous materials, are much less toxic than the hydrogen chloride gas from decomposing PVC and CPVC. Although there would be some toxic smoke from pipe-joining compounds in metal systems, it would be an insignificant amount. We currently believe that the extra smoke from plastic pipe in multistory fire-rated construction would be unlikely to lead to a significant increase in fatalities or long-term incapacitation, either to occupants or fire fighters, when their ability to escape other fire hazards is considered. However, the hydrogen chloride hazard will not be well understood until more agreement on an acceptable test for smoke toxicity is reached, and we recommend that any decision be reconsidered when results from generally accepted tests on plastic pipe are reported. Meanwhile, fire fighters--who may be chronically exposed to smoke toxicants and be more subject to long-term illness--should be encouraged to use the breathing equipment provided them.

Although the life cycle cost of plastic pipe appears to be marginally less than that of metal pipe in typical residences, the difference is not sufficient to generate any increase in residential construction or to induce significant growth in California's population through lowered housing cost. Small shifts will occur from employment in metal pipe industries to that in plastic pipe industries, and a small decrease in the work available to plumbers will occur, principally because it is easy for do-it-yourselfers to install, replace, and repair plastic plumbing. None of these impacts appears to be significant as a state issue.

Among the miscellaneous other impacts, there will be a small decrease in total energy use and a small increase in petroleum use if plastic becomes more common. Plastic DWV appears to be noticeably noisier than cast iron in otherwise identical installations, and may be annoying in the multifamily

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residences most likely to be fire-rated and affected by the code changes. Neither these nor other potential impacts are considered significant, however.

In summary, no clear environmental preference between plastic and metal pipes has emerged from our investigations, but some concerns about both types remain from lack of information. Even after the recommended testing, residual uncertainties will exist, and DHCD will need to balance the possible residual risks against the benefits of allowing more flexibility in the choice of plumbing materials.

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I INTRODUCTION

A. Plastic Pipe in California

Plastic pipe is widely used for plumbing systems in California. In some communities, it is allowed for virtually every application for which it is technically feasible. In other communities, almost no plastic piping is allowed, at least in residential uses. The official state position for residential applications is that certain types of plastic may be used in drain, waste, and vent applications inside dwellings that are not rated with respect to their fire safety and that other types may be used outside buildings for cold water supply to the dwelling or for irrigation. Thus, a homeowner can easily purchase ABS* drain pipe or PVC water pipe at a building supply store, and contractors use large amounts of such pipe and fittings. In fact, it is very rare to find conventional pipe (cast iron drain pipe, galvanized water pipe, and so on) in drain, waste, and vent or external water supply applications any longer.

On the other hand, the state does not allow plastic pipe for hot and cold water supply inside buildings, nor does it allow plastic pipe of any sort in residences that are fire-rated (generally, any residential building of three stories or more). Even though local jurisdictions are allowed under certain circumstances to permit uses that the state does not, the uses not approved by the state are not widespread in California. In this respect, California is somewhat unusual, in that many states allow plastic water pipe inside buildings. In California, copper and galvanized pipe are

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*Both the types of pipe involved and their applications, as well as the approval authorities, will be described more precisely and in greater detail in later sections.

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still common for water supply, and metal pipes will also be found for drains in fire-rated buildings.

The state is currently considering allowing additional uses of plastic pipe, but it is concerned that unacceptable environmental impacts could occur as a result of this proposed action. Therefore, the state has commissioned this environmental review before preparing an Environmental Impact Report (EIR) for the action.

B. The Role of State Government*

In California, the state government has the authority to preempt local government on matters of building codes and standards but ordinarily allows local jurisdictions wide latitude within broad guidance, unless issues of public safety are involved. The state's authority in the arena of building codes and standards is given by the State Health and Safety Code, which authorizes the State Housing Law. The State Housing Law in turn grants the authority to the Department of Housing and Community Development, which issues regular guidance to local jurisdictions in the form of various codes:

- Housing Code
- Mechanical Code
- Plumbing Code
- Building Code
- Electrical Code.

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*The first two paragraphs in this subsection are based heavily on conversations with M. E. King (1983) of DHCD; any errors in interpretation, however, are the authors'. (Full references for cited sources can be found in the Bibliography, Section VII.)

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A National Fire Code also affects building in California, but the state has no formal fire code.

The Department of Housing and Community Development (DHCD) has the lead responsibility for control of plumbing standards in California. Under the authority of the State Housing Law, DHCD reviews and adopts, with suitable amendments, proposed model codes such as the Uniform Plumbing Code (UPC) issued every 3 years by the International Association of Plumbing and Mechanical Officials (IAPMO). After concurrence by the California Building Standards Commission, local jurisdictions have a year to adopt the state code or amend it on a finding of compelling local need, such as unusual water quality. At present, DHCD has no authority to dispute such amendments. Moreover, DHCD's influence extends technically only to residential building codes, including hotels and motels; it affects standards for commercial and other construction only indirectly through association (the UPC, for example, is intended to apply to commercial as well as residential construction).

In order for the state to modify the Plumbing Code and have it take effect at the local level, a complex series of interactions must take place. The principal steps are outlined in Figure I-1, which shows the organizations and authorities involved.

In addition to following the formal process, DHCD seeks the advice of various other state agencies with interests in the use of plumbing materials in California. Federal agencies with responsibilities in California are also interested. Interested agencies and their areas of interest are listed in Table I-1. Certain of these agencies are formally represented on the Plastic Plumbing Pipe EIR Task Force, which also includes representatives of various interested nongovernment parties. The membership of the Task Force, which advises DHCD during the development of the EIR, is shown in Table I-2.

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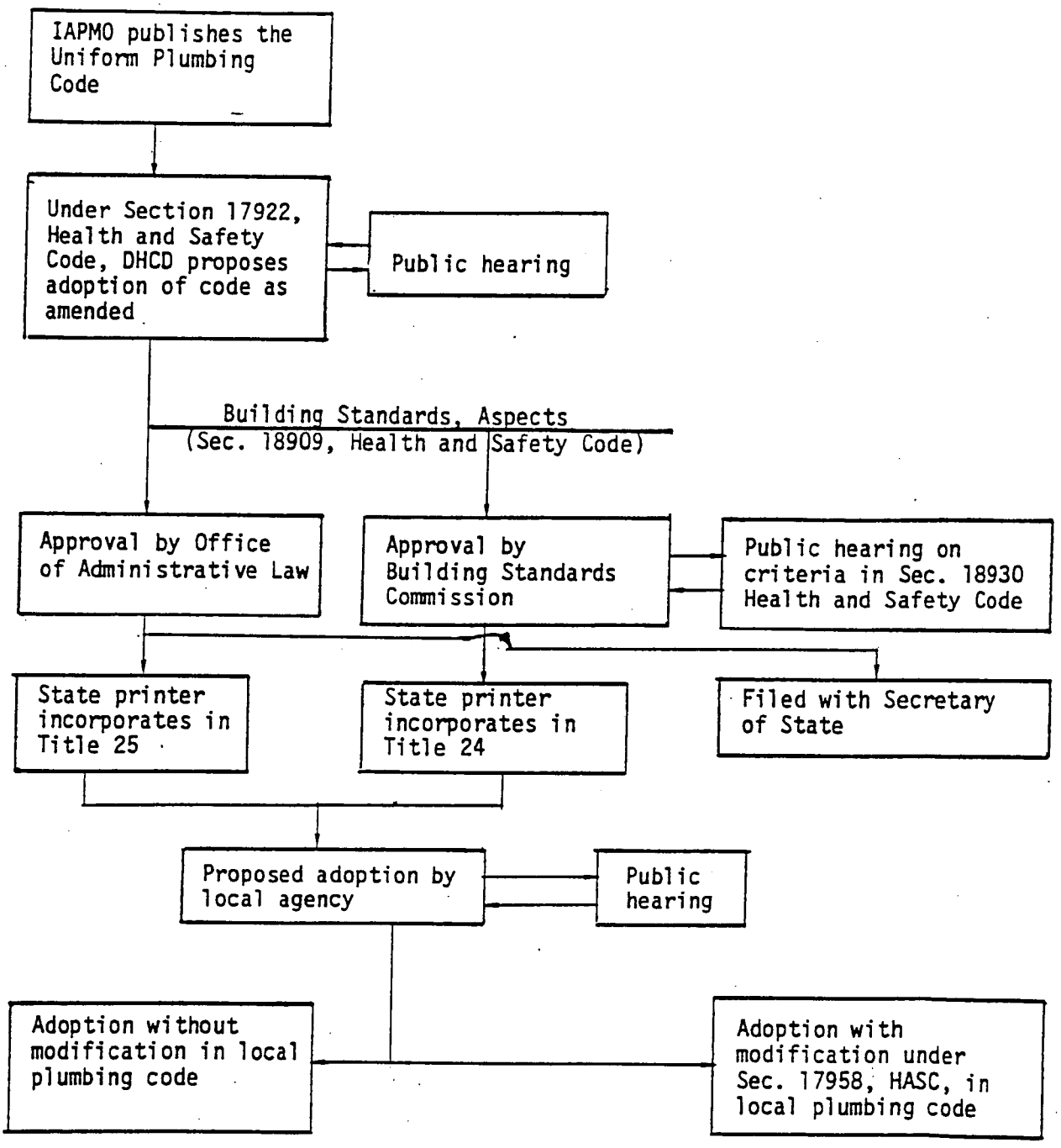

FIGURE I-1 ADMINISTRATIVE ACTIONS REQUIRED FOR PLUMBING CODE CHANGES

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Table I-1

INTERESTED AGENCIES

State of California	Area of Interest
Air Resources Board	Air quality
Building Standards Commission	Impact on standards
California Energy Commission	Relative energy consumption
Department of Conservation	Ecological impacts
Department of Consumer Affairs	Public health and safety
Department of Fish and Game	Water quality
Department of Health Services	Public health
Department of Industrial Relations	Worker health and safety
Office of Planning and Research	General interest
Office of Statewide Health Planning	Public health
Office of the State Architect	Building standards
Solid Waste Management Board	Hazardous wastes
State Fire Marshal	Fire spread and smoke toxicity
State Water Resources Control Board	Water quality
U.S. Government	
Environmental Protection Agency	Public health and environmental quality

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Table I-2

PLASTIC PLUMBING PIPE EIR TASK FORCE MEMBERS

Myron Moskovitz
Hearing Officer and Task Force Chairman
Department of Housing and Community Development

Thomas R. Adams
Adams, Broadwell & Russell
Representing Local 467, Plumbers and Steamfitters Union

Paula C. Dunnigan
The B. F. Goodrich Company
Representing the Society of the Plastics Industry

William J. Hayes
Acting Director
Department of Consumer Affairs

William G. Holliman, Jr.
McDonough, Holland & Allen
Representing Shell Oil Company

Raymond J. Leonardini
Leonardini & Fathy
Representing the California Pipe Trades Council

J. David Quinton
Department of Health Services--OLEHP

David Spath
Department of Health Services--Sanitary Engineering

William Steffan
Division of Occupational Safety and Health

John B. Stohlton
Hoge, Fenton, Jones, & Appel
Representing Monsanto, Dow Chemical,
Borg-Warner Chemicals, and U.S.S. Chemicals

Edna Walz
State Attorney General's Office

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C. Project Background

The following history is excerpted from the Request for Proposals issued by DHCD to procure the services of a contractor to develop the basis for an EIR for expanded uses of plastic plumbing pipe in California.

> Applications of plastic pipe for water supply can be grouped into three major categories: public utilities, mobilehomes and recreational vehicles, and dwellings and structures. In the 1960's, the State Public Utility Commission approved the use of selected plastic pipes by public utilities for water distribution systems. During the same period, the Department of Housing and Community Development approved the limited use of plastic pipe in mobilehomes and in recreational vehicles. The Department is now considering whether to allow the expanded use of plastic pipe in dwellings and structures, expanded beyond the limited applications provided in the 1979 Uniform Plumbing Code (and adopted into State Housing Law) to those proposed in the 1982 Uniform Plumbing Code.
>
> . . . . . .
>
> The Commission of Housing and Community Development was established in 1971 to assist the legislature and provide a public forum to find solutions to critical housing issues. Composed of nine governor-appointed individuals, the Commission met at monthly public meetings to adopt changes in the rules and regulations of the State Housing Law and other housing-related laws under their jurisdiction.
>
> Since 1977, the Commission has held hearings and taken evidence, both oral and written, on whether to approve the expanded use of plastic pipe for drinking water intake pipe, and drain, waste, and vent pipe. In 1978, the Commission filed a Negative Declaration[*] on the use of plastic pipe. However, further questions were raised about the safety of such use, and in October, 1980, a draft report of tests performed by the James M. Montgomery Laboratory for the California Department of Health Services was presented to the Commission. These tests disclosed new information about the leaching of toxic materials from plastic pipe into drinking water.
>
> Based on the Montgomery report and other evidence received, on November 24, 1980, the Commission determined that new information to the project contained substantial evidence upon which it

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*An administrative action stating that no significant adverse environmental impacts are expected and no EIR need be prepared.

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could be fairly argued that the project may have a significant effect on the environment. Accordingly, the Commission determined to require an EIR prior to the approval of the use of PVC, CPVC, and ABS for drinking water and/or drain, waste, and vent pipe. On April 20, 1981, the Commission voted to also require the preparation of an EIR for PB pipe. The kinds of plastic now under consideration are polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), chlorinated polyvinyl chloride (CPVC), polyethylene (PE), and polybutylene (PB).

During 1981, however, the State Legislature removed funding for the Commission. The Department of Housing and Community Development, as the logical successor agency to the Commission, has given assurances that it would continue work upon the plastic pipe EIR without interruption and would follow that process through to completion. Myron Moskovitz, former chairman of the Commission, has been appointed State Hearing Officer on the plastic pipe issue as well as chairman of the plastic pipe EIR task force.

. . . . . .

A brief review of the more significant evidence that was presented to the Commission concerning the need for an EIR will give a clearer understanding of the likely scope of the EIR. Allegations were made that the solvent used to glue plastic pipe as well as the different types of pipes themselves leached hazardous chemicals into the water supply. The James M. Montgomery report was a study of what actually leached from PVC and CPVC plastic pipes and the solvents used to join them. The following solvents used to join plastic pipe were detected by Montgomery in water stored in this pipe: methyl ethyl ketone (MEK), tetrahydrofuran (THF), dimethyl-formamide (DMF) and cyclohexanone. In addition, other chemicals of concern were detected such as chloroform, carbon tetrachloride, tetrachloroethene, and trichloroethene. . . . Evidence was also submitted indicating that DEHP [diethylhexyl phthalate] is found in PB pipe. Finally, there was evidence which suggested that acrylonitrile could leach from ABS pipe. The potential hazards associated with the use of ABS and PB pipes is not as well known since they were not part of the Montgomery study.

The California Department of Health Services prepared a report for the Commission based on the results of the Montgomery study. The report discussed the potential dangers to the public and to workers installing plastic pipe. The Health Services report concluded that if adequate flushing of the piping system is performed prior to occupancy of a dwelling, substantial reaccumulation of solvent concentrations to potentially toxic levels is unlikely and normal water usage is likely to further prevent the buildup of toxic levels of any of the major solvents.

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Based upon field studies by the State Division of Occupational Safety and Health Administration, the Department of Health Services concluded that adverse worker health effects from inhalation of the major solvents is unlikely based on their relatively low toxicity and field measurement of worker exposure. The Department noted that further study was necessary to draw conclusions about suggestions made that there is a higher incidence of cancer among workers exposed to the solvents. Finally, the report also noted that some workers may not wear adequate protective gear such as rubber gloves when working with the solvents, raising the possibility of dermal exposures that were not part of the field study.

Another major issue of concern regarding the approval of the expanded use of plastic plumbing pipe is fire safety. In May 1980, the State Fire Marshal prepared a report on the fire hazards of plastic pipe. The report concluded that the use of plastic pipe in non-fire-rated construction, whether in residential, commercial, or industrial occupancies, did not present an unusual fire risk. The State Fire Marshal, however, concluded more fire testing was needed on the fire safety of plastic pipe in three or more story fire-rated construction. More testing was needed to ensure that plastic pipe will not contribute to unusual fire spread and that the toxicity generated by the combustion of plastic pipe will not extend beyond the area of initial exposure in quantities sufficient to prove hazardous.

D. Environmental Review

Prior to preparation of a formal EIR for the proposed action to allow expanded uses for plastic plumbing pipe, SRI International of Menlo Park, California, has prepared this environmental review of the proposed action. It attempts to review and interpret available information about the likely environmental consequences of shifting toward increased use of plastic pipe and decreased use of conventional metal pipe in those applications that would be newly allowed by the state's action. SRI also attempts to identify the major uncertainties regarding those environmental consequences and to assess what tests could yield significant information for the EIR within a reasonable time.

Section II of this document discusses the proposed code changes and their likely consequences, both in administrative terms and in terms of the actual installation and use of the newly approved materials. Section III

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sets the environment in which the proposed changes could exert their effects by characterizing the manufacture, installation, and use of conventional and plastic pipe systems. Section IV discusses in detail the possible areas of environmental impact, focusing most strongly on the issues agreed by SRI and DHCD to be of prime concern: water quality and public health, worker safety and health, fire safety (including smoke toxicity), and fiscal impacts. The section also describes possible mitigation measures for potentially significant effects. Section V presents the conclusions of the study, as prescribed by the California Environmental Quality Act (CEQA); at this stage, these must be considered preliminary and subject to change in the draft and final versions of the EIR. Testing needs, as well as other information gaps that must be considered in the final decision, are discussed in Section VI. Section VII is the Bibliography, and other useful information is presented in the Appendices.

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II PROJECT DESCRIPTION

This section explains the administrative action being proposed that would allow greater use of plastic pipe in California. Although the action in itself is not a "project" with direct environmental consequences, it provides the impetus for a series of actions that could eventually result in changes of plumbing materials, which in turn have the potential for causing environmental effects. The first subsection describes the proposed code changes and other administrative actions that may result from them; the second provides estimates of the shifts in use of plumbing materials that could occur as a consequence. The growth of population in communities allowing plastic pipe is projected in the third subsection, and additional assumptions are presented in the fourth.

A. Proposed Code Changes

In the simplest terms, the subject of this environmental review is a change in the 1982 Uniform Plumbing Code (UPC) that, if adopted by the California Department of Housing and Community Development (DHCD), would permit certain new uses of plastic plumbing pipe in dwellings in California. The principal issue, therefore, is the extent to which adopting the proposed changes would affect the quality of the natural and human environment, through increased use of plastic pipe and corresponding decreased use of pipes made of metal or other materials. (No restrictions on the use of piping materials currently allowed are proposed.) To provide a factual basis for deciding whether to approve the proposed new applications of plastic pipe, DHCD has commissioned studies both of the primary impacts of making, installing, and using the pipe and of such secondary impacts as effects related to manufacture of pipe system constituents or changes in demand for housing stimulated by lower pipe

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prices. In this analysis, the potential impacts of the expanded use of plastic pipe must always be considered in comparison with impacts traceable to the continued use of metal and other currently approved pipe materials that might be displaced by plastic pipe under the proposed code changes. Furthermore, the narrow action of approving limited new uses of plastic plumbing pipe must be seen in the broader context of plastic pipe and metal pipe manufacture and use in general.

The proposed action technically covers only piping used in dwellings and other residential structures such as hotels and motels; it does not affect the piping allowed in public water distribution and wastewater collection systems, mobile homes and recreational vehicles, or commercial and industrial applications. Nor does it affect uses of plastic conduit for electrical wiring applications or any other applications of plastic tubing. However, action by the DHCD to allow plastic pipe for residential applications also may stimulate use in commercial buildings, which are covered by the UPC. Specifically, the proposed action concerns cold and hot potable-water (PW) supply lines from the water meter to the plumbing fixtures, and drain, waste, and vent (DWV) lines from the fixtures to the local sewer line, septic tank, or cesspool.

Five types of plastic have been used or are proposed for residential use in California in water supply and DWV applications: acrylonitrile-butadiene-styrene (ABS), polybutylene (PB), polyethylene (PE), polyvinyl chloride (PVC), and chlorinated polyvinyl chloride (CPVC). PE, a relatively flexible pipe often sold in black coils, is currently allowed by the state code only for cold water supply outside a building, and no expanded use is proposed. At the opposite extreme, neither PB, another flexible black polyolefin pipe, nor CPVC, a rigid, usually gray or tan pipe, has been allowed by the state code previously. Both types of plastic are proposed for use in exterior and interior hot and cold water supply but not in exposed locations in buildings that are of fire-rated construction. (PB is specifically named in the 1982 UPC; CPVC would fall in the "other approved materials" local option.) In addition, CPVC is proposed for DWV applications outside buildings, inside buildings that are not fire-rated,

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and inside fire-resistive construction in fire-rated buildings. ABS and PVC are the most commonly used materials in plastic pipe today: ABS, usually black, is currently allowed for DWV applications in all but fire-rated buildings. The new code would allow ABS for DWV use in fire-resistive construction in fire-rated buildings, but would not permit its use for water supply. PVC, the white pipe used extensively in sprinkler systems, is currently allowed for cold water supply outside buildings and for DWV applications except in fire-rated construction. As in the case of ABS, the proposed changes would allow PVC use in fire-resistive construction in fire-rated buildings. Table II-1 summarizes the existing and proposed applications of plastic pipe; Exhibit II-1 shows the detailed changes in the UPC that are proposed for the state code.

Strictly speaking, changing the state plumbing code provides only the potential for environmental impacts. Before such impacts are realized:

- The California Building Standards Commission must ratify DHCD's action.
- Local jurisdictions must adopt or amend the provisions of the code, as required by Section 17958 of the Health and Safety Code, State Housing Law.
- Manufacturers must decide to manufacture and market in California the types of plastic pipe newly approved.
- Plumbing contractors or homeowners must decide that the newly approved types of plastic piping are preferable to existing metal or plastic piping for selected applications.
- Actual manufacture, installation, and use must occur.

Figure II-1 shows the flow of decisions required for expanded use of plastic pipe.

No one can predict with complete accuracy whether and to what extent these events will occur. Most communities will adopt the state code routinely, but a community may elect to forbid some or all of the expanded uses, or may have already permitted some of the expanded uses in amending previous versions of the code. Furthermore, some of the expanded uses may

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Table II-1

PLASTIC PIPE USE MATRIX

Application	ABS	PB	PE	PVC	CPVC*
Inside a building					
Not fire-rated					
Cold water		New+			New
Hot water	Pres#	New			New
Drain, waste, vent				Pres	New
Fire-rated**					
Cold water		New			New
Hot water		New			New
Drain, waste, vent	New			New	New
Outside a building					
Cold water		New	Pres	Pres	New
Hot water	Pres	New			New
Drain, waste, vent				Pres	New

*CPVC is not mentioned by name in the UPC and would be approved only under the "other approved materials" local option.

+New: Proposed new approved use.

#Pres: Presently approved use.

**Within fire-resistive construction; no plastic pipe is approved for exposed locations.

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Exhibit II-1

PROPOSED CODE CHANGES*

Section 401 - Materials (from Chapter 4, Drainage System, p. 37 of UPC)

(a) Drainage pipe shall be cast iron, galvanized steel, galvanized wrought iron, lead, copper, brass, ABS, PVC or other approved materials having a smooth and uniform bore, except: 1. That no galvanized wrought iron or galvanized steel pipe shall be used underground and shall be kept at least six (6) inches (152.4 mm) above ground. 2. ABS or PVC DWV piping installations shall be limited to those structures where combustible construction is allowed.+ [residential construction, not more than two (2) stories in height.]

(b) Drainage fittings shall be of cast iron, malleable iron, lead, brass, copper, ABS, PVC or other approved materials having a smooth interior waterway of the same diameter as the piping served and all such fittings shall conform to the type of pipe used.

1. Fittings on screwed pipe shall be the recessed drainage type. Burred ends shall be reamed to the full bore of the pipe.

2. The threads of drainage fittings shall be tapped so as to allow one fourth (1/4) inch per foot (20.9 mm/m) grade.

---

* Underlines indicate additions to the 1979 UPC and [brackets] indicate deletions to the 1979 UPC to produce the 1982 UPC.

+ DHCD is proposing to allow ABS, PVC, and CPVC DWV piping in fire-resistive construction.

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Exhibit II-1 (Continued)

Section 503 - Materials (from Chapter 5, Vents and Venting, p. 45 of UPC)

(a) Vent pipe shall be cast iron, galvanized steel, galvanized wrought iron, lead, copper, brass, ABS, PVC or other approved materials; except:

1. That no galvanized wrought iron or galvanized steel pipe shall be used underground and shall be least six (6) inches (152.4 mm) above ground.
2. ABS or PVC DWV piping installations shall be limited to those structures where combustible construction is allowed. [residential construction, not more than two (2) stories in height.]

(b) Vent fittings shall be cast iron, galvanized malleable iron or galvanized steel, lead, copper, brass, ABS, PVC, or other approved materials, except that no galvanized malleable iron or galvanized steel fittings shall be used underground and shall be kept at least six (6) inches (152.4 mm) above ground.

(c) Changes in direction of vent piping shall be made by the appropriate use of approved fittings and no such pipe shall be strained or bent. Burred ends shall be reamed to the full bore of the pipe.

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Exhibit II-1 (Concluded)

Section 1004 - Materials (from Chapter 10, Water distribution, p. 75 of UPC)

(a) Water pipe and fittings shall be of brass, copper, cast iron, galvanized malleable iron, galvanized wrought iron, galvanized steel, lead or other approved materials. Asbestos-cement, PB, PE, or PVC water pipe manufactured to recognized standards may be used for cold water distribution systems outside a building. PB water pipe and tubing may be used for hot and cold water distribution systems within a building. All materials used in the water supply system, except valves and similar devices shall be of a like material, except where otherwise approved by the Administrative Authority.

(b) Cast iron fittings up to and including two (2) inches (50.8 mm) in size, when used in connection with potable water piping shall be galvanized.

(c) All malleable iron water fittings shall be galvanized.

(d) Piping and tubing which has previously been used for any purpose other than for potable water systems shall not be used.

(e) Approved plastic materials may be used in water service piping provided that where metal water service piping is used for electrical grounding purposes then replacement piping thereof shall be of like materials.

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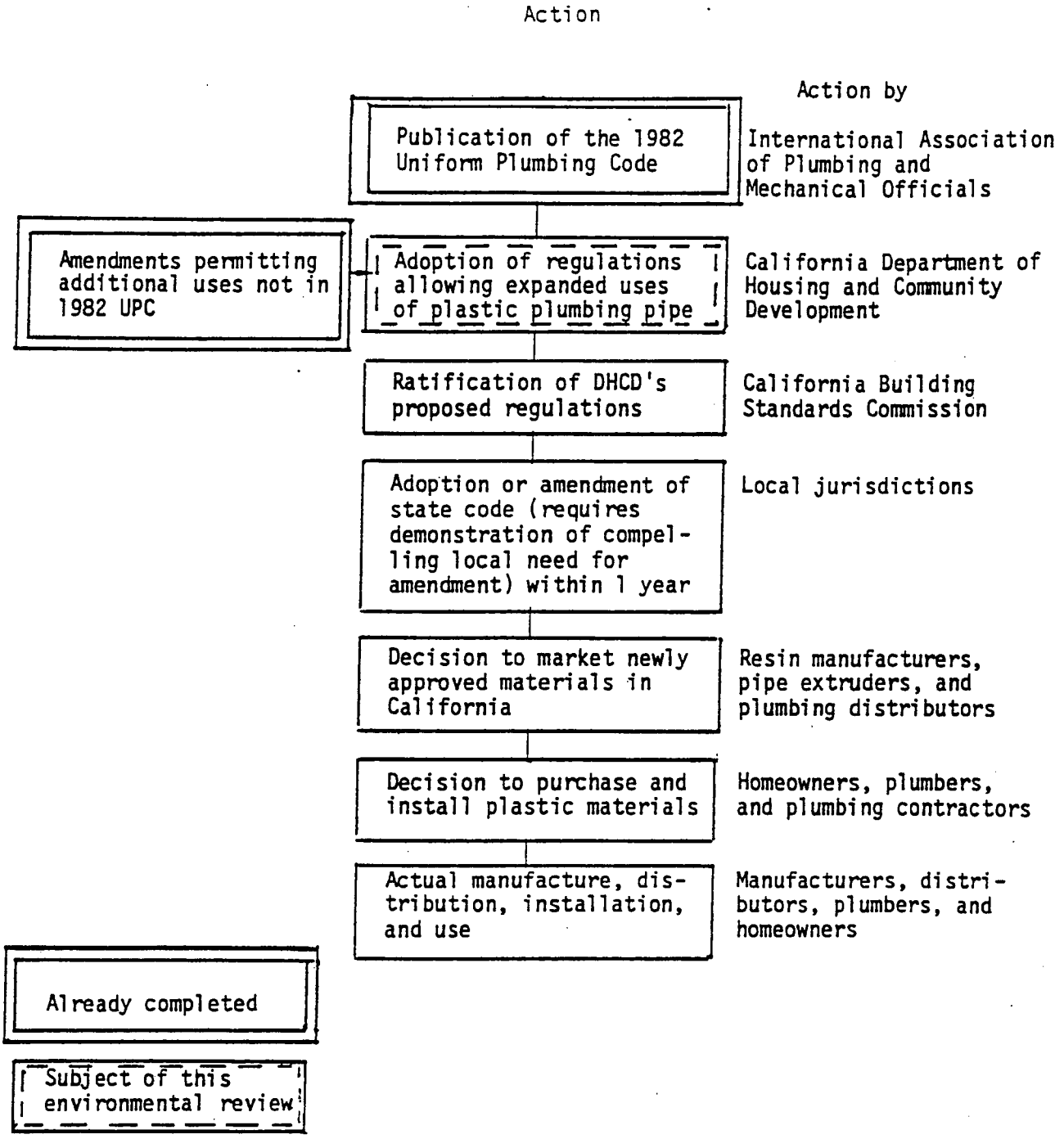

FIGURE II-1 DECISIONS LEADING TO EXPANDED USE OF PLASTIC PLUMBING PIPE

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already be permitted in the locally adopted versions of other codes, such as the Uniform Building Code. Because manufacturers seek profits and believe that plastics are competitive, they are highly likely to make them available. Because the total cost of installation (labor and materials) is generally agreed to be less for plastic pipe than for metal pipe, plastic pipe is also likely to be in demand. However, complete replacement of metal by plastic piping is unlikely because of concerns about durability, special installation conditions, the need to match materials in replacing or repairing old systems (e.g., to retain an electrical ground through metal pipe), or simple personal preference. Moreover, the amounts of plastic or metal pipe installed under the proposed new code will depend strongly on the pace of new construction and (less so) on replacement rates. Lower plumbing prices might stimulate overall construction rates as well. Looking at the plastics alone, PB and CPVC (if it were less expensive) could make inroads in the markets for PE and PVC in cold water supply applications, and CPVC could compete, although at a cost disadvantage, with ABS and PVC for DWV in non-fire-rated construction.

Consequently, the description of the proposed "project" must to some extent be hypothetical, a scenario rather than a prediction. The projections and assumptions presented below are thought to be reasonable, but the true outcomes could be quite different in many cases. Where conclusions about the significance of environmental impacts would depend markedly on the level of pipe use or the frequency of external events (fires, earthquakes, and so on), a range of projections or assumptions has been considered.

B. Projected Changes in Pipe Use

The magnitude and significance of the impacts likely to occur will depend on the changes in the level of use of plastic and conventional plumbing materials precipitated by state adoption of the proposed regulations allowing expanded uses of plastic plumbing pipe. These comparative use levels will in turn depend on the number of local

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jurisdictions that adopt the plastic pipe amendments to the state plumbing code, the willingness of contractors and consumers to use the various plastics in the newly permitted applications, and the willingness of suppliers to respond to the consumer demand by producing and marketing the newly approved materials.

Local jurisdictions must either adopt or amend the state code within 1 year of its adoption by the state. Jurisdictions that fail to act on the state code by the end of the year adopt it by default. Jurisdictions wishing to amend the state code must demonstrate a compelling local need for the amendment.

For discussion, we assume that final approval for the new uses will be given by DHCD in 1984 and will be adopted by local jurisdictions by early 1985. Use of plastic pipe in the new applications would begin with local adoption of the code changes. The nature and magnitude of impacts resulting from such use in 1985 will be representative of impacts that would occur in all subsequent years.

In practice, some jurisdictions have amended the state code without showing a compelling need, e.g., Hayward's ban on plastic DWV. In general, however, local jurisdictions to date have tended to adopt those portions of the state code allowing use of plastics in specific applications, as evidenced by the widespread local adoption of state regulations allowing the use of ABS and PVC for DWV. Some jurisdictions also have allowed practices not permitted by the state code; e.g., some unincorporated areas of Los Angeles County permit CPVC to be used for water supply, and at least three major metropolitan areas in the state permit the use of PB. Given the apparent local tendency to allow the use of plastics, we assume that 90% of the local jurisdictions in the state, including all major metropolitan areas, will adopt--directly or by default--the state regulations allowing expanded uses of plastic plumbing pipe.

A consumer's decision to purchase and use the newly approved plastic pipes will be based on the price, performance characteristics, and

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availability of these plastics compared with currently approved plumbing materials. We assume that state and local approval of expanded uses of plastic pipe will allay any concerns regarding the health and environmental effects of these new uses that may be aroused in consumers during the regulatory decisionmaking process. We also assume that producers (i.e., resin manufacturers, pipe extruders, and plumbing materials distributors) will respond to any consumer demand for the newly approved plastic plumbing, materials, so that these materials will be readily available for purchase and use. Therefore, a consumer's decision to use the newly approved plastic plumbing materials will depend on their price and performance characteristics relative to those of plumbing materials currently in use.

Typical plumbing systems in new residential construction currently consist of a combination of plastic and metal pipe and fittings. Copper or galvanized steel is usually used for the water supply system inside the building, and PVC or copper for water supply outside the building. The principal materials for the DWV system inside and outside the building are ABS, PVC, no-hub cast iron, copper, and occasionally, especially for vents, galvanized steel. In general, two or more dissimilar metals are not used within one system (i.e., water supply system or DWV system) because electrolytic corrosion problems are likely to result. A metal is commonly combined with a plastic within a given system, with the metal typically used inside the building and the plastic used outside the building. Two different plastics are rarely used within a given DWV system because of differences in cost and performance capabilities.

Remodeling jobs and renovations may pose exceptions to these guidelines. For example, a metal may be combined with plastic for DWV inside a building being remodeled, and renovations will often use the original plumbing materials regardless of their cost or performance characteristics.

In selecting the materials for a plumbing system, an individual will typically choose the material that provides the required performance characteristics for the lowest cost. The cost consists of two components:

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the cost to purchase the necessary materials that comprise the system and the cost of the time required to install the system. Copper is commonly used for water supply inside new residences and PVC outside the building because these are the least costly (materials and labor costs combined) materials approved for these applications. For the same reason, ABS is typically used for DWV inside and outside new homes at least in California; elsewhere, PVC is often the material of choice for DWV. No-hub cast iron is, however, close in cost (materials and labor) to ABS and is often used, particularly in areas where the local policy regarding use of ABS is unclear or uncertain.

The newly approved plastics will be used instead of these currently approved materials if they are less expensive or offer performance characteristics better suited to the conditions at hand. Materials selection decisions that are not based on these factors under the current code would not be affected by the proposed code changes.

For water supply outside a building, PB or CPVC would probably be used in place of copper. Prices on PB pipe and fittings run 40% to 60% of those for copper materials, and CPVC materials prices are about 10% to 25% greater than copper prices (Adams, 1982; NAHB, 1981). Installation times for PB and CPVC are similar: approximately 80% of the time required to install copper (NAHB, 1981; GCES, 1976-77). CPVC is a rigid plastic capable of handling high temperatures (210°F), and fittings must be special ordered. PB is more flexible, and fittings are readily available. The choice between the two depends on the use to which they will be put. Both, however, generally are less expensive (materials and labor costs combined) than copper.

For cold water supply outside the building, PB is likely to be substituted for PE (a flexible plastic like PB) because PB materials prices are about 25% lower than PE prices and the installation time is

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comparable.* Use of CPVC in place of PVC (a rigid plastic capable of handling temperatures up to 140°F) is very unlikely because CPVC pipe is at least twice as expensive as PVC pipe (Service Plumbing, 1979; Plumbing Suppliers Survey, 1983).

For the DWV system outside buildings and inside non-fire-rated buildings, CPVC is not likely to replace the currently permitted, widely used, and much cheaper ABS except under special conditions requiring greater heat and chemical resistance than is afforded by ABS. For the DWV system inside fire-rated buildings (within fire-resistive construction), ABS--and, to a limited extent, PVC and CPVC--would probably be used in place of no-hub cast iron in at least 50% of plumbing jobs because ABS pipe and fittings are about half the price of cast iron pipe and fittings and ABS takes less time to install (Plumbing Suppliers Survey, 1983; Service Plumbing, 1979). The only buildings that are fire-rated, however, are residential and commercial structures having three or more stories and structures of any height whose occupants might not be capable of rescuing themselves in the event of a fire (e.g., schools, hospitals, and nursing homes). Therefore, fire-rated buildings account for only a very small portion of total new residential and commercial construction.

When remodeling structures, selections of materials for the waste supply and DWV systems will be similar to those discussed above if the entire system inside or outside the structure is to be replaced. We assume that 25% of remodeling jobs involve replacing the plumbing system. In cases requiring only partial replacement of a plumbing system, replacement materials will probably be the same as the materials originally used in the system. Renovations are likely to use the original plumbing materials in replacing part or all of the plumbing systems.

---

* Wholesale prices on 1-inch water supply pipe from Plumbing Suppliers Survey (1983).

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To summarize, the proposed changes to the state and presumably local codes expanding the allowable uses of plastic plumbing materials are likely to result in the following substitutions of plumbing materials:

- PB and, to a limited extent CPVC, would replace copper for water supply inside most new residential and commercial construction.
- PB would be used in place of PE for cold water supply outside new buildings.
- The above two substitutions would also apply to 25% of remodeling jobs.
- ABS and, to a limited extent PVC and CPVC, would be used in lieu of no-hub cast iron for DWV inside about 50% of new fire-rated buildings and in 10% of remodeling work on fire-rated buildings.

These substitutions would have the following implications for the use of plastics and metals in California. Let us first assume that by 1984 the housing market recovers from the slow activity characterizing the last 2 years, growing at a rate like that in 1980: about 90,000 single-family and 60,000 multiple-family dwelling units per year (Harwich, 1983). Let us further assume that commercial construction will account for the same proportion of residential construction in 1984 as it did in 1980, which would amount to about 55,000 commercial units. Last, let us assume that 100% of the new single-family dwelling units, 75% of the new multiple-family units, and 50% of the new commercial establishments are of non-fire-rated construction.

A typical moderately large single-family residence may require about 250 to 300 feet of DWV pipe, typically 1-1/2 to 3 inches in diameter, and about 300 to 400 feet of water supply pipe, typically 1/2 to 1 inch in diameter. For subsequent calculations, we assume that the schedules shown in Tables II-2 and II-3 are typical. The average dwelling may require less, and apartments much less per unit. Table II-4 converts the schedules to weights of materials.

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Table II-2

DWV SYSTEM: CURRENT CODE

Materials: ABS	Size	Quantity	Wholesale Price
Comb Wye	3"	2	$6.50
Wye	3"	1	1.75
Wye	2"	1	1.25
San Tee	3"	1	1.68
San Tee	2"	4	7.20
San Tee	2x1 1/2"	5	7.15
San Tee	2x1 1/2x2"	1	1.52
San Tee	2x1 1/2x1 1/2"	2	2.86
San Tee	1 1/2"	1	1.30
Upright Wye	3"	1	2.25
1/4 Bend L.S.	3"	2	3.26
1/4 Bend L.S.	2"	7	5.60
1/4 Bend L.S.	1 1/2"	4	1.72
1/4 Bend M.S.	2"	8	3.68
1/4 Bend M.S.	1 1/2"	6	2.40
1/8 Bend	3"	1	1.08
1/8 Bend	2"	5	1.50
1/8 Bend	1 1/2"	2	0.74
C.O. Adaptor	2"	2	0.76
C.O. Plugs	2"	1	0.24
C.O. Plugs	1 1/2"	1	0.20
1/4 Bend H.O.	3 x 2"	2	6.56
Double Fixtures	2 x 1 1/2"	2	5.72
Closet Bends	4 x 3"	3	8.76
Closet Flngs	4"	3	8.61
Couplings	3"	5	2.85
Couplings	2"	8	1.92
Couplings	1 1/2"	8	1.44
D.S. Trap	2"	1	1.67
Tub Trap	1 1/2"	2	1.84
Pipe	3"	71'	84.49
Pipe	2"	115'	65.55
Pipe	1 1/2"	92'	39.56
Pipe	4"	60'	104.40
Subtotal			387.99
Sales tax (@6%)			23.28
TOTAL			$411.27

Source: Plumbing Suppliers Survey (1983).

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Table II-3

WATER SUPPLY SYSTEM: CURRENT CODE

Materials: ABS	Size	Quantity	Wholesale Price
Pipe (Type M Copper)	1/2"	165'	$51.15
Pipe (Type M Copper)	3/4"	134'	65.66
Solder (50/50)	lb.	2 lbs.	11.00
Flux	oz.	6 oz.	2.75
Elbows			
45° Ftg x C	1/2"	2	1.28
90° C x C	1/2"	39	3.90
90° Ftg x C	1/2"	4	2.56
Drop Ear C x FIP	1/2"	4	2.76
45° Ftg x C	3/4"	1	0.84
90° C x C	3/4"	26	5.98
Tees			
C x C x C	1/2"	3	0.54
C x C x C	3/4"	2	0.46
C x C x C, reduce on run	3/4"	12	4.92
C x C Couplings	1/2"	3	0.30
Drive Straps (J-hooks)		36	14.11
Pipe (Schedule 40 PVC)	1"	60'	24.60
Subtotal			192.81
Sales tax (@6%)			11.57
TOTAL			$204.38

Source: Plumbing Suppliers Survey (1983).

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Table II-4

TYPICAL WEIGHTS OF PIPE AND FITTINGS
FOR A MODERATELY LARGE HOUSE

DWV Materials

Size	Lineal Ft	Pounds of Pipe PVC	ABS	Cast Iron
4 inch*	60	130	90	500
3 inch	70	105	70	420
2 inch	115	90	70	400
1-1/2 inch	90	45	30	225
Fittings+		55	40	230
Total		425	300	1,775

PW Materials

Size	Lineal Ft	Pounds of Pipe PB	CPVC	Copper	Galv Steel
1 inch#	60	8.2	12.0	30	96
3/4 inch	135	11.0	18.2	40	162
1/2 inch	165	7.8	13.2	35	148
Fittings+		4.0	6.5	15	60
Total		31.0	49.9	120	466

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* Building sewer line.

+ Weight estimated at about 15% of pipe weight.

Water service line.

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If the newly permitted plastics are substituted for copper or other metals for water supply inside and for currently allowed plastics for water supply outside new non-fire-rated single-family dwelling units, use of newly approved plastics per dwelling unit would increase by about 33 pounds, replacing 8 pounds of currently approved plastic (PE) and 90 pounds of metal per dwelling unit.* Assuming that multiple-family dwelling units use about half the amount of pipe and fittings used in a single-family unit, each new non-fire-rated multifamily unit would use about 13 pounds of newly approved plastic in place of 4 pounds of PE and 45 pounds of metal. Let us assume that non-fire-rated commercial units would use roughly the same amount of pipe and fittings as single-family units. Then the proposed code change would result in a total increase of 3.5 million pounds in use of plastic, a transfer of 1.2 million pounds in use of one plastic to use of another, and a decrease of 12.6 million pounds in use of metal for non-fire-rated buildings in California.

In new fire-rated single-family dwelling units, substitution of the newly permitted plastics for metals and other plastics as assumed above would increase the use of newly approved plastics per dwelling unit by 230 pounds, shift 8 pounds of currently approved plastic to newly permitted plastic, and decrease metal use by 1,325 pounds.+ Using the same assumptions regarding use of pipe and fittings in multifamily and commercial units, the proposed code change would result in a total increase of 8 million pounds in use of newly approved plastics, a shift of 0.3 million pounds in use of one plastic to another, and a decrease of 46.4 million pounds in use of metal in fire-rated buildings in California.

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* Pipe use per 2-1/2 bath dwelling unit from NAHB (March 1981). Weight of plastic based on PB data from Shell (1983). Weight of metal based on data for Type M copper from "Energy Costs Versus Installed Costs of Piping," (DHCD, 1979)

+ Pipe use per 2-1/2 bath dwelling unit for DWV. Weight of plastic for DWV based on ABS, weight of metal based on weight of cast iron. Data from "Energy Costs Versus Installed Costs of Piping," (DHCO, 1979).

002811

To summarize, if the proposed code change is adopted by 90% of the local jurisdictions in the state and these jurisdictions account for 90% of construction activity in California, it could result in a total annual increase of 10.4 million pounds in use of the newly approved plastics, a transfer of 1.4 million pounds from use of currently approved plstics to newly approved plastics, and a decrease of 53.1 million pounds in the use of metals in fire-rated and non-fire-rated construction in California. These figures may be overestimated because the new construction levels assume economic recovery of the housing market by 1984, and because some of the proposed new plastics are already allowed and used in many local jurisdictions. These factors are somewhat offset by the exclusion of material substitutions in remodeling jobs from the figures. Because total expenditures on plumbing additions, alterations, and repairs, including expenditures for plumbing fixtures, account for 1% and 3% of the total value of new residential and commercial construction in the state respectively, their exclusion should not significantly affect the substitution figures.*

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* According to the U.S. Census Construction Reports (April 1981), expenditures on plumbing additions, alterations, and repairs, including expenditures for plumbing fixtures, accounted for 5% of total expenditures on alterations and repairs of residential properties the United States in 1980. Assuming that plumbing expenditues account for a similar proportion of the total value of alterations and additions in California, they amounted to $62,000,000 for residential properties and $104,800,000 for commercial properties in 1982 (Harwich, 1983). Assuming that plumbing fixtures account for 50% of these plumbing expenditures, that 90% of the residential and 50% of the commercial properties are of non-fire-rated construction, and that 25% of the jobs in non-fire-rated structures and 10% of the jobs in fire-rated structures would substitute the newly approved plastics for the currently approved materials, the current total value of the materials substitution would amount to $17,000,000.

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C. Growth of Population Living in Dwellings with Plastic Water Pipe

If about 150,000 new units are built per year, and an average of about 2.75 people occupy each unit, then about 400,000 people might move each year into new or replumbed units in California. Suppose that about 75% of the units were in communities that changed their code to permit the new uses of plastic pipe, and that about 80% of those were in fact plumbed with plastic water pipe. Then about 240,000 people might move into homes with new plastic water pipe each year. To account for growth of the population and uncertainties, we assume a round figure of 300,000 per year, or about 8 million by the year 2010. By that time, California's population may grow from less than 24 million in 1980 to over 30 million. Thus, by the early 21st century, over one-quarter of Californians may live in dwellings plumbed with plastic water pipe. Figure II-2 shows a very conceptual chart of the increase in the number of people living in such dwellings.

If any adverse consequences due to plastic pipe (or any reductions in the consequences of metal pipe systems) are to be felt, the rise will tend to parallel the use levels, although possibly displaced in time. For example, if any cancers are caused by the ingestion of leachates, they would not be expected to occur until several years after first exposure to the water from pipes. Even if the rate of cancer initiation were to become significant by 2010, any possible cancer epidemic might not be observed until 2030 or later.

D. Other Major Assumptions

As we discuss in more detail in Section VI on information gaps, probably the most critical assumptions have to do with compliance with installation and worker safety standards. Many potential impacts that would be insignificant if all standards were completely observed could become significant if they were not, both for plastic and for metal pipe systems. The principal compliance questions are:

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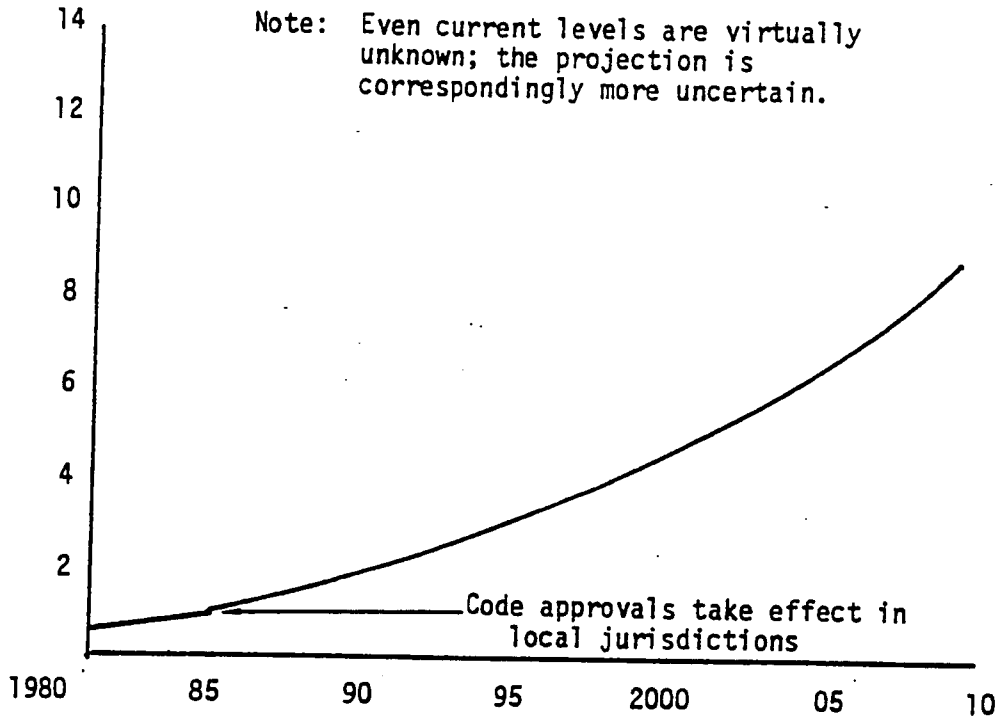

FIGURE II-2 POTENTIAL GROWTH OF POPULATION IN PLASTIC-PLUMBED DWELLINGS

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- Will plumbers and do-it-yourself owner-installers follow all recommended precautions, such as use of impermeable gloves, eye protection, and proper ventilation?

- Will they install pipe properly, including cleaning and deburring pipe sections; applying indicated amounts of solvent cement, solder, or pipe joint compound; joining materials in indicated times; and allowing proper suspension for expansion and contraction?

- Will they follow required procedures for installing pipe, especially DWV, in fire-resistive construction and avoid installation in exposed areas of fire-rated construction? Specifically, will they use approved metal sleeves and other devices to reduce the probability of fire spread?

- Will voluntary standards organizations, such as the National Sanitation Foundation, catch the majority of errors in manufacturing pipe and related materials?

- Will building inspectors catch and correct the majority of installation errors?

- Will fire fighters observe proper protective measures when combating fires in which plastics might be involved?

- Will plumbing systems be properly flushed by contractors and homeowners before use for potable water?

- Will building inspectors prohibit use of plastic water supply lines in soils contaminated by materials that could permeate plastic pipe?

Our analysis attempts to indicate the consequences of deviation from ideal practice but cannot predict the incidence of such deviations.

002815

III ENVIRONMENTAL SETTING: PIPE AND PLUMBING

In a conventional EIR, this section would describe the specific geographic setting for a project in terms of its ecologic resources, air and water quality, degree of development, and so on. In this environmental review document, it is more appropriate to describe the manufacture of pipe and its constituents, the installation of pipe (plumbing), the use of plumbing systems, and the overall water supply/waste disposal system in which they fit in California. The overall structure of our analysis is shown in Figure III-1. With each major activity related to the use of plastic and metal pipes, we have listed the major issue areas that have been raised as criteria for the decision on expanded uses of plastic pipe. The following activities all influence the environmental consequences of the proposed action to allow expanded use of plastic pipe:

- Manufacture of basic materials for pipe systems--for example resins and solvents for use in plastic pipe and pipe joining, or copper and acids for metal systems.
- Manufacture of pipe, fittings, joining materials--including solvent cements, solder, and pipe joint compounds--and attendant materials such as primers for plastic or cutting oils for galvanized steel pipe.
- Installation of pipe and fittings--with attention to plumbing, building, and fire codes--by plumbers and homeowners.
- Use of plumbing systems, including flushing before use, inspection before approval for use, usual system use, and unusual situations such as fire or earthquakes.
- Interaction of plumbing systems with the overall water distribution and waste collection systems, placing residential plumbing in perspective.

Each of these major activities will be described in a separate section below.

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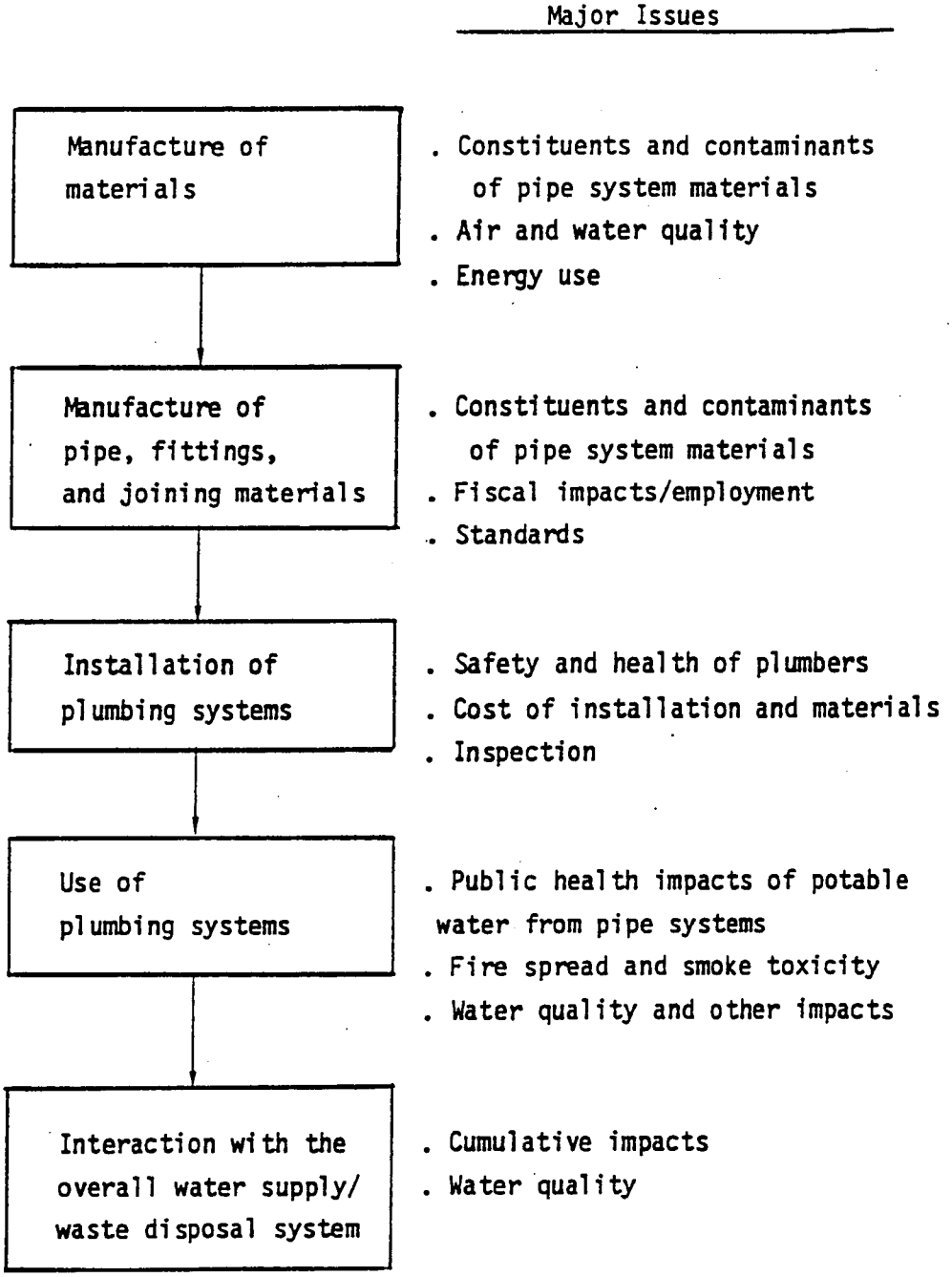

Figure III-1 STRUCTURE OF ANALYSIS AND MAJOR ISSUES

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A. Manufacture of Basic Materials

This environmental review requires a comparison of two basic classes of piping systems--traditional metals and more recent (although in some cases decades-old) plastic materials. Table III-1 shows a matrix of the principal system types used in each class by application.

Table III-1

MATRIX OF PIPE SYSTEMS

Use	Metal Pipe	Plastic Pipe
Potable water	Copper/soldered joints	PB and PE*/mechanical joints
	Galvanized iron/threaded joints	CPVC and PVC*/cemented joints
Drain, waste, and vent	Cast iron/mechanical joints	ABS/cemented joints
	Copper+/soldered joints	PVC#/cemented joints

* Cold water only.

+ Used mainly in smaller diameters because of cost.

CPVC is also proposed but generally is too expensive.

These are by no means the only materials allowed to be used or in use in California, but they are by far the most common. Understanding them will provide all the understanding needed to determine the environmental significance of the proposed code revisions.

The components/materials contributing to the systems listed in Table III-1 are shown in Table III-2.

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Table III-2

COMPONENTS AND MATERIALS OF MAJOR SYSTEMS

Metal	Copper	Copper pipe fittings Solder Soldering flux
	Galvanized iron	Galvanized iron pipe and fittings Cutting oils Pipe joint compounds or tape
	Cast iron	Cast iron pipe Fittings and seals Cutting oils
Plastic	PB and PE	Basic polymer Pipe compound additives
	ABS, PVC, and CPVC	Basic polymer Pipe compound additives Primers and solvent cements

The manufacturing processes for the pipe materials are described by system type below.

1. Copper

Copper ore is mined and smelted to yield an ingot stock for later conversion to pipe. Copper makes up the vast majority of the metal (|99.9%); minor constituents include antimony, arsenic, cadmium, lead, manganese, mercury, selenium, tellurium, tin, and zinc, none greater than 10 ppm (Copper Development Association, no date b). So much copper is used in applications other than residential plumbing that the effect of decreased use of copper pipe would lead to negligible environmental improvements. No production or processing of copper occurs in California. The most common solder for joining copper pipe consists of a tin (40% to 50%) and lead (50% to 60%) alloy; a tin (95%) and antimony (5%) solder is also satisfactory and enjoying increasing favor as an environmentally superior alternative in

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spite of its greater cost. Interest is growing in tin-silver solder for the same reason. Soldering fluxes basically clean the copper thoroughly and prevent oxidation to allow a quick and effective solder joint. They contain a mixture of inorganic salts such as zinc and ammonium chlorides, as well as inactive ingredients such as petrolatum or resin to provide adhesion to the pipe. None of these solder or flux materials is so unique to pipe systems that a change in use would significantly affect the environmental impacts of their manufacture.

2. Galvanized Steel

Steel for the pipe rolling process is produced by the usual mine to blast furnace to Bessemer converter or electric furnace methods, and residential plumbing pipe is a negligible use of steel. Zinc, at least 98% pure but containing arsenic, cadmium, lead, and manganese as trace contaminants, is the galvanizing material used for a thin external and internal layer that protects the pipe from corrosion. Little if any steel or zinc is produced in California for the pipe market. When pipe is cut and threaded during installation, a cutting oil is often used to lubricate the saw and threading die. The oil contains sulfur, animal fats, and sometimes mineral oils, none of which is unique to pipe use.

3. Cast Iron

Cast iron for residential DWV pipe also comes from iron ore mines and iron blast furnaces, and is again a negligible portion of all iron and steel produced. Little if any iron for pipe is produced in California. Cutting oils may also be used for cast iron installations. The pipe is usually joined with "hubless connectors" (see section on installation below), but in now rare instances may be welded or joined with gasket or lead seals. None of these materials is unique to pipe systems, and negligible changes in environmental impacts in manufacturing should occur through reduced demand for cast iron DWV systems.

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4. PB and PE

Polybutylene and polyethylene are olefin polymers created by joining ethylene ($CH_2 = CH_2$) and butene-1 ($CH_2 = CH - CH_2 - CH_3$) molecules end-to-end, respectively. Some branching of the polymer chains occurs, but in pipe-grade resins it is not great. The polymerization of these gases takes place in a vessel containing organic solvents such as isobutane or isopentane and catalysts such as chromium oxide, silica, titanium tetrachloride, and alkyl aluminum, minor residues of which can remain in the polymer.

Polymer characteristics such as viscosity, average molecular weight, strength, and so on, are controlled by standards like those of the American Society for Testing and Materials (ASTM). These standards are in general performance standards rather than identity standards; however, they are sufficiently specific, especially for pipe-grade materials, that little variation in chemical content can be tolerated. An estimated 95% or more of the polymers intended for potable-water pipe are also submitted for acceptance to the National Sanitation Foundation (NSF) (McClelland, 1983). PB resin (the polymer itself) is made only by the Shell Chemical Company. PE is made by a variety of manufacturers; however, no change in the code with respect to PE is contemplated, so the only effects would be its possible displacement by other plastics that would "spill over" from indoor to outdoor applications.

Pipe compounds are made by adding various processing aids and other materials to the basic resin, which makes up well over 95% of the final product. The principal additives for the polyolefins PB and PE are antioxidants, which prevent the degradation of the polymer, especially when heated for extrusion; UV stabilizers, which prevent breakdown of the polymer under the ultraviolet wavelengths of sunlight; and pigments--usually carbon black--for coloring the pipe and further UV protection. In PB, carbon black is the only UV stabilizer. Polyolefin pipe compounds also contain tracers, which are metals, metal carbonates, or metal oxides that serve to identify the producer of a specific batch of resin and prevent unauthorized use of

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reworked material from other producers (McClelland, 1983). Neither PB nor PE is produced in California (SRI, 1982).

Polyethylene is produced for so many different uses that changes in its use for pipe will lead to negligible changes in the environmental impacts of its manufacture. Although about 15% of PE resin goes to the "pipe" market, relatively little of that appears to be for potable water. Polybutylene has much more limited applications than PE, but as pipe material it is used extensively throughout the United States and elsewhere, including in some California communities. About 40-50 million pounds of PB are produced annually, but information on the current level of use for pipe was not found. Increased use in California will lead to only minor changes in environmental impacts at producing facilities. Shell has no producing facilities in California. Because PB and PE are not joined with solvent cements, such materials are not affected.

5. PVC and CPVC

Polyvinyl chloride is produced by end-to-end polymerization of vinyl chloride ($CH_2 = CHCl$) in a water suspension of an oil-soluble catalyst. The resulting structure is regular:
$...CH_2 - CHCl - CH_2 - CHCl....$ CPVC is produced by postchlorination of PVC by introducing gaseous chlorine into the PVC polymer, either in solution or as a suspended solid in water. Formerly, the PVC was "swelled" first with chloroform ($CHCl_3$), but this process is no longer used, at least domestically. The chlorine attachs randomly to the polymer chain, replacing hydrogen, but the final chlorine concent is around 2/3 by weight, implying that there is about one chlorine atom for every carbon atom. The suspension aids for PVC and CPVC are typically cellulose ethers or polyvinyl alcohol, and the polymerization catalysts are typically organic peroxides; both types of material may occur in small residual amounts in the finished polymer. The peroxides will rapidly degrade to other compounds.

Some PVC and CPVC pipe compounds contain other polymers as impact modifiers, because without them the impact strength of the pipe in low

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temperatures is too limited. However, relatively small amounts (15% total) are needed to perform the function. The chlorinated polymers also need a thermal stabilizer to prevent polymer breakdown and scorching during extrusion, and the usual pigments for color--often titanium dioxide, a white pigment. PVC may also contain a filler (e.g., calcium carbonate) for reasons of production economics. PVC and CPVC need a lubricant for extrusion, often a fatty acid-metal salt or oxidized polyethylene wax.

PVC is used in a great variety of plastic products, many of them heavily plasticized for flexibility. PVC pipe compound, however, is intended to be rigid and is rarely if ever plasticized, because plasticizers severely affect its strength and resistance to sagging. About 30% of the PVC manufactured is used for pipe and fittings of all types. PVC resin is manufactured by at least three manufacturers in California. CPVC is not manufactured in California; B.F. Goodrich is the sole U.S. producer (SRI, 1982; Dunnigan, 1983). One or two foreign firms import CPVC into the United States for use in pipe. As with the polyolefins, over 95% of the CPVC resins sold for potable water pipe are accepted by the NSF (McClelland, 1983). PVC resins intended for potable water would also be so controlled; a significant fraction of the DWV PVCs might not be submitted to NSF, although these would be mainly from firms selling into a narrow local market (McClelland, 1983).

In terms of potential environmental impacts at the manufacturing level, PVC changes would be negligible, whereas CPVC changes would be minor.

PVC and CPVC systems are both joined by solvent cements, frequently preceded by a primer that cleans and presoftens the polymer. The primer is a mixture of relatively pure solvents, while the cement contains solvents and resin or complete pipe compound of the appropriate type. Most of the solvents are commonplace and manufactured widely in the United States, so changes in impacts will be negligible. However, nationwide, PVC cement use accounts for a significant fraction (perhaps 40%) of all tetrahydrofuran made. None of the solvents is manufactured in California (SRI, 1982).

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Solvent cements and primers for potable-water PVC and CPVC are also generally submitted to NSF for approval.

6. ABS

ABS is a terpolymer of acrylonitrile ($CH_2 = CH - CN$), butadiene ($CH_2 = CH - CH = CH_2$), and styrene (vinylbenzene). The relative amounts of the materials are variable, but typically about half by weight is styrene, with each of the others at about 25%, implying a 1:1:1 molecular ratio. Blends or graft copolymers of styrene-acrylonitrile and styrene-butadiene polymers may also be present. The final system probably consists of polybutadiene dispersed in a rigid styrene-acrylonitrile copolymer matrix. The polymer is typically produced by suspending the monomers in water with, for example, polyvinyl alcohol with free radical initiators such as benzoyl peroxide. These materials may become residuals in the polymer, but the peroxide should degrade to simpler forms. Pipe demands about 200 million pounds of ABS each year nationally, about a fourth of all ABS produced. Two-thirds (about 140 million pounds) is DWV. Truckload quantities of ABS resin cost around 60 cents per pound for pipe grades, 90 cents for molding grades.

The additives for ABS are similar to those for the other polymers: antioxidants, lubricants, pigments, and fillers. Typically, ABS uses carbon black as a pigment.

At least one firm manufactures ABS in California (Dunnigan, 1983). Since ABS has already extensively penetrated the California DWV market, changes in environmental impacts for manufacturing due to the code changes would be minor.

ABS pipe and fittings are joined with solvent cements. Primers for ABS seem to be rarer than for PVC. The same general solvents are used for ABS as for the chlorinated materials, although ABS is more accepting of lower-quality, cheaper solvents, and reports of a wider variety being used are frequent. Because ABS is not used for potable water in California, it

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is less likely to have NSF approval than are the PW plastics, and the same is true for the solvents specifically marketed for ABS.

A summary of materials found in various plastic pipe systems appears as Table III-3.

B. Manufacture of Pipe, Fittings, and Associated Materials

Although "pipe" is a generic term for all plumbing, the small pieces that join straight, cylindrical pipe together (couplings), change its direction (elbows), or provide branches (tees and wyes), are known as "fittings," as are special pieces such as traps, valves, and the like. "Fixtures" are sinks, tubs, toilets, and so on; the plumbing is attached to their faucets or drains. Fixtures are not affected by the proposed code change. ASTM and other standards apply to the size and strength of all kinds of pipe; standards of identity and sanitary performance apply only to plastic pipe for potable water and are administered through the NSF.

The manufacturing process used for pipe and fittings depends on both the starting materials and the specifics of the pieces manufactured. Table III-4 gives an overview of the principal manufacturing processes involved.

1. Copper

Copper ingots are heated and the molten copper is drawn through a U-shaped ceramic mold, in which it cools and solidifies into the pipe (normally referred to as tubing). The tubing is drawn upward through sizing rollers, allowing more molten copper to flow into the mold. Some smaller-diameter tubing is made by rolling copper into thin sheets, then bending it into a tube and soldering the seam. Little such tubing is used for plumbing. Copper fittings are made by deforming heavy-gauge tubing to the proper shape. No copper tubing or fittings are made in California (Brown, 1983). The changes in environmental impacts with a reduction in manufacture of copper pipe and fittings would be minor. Producer costs for

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Table III-3

COMPONENTS OF PLASTIC PIPE SYSTEMS

Product	Function	ABS	%	PB	%	PE	%	PVC	%	CPVC	%
Pipe and Fittings	Resin (polymer)	Acrylonitrile-butadiene-styrene terpolymer 25-25-50	>96	Poly(butene-1) (polybutylene)	>98	Polyethene (polyethylene)	>95	Polychloroethene (polyvinyl chloride)	>80	Chlorinated PVC (~ 2/3 chlorine by weight)	>80
	Impact modifiers	None		None		None		Chlorinated polyethylene Acrylonitrile-butadiene-styrene Methylmethacrylate-butadiene styrene Alpha-methyl styrene	< 5	Chlorinated polyethylene Acrylonitrile-butadiene-styrene (fittings) methyl-methacrylate-butadiene-styrene-alpha-methyl styrene	< 3 <15
	Stabilizers/ antioxidants	Dilauryl thiodipropionate,4-di-2-methyl-6-t-butyl phenol (Topanol) Naphthyl amines	<0.2 <0.6	Tetrakis (methylene (3,5-di-tert-butyl-4-hydroxy-hydrocinnamate methane) (Irganox 1010)	<0.5	Irganox 1010 Bis (2-methyl-4-hydroxy-5-t butylphenyl)sulfide (Santonox R) 2,6-di-tert-butyl-p-cresol (Ionol)	<0.5	Organotins Organoantimonys Barium carbonate-barium alkyl phenolate Mineral oil (FDA generally recognized as safe)	< 2 <0.4 <1.0 <1.0	Organotins (e.g., dibutyl tin bis (isooctyl thioglycolate)	<3.5
	Lubricants	Acrawax C Magnesium stearate or other fatty acid salts	<3.0 <0.3	None		None		Oxidized polyethylene wax Paraffin wax Calcium stearate	<1.5 <2.0 <2.5	Oxidized polyethylene wax	<1.5
	Pigments/ fillers/UV stabilizers	Titanium dioxide Carbon black Others	<1.0	Titanium dioxide Carbon black Talc	<2.0 <0.5 <2.0	Carbon black Calcium carbonate	<4.5 <3.0	Titanium dioxide Carbon black Others	<2.0 <0.5 <1.0	Titanium dioxide Carbon black Others	<5.0 <0.05 <0.1
	Mold release agent	Silicone oil (fittings) surficial	trace					Silicone oil (fittings) surficial	trace		
Solvent Cement	Solvents	2-butanone (methyl ethyl ketone) Others	~15	None		None		Tetrahydrofuran Cyclohexanone 2-butanone (methyl ethyl ketone) N,N-dimethyl formamide	80-90	Tetrahydrofuran Cyclohexanone 2-butanone (methyl ethyl ketone) N,N-dimethyl formamide	80-90
	Resin/compound	ABS or ABS pipe compound	<15					PVC or PVC pipe compound	<20	CPVC or CPVC pipe compound	<20
	Pigments	Carbon black	<0.5					Titanium dioxide Carbon black Others	<0.5	Titanium dioxide Carbon black Others	<0.5
Primers	Solvents	Toluene as an example	≤100	None		None		Tetrahydrofuran Cyclohexanone 2-butanone (methyl ethyl ketone) N,N-dimethyl formamide	<99.5	Tetrahydrofuran Cyclohexanone 2-butanone (methyl ethyl ketone) N,N-dimethyl formamide	80-90
	Pigments							Titanium dioxide Carbon black Others	<0.5	Titanium dioxide Carbon black Others	<0.5

Sources: McClelland, 1983; SRI estimates.

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Table III-4

PIPE AND FITTING MANUFACTURING PROCESSES

	Processes	
	Pipe	Fittings
Metal		
Copper	Drawing	Forming/soldering
Galvanized steel	Rolling/welding Galvanizing	Forming/welding Galvanizing
Cast Iron	Casting	Casting
Plastic	Extrusion	Injection molding

copper pipe are in the vicinity of $1.50 per pound, but markups bring it over $3 at the wholesale level.

2. Galvanized Steel

Steel is rolled flat and then formed into cylinders, welded, and passed through pinch rollers for sizing. Fittings are also made by forming and welding. Both are machine-threaded at this stage. The pipe then goes into a galvanizing plant in which first the rust and mill scale are removed in an acid bath and then the pipe is fluxed in a zinc ammonium chloride solution. Next the pipe is passed through a molten-zinc bath (or electroplated with zinc), then cooled in dilute sodium dichromate. If this is done properly, the zinc forms a very thin continuous coating over the entire pipe or fitting. At present, no firm in California manufactures galvanized steel pipe, but one is considering doing so (Torrance Tube, 1983). Both steel rolling and galvanizing operations are so commonplace that negligible impacts would be expected from a change in the plumbing code. Galvanized steel has a producer cost of around 30 cents per pound of pipe.

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3. Cast Iron

Pig iron is remelted in a foundry's cupola furnace and is poured into ceramic (sand) molds to produce cast iron pipe and fixtures. No cast iron pipe is made in California, but it still captures perhaps a minor fraction of the total DWV market, principally for fire-rated construction and replacement applications. Cast iron has the lowest producer costs among the materials used for pipe and fittings--about 20 cents per pound. Since pipe represents a small fraction of all cast iron used, changes in this use would have negligible environmental impacts associated with manufacturing.

4. Plastic

This section is based heavily on descriptions in the Encyclopedia of PVC (NASS, 1976) and on a conversation with staff of R&G Sloane (Blumenkranz, 1983). Polymer resins are mixed with additives--often combined as a "master batch"--to form a pipe compound. The compound may be made and sold by the resin manufacturer, by so-called "special compounders" who buy resin and additives and sell compound to molders, or by the manufacturers of plastic pipe and fittings themselves. It is common for pipe manufacturers to make their own compound, while fitting manufacturers will sometimes buy compound from special compounders or the resin manufacturer. Compounds are in the form of pellets or granules of completely mixed polymer, stabilizer, pigment, lubricant, and so on; after compounding, these components are not ordinarily separate. The compound is solid at ordinary temperatures.

The compound is fed into a screw conveyor and heated so that it softens and coalesces into a viscous fluid; then it is either forced through a screw-extrusion die (Figure III-2) for pipe or injected into molds (Figure III-3) for fittings. The compound will be somewhat different for pipe than for fittings, both because the processing conditions are different and because the fitting must generally have higher impact resistance than the pipe. For some manual release of molds for fittings, a mold release agent--typically a silicone oil--may be used. Only small quantities will be

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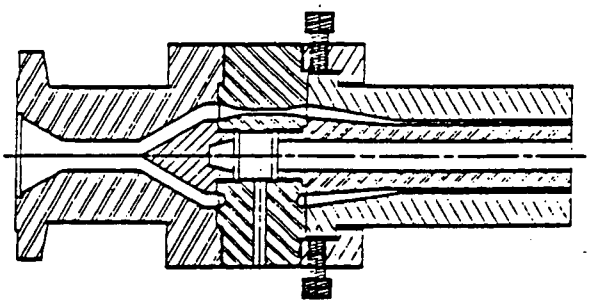


FIGURE III-2 PIPE DIE FOR SINGLE-SCREW EXTRUDER

Source: Nass, 1978

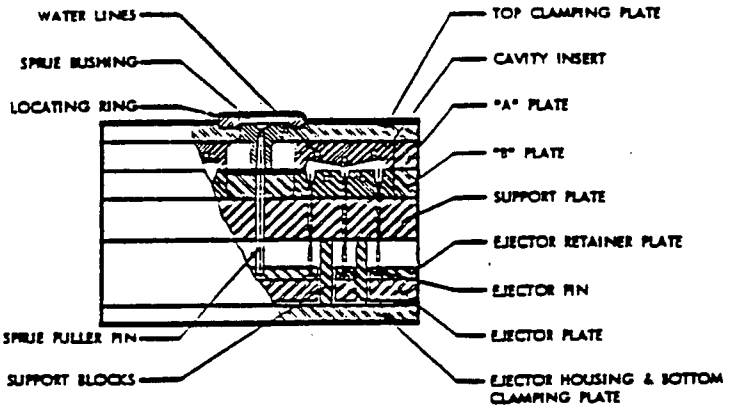
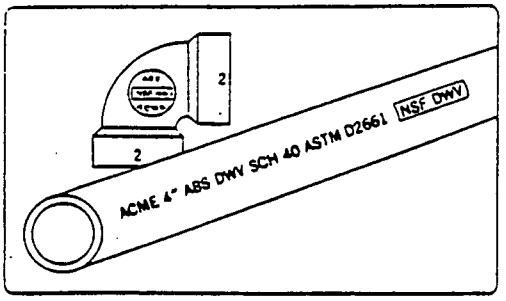


FIGURE III-3 COMPONENT PARTS OF A TYPICAL MOLD

Source: Nass, 1978



Source: McGuiness, 1980

ACME	The name of the manufacturer.
4 in.	Diameter of the pipe.
ABS	Acrylonitrile-Butadiene-Styrene, the material.
DWV	Suitable for drainage waste and vent.
SCH 40	Schedule 40. This identifies the wall thickness of the pipe.
ASTM D2661	"Standards Number" assigned by the American Society for Testing Materials.
NSF DWV	Tested by the National Sanitation Foundation Testing Laboratory. The pipe meets or exceeds the current standards for sanitary service.

FIGURE III-4 TYPICAL IDENTIFICATION SYMBOLS ON PLASTIC PIPE

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used so that they do not interfere with the fusing of the streams of material at the end of the mold. They are not used if unmolding is automated.

Various markings are placed on the pipe or fitting to indicate its intended use and what standards it meets. Figure III-4 shows the marking for a potable-water plastic pipe; it is applied by an inked marking wheel after the pipe has cooled. The labeling for fittings is generally molded in raised lettering on the fitting, but smaller fittings may not be marked. Pipe is bundled and shipped, whereas fittings are boxed and shipped.

Both pipe and fittings of various plastics are made in California. Table III-5 shows a partial list, taken from the NSF list (1982) of firms having NSF authorization for at least some of their products. There are also California firms that make pipe and fittings, especially for DWV applications, that do not seek NSF approval (Gaspar, 1983; Dunnigan, 1983) Little information is available on total plastic pipe production in California; limited evidence (California Manufacturers, 1982) suggests that the total value might be about $50 million annually; at $1 per pound this would mean around 50 million pounds of pipe, much of which would not enter the residential market.

5. Joining Materials

The polyolefin plastic pipes (PB and PE) are joined mechanically or sometimes (PE only) by thermal welding. PVC, CPVC, and ABS all are joined by solvent cements except when they are threaded for connecting to metal systems or for special assemblies. The solvent cements are simply blended from the raw solvents and pipe polymer or pipe compound. Thus, a typical cement will have at least two solvents, less than 20% resin, and small amounts of pigment and stabilizer. They will ordinarily not contain lubricant or filler. The two solvents are necessary to provide both a "fast set" and a "slow cure" behavior for the joint, in which the polymer molecules are loosened and intertwined between the two parts. The joint is frequently described as a "weld," implying that the pieces become

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Table III-5

SELECTED COMPANIES MAKING PLASTIC PIPE AND FITTINGS IN CALIFORNIA*

Company	Location(s)	Types	Pipe	Fittings
PW Maclin Co.	City of Industry	PVC		(compound)
American Rahn Corp.	Tracy	PB	X	
Apache Plastic Products	Stockton Santa Ana Lindsay	PVC PE	X X	
Barnes Plastics	Gardena	PVC		X
Carlon	Woodland	PVC	X	
Certain-teed	Cameron Park	PVC	X	
Colby Plastics	Anaheim	PVC	X	
Dura Plastic Products	Beaumont	PVC		X
Extended Plastics Co.	Santa Ana	PVC	X	
Flo-Control Inc.	Burbank	PVC CPVC		X X
Gifford-Hill & Co.	Visalia	PVC	X	X
Hancor	Patterson	PE	X	
Johns Manville	Stockton	PVC	X	X

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Table III-5 (Continued)

Company	Location(s)	Types	Pipe	Fittings
PW (concluded)				
Lasco Industries	Anaheim Montebello	PVC CPVC	X	X X
Mirada Enterprises	La Mirada	PVC		X
Orangeburg Industries+	Los Angeles	PE	X	
Pacific Plastics	Orange	PVC	X	
Phillips Driscopipe	Watsonville	PE	X	
R&G Sloane	Sun Valley Bakersfield	PVC CPVC	X X	X X
Spears Mfg. Co.	Sylmar	PVC		X
Wesflex Mfg. Co.	Richmond	PB PE	X X	
Western Plastics Corp.	Downey Union City	PVC	X	
DWV				
Maclin Co.	City of Industry	PVC		(compound)
R&G Sloane	Sun Valley	PVC ABS		X X
Univco Plastics	Pasadena	ABS		X
Cements				
Ameron	Brea	Epoxy	X	

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Table III-5 (Concluded)

Company	Location(s)	Types	Pipe	Fittings
Cements (concluded)				
Craig Plastic Products	Vista	PVC	X	
Industrial Polychemical Services	Gardena	PVC	X	X
		CPVC	X	X
		ABS	X	
Permalite Plastics Corp.	Newport Beach	PVC	X	X
		CPVC	X	X
		ABS	X	
R&G Sloane#	Sun Valley	PVC	X	X
		CPVC	X	X
		ABS	X	

*Companies have NSF approval; not all may be in current production.

+May not manufacture in California.

#Purchase from Industrial Polychemical Services and resell.

Source: NSF, 1982

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essentially one unit. Anecdotal evidence suggests, however, that joints are sometimes imperfect, perhaps through inadequate preparation or excessive working, and will separate under strong forces.

A few California producers have NSF approval for solvent cements; they are also listed in Table III-5. Their total output is less than $10 million annually, which at $1 to $2 per pound would yield 5 million to 10 million pounds of cement and primers, far more than is needed for the 50 million pounds of pipe produced in the state. SRI estimates that less than 1 pound of cement would be needed for 100 pounds of pipe.

6. Role of Standards in Materials Manufacture

As explained in the "Project Description" (Section II), expanded uses of plastic pipe will depend on adoption of building code changes by local jurisdictions, stimulated by the proposed changes in the state plumbing code. These two levels of approval are the only official, mandatory controls on pipe systems except where they are superseded by health-oriented regulations. However, the state code is built on a whole framework of voluntary standards and consensus agreements.

The state code is an adaptation of a model plumbing code (the "Uniform Plumbing Code," or UPC), which is revised on a 3-year schedule by the IAPMO. The UPC, in turn, refers extensively to "approved acceptable standards" and "recognized standards," as well as specifically to a variety of size, strength, and identity standards published by such groups as the American Society for Testing and Materials, the American National Standards Institute, and the American Water Works Association.

It is generally understood that the UPC's reference "manufactured to recognized standards" means listing by the National Sanitation Foundation, at least for potable-water applications. NSF, a not-for-profit voluntary standards organization, provides control over plastic pipe--but not over metal pipe--through its Standard 14 (NSF, 1980). Every manufacturer of pipe, fittings, pipe ingredients, or solvent cements who desires the NSF

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seal ("listing") must agree to use NSF-accepted ingredients in an NSF-qualified formulation and to submit to frequent NSF monitoring of its product.

NSF "accepts" ingredients by standard tests for extraction of the ingredient from the proposed product and by testing the substance for toxicity by feeding it to laboratory animals for 90 days if the ingredient is not already sanctioned by the U.S. Food and Drug Administration. Complete disclosure of chemical identity for ingredients is required by NSF. The formulation is qualified if it passes the extraction tests with each specified extractant below its "maximum permissible level" (MPL). The product can maintain its listing as long as it continues to pass the extraction test and other size and strength tests, for example, impact resistance and static water pressure/rupture tests.

NSF samples from plants about three times a year and also inspects the plants for conformance to formulations, quality control, and other sanitary practices. The samples for pipe and fittings are subjected to a standard extraction protocol and the water is analyzed for nine metals, phenolic substances, and suspended solids. The choice of substances to be analyzed is based on EPA drinking water regulations and other considerations. Taste and odor are also evaluated subjectively. For PVC and CPVC, the pipe is ground up and then analyzed for residual vinyl chloride monomer. No other organic materials are routinely sampled because EPA drinking-water standards have not been established for them. NSF is beginning a program to detect trihalomethanes, such as chloroform, in extractant samples and in solvent cements. The major constituents of solvent cements and primers are already being checked by gas chromatography and mass spectroscopy.

If samples fail a test, the manufacturer is given a short time to correct the problem and is then resampled. If problems persist, the product is delisted, and the company's other products may be delisted in extreme cases. If a failure disqualifies a product for use, NSF requires the manufacturer to destroy the defective inventory. Destruction is much more frequently a result of performance failures than extraction failures.

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NSF detects both errors in manufacturing and failures to pass the extraction and performance testing of samples. Tables III-6 and III-7 show summaries of NSF experience for their testing and inspections, respectively.

Because NSF covers most PW applications in California and because the NSF seal will be withdrawn for repeated failures, long-term average levels in drinking water will almost surely be below NSF MPLs for the substances analyzed. However, until NSF substantially expands its list of substances into the organics area, NSF will affect the quality of pipe with respect to them only through attention to consistent formulation and good manufacturing practice.

Table III-6

SUMMARY OF TESTING RESULTS FOR
PLASTIC PIPE AND FITTINGS
January-September 1982

Substance*	MPL**	Failures***	
		Number	Percent
Antimony	0.05	0	0
Arsenic	0.05	0	0
Barium	1.0	0	0
Cadmium	0.01	1	0.2
Chromium	0.05	0	0
Lead	0.05	1	0.2
Mercury	0.002	1	0.2
Selenium	0.01	4	0.7
Tin	0.05	8	1.5
RVCM****	10.0	0	0

* Results from 541 samples, except for RVCM with 303 samples.

** NSF Maximum Permissible Level, mg/l.

*** Samples in excess of MPL: PW pipe is subjected to extraction as well as performance testing; DWV pipe receives only performance testing.

**** Residual vinyl chloride polymer--level in plastic.

Source: Adapted from McClelland (1983).

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Table III-7

SUMMARY OF INSPECTION RESULTS
FOR PLASTIC PIPE AND ASSOCIATED MATERIALS

Nature of Deficiencies	1979*	1980+	1981#
Dimensional variations	91	88	81
Unauthorized formulations**	16	15	17
Incomplete/illegible markings	35	52	57
Lack of quality control			
Equipment	34	28	17
Records	63	45	31
Failures witnessed	56	70	76

*782 inspections.

+797 inspections.

#725 inspections.

**Usually entail use of unauthorized materials; most such materials are later accepted by NSF and the product is released for sale.

Source: Adapted from McClelland, 1983.

To the extent that local jurisdictions adopt the UPC via the state code, all of California's potable-water pipe should be covered by the NSF listing procedure. Some pipe intended for other use may be installed--by homeowners, for example--and escape inspection, but less than 5% of the total is probably involved. Considerably more DWV pipe would not carry the NSF seal, but more than half probably does. The NSF seal is an important marketing advantage for most markets, especially for PW pipe and fittings, so loss of the seal is an important deterrent to poor manufacturing practice. Moreover, because the only incentive for intentionally departing from NSF standards would be lower manufacturing cost, other high-quality manufacturers, at a competitive disadvantage, have an incentive to report

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their competitors' wrongdoings and do so. Departures from NSF standards therefore are likely to be limited to relatively short production runs before either inadvertent departures are corrected or deliberate departures are punished by NSF actions.

7. Total Production of Plastic Pipes

About 2.5 billion pounds of plastic pipe and fittings were sold in the United States in 1981. This quantity breaks down approximately as shown in Table III-8.

Table III-8

QUANTITY OF PLASTIC PIPE PRODUCED
(Millions of Pounds)

Type	Water Supply	DWV	Other
ABS	--	--	30
PB	5	--	2
PE	230	--	5
PVC	880*	250	770
CPVC	7	--	2

*Much of this quantity may be non-structural, e.g., agricultural.

Source: SRI estimates

C. Installation of Plumbing Systems

Whether installation of plumbing systems is done properly or not is a key question in determining the environmental consequences of either plastic or metal pipe. This subsection describes plumbers' practices in installing

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both potable-water supply piping and drain, waste, and vent piping in residences, using both plastic and metal materials.

The blocked quotes below have been taken from McGuinness, et al. (1980).

1. Water Supply Piping

> The conveying of water through buildings to locations of use implies the design of a system of piping or tubing efficient for its purpose, easily maintained and interfering as little as possible with the interior architectural form. It may be assumed that, except in basements, utility rooms, and at point of access to controls, the system will usually be concealed. Stud and joist construction provides space for concealment but, in fireproof buildings, vertical and horizontal furred spaces must often be provided.
>
> The corrosive effects of water and the resistance of metal to corrosion are usually matters for the attention of chemists and metallurgists. In general, however, public or private treatment should be provided to correct corrosive qualities. Theoretically, when this is done, it is sometimes suitable to use a cheaper piping material--steel; yet, prudence suggests that a better material be selected. In the nonferrous group, red brass and copper tubing are effective in corrosion resistance. Copper tubing is a very popular choice. It is less expensive than brass, assembles more easily, and is not subject to dezincification, which is the attack by acids on the zinc in brass. For use in handling aggressive waters, plastic is often a good choice. Like copper, it is light in weight and assembles with great ease.

(See Table III-9 for a listing of common metal pipe materials.)

> Plastic Pipe. Most of the plastic pipes and fittings now produced are synthetic resins. These do not appear in nature but are derived from such materials as coal and petroleum.
>
> Rapid increase in the development, acceptance, and use of plastics for water piping, fittings, and indeed, for drainage systems suggests a separate discussion of this family of material.
>
> Selection of Material. The chemistry of plastics is quite intricate and the material can appear in a great variety of forms, a few of which, especially suitable for water piping, are listed in Table III-10.

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Plastic pipe has been widely accepted in the industry, as witnessed by its acceptance under a wide variety of codes:

- BOCA Basic Plumbing Code, Building Officials and Code Administrators International.
- National Standard Plumbing Code, National Association of Plumbing, Heating, Cooling Contractors.
- Southern Standard Plumbing Code, Southern Building Code Congress.
- Uniform Plumbing Code,* International Association of Plumbing and Mechanical Officials.

2. Drain, Waste and Vent (DWV) Service Piping

The principal materials used for soil and waste piping and for venting are cast iron, copper, and plastic. Galvanized steel is sometimes chosen for vents and for tall stacks in high-rise structures.

Cast Iron. Supplanting the tubing and culverts of early epochs that employed clay, lead, bronze, and wood, cast iron was the earliest of the modern materials used for piping. Used first in Germany around 1562 and appearing in the United States about 1813, its durability and resistance to corrosion has made it eminently suitable for the components of sanitary drainage systems. Its suitability ranges from its use in small residential work to the stacks and branches of tall buildings.

Copper Tube. Like cast iron, copper is a material that has a history of use in ancient installations. Updated and highly developed in recent decades, its use is now widespread. There are several tube classifications [of different wall thickness] for the copper products used in plumbing systems. K, L, and M are the choices for water systems and DWV for use in drainage, waste, and vent installations (as the initials indicate).

Plastic Materials. Along with copper and cast iron, plastics are also very suitable for sanitary drainage systems. They comprise a family of materials. Table III-11 lists the three kinds of plastics most suitable for drainage, waste, and vent. One of these materials, acrylonitrile-butadiene-styrene (ABS) is...

the most widely used in California, and is under consideration in this environmental review.

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Table III-9

CHARACTERISTICS OF PIPE AND TUBING FOR WATER SERVICES

Kind of Pipe	Material of Manufacture	Connections	Qualities	Notes
Steel	Butt welded to 2 in. diameter, seamless large sizes	Threaded	Basic	Should be used when water is not corrosive
Brass, red	85% copper 15% zinc	Threaded, "IPS," (iron pipe size)	Corrosion-resistant	Bulky because of need for threading
Copper tube type "K"	Seamless, hard or soft temper	Soldered fittings	Corrosion-resistant and easy to fabricate	Thinner-walled than brass, easy to put together and dismantle
Copper tube type "L"	Seamless, thinner walls than type "K," hard or soft temper	Soldered fittings	Corrosion-resistant and easy to fabricate	Thinner-walled than brass, easy to put together and dismantle
Plastic*	See Table B**	Solvent cement weld	Very easy to fabricate	Not subject to electrolytic corrosion
Nickel silver and chrome	Copper, nickel, and zinc, steel and chromium	Threaded	Corrosion-resistant	Special application
Galvanized steel	Zinc-coated steel	Threaded	Moderately corrosion-resistant	Suitable for mild acid waters

*Upper limit of temperature, hot water, 180° F.
**For ABS and PVC.

Source: McGuinness, 1980

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Table III-10

SUITABLE CHOICES OF MATERIAL FOR
PLASTIC PIPING IN WATER SERVICES

Symbol	Material	Cold Water	Hot Water
PE	Polyethylene	X	
ABS	Acrylonitrile-Butadiene Styrene	X	
PVC	Polyvinyl Chloride	X	
PVDC	Polyvinyl Dichloride	X	X*
PB	Polybutylene	X	X*

*Developed recently for this special use. Other plastic materials not currently approved for hot water piping.

Source: Adapted from McGuinness, 1980

Table III-11

SUITABLE CHOICES OF MATERIAL FOR PLASTIC PIPING IN
DWV (DRAINAGE, WASTE, AND VENT) AND SEWER SYSTEMS

Symbol	Material	DWV	Sewer
ABS	Acrylonitrile-Butadiene-Styrene	X X	X X
PVC	Polyvinyl Chloride	X	X
SRP	Styrene Rubber Plastic		X

Source: Progressive Architecture

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3. Pipe Joining

The materials of importance in the plumbing trade are not limited to the piping alone. Indeed, it is the methods used to join the lengths of pipe that govern the nature of chemical exposures to the plumber. The joints between pipe sections may be made by any of a variety of means.

Although there are major differences within the categories of water and drain piping, it is convenient to continue the differentiation on that basis.

a. Pipe Joining--Water Service

i. Threaded Joints--Threaded joints are used for all galvanized steel joints as well as other ferrous pipe and "iron pipe size" brass. The tapered thread on the pipe is covered with pipe compound (Teflon tape is often used now as well), and then made up tight against the internal tapered thread of the coupling or other fitting. The chemical exposure is limited to the pipe compound ("pipe doping," see Table III-12) as well as any cutting oils that may be needed in the cutting of the pipe to length, and threading it. Figure III-5 shows some of the wide variety of pipe fittings used by plumbers to join pipe and bring it to the fixture.

ii. Soldered Joints--The differences between soldered and threaded joints are shown in Figure III-6. McGuinness (1980) states:

> The solder-joint connection in copper depends on capillary attraction that draws the solder into a cylinder of clearance between the mating surfaces of tube and fitting. This occurs after polishing and fluxing the surfaces and placing the parts together in final position. They are then heated and molten solder is applied to the circular opening where the fitting-edge surrounds the tube with a small clearance. It is then drawn into the cylindrical connection by capillary action. Solders are tin-lead or tin-antimony alloys. This kind of joint permits the advantageous setting up of an entire tubing assembly without turning the parts as in threaded installations and before the soldering commences. For the same strength, copper tubing may have thinner walls because no threads need to be cut into it. Its smooth interior surface offers less friction to flowing water.

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Table III-12

REPRESENTATIVE PIPE JOINT COMPOUNDS

MATERIAL	Percent
Compound A[1]	
Chalk	32
Kaolin	33.5
Linseed Oil	33
Litharge (PbO)	1.5
Compound B[1]	
Black strap molasses	40-50
Amorphous graphite	40-50
Vermiculite	0-30
Bentonite	0-15
Lithopone	0-15
Sodium pentachlorophenate	1

(may contain Linseed Oil, Slate, or Titanium Dioxide)

PERMATEX^{R} Pipe Joint Compound, Part No. 51 [2]
"Polymerized vegetable oil and wood-derived resin with inert fillers dissolved in isopropyl alcohol." (isopropanol less than 20% by weight)

PERMATEX^{R} Thread Sealant with Teflon^{R}, Part No. 14 [2]
"A proprietary polymeric material containing dispersed PTFE and isopropyl alcohol." (isopropanol less than 40% by weight; PTFE = polytetrafluoroethylene)

Sources: Gosselin et al. (1976)
Technical Data Bulletins and Material Safety Data Sheets from Loctite Corporation.

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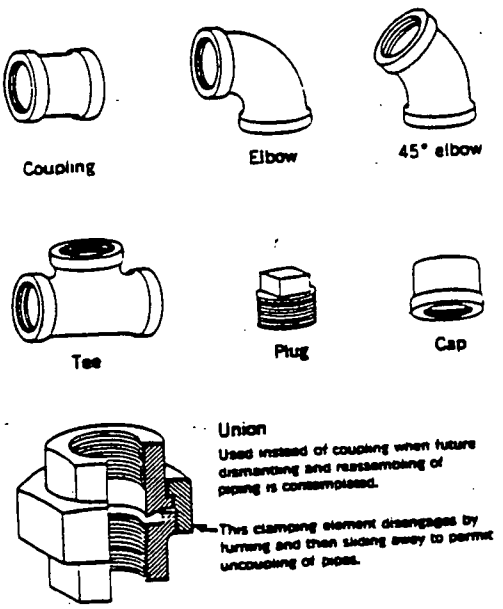
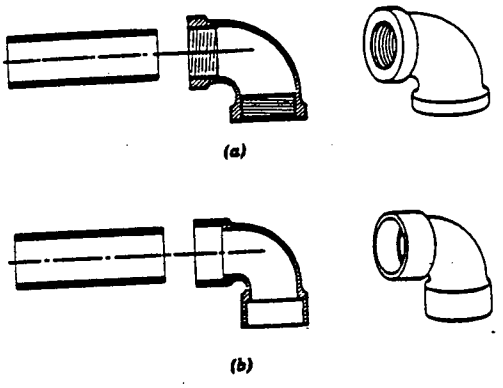


Source: McGuiness, 1980

FIGURE III-5 EXAMPLES OF THREADED PIPE FITTINGS FOR FERROUS OR BRASS PIPE



Source: McGuiness, 1980

FIGURE III-6 METHODS OF CONNECTING PIPES AND FITTINGS, AND TUBES AND FITTINGS (a) Threaded: For ferrous pipe fitting and for "iron pipe size" (IPS) brass. (b) Soldered: For copper tubing and fittings. A sliding fit similar to that of (b) is used for the solvent weld of plastic connections.

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The process of making a joint is best described by a direct quotation from the Copper Tube Product Handbook (Copper Development Association, no date):

> Measure length of tube
> Cut tube square
> Ream cut end
> Clean tube end
> Clean fitting socket
> Apply flux to tube end
> Apply flux to fitting socket
> Assemble
> Remove excess flux
> Apply heat
> Apply solder
> Allow joint to cool.

iii. Solders and Fluxes--Tables III-13 and III-14 show the composition of typical solders and fluxes. One omission from those tables is the measurable cadmium content in silver solder, which has caused extensive occupational disease in past years when the cadmium fume was inhaled. It is rarely found at present in general soldering work and is usually on any list of prohibited compounds in any well-run establishment. Only the 50/50 tin-lead and 95/5 tin-antimony solders would be commonly found in current residential plumbing. About 1 pound of solder and 2 ounces of flux would be used in a typical house (Copper Development Association, undated).

iv. Other Joints--As McGuinness (1980) has stated:

> While threaded- and solder-joint connections are the most common in small work, there are many other types. Ferrous pipes in the larger sizes are often welded or connected by bolted flanges.

In addition, of course, the joining of plastic pipes requires different techniques. These are discussed in the section below--on DWV joints--because of the greater extent of use of plastics in this service. An exception is the method used to join polybutylene pipe (PB). PB is relatively flexible, and is frequently joined by barbed hose nipples if two lengths of pipe are to be joined. The general nature of the joint is shown

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Table III-13

COMPOSITION OF A NON-ACID SOLDERING FLUX APPROVED BY IAPMO [LA-CO REGULAR SOLDERING FLUX] FOR COPPER WATER PIPE

	Percent
Active Ingredients	45%
Ammonium chloride "Amine hydrochloride"	
Inert Ingredients	55%
"Microcrystalline wax" "Non-ionic surfactant" (water dispersible)	

Source: Shedroff, 1983.

Table III-14

SOLDERS IN MODERN USE FOR COPPER ALLOY SOLDERING

Composition %				Solidus °F	Liquidus °F	Remarks
Tin	Lead	Antimony	Silver			
50	50			361	421	General Purpose
60	40			361	374	General Purpose-"Fine Solder"
63	37			361	376	General Purpose-"Fine Solder"
95			5	452	464	General Purpose
96.5			3.5	430	430	Fine Instrument Work
95		5		430	473	Fine Instrument Work
1.0	97.5		1.5	588	588	General Purpose-Torch Heating
	97.5		2.5	579	579	Susceptible to Corrosion
	94.5		5.5	579	689	Susceptible to Corrosion

Source: NASA (1969)

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in Figure III-7. Polyethylene is frequently joined in a similar manner, but can also be joined by thermal "welding."

b. Pipe Joining--DWV Service

i. Cast Iron Pipe Joints--Until recently, cast iron pipe has been the most common material in DWV piping but it has been rapidly supplanted by ABS pipe in residential applications. One supplier (Gaspar, 1983) estimates that 95% of new one and two story residential buildings are plumbed with ABS. The three major types of joints currently used for cast iron are shown in Figure III-8 (McGuinness, 1980). The lead and oakum joint ("bell and spigot") is principally of historical interest now, although it is occasionally needed in the repair or restoration of older systems. When needed, the lead is usually not poured (which requires molten lead with--usually--excessive exposure to lead fumes) but is formed of lead wool which is calked into the joint. By far the most common joint in modern cast iron installations is the "no-hub" joint, which requires no chemical exposure, is fast, and can be installed by (relatively) unskilled personnel.

ii. Copper Pipe Joints--The methods for joining copper pipe (which is most commonly used in DWV systems for vent pipe) have been discussed above. The major difference is that the pipe and coupling, being larger, are more difficult to heat evenly (so as to draw the solder into the joint) and thus greater skill is required than in joining the usually smaller water pipe.

iii. Plastic Pipe Joints--The general procedure for joining plastic pipe is as shown in Figure III-9 (McGuinness, 1980). The pipe end and the fitting to which it is to be joined are "painted" externally and internally respectively with the appropriate solvent-based cement; twisted together in the proper position; and then held in place for a few seconds until the cement "sets." The usual solvents nominally recommended for the several kinds of pipe are shown in Table III-15. Tables III-16 and III-17 indicate the composition of cements found in the field.

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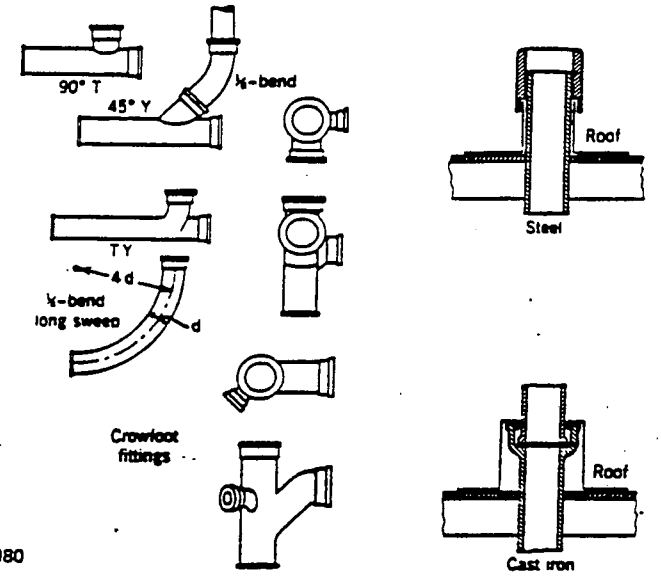
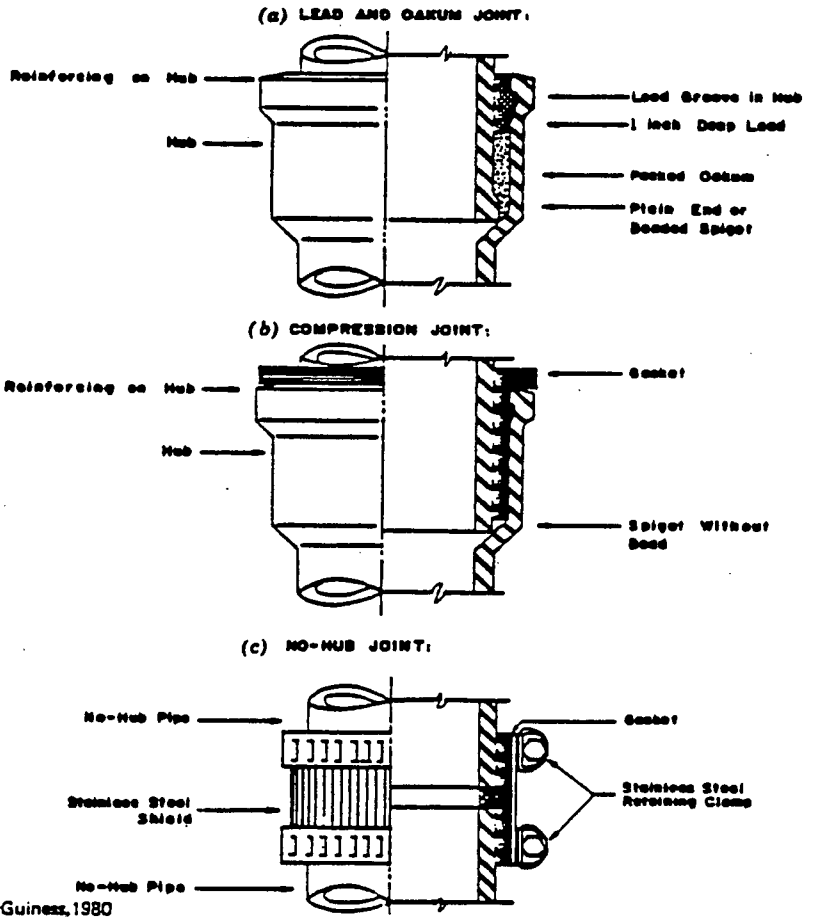


Source: McGuiness,1980

FIGURE III-7 CAST-IRON FITTINGS–PRINCIPAL TYPES AND METHOD OF FLASHING AT ROOFS



Source: McGuiness,1980

FIGURE III-8 THE VARIOUS JOINTS PRESENTLY BEING USED TO CONNECT CAST-IRON SOIL PIPE AND FITTINGS

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Table III-15

MOST COMMONLY USED SOLVENTS IN PLASTIC PIPE CEMENTS
AND PROPERTIES OF SOLVENTS USED IN SOLVENT CEMENTS FOR PLASTIC PIPE

Most Commonly Used Solvents in Plastic Pipe Cements

Type of Cement	Primary--Major Solvent	Secondary or Minor Solvent
PVC	Tetrahydrofuran (THF)	Methyl Ethyl Ketone (MEK) Cyclohexanone
CPVC	Tetrahydrofuran (THF)	Cyclohexanone
ABS	Methyl Ethyl Ketone (MEK)	None
Styrene	Methyl Ethyl Ketone (MEK)	None

Properties of Solvents Used in Solvent Cements for Plastic Pipe

Chemical	Boiling Point °F	Evaporation Rate BUAC=1*	Flash Point	Threshold*** Limit Value (TLV) PPM	Odor** Detection Level PPM	Comments
Tetrahydrofuran	151	8.0 Very Fast	6	200	25-50	Distinct etheral odor
Methyl Ethyl Ketone	175	5.7 Very Fast	22	200	25-50	(Acetone like) Mint-like sharp odor
Cyclohexanone	312	0.2 Very Slow	110	25	Very Low	Distinct peppermint sharp odor

* BUAC = Butyl Acetate

** Odor detected by most individuals

*** Threshold limit values refer to airborne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect. It refers to time-weighted concentrations for a 7 or 8 hour workday and 40 hour workweek. Reference: The American Conference of Governmental Industrial Hygienists, "Threshold Limit Values of Airborne Contaminants."

Source: Letter from Naresh D. Patel, Technical Director of Industrial Polychemical Service, Gardena, CA, to Myron Moskovitz, November 16, 1979.

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Table III-16

ABS PLASTIC PIPE CEMENTING CHEMICALS AT JOB SITES

Company and Product	Chemicals Listed On Label	Chemicals by Laboratory Analysis
Oatey Cement	MEK	100% MEK
E-Z Weld	No label available	98% MEK 2% THF
Rectorseal TFE-Fluorocarbon Threaded Sealing Paste	None	No analysis available
ABS Rectorseal Solvent Cement	MEK	No analysis available
Weld-On 773	None	MEK
Hercules ABS Plastic Pipe Cement	MEK	MEK, THF, and Cyclo (trace amounts)

Source: CDHS--Interim Report, April 29, 1980

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Table III-17

PVC PLASTIC PIPE CEMENTING CHEMICALS AT JOB SITES

Company and Product	Chemicals Listed On Label	Chemicals by Laboratory Analysis
Weld-On 710 PVC	MEK, THF, Cyclo	No analysis available
Weld-On Primer P-70	No label available	MEK, THF, Cyclo, DMF
Weld-On 717	No label available	MEK, THF, Cyclo
Oatey PVC Glue	No label available	MEK, THF
Weld-On 711	No label available	MEK, THF, DMF
PIP-P470 PVC Primer	THF, ketones	THF, MEK
Celanese PVC Solvent Cement	THF, Cyclo, MEK	THF, MEK

Source: California Department of Health Services-Interim Report, April 19, 1980

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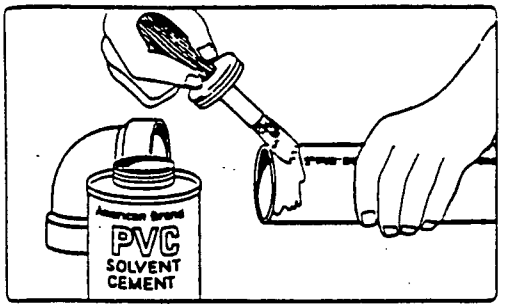
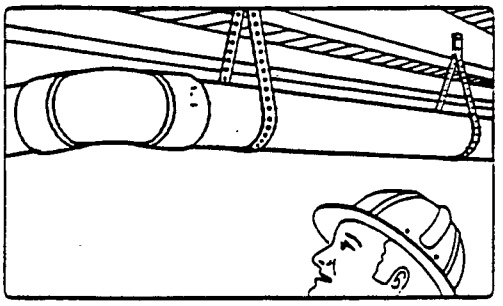


(a)



(b)

Source: McGuiness, 1980

FIGURE III-9 DETAILS IN THE USE OF PLASTIC PIPE. (A) One of the steps in making a "solvent weld" of a plastic pipe to a plastic fitting. (B) In wood frame construction, plastic pipe assemblies can be supported by metal straps nailed to the wood joints. Flexibility of the plastic material suggests that the supports be more closely spaced than in the case of metal piping. Courtesy of the Plastic Pipe Institute.

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iv. Other Joints--DWV--As with water service piping, a wide variety of other joints have been used. Many of these are of historical interest only, such as the "wiped" joint. Some use is made of welding; the extent of such use at this time is unknown. Similarly, where cement or vitrified clay pipes are allowed in sewer service (prior to the street main) joints using grouting compound may be found. Threaded fittings (for cast iron and galvanized steel) are also occasionally used.

4. Plumbing in Residences

Figure III-10 shows a diagram of where plastic pipe might be found in a typical house. This idealized view is not reflective of the actual complexity of modern plumbing, which must fit (with reasonable exactitude) into an architect's drawing realized in wood, steel, and cement. Figure III-11 shows how the plumbing is part of the building structure, with complexities in both elevation and plan views.

5. Plumbing Trade Practices

The plumbing trade can be divided into three main segments: new construction, remodeling/replacement, and repair. The last-named (characteristically performed by a neighborhood plumbing shop) has very little exposure to chemicals, since most of the work involves simple replacement of fixtures, washers, and the like. It is in the first two that significant chemical exposures may be found; they differ in both the time-course and intensity of exposure, as will be discussed later in Section IV.C.

Regardless of the age of the building being plumbed, there will be four major operations that must be performed by the plumber. These are: layout, pipe-cutting, preassembly (sometimes not performed--see below), and installation.

Layout is the marking of joists and studs for holes to accept pipes (and often the cutting of the holes), measurement of pipe lengths needed,

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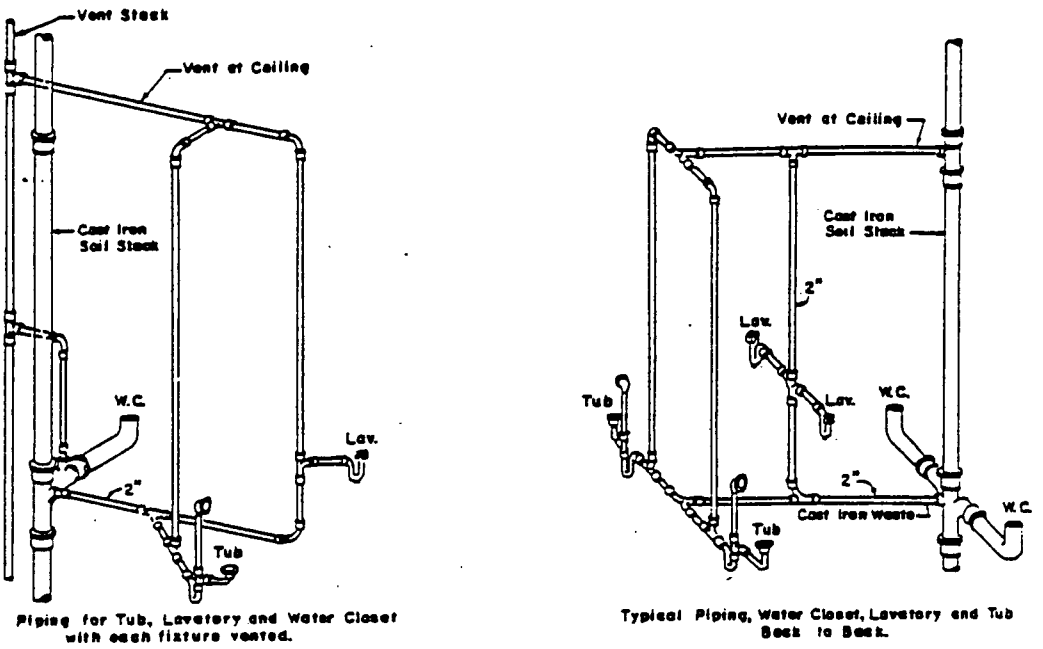

Source: McGuiness, 1980

FIGURE III-10 TWO TYPICAL PIPING ARRANGEMENTS FOR WATER CLOSET, LAVATORY, AND TUB

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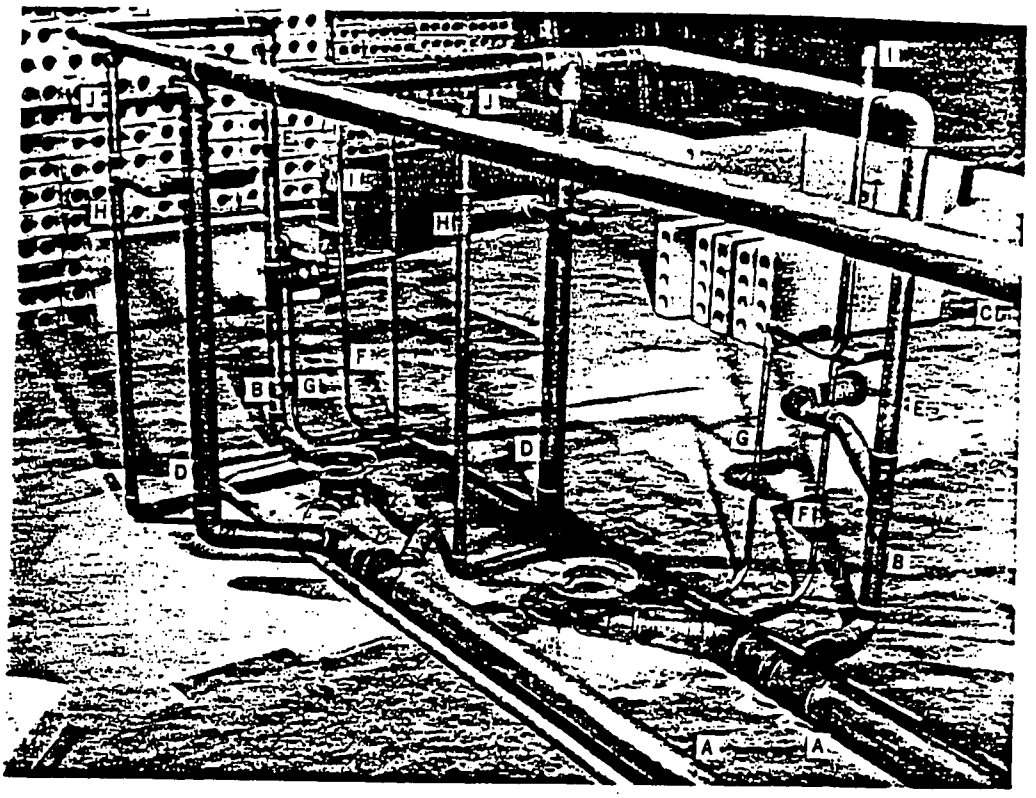

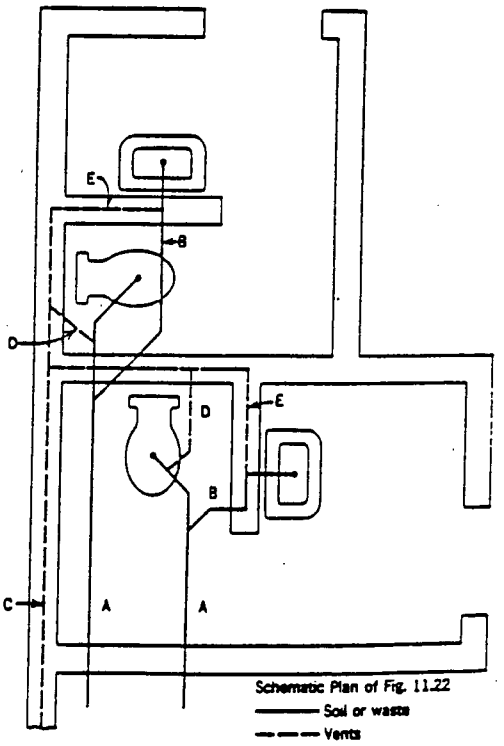

Drainage	Water
A Branch soil	*F Hot*
B Lavatory waste	*G Cold*
C Branch vent	*H Flushometer supply* ($1\frac{1}{4}$ *in.*)
D Water closet vent	*I* Capped *air chamber*
E Lavatory vent	*J* Capped *air chamber* (*flushometer*) (*I and J absorb expansion and shock*)

FIGURE III-11 AN EXAMPLE OF PLUMBING ROUGHING FOR TWO LAVATORY ROOMS IN A FIREPROOF OFFICE BUILDING

Source: McGuiness, 1980

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and planning for the complete plumbing job to turn the design into reality. This is the task requiring the greatest skill, and often is the most time-consuming part of the job. Horizontal runs of drain pipes must have minimum slopes (to prevent pooling of wastes in the lines), and the holes in joists and studs must be drilled precisely if rigid pipe is to be inserted (see Table III-18). The senior man on the crew will almost always perform the layout, which involves no chemical exposure.

In addition to the potential for exposure to chemicals, it must be recognized that there are substantial safety hazards involved with the various plumbing operations--as indicated in the introduction to this section. Plumbers work with heavy materials in enclosed spaces; they must place sections of pipe in position and then use saws, torches, and other dangerous instruments; they are at risk of fires set by torches (or accelerated in spread by combustible solvents) and they are at risk of all of the safety hazards associated with construction sites.

After layout is completed, and the journeyman plumber has made measurements of the lengths of pipe required, then the 10 or 20 foot long lengths of pipe, commercially supplied, must be cut to lengths suitable for the intended use and threaded if necessary. This task is usually assigned to a new apprentice (when a large crew is on-site) or will be done by the plumber as he works through the layout or the installation. The cutting will be done by hack saw (steel pipe, some iron, and occasionally plastic), hammer and chisel (cast iron--this is a vanishing art), tubing cutter (copper and rigid plastic tubing), knife or bolt cutter (some plastics).

a. Preassembly-Prefabrication

As noted above, preassembly of components is not always done--particularly on small jobs (see discussion below on new construction activities). However, when a large number of similar installations are planned, as in a large commercial building (or set of similar buildings) or in a residential tract where identical layouts for fixtures are found, then

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Table III-18

MINIMUM SLOPES FOR HORIZONTAL DRAINAGE PIPES

Diameter of pipe in inches	1-1/4	1-1/2	2	2-1/2	3	4	5	6	8	10	12
Minimum slope recommended by "Plumbing Manual"* (inches per feet)	1/4	1/4	1/4	1/8	1/8	1/8	1/16	1/16	1/16	1/16	1/16
Minimum slope recommended by "Housing Code,"** (inches per feet)	1/4	1/4	1/4	1/4	1/4	1/8	1/8	1/8	1/8	1/16	1/16

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*"Plumbing Manual," Report BMS66, National Bureau of Standards, 1940.

**"The Uniform Plumbing Code for Housing," Housing and House Finance Agency, February, 1948

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preassembly of significant complex pieces of the plumbing array can be cost-effective. This work will sometimes be done in the shop, although field pre-fab on the job site is more common, and some plumbers specialize in this aspect of the trade. The potential exists for substantial chemical exposures to any materials used in the preassembly plumbing array.

Figures III-12 and III-13 show the complexity of typical preassemblies. Substantial preassembly is usually limited to copper or plastic (and some small cast iron arrays) because of the weight factor; it is desirable to limit the weight of the assembly to that which can be handled by one plumber.

b. Roughing, Topping Off, and Finishing

There are three major phases of the actual installation: "roughing," "topping off," and "finishing work" (CDHS, 1980). The "roughing" phase consists of the installation of the pipes leading from the main city sewer and water lines to and throughout the crawl space or basement of the building. This is usually done in the open at the point when the building construction consists of the foundation and floor studs.

Following the roughing phase, floor boards are laid and walls are constructed, although not covered. The next phase, "topping off," is the installation of the pipes branching off from the floor board pipes, up through the walls and ceiling of the structure to the point where fixtures will be installed.

Finally, the "finishing work" is the connection of plumbing after the fixture and cabinets, vanities, and wet bars have been installed. This involves the attachment of the fixture to the pipes in the wall--usually inside cabinets under the sinks or other fixtures.

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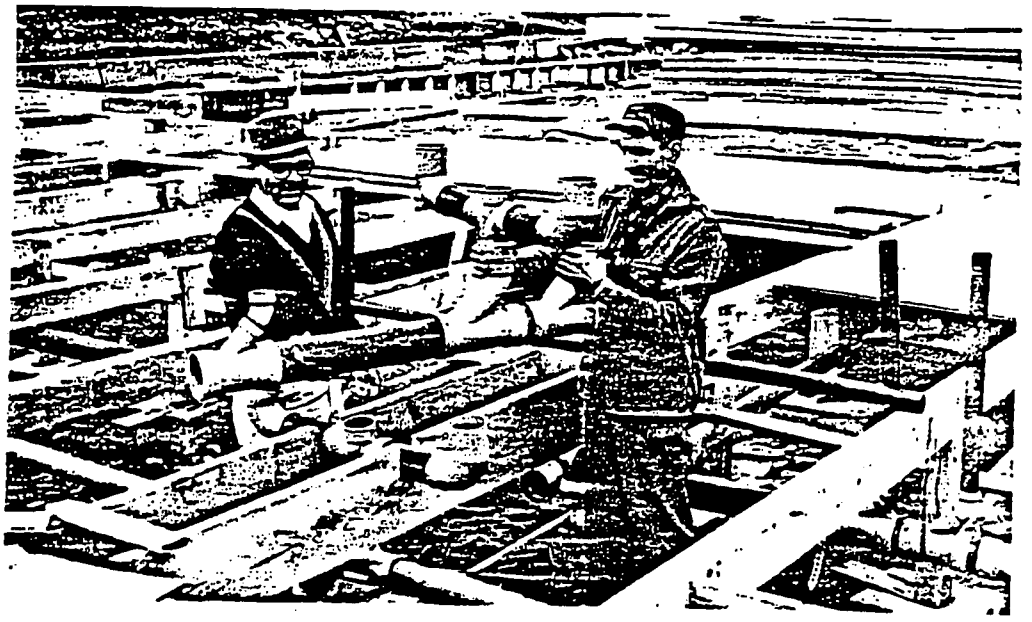

Source: Mc Guiness, 1980

FIGURE III-12 PLASTICS LEND THEMSELVES TO PREASSEMBLY OF SECTIONS OF DWV PIPING

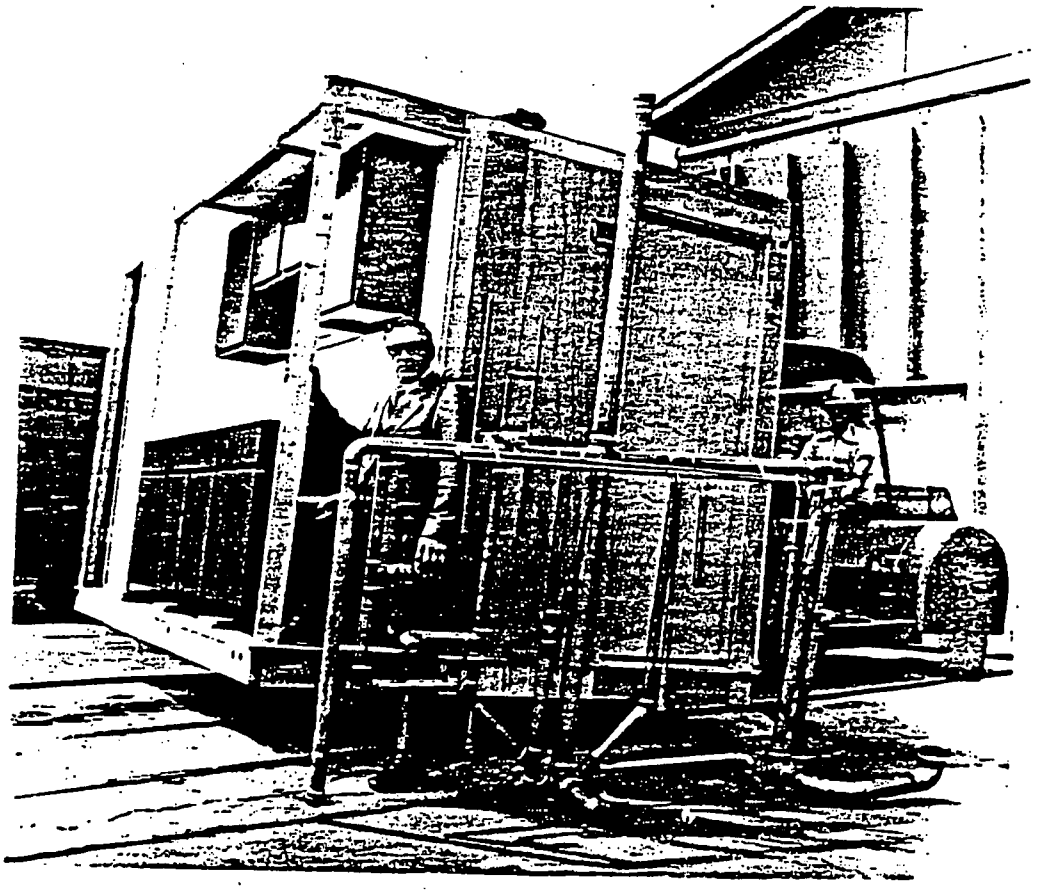

FIGURE III-13 PREASSEMBLY–A COPPER PLUMBING TREE

Source: McGuiness, 1980

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D. Use of Plumbing Systems

1. Water Use

Water is drawn from the potable water supply, used, and often returned to the drain and waste system. The total water withdrawn is termed "consumptive use." The system's delivered water enters various categories of end use:

- Domestic
  - Drinking, culinary
  - Washing, bathing
  - Laundering, auto washing
  - House cleaning
  - Heating, air conditioning
  - Sanitary flushing
  - Lawn and garden watering
  - Wading pool and swimming pool make-up water
- Commercial and industrial
  - Process
  - Cooling
  - Steam generation
  - Washdown
- Municipal
  - Street cleaning
  - Parks and recreation, including irrigation, fountains, and the like
  - Fire fighting
  - Public buildings
- Water unaccounted for (mainly losses due to leakage).

Total water consumption per capita, for the purposes noted above, can have a wide range of values. Differences around the state are subject to climate, delivery pressures, amount of sewerage available, standards of living, types of commercial/industrial activity, ratio of single-family residences to apartment houses ratio, degree of metering, cost of water, and public attitude (e.g., toward water conservation, among other factors). Nevertheless, to gain some sense of magnitude, Table III-19 can help.

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Table III-19

WATER CONSUMPTION IN
VARIOUS MAJOR USES

Class	Gallons Per Capita Per Day		
	Normal Range	Average	Percent
Domestic	15 - 70	50	33
Commercial/industrial	10 - 100	65	43
Public	5 - 20	10	7
Water unaccounted for	10 - 40	25	17
Total	40 - 230	150	100

Source: Fair et al. (1966).

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Though still using rough averages, we can further quantify the domestic portion of the supplied water (see Table III-20). The 2.5 gallons indicated for Drinking is the amount coming through the tap; the ingested quantity is only a portion of this. Further explanation of the use of water and plumbing systems is included in Section IV-A.

2. The Role of Building Inspection

Standards for the proper choice of plumbing materials and proper installation of plumbing, whether plastic or metal, provide little protection unless they are observed much more often than not. Plumbing codes and standards could easily be ineffective if there were no provision for enforcement. The principal agents of code enforcement are the building inspectors, who can deny permission to continue construction or to occupy a building if they find code violations. In the case of fire-rated construction, the fire inspectors can also deny permission to occupy. The existence of a strong building inspector capability is thus an effective deterrent to use of substandard materials or faulty installation practices. However, at present building inspectors tend to look more for practices that would degrade performance than for ones that would cause environmental problems.

Building and fire inspectors can detect the following types of improper practices:

- Use of unapproved pipe, fittings, and fixtures. By inspection for the NSF-PW seal on water pipe, and various markings on DWV pipe, this type of error can be relatively easily detected.
- Poor mechanical installation practices. Inspection for too sudden bends, improper suspension and clearances, contact of drain pipe with wallboard, and so on, can detect these deficiencies relatively easily and can reduce failure rates and noise problems.
- Poor joining techniques. Excessive or careless use of cements, solders, pipe joint compounds, and the like can sometimes be detected by external inspection after the fact. Inspection during installation, however, would be more likely to detect such problems.

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Table III-20

DISTRIBUTION OF DOMESTIC WATER CONSUMPTION

Use	Percentage	Average Consumption*
Flushing toilets	41	20.5
Washing/bathing	37	18.5
Kitchen	6	3
Drinking	5	2.5+
Washing clothes	4	2
Household cleansing	3	1.5
Garden watering	3	1.5
Auto washing	1	0.5
Total	100	50.0

*Based on Table III-19.

+Through tap--see text.

Source: U.S.G.S. (1964).

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- Inadequate flushing. In principle, building inspectors could require flushing to be conducted while they are present. This practice is rarely, if ever, done at present.

- Fire Protection. Regular building inspection will detect inadequate fire blocking and excessive clearances around pipe. In fire-rated buildings, inspectors could look for features such as metal sleeves or guillotines in use with plastic pipe that would preserve the fire rating of fire-resistive structures. However, at present there do not appear to be specific observable features that would assure a fire inspector that a fire wall would retain its rating with plastic plumbing.

It is believed that most new construction and major interior renovations, replacements, and repairs undergo inspection. However, certain homeowner-installed piping, especially for external use in gardens, can escape inspection (Nelson, 1983). Nelson also believes that do-it-yourselfers often do a good job of installation, however.

E. Water Distribution and Waste Water Collection

1. Purpose

This section first provides an overview of how fresh water arrives at dwellings and structures and how spent water is handled on leaving them. Then, it describes material, installation, and cost factors that constitute the plumbing network in dwellings--the plumbing system element of prime concern of this environmental review.

2. General

a. A Macro Look at the Water Supply/Wastewater Disposal System

Although there are differences between rural and urban settings and between small and large systems, Figure III-14 illustrates generally the flow of consumer water from source through consumption and then its return again to the source to repeat the cycle. For simplicity, the return of

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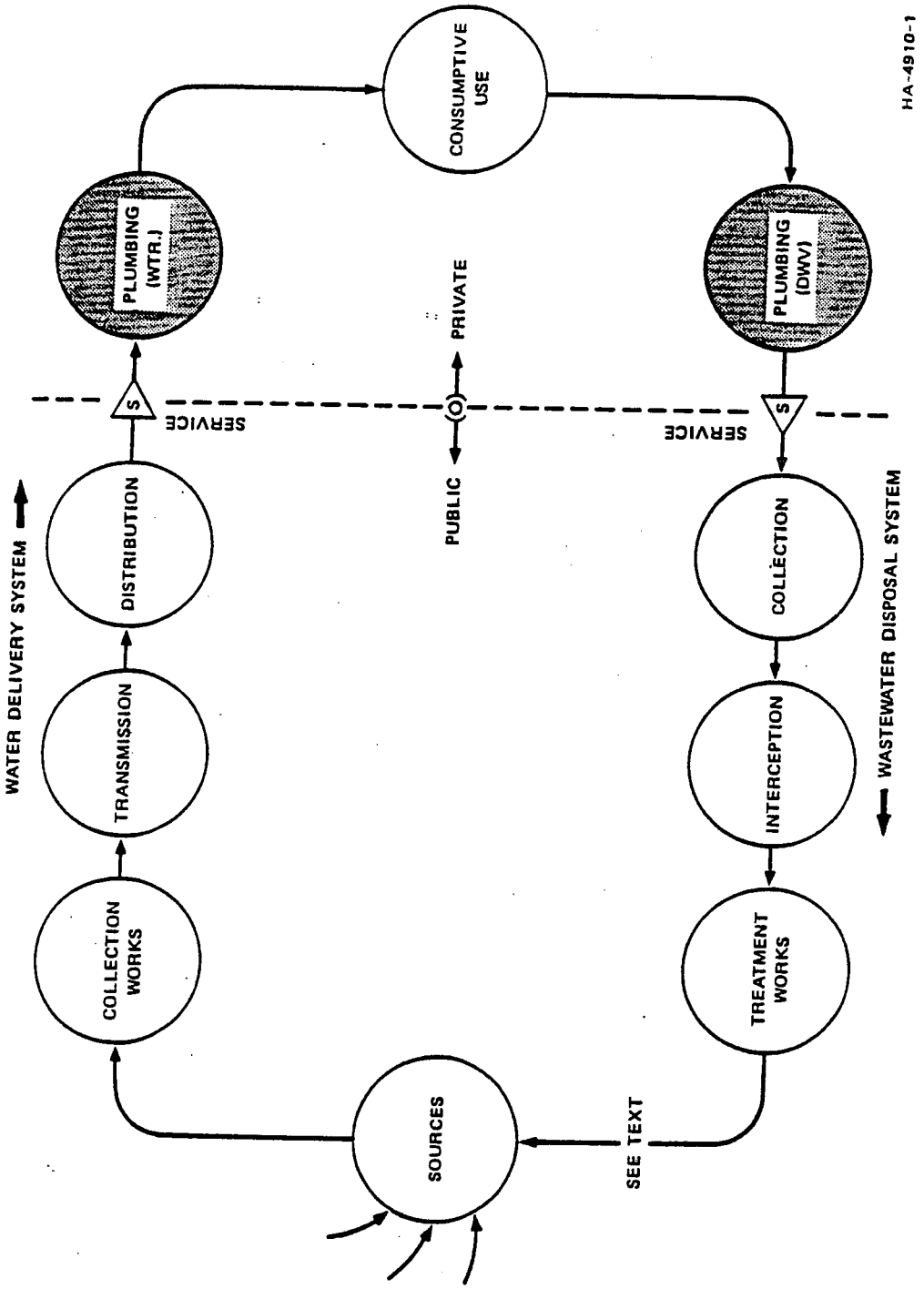

FIGURE III-14 WATER DELIVERY AND WASTEWATER DISPOSAL SYSTEM

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spent water is shown as a single pathway to the source. Clearly, in a more detailed presentation, the hydrological cycle and hydrogeologic phenomena come into play.

To place the environmental impacts of the plumbing system itself in perspective, it is useful to understand the many materials that a molecule of consumer-used water comes in contact with outside that system--e.g., contact with a wide array of thermoplastic materials and polymer-based compounds.

The "Service" notation shown merely represents the physical interface between public-agency and (generally) private-sector elements. On the water delivery side of the cycle, this would consist of the connection to the public water main, a relatively short reach of pipe, a curb stop (i.e., property line valve), and a recording flow meter. On the wastewater side, it will generally be the wye branch connection to a public collection pipe in a street, alley, or public easement and a run of sewer pipe (i.e., the sewer lateral) to the property line. In Figure III-14, it is the right side of both these interfaces that is the primary issue here.

b. Features of the System Elements

i. Sources of Supply--It is often the source of supply that will determine the nature of the collection, transmission, and distribution works. This is especially true for purification facilities--not only as to their process but to where in the "supply" chain they are most effectively located. Fresh-water sources are generally categorized as (1) surface waters (e.g., streams, rivers, ponds, lakes, and snowpacks) and (2) groundwaters (e.g., springs, groundwater table, shallow and relatively deeper aquifers, subterranean reservoirs, etc.).

ii. Collection Works--These works include infiltration galleries, pumps, wells, and impounding reservoirs (natural and dammed), and may include some purification capability, depending on the distance to and size of the first users off the transmission line.

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iii. Transmission--Included in this system element are open channels (e.g., earthen, lined), covered and open aqueducts (e.g., concrete, rock), and totally closed pipelines (for pipeline materials see Table III-21). Often booster pumps and associated mechanical features are necessary along the transmission route.

iv. Distribution--This element has several important parts or functions. These are (1) the piping networks serving consumer purposes, (2) piping or system capacity, (sometimes separate from the above, e.g., in high-value mercantile districts) for firefighting purposes, and (3) terminal storage--sometimes referred to as distribution storage--to accommodate peak demands and firefighting capacity. This latter may include open and covered reservoirs, elevated and ground-level tanks, standpipes, and the like.

v. Plumbing (Water Supply)--Four functional subelements are distinguishable for analysis:

(1) Cold water piping--generally characterized by greater throughput (i.e., volume) than hot water piping.

(2) Hot water piping--characterized by the need to accommodate higher temperatures than cold water piping.

(3) Hot water storage--the tank system used to provide both the heating vessel and a stored supply of hot water.

(4) Cold water storage--not as universal as hot water storage, yet equally important when elevated storage is required for purposes of system pressure or fire safety in multistory buildings.

vi. Plumbing (Wastewater)--Basically, the two primary components of the wastewater plumbing systems are:

(1) Sewage and liquid waste drainage pipes--carrying sanitary wastewaters (e.g., from toilets, urinals), what is sometimes referred to as "grey wastes" (e.g., wastewaters from lavatories, sinks, tubs, and wash-down drains), food wastes (e.g., from garbage disposals), and process and other water-borne wastes.

(2) Air vent pipes--provide flow of air to and from the drainage system to protect trap seals from siphoning and backpressure.

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Table III-21

MATERIALS OF CONSTRUCTION
WATER DELIVERY SYSTEM

Piping*:	Cast iron Ductile steel Concrete (pressure type) Asbestos-cement Thermoplastic (e.g., PVC, PE) Composite plastic (e.g., epoxy-cased fiberglass) Plastic bonded steel (e.g., IPM watermain pipe)
Pipe linings:	Cement mortar Heat fused polyethylene (e.g., "Polybond") Polypropylene Coal tar Other bituminous materials (cold applied) Epoxies Mineral-based compounds
Storage vessels:	Earth, concrete, steel, wood, membrane-lined
Membrane Linings:	Polychloroprene Chlorinated polyethylene Chlorosulfonated polyethylene Polyisobutylene Polyolefin EPDM (ethylene propylene diene monomer)

*Not listed are a wide range of materials used in valves, seals, fittings, joints, and other miscellaneous castings, or the materials used for channels and aqueducts.

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vii. Collection--This system element consists of a network of pipes, manholes, cleanouts, lift stations (i.e., pumping facilities to increase the system pressure head), and possibly temporary holding basins. Its function is to carry spent waters as well as water-borne solid wastes from the plumbing system to the nearest interceptor or, in smaller cities, directly to the point of disposal. Types of pipe used for this purpose are indicated in Table III-22.

viii. Interception--This is relatively large diameter pipe or other form of conduit that collects, in a single carrier, the outflows of several collection networks.

ix. Waste Treatment Works--This element in the water supply and return cycle generally consists of one or more of the following processes:

- Aeration (surface to air contact)
- Screening (removal of bulky floating matter)
- Skimming (oils and grease flotation)
- Settling (removal of settlable solids)
- Flocculation/precipitation (removal of suspended and dissolved solids)
- Digestion (removal of colloidal and dissolved organic matter)
- Biological filtering (transformation of solids)
- Disinfection (removal of pathogenic bacterial or other organisms)

Depending on location, policy, costs, and other factors, treatment of wastewater will vary from none to the most sophisticated.

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Table III-22

MATERIALS OF CONSTRUCTION
WASTEWATER DISPOSAL SYSTEMS

Piping:	Vitrified clay (VCP) Concrete sewer pipe Asbestos-cement Thermoplastic Composite (fiberglass-reinforced epoxy resin) Ductile and cast iron (more for pressure mains; requires lining) Steel (more for interceptors; requires lining)
Lining:	Cement mortar Coal tar Coal tar epoxy Other bituminous coatings Epoxy mortars Polyethylene (e.g., ductile and cast iron pressure pipe) Glass (e.g., industrial waste treatment applications) Slip lining (actually a polyethylene or other pipe slipped into older metal pipes for rehabilitation)

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c. Additional Flows of Concern

Figure III-15 illustrates some additional water and waste flows that, in effect, suggest that:

- Not all water produced reaches the consumer because of leakage.
- Not all water spent reaches its otherwise prescribed destination.
- Spent water emanating from the plumbing systems of the state's dwelling units may in some cases represent only a portion of total wastes disposed of.
- There is a high degree of wastewater dilution when discharge is handled via combined sanitary- and storm-sewer systems.

3. The Plumbing Systems

a. General

Figure III-16 illustrates how the basic residential water and waste plumbing systems connect to the external water supply and sewer systems. As can be seen in Table III-23, the plumbing in residences may run from about 3% to over 10% of housing cost, comparable to the range seen for commercial buildings.

b. Water Supply Plumbing

As indicated in Section III.C, the majority of this system is inside, installed within walls and ceiling-joist framing. A smaller amount occurs in open crawl space and basement areas. The outside cold water service pipe is relatively short, varying from only a few feet to possibly 50 feet in length in deep-setback districts. On the other hand, the outdoor plumbing for garden, lawn, swimming pool, and wash down can be extensive.

Because of service piping, water heater cold-side piping, and external plumbing, the size of the cold water system will always exceed that of the

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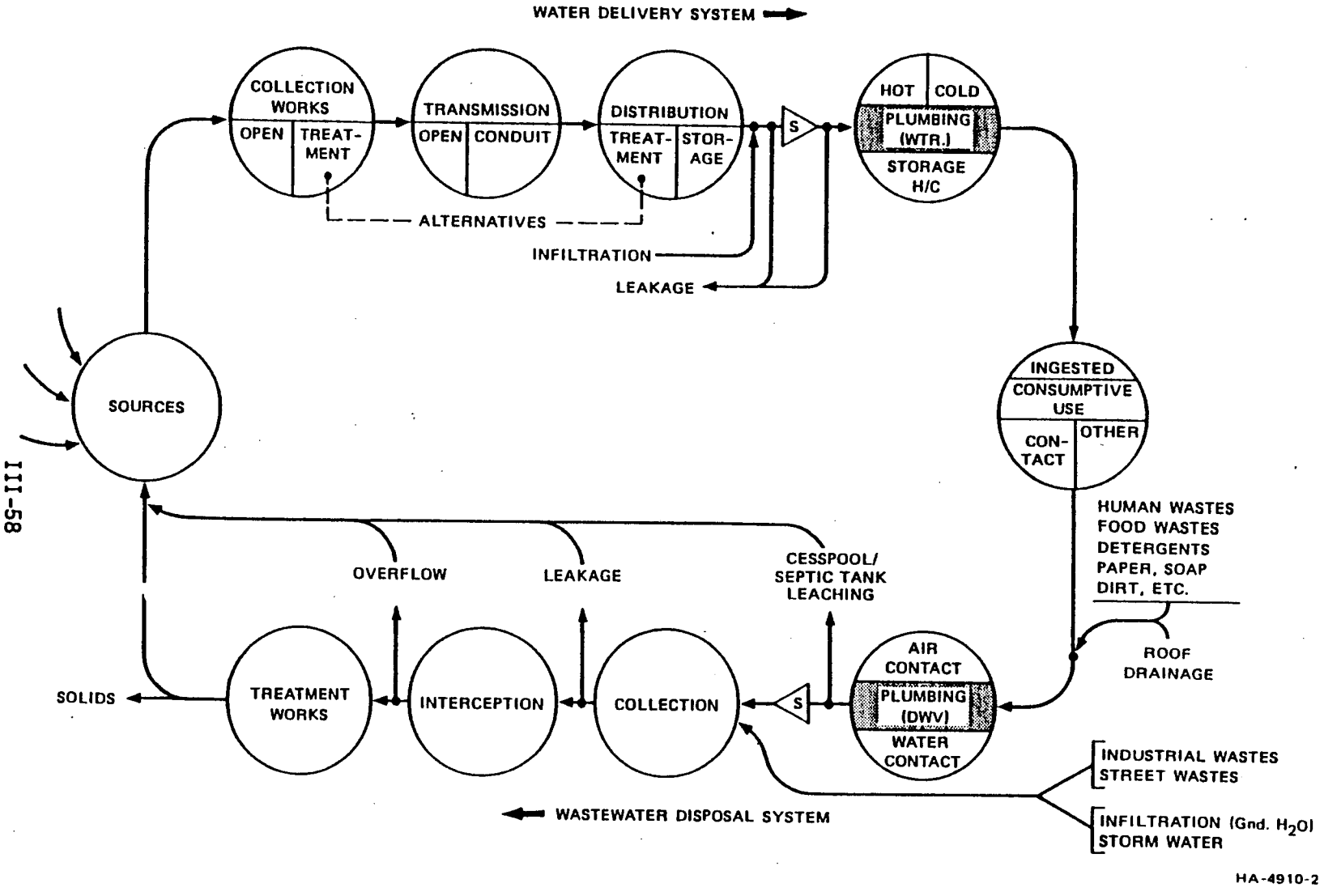

FIGURE III-15 DETAILS OF WATER DELIVERY AND WASTEWATER DISPOSAL SYSTEM

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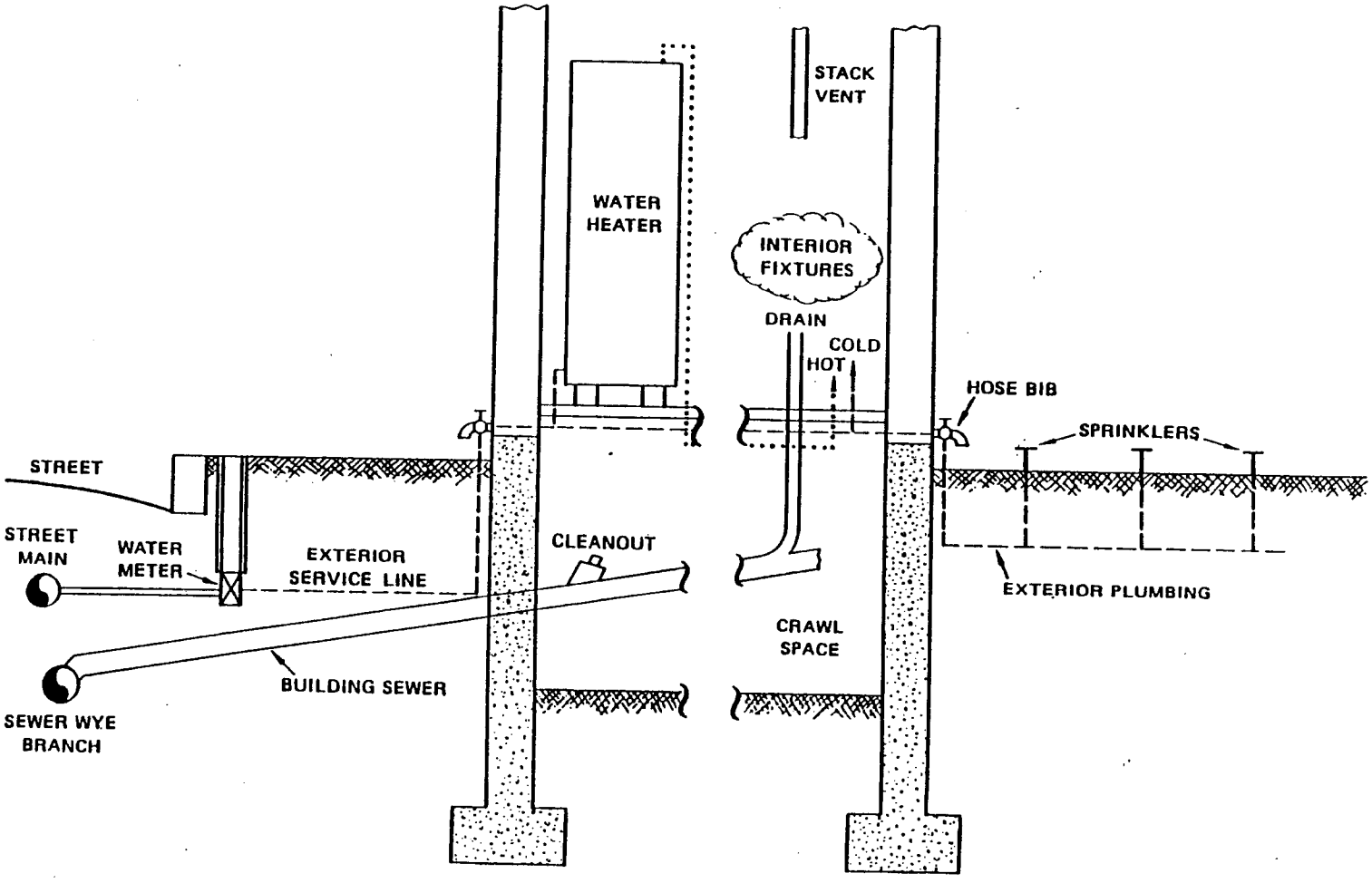

FIGURE III-16 ILLUSTRATIVE CONNECTIONS TO WATER DISTRIBUTION AND WASTE COLLECTION SYSTEMS

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Table III-23

PLUMBING COSTS AS A PERCENT OF CONSTRUCTION COSTS

Building Type	Range (%)	Mean (%)	Number of Samples
Retail Store	2 - 7	3.6	7
Church	2 - 7	4.0	5
Theater	4 - 5	4.3	3
Bank	3 - 7	4.5	8
Warehouse	3 - 7	4.7	6
Residence (W/Swimming Pool)	3 - 7	5.3	4
Gymnasium	4 - 11	6.7	3
Office	3 - 11	7.0	8
Supermarket	5 - 10	7.2	6
School (Elementary)	4 - 11	7.3	6
Restaurant	6 - 14	9.0	8
School (High School)	4 - 11	9.3	7
Garage (Vehicle Repair)	7 - 13	9.7	3
Apartment	9 - 11	10.2	6
Motel/Hotel	9 - 11	10.5	4
Clinic	7 - 15	10.8	6
Nursing Home	7 - 20	11.5	6
Low Rent Housing	8 - 14	11.5	4

Source: Dodge Digest of Building Costs and Specifications; McGraw-Hill, New York; 1977

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hot water system--possibly accounting for 60% to 70% of the total supply installation.

Pipe sizing is a function of: (1) the number of fixture units served (Table III-24), (2) the supply pressure, and (3) the length of run to the farthest outlet. These parameters are those easily understood in the industry and serve as rough surrogates for quantity of flow, rate of flow, and head loss due to pipe friction. For example, a 3/4-inch inside supply pipe (i.e., exclusive of the outside system) would be required for the basic system shown in Figure III-16, given 16 fixture units (i.e., the indoor fixtures shown plus two hose bibs), a pressure range of 40 to 60 pounds, and no run longer than 100 feet.

Pipe cost differences are covered in Section IV.F of this report. As to the cost of installation, Table III-25 provides some insights into the influence of different piping materials on labor costs. The table is based on installation units of 100 feet. As noted, the times indicated do not include the installation of fittings, valves, and hangers. Though far more complex, precise cost-comparative analysis would be likely to consider such features.

c. Wastewater Plumbing--Drainage and Venting

As with the water supply system, drainage and vent pipe sizes are based on the number of connected fixture units (Table III-26). Although satisfactory for venting purposes, sizes below 2 inches in diameter tend not to be used for waste piping because of their tendency become clogged.

Table III-27 provides an indication of installation time differences between DWV piping types. Polypropylene pipe is included in the table only as a basis for comparing plastic pipe with the metal types shown, not to imply its use in the situation at hand. Table III-28 provides some additional comparisons of water pipe installation times.

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Table III-24

FIXTURE UNIT VALUES FOR COMBINED HOT
AND COLD WATER DEMANDS

Fixture	Number of Fixture Units
Bathtub (with or without shower over)	2
Hose bib or still cock (standard type)	3
Laundry tub or clothes washer (each pair of faucets)	2
Lavatory	1
Lawn sprinklers (standard type, each head)	1
Shower	2
Sink or dishwasher	2
Water closet (flush tank)	3

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Table III-25

INSTALLATION TIMES FOR WATER SUPPLY PIPE
(Manhours per 100 Feet of Pipe)*

	Galv. Steel (A-120, Std. Wt.)			Copper (Type K Outside-Type L Inside)		
	Outside	Inside+	Inside#	Outside	Inside+	Inside#
1/2, 3/4, 1 inch	2.4	4.0	5.0	2.0	3.4	4.3
2 inch	3.1	5.3	7.0	2.6	4.5	6.0
3 inch	4.0	6.5	8.5	3.4	5.5	7.2
4 inch	4.8	8.0	10.0	--	--	--

	Red Brass (Sch. 40)			CPVC Plastic (Sch. 40 Hi-Temp)		
	Outside	Inside+	Inside#	Outside	Inside+	Inside#
1/2, 3/4, 1 inch	3.1	4.0	5.0	1.6	3.2	4.0
2 inch	3.1	5.3	7.0	2.1	4.2	5.6
3 inch	4.0	6.5	8.5	2.7	4.2	5.6
4 inch	4.8	8.0	10.5	3.2	6.4	8.0

*Horizontally or vertically installed; maximum ceiling height of 12 feet. Does not include fittings, valves, and support devices. Outside lengths 20 feet.

+Single-story buildings.

#Multi-story buildings.

Source: General Construction Estimating Standards, Vol. 3; 1976-77, Richardson Engineering Services, Inc., California

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Table III-26

FIXTURE UNIT VALUES FOR DRAIN AND WASTE LINES

Type of Fixture	Fixture Unit Value (d.f.u.)	Min. Trap and Fixture Drain size (in.)
Automatic clothes washer (2 inch standpipe)	3	2
Bathroom group consisting of a water closet, lavatory, and bath-tub or shower stall:		
Flushometer valve closet	8	
Tank-type closet	6	
Bathtub (with or without overhead shower)	2	1-1/2
Combination sink with food waste grinder	2	1-1/2
Combination sink and tray with separate 1-1/2 inch traps	3	1-1/2
Dishwasher	2	1-1/2
Kitchen sink, with one 1-1/2 inch waste	2	1-1/2
Kitchen sink, with or without food waste grinder	2	1-1/2
Lavatory	1	1-1/4
Laundry tray (1 or 2 compartments)	2	1-1/2
Shower stall, domestic	2	2
Water closet, tank-operated	4	3
Water closet, valve-operated	6	3

LISTS MAXIMUM LOADING OF DRAINAGE AND VENT PIPING
Based Upon 1/4 In./Ft. Slope

Size of Pipe (Inches)	1-1/4"	1-1/2"	2"	3"	4"
Drainage Piping	1	3	12	42	180
Vent Piping	2	10	24	100	300

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Table III-27

INSTALLATION TIME FOR INSIDE DRAINAGE AND VENT PIPE
(Manhours per 100 Feet of Pipe)*

Size	Cast Iron Soil Pipe (Std. Wt.) with One No-Hub Coupler per Length		Galvanized Steel Pipe A-120 (Std. Wt.)		Plastic Sch. 40 Flame Retardant Polypropylene	
	Single Story	Multi-Story	Single-Story	Multi-Story	Single-Story	Multi-Story
2 inch	6.5	9.0	4.5	6.0	5.5	7.0
3 inch	8.0	10.5	5.5	7.5	6.5	8.5
4 inch	10.0	12.5	7.0	9.0	8.0	10.0

*Horizontally or vertically installed; maximum ceiling height of 12 feet. Does not include fittings, valves, and support devices.

Source: General Construction Estimating Standards, Vol. 3; 1976-77, Richardson Engineering Services, Inc., California

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Table III-28

EASE OF INSTALLATION
FOR WATER AND WASTE PIPE
(Linear Feet Installed Per Day By 2-Plumber Crew)*

Size	Galvanized Iron (Sch. 40)	Copper (Type L) with Wrought Copper Fittings; Solder	Plastic (Sch. 40) Water Pipe
1/2 inch	100	120	150
3/4 inch	90	100	140
1 inch	85	80	135
2 inch	60	70	80
3 inch	50	55	55
4 inch	50	40	45

Size	Cast Iron Soil Pipe No-Hub	Plastic DWV Pipe
2 inch	100	116
3 inch	80	110
4 inch	75	100

*With fittings every 10 feet and hangers included.

Source: 1978 Dodge Manual for Building Construction Pricing and Scheduling, Annual Edition No. 13, Dodge Building Cost Services, New York.

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IV ENVIRONMENTAL IMPACTS AND MITIGATIONS

A. Water Quality

This subsection discusses the leaching of chemicals from both plastic and metal piping systems into potable water. Where data are adequate, it attempts to estimate the range of concentrations of selected chemicals in drinking water as a function of time after installation of the plumbing system. These concentrations are then the input for the public health impacts analysis (Section IV-B) as well as the assessment of water quality impacts on ecological resources (Section IV-G). Before describing the scientific basis for the estimates, we give a general overview of the use of water in residences and the qualitative behavior of leachates in the water used.

1. General Overview of Water Quality

a. Water Use in Residences

The amount of water stored in the piping system of a typical residence may be only 5 gallons or even less, but 40 to 80 gallons may be stored in the water heater and toilet tanks. On the other hand, typical water usage per capita in a metropolitan area is about 150 gallons per day (150 gpcd), as is explained in more detail in Section III-D. Of this quantity, two-thirds is used for industrial and public (fire, irrigation) purposes; only about 50 gpcd goes to residences. At 2.75 persons per unit, the water in a dwelling turns over 1-1/2 to 3 times per day, but water in little-used lines would turn over more slowly and frequently used lines would empty much more frequently. Of the 50 gpcd, about 80 percent is used for bathing and flushing toilets, whereas only 2.5 gallons is for "drinking" (i.e., uses

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related to consumption). Only about 1.5 to 2.0 liters of water in all forms is actually ingested (Sharrett et al., 1982), and up to about half of that may come from purchased beverages (milk, juices, soft drinks, beer, and so on) rather than from the tap. Larger people may consume up to 3 liters per day, whereas infants may consume 1 liter per day or less. Of course, the purchased beverages may also have been made with water from the public water supply. (The health effects of ingesting coffee, tea, ades, and other homemade beverages can be considered nearly equivalent to those of ingesting an equivalent amount of tap water as far as the leachate content is concerned.)

b. Variations in Water Use

In determining the possible impacts of chemicals in pipe leaching into potable water, the time that the water remains in the pipe is a critical variable. Whenever a fixture operates, water is withdrawn from the pipe and replaced with fresh water from the water distribution system. (Although that water itself may contain hazardous contaminants from the distribution system, the water treatment works, or the raw water supply, only contamination from the residential plumbing is the subject of this environmental review.)

The time between withdrawals, and the quantity of water withdrawn in comparison to the volume in the pipe under static conditions (void volume) both influence the levels of leachate concentrations that can be observed. Because most potable water is drawn from sink faucets, the void volume of most interest is that from the faucet back to the last junction with the main water supply line, usually 10 feet or less. The volume of a 1/2-inch pipe 10 feet long is about 1/3 liter, or two small glasses of water; running the water to "let it cool" would flush out the faucet stub, but drinking the first water drawn would capture maximum contamination levels.

The supply lines to bathrooms ordinarily supply the toilet as well, and would be well flushed with each toilet flush. Shower and bathtub use would also flush these lines. Kitchen water lines would be flushed by hand or

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machine dishwashing. Hose bib lines would be flushed by garden use; use of any other water for drinking would be unusual. Hot water lines are rarely used for drinking unless hot water for making beverages is desired; in that case the line would ordinarily be flushed as hot water is drawn from the water heater.

Maximum concentrations of leachates could be expected (1) early after the installation of the pipe and (2) after the longest periods of disuse. Clearly, the highest concentrations would occur immediately after first occupancy unless the system were flushed first.

Many sources suggest that systems are "naturally" flushed by water use during plumbing inspection and finishing of the house (e.g., for cleaning dirt off the driveway, etc.). One estimate (Payne, 1980) shows 1,000 gallons, or several hundred void volumes of pipe, as typical. However, it is not clear that all lines would be equally flushed, or that a homeowner would typically flush the lines again upon moving in. That final flush would be well advised.

After this initial period with an uncertain degree of flushing, the highest concentrations would occur after extended periods of non-use, such as a vacation, or infrequent use, as in a guest bathroom. The significance of these levels, however, is considerably reduced by the fact that only the first water out will contain the higher concentrations. Thus, if users ran the water for a time after a period of disuse, the longer dwell times would pose of special problems.

Water for cooking comes from the kitchen tap and could be a minor contribution to the total amount of water consumed by residents. Dermal exposures from bathing or even clothes washing have been suggested, but would be significant only for chemicals that had huge lipid (fat) solubilities in comparison with their water solubilities; such chemicals would not be in high concentrations in the water in the first place.

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c. Leaching of Materials into the Residential Water Supply

The health and water quality impacts of leached chemicals can depend on either the instantaneous concentration levels of the chemicals in the water or on the cumulative exposures of humans or other living things to the varying concentrations over time, or on both. Thus, a scientifically complete analysis of the water quality (leachate) issue in principle depends on knowing the variation of concentrations over time that could occur in plastic and metal plumbing systems.

We would ideally like to be able to know concentration levels as a detailed function of time after installation. Figure IV-1 shows a decreasing level of concentration over time from first installation, as the chemicals in the original pipe or joining substances are depleted or immobilized. This general pattern of decreasing concentrations over time would be expected for essentially all chemicals in either plastic or metal pipes; for example, the solvents in solvent cements would either evaporate to the atmosphere or leach into water that is later flushed from the system, and the metals in copper pipe solder would be protected by deposits of inactive chemical compounds on the inner surface of the pipe. Different chemicals would show more or less rapid declines over time after installation, depending on their physical and chemical properties.

This general pattern, however, is only a large-scale picture; many events disturb the even downward trend. When water stands in the pipe for a period of time ("dwell time")--overnight or during a vacation period--concentrations build up. When the system is flushed, either deliberately or as a consequence of water use, concentrations drop to near zero or to the levels in the incoming water supply. The variation over a day or two might look something like that in Figure IV-2.

The exact details of these variations depend strongly on the properties of each specific chemical. Some chemicals will either initially be near the surface of the pipe or diffuse there rapidly; the short-term buildup of their concentrations in water will depend on their relative affinities for

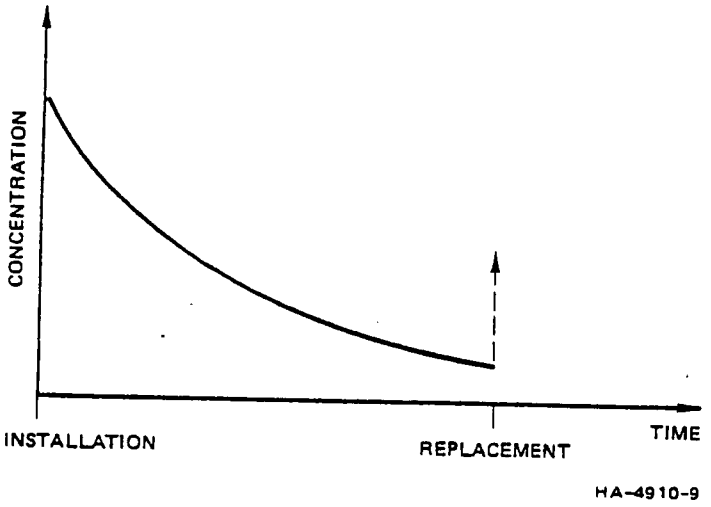

FIGURE IV-1 LONG-TERM PATTERN OF DECLINE IN CONCENTRATION

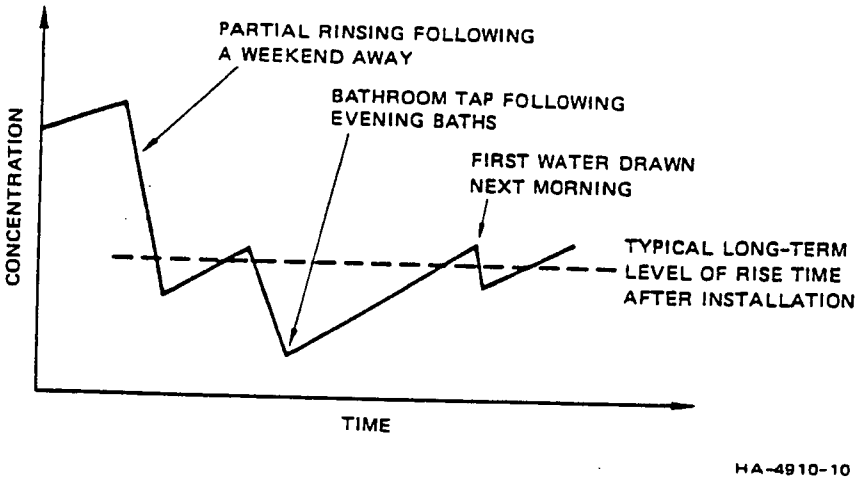

FIGURE IV-2 SHORT-TERM VARIATIONS IN CONCENTRATION

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plastic and water, and movement into water will be limited by equilibrium between the two, as indicated in Figure IV-3a. Other chemicals diffuse relatively slowly through the pipe matrix, and the buildup rate in water will be limited by this diffusion rate rather than by the equilibrium between concentrations in plastic and water. In this case, the buildup will continue to increase with dwell time as shown in Figure IV-3b.

For equilibrium-limited chemicals, the maximum concentration will decline with time after installation, as the chemical is depleted or protected, whereas for diffusion-limited chemicals, the rate of leaching (slope of the lines in Figure IV-3b) will decline over time.

In both cases, concentrations after any given dwell times will eventually decline to negligible levels as the source of chemicals in the pipe is depleted or protected. If chemicals in the pipe break down to form other chemicals, the source strength for such chemicals may increase for a time before eventually decreasing. If chemicals must move to the surface before leaching, a delay in their appearance will also be observed.)

Thus the patterns of concentrations in potable water depend on many factors, including the original amount of the chemical in or on the pipe, the details of its original distribution, its ability to diffuse through plastic, its tendency to leave the pipe externally into air or soil, and its relative solubility in plastic and water. Few of these properties can be confidently described for all chemicals; even for one chemical, all the properties are unlikely to be known.

However, the situation is not hopeless. Measurements have shown us that few of the chemicals are likely to reach acutely toxic concentrations, even after considerable dwell times. The issue is therefore much more one of chronic toxicity as a result of the long-term ingestion of water containing leachates. (This observation does not imply that short-term exposures cannot cause later effects like cancer; in fact, we know that such is possible for some chemicals. However, the probability of toxic effects decreases rapidly as the total amount of exposure decreases.)

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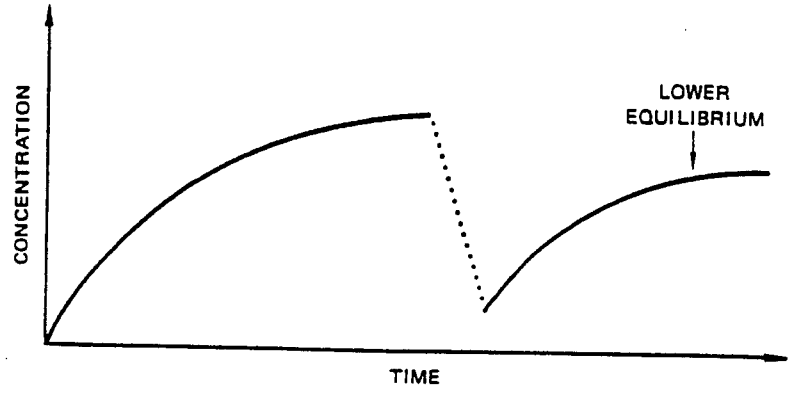
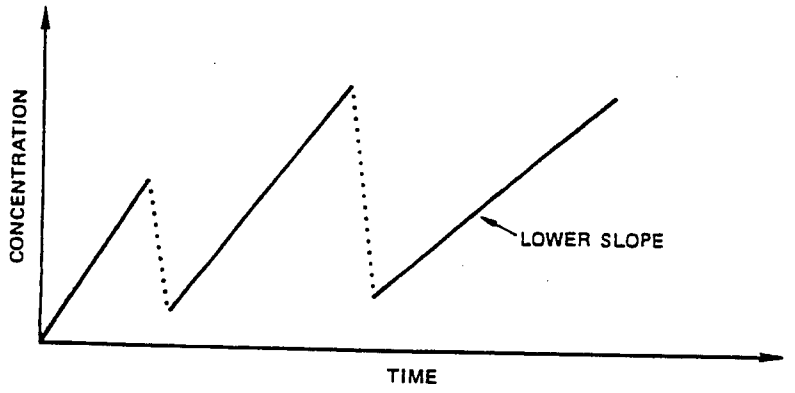


(a) EQUILIBRIUM-LIMITED



(b) DIFFUSION-LIMITED

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FIGURE IV-3 DIFFERENT BEHAVIORS OF LEACHING DURING DWELL PERIODS

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The consequence of this observation is that the long-term averages are more important than the peaks of concentration, assuming that people are not likely to drink much more water after long dwell times than they are at other times. Using only the peak, worst case values would lead to a gross overstatement of the problem, whereas using only the "running water" values would completely ignore the buildup with dwell time.

Furthermore, the question of whether or not the system is well flushed after construction becomes much less significant. The few glasses of water containing high concentrations that might be drunk will still contribute many fewer molecules to a lifetime dose than will the tens of thousands of glasses drunk with later and lower levels.

2. Leaching Models

The estimation of the health effects of leachates from plastic pipes requires knowledge of the concentration of leachates in pipe water as a function of time. If water stands in a pipe, the concentration of a specific chemical in the water will be determined by the leaching rate, or flux, of the chemical integrated over time. The leaching rate in turn will be determined by the amount and distribution of the chemical in the pipe, diffusion of the chemical in the pipe and in the water, the equilibrium partitioning of the chemical between the pipe and the water, and diffusion of the leachate out of the pipe into the air.

Unfortunately, few data exist on plastic pipe diffusion coefficients or pipe/water partitioning coefficients of organic chemicals. Because these coefficients are likely to be very sensitive to specific chemical/pipe interactions, they are difficult to predict.

Whereas a general predictive model of leaching from plastic pipes would therefore be unreliable, it is nevertheless important to develop simple leaching models in order to critically evaluate published data and to design useful experiments. The models described below deliberately simplify

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leaching from pipes to focus attention on the critical factors determining the flux of chemicals from pipes.

The differential equations that describe mass transfer in the pipe and in the water are given by Fick's second law of diffusion:

$$\partial C_p/\partial t = D_p(\partial^2 C_p/\partial x^2) \qquad (4\text{-}1)$$

$$\partial C_w/\partial t = D_w(\partial^2 C_w/\partial x^2) \qquad (4\text{-}2)$$

where C_p and C_w are the concentrations and D_p and D_w are the diffusion coefficients of the chemical in the pipe and in the water, respectively. Equations (4-1) and (4-2) describe the concentration of the chemical as a function of time (t) and distance (x) from the pipe/water interface.

The solution of equation (4-2) will depend on the initial and boundary conditions for the pipe/water system. Two relatively simple cases for pipe leaching appear to be reasonable. In the first case, a surface film of leachate covers the inner surface of the pipe and diffuses into an initially pure water phase. In the second case, the leachate is initially distributed uniformly in the pipe and diffuses into an initially pure water phase.

The first case is relatively easy to solve and is probably appropriate for the initial leaching of pipe cement solvents from the interior face of the pipe. The formula to be given refers to the average concentration C_w in a pipe of radius r_o. The initial and boundary conditions are:

$$\bar{C}_w = 0 \text{ for } 0 \leq r < r_o \text{ and } t = 0 \qquad (4\text{-}3)$$

$$\bar{C}_w = C_w^o \text{ for } r = r_o \text{ and } t > 0 \qquad (4\text{-}4)$$

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where C_w^o is the equilibrium concentration. The solution to equations (4-2), (4-3), and (4-4) is (Jost, 1960):

$$1 - \frac{\bar{C}_w}{C_w^o} = \sum_1^\infty \frac{4}{\varepsilon_n} \exp - \frac{\varepsilon_n^2 D_w t}{r_o^2} \qquad (4\text{-}5)$$

where ε_n are the roots of the equations $J_0(x) = 0$ and $J_0(x)$ is the Bessel function of zero order. For t sufficiently large, the first term of the series is a good approximation. The first term is:

$$1 - \frac{\bar{C}_w}{C_w^o} \approx 0.69 \exp [-t/\tau] \qquad (4\text{-}6)$$

$$\text{with} \qquad \tau = \frac{0.173\ r_o^2}{D_w} \qquad (4\text{-}7)$$

Thus, a plot of log $C_w^o - \bar{C}_w$ versus t should give a straight line with a slope of τ^{-1}.

After (n + 1) equilibrium dwell periods, the concentration in the water will be:

$$C_w^n = \left(\frac{H'}{1 + H'}\right)^n C_w^o \qquad (4\text{-}8)$$

where C_w^o and C_w^n are the equilibrium concentrations in the water during the initial and (n + 1) dwell periods, respectively, and

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$$H' = n_p^o / n_w^o \qquad (4\text{-}9)$$

where n_p^o is the initial amount of leachate in the surface film, in equilibrium with an amount of leachate n_w^o in the pipe water. The partitioning coefficient H' is assumed to be constant.

The ratio C_w^n/C_w^o is plotted as a function of n and H' in Figure IV-4. If H' is small (the chemical tends to partition in the water), C_w^n/C_w^o falls rapidly with the number of equilibrium dwell periods, as expected. A plot of log C_w versus n should give a straight line, from which H' can be calculated.

This model is inappropriate after the surface film has been depleted or if the leachate is uniformly distributed in the pipe. A simple model can also be developed for the case where the leachate is uniformly distributed in the pipe. We assume that D_p and D_w are independent of concentration, that the pipe/water interface is flat, and that the chemical diffuses only a short distance relative to the thickness or diameter of the pipe during a dwell period. Moreover, we assume that at all times equilibrium is established at the pipe/water interface ($x = r - r_o = 0$) with:

$$C_p/C_w = H \qquad (4\text{-}10)$$

where the partitioning coefficient H is assumed to be constant.

Subject to these initial and boundary conditions, equation (4-2) can be solved:

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$$C_w = C_p^o \left(\frac{D_p^{1/2}}{HD_p^{1/2} + D_w^{1/2}} \right) \left[1 - \text{erf} \left(\frac{x}{2(D_w t)^{1/2}} \right) \right] \qquad (4\text{-}11)$$

where C_p^o is the initial concentration of the chemical in the pipe and erf is the error function. The average concentration of the chemical in the water inside a pipe of diameter d would thus be:

$$\bar{C}_w = C_p^o \left(\frac{4}{d\pi^{1/2}} \right) \left[\frac{(D_p D_w)^{1/2}}{HD_p^{1/2} + D_w^{1/2}} \right] \left(t_2^{1/2} - t_1^{1/2} \right) \qquad (4\text{-}12)$$

where t_1 is the beginning time and t_2 is the end time of a given dwell period ($C_p = C_p^o$ at $t_1 = 0$).

This model can be made more realistic by assuming a finite pipe thickness n and allowing the leachate to diffuse out of the pipe into the surrounding air. These boundary condition complicate the solution of equation (4-2). However, at short times, the solution is similar to equation (4-12):

$$\bar{C}_w = C_p^o \left(\frac{\varepsilon}{d} \right) \left[\frac{(D_p D_w)^{\frac{1}{2}}}{HD_p^{\frac{1}{2}} + D_w^{\frac{1}{2}}} \right] \left(t_2^{\frac{1}{2}} - t_1^{\frac{1}{2}} \right) \left[i \text{ erf}(0) - 2i \text{ erf} \left(\frac{h}{2(D_p t)^{\frac{1}{2}}} \right) \right|_{t_1}^{t_2} \ldots \Bigg] \qquad (4\text{-}13)$$

where i erf is the integral (i) of the error function (erf).

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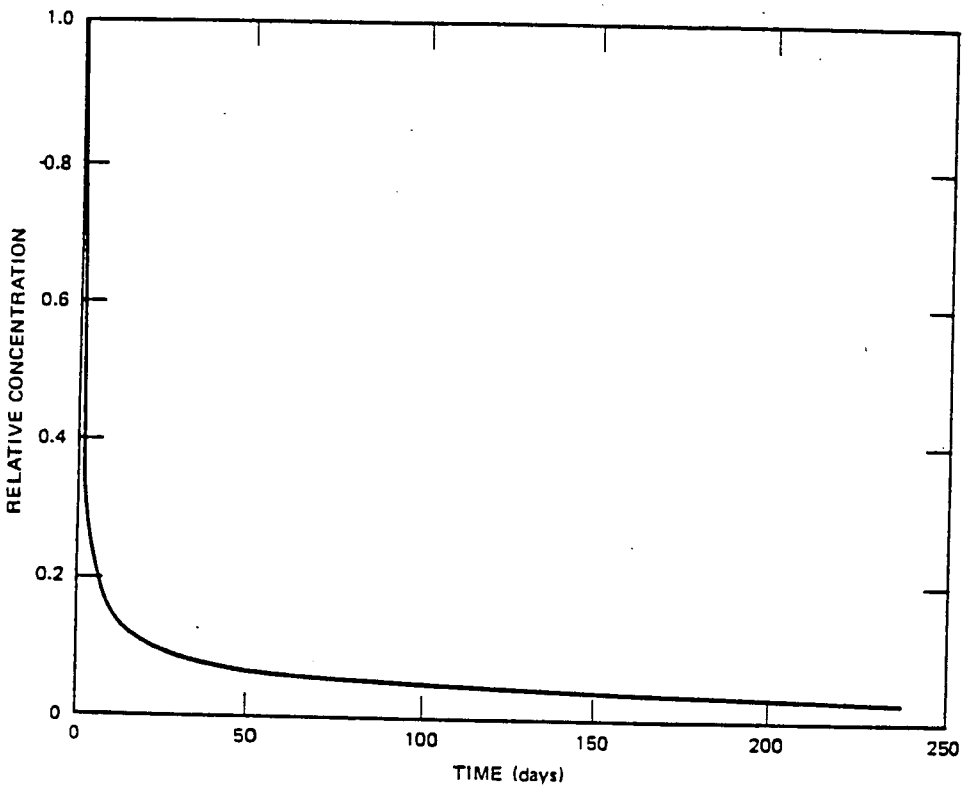

FIGURE IV-4 CONCENTRATION VERSUS TIME PROFILE OF LEACHATE IN WATER ACCORDING TO EQUATION (4-16)

Assume daily sampling and concentration in units of initial sample concentration.

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Several observations can be made about equations (4-12) and (4-13). First $\bar{C}_w$ will be proportional to the initial amount of chemical (C_p^o) in the pipe. Second, $\bar{C}_w$ will be inversely proportional to the internal diameter of the pipe. Third, $\bar{C}_w$ will depend on the relative magnitude of $HD_p^{1/2}$ and $D_w^{1/2}$:

$$\frac{\left(D_p\ D_w\right)^{1/2}}{HD_p^{1/2} + D_w^{1/2}} = D_p^{1/2} \quad \text{for } D_w^{1/2} >> HD_p^{1/2} \qquad (4\text{-}14)$$

$$= \frac{D_w^{1/2}}{H} \quad \text{for } HD_p^{1/2} >> D_w^{1/2} \qquad (4\text{-}15)$$

Equation (4-14) will be expected for leachates with high aqueous solubilities and low diffusion coefficients in the pipe. Conversely, equation (4-15) may be appropriate for leachates with low aqueous solubilities and high diffusion coefficients in pipes. Table IV-1 lists diffusion coefficients of several chemicals. Few data are available in the literature for PB, PVC, and CPVC, but these data do indicate that the diffusion of chemicals in rigid pipe should be orders of magnitude less than that in water and should, in general, decrease as the molecular size of the leachate increases.

Finally, and most importantly, pipe leaching in the model has a $t^{1/2}$ time dependence. Thus, we can write equation (4-12) or (4-13) as:

$$\bar{C}_w \approx K\left(t_2^{1/2} - t_1^{1/2}\right) \qquad (4\text{-}16)$$

where K is a constant. If a new pipe is installed and water is allowed to stand in the pipe for a given initial period (t_2^o) and then sampled, the initial concentration will be C_w^o. If at a subsequent time t_1, water

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Table IV-1

DIFFUSION COEFFICIENTS OF ORGANICS IN PVC PIPES AND WATER AT 25°C

Chemical	$D_w \times 10^6$ ($cm^2\ s^{-1}$)	$D_p \times 10^6$ ($cm^2\ s^{-1}$)	
		PVC	Teflon
O_2	24.1	0.0118	0.184
CO_2	20.0	0.0025	0.105
CH_4	14.9 at 20°C	0.00126	0.0298
C_2H_6			0.0047
C_3H_8			0.00077
C_2H_4			0.0098

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is allowed to stand in the pipe for some length of time ($t_2 - t_1 = t^o$), C_w (as a fraction of C_w^o) can be ploted as a function of time (in units of t_2^o) as shown in Figure IV-5. For example, if water stood in a new pipe for one day and the concentration of a chemical in the water was found to be 1 ppm, the amount of chemical diffusing into the water per day during subsequent days would be given by Figure IV-5 with the y-axis in ppm and the x-axis in days.

Figure IV-5 shows that for equal dwell times, the concentration of chemicals in the water is expected to fall very rapidly as the pipe is repeatedly exposed to fresh volumes of water.

In summary:

- Model 1--The leachate is concentrated at the pipe/water interface. The leachate equilibrates with the water relatively rapidly and the amount of leachate in the water depends on the equilibrium partitioning of the leachate between the surface film and the water and on the number of equilibrium dwell periods that water has stood in the pipe.

- Model 2--The leachate is initially uniformly distributed in the pipe. Equilibrium is not attained during a dwell period and the amount of the leachate in the water in a given dwell period will diminish rapidly with elapsed time (Figure IV-5).

3. Literature Review

The administrative record was reviewed for information concerning the composition of plastic pipes and the leachability of plastic and metal pipes. Information was also obtained from a manual and computer search of the literature for plastic pipes. The literature review focused on PB, CPVC, and PVC plastic pipes and copper and galvanized steel metal pipes.

a. Plastic Pipe Composition

The composition of plastic pipes should be known to determine possible leachates. Nonproprietary specifications supplied by manufacturers of plastic pipe and the National Sanitation Foundation are summarized in

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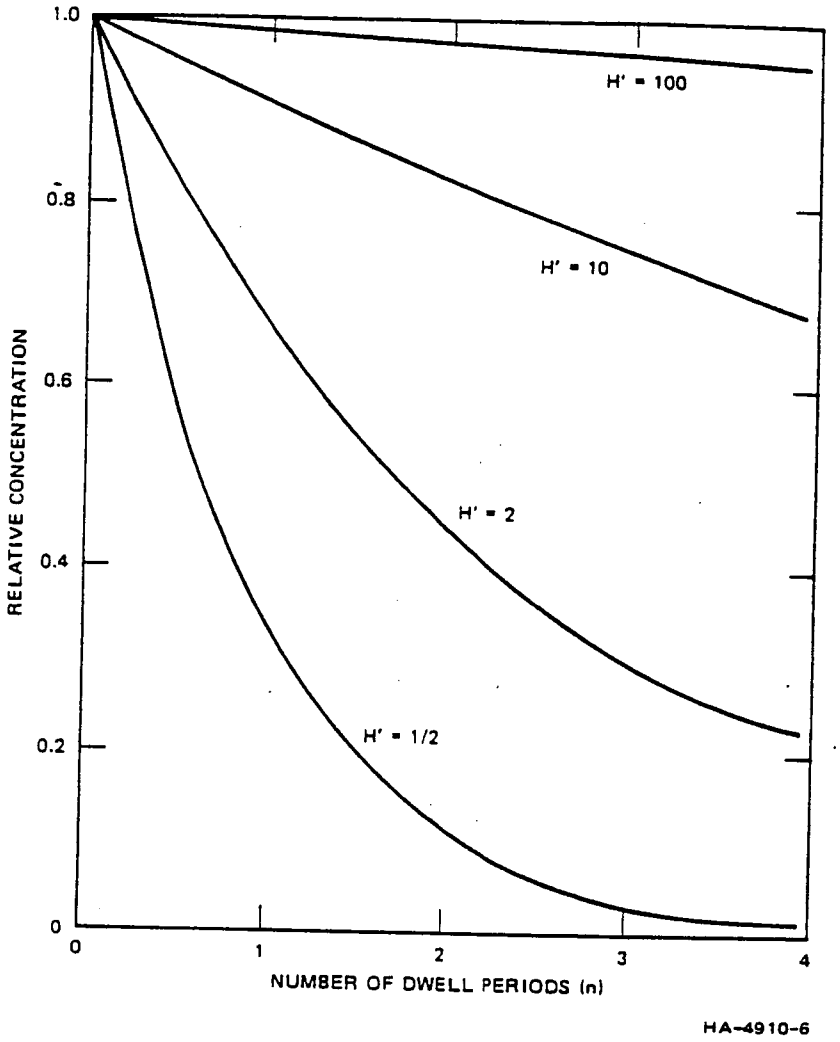

FIGURE IV-5 CONCENTRATION OF LEACHATE IN WATER ACCORDING TO EQUATION (4-8)

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Table III-3. As discussed in Section III, PB is composed primarily of the resin polymer and contains small amounts of pigments (such as titanium dioxide, carbon black, or talc) and a small amount of antioxidant (such as Irganox 1010). The composition of CPVC is more complex and requires a solvent cement for joining pipes. Potential health problems associated with toxic chemicals leached from joined CPVC pipes are accordingly more difficult to assess than potential water quality problems with PB.

b. Plastic Pipe Leaching

Experimental data on the concentration of plastic pipe leachates in water are critical to a realistic assessment of toxicological hazards of plastic pipes. In this section, criteria for evaluating leaching data are discussed and specific studies of pipe leachability are reviewed.

1) Data Quality

The quality of experimental leaching data is determined by the quality of the measured concentrations of leachates in water and by the usefulness of the data. Criteria for evaluating leaching data are summarized in Table IV-2.

The composition of pipe leachate water is likely to be a complex mixture (particularly for CPVC) of organic compounds in very dilute concentrations. Therefore, sampling and analytical methods are critical to the quality of the data and should be reported in detail. The volume of water exposed to the pipe should be well mixed to assure representative analytical samples, and handling losses (caused by adsorption, differential volatilization, etc.) should be minimized. For a complex mixture of organics, it is likely that gas or liquid chromatography will be required to resolve individual leachates, and the sensitivity of the detector for specific leachates should be known. Standards with known compositions of potential leachates should be run to determine the resolution and sensitivity of the analytical method and to help identify unknown leachates. Blanks should be run to determine the background composition of

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Table IV-2

CRITERIA FOR EVALUATING DATA

A. Quality of measurement

1. Sampling
   - Representativeness
   - Handling losses

2. Analysis
   - Resolution
   - Sensitivity
   - Standards

3. Completeness of data
   - Blanks
   - Replicate measurements

B. Usefulness of data

1. Definition of experimental conditions
   - Pipe identification and history
   - Temperature of pipe and water
   - Test configuration and test protocol

2. Representativeness of test system and use

3. Predictive value
   - Precision of data
   - Time dependence of leaching

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the sample water. Finally, random errors in sampling and analysis should be determined by statistical analysis of replicate measurements of leachate concentrations.

Whereas data may have high precision, data utility will nevertheless be very low if the test results cannot be extrapolated to actual conditions of pipe use. To extrapolate test results, experimental conditions should be defined as well as possible. The pipe should be identified by manufacturer and its age and history should be known. If possible, the pipe formulations should be known and the manufacturing process should be identified. The thickness and diameter of the pipe should also be given. The temperature of the pipe and water during exposure should be known. Test configurations and test protocols (static or dynamic tests, elapsed time and dwell time of measurements, volume and duration of rinses, etc.) should be given in detail.

With this information, the representativeness of the test relative to the use of a typical residential plumbing system can be determined. A summary of data for a typical residential plumbing system is given in Table IV-3. These values can be used as a guide to judge the representativeness of laboratory simulations.

If long-term data are required for a health assessment, laboratory measurements measured over a short term will have to be extrapolated to longer times. The quality of the extrapolated data will depend on the precision of the short-term data and the quality of the mathematical expression used to extrapolate the data. Therefore, the precision of the short-term data should be known by making replicate measurements, and the short-term data should be collected over a time period sufficiently long to determine the time dependence of the leaching rate.

Another aspect of data quality, not listed in Table IV-2 but critical to this review, is the possibility of bias. To minimize the possibility of bias, experimental work should be performed by disinterested and objective researchers. Unfortunately, much of the work reviewed for this report was

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Table IV-3

PHYSICAL PARAMETERS OF POTABLE-WATER PLUMBING SYSTEM FOR A TYPICAL HOUSE*

Number of joints	200
Length of pipe per joint	0.5m joint^{-1}
Volume	27 L
Mass	
PB	14 kg
CPVC	23 kg
Inner surface area to volume ratio	0.16-0.32 m^2 L^{-1}
Volume of water flushed through house prior to initial occupancy (Lappe, 1980, Appendix VIa)	3,800 L 140 void volumes
Volume of water flushed through house per day (Reid, 1980)	950 L 35 void volumes

*Based on Table II-4

002902

performed by parties that had institutional interests in the question of pipe water quality.

2) Specific Studies

Specific studies of plastic pipe leachability are reviewed in this section. For each study, the objectives and description of the tests are given, and the results are summarized and analyzed with attention given to the quality of the measurements and the usefulness of the data.

i. James M. Montgomery Report (1980)

James M. Montgomery, Consulting Engineers, Inc., under contract to the California Department of Health Services (CDHS), measured the water leachability of PVC and CPVC pipes. The testing protocol, developed by CDHS, consisted of static, simulation, and kinetic tests. The static test was designed to estimate the concentrations of chemicals in water expected during initial occupancy. The kinetic test was designed to estimate the rate of leaching, so that the concentration of the chemical in water could be predicted as a function of time. Two time-related variables were identified: individual dwell times of the water in the pipe and the cumulative elapsed time of the series of consecutive dwell periods. The simulation test was designed to estimate leachability during typical home use.

Analysis of water samples was limited to the 38 volatile organic compounds listed in Table IV-4 plus N,N-dimethyl formamide (DMF) and the extractable compounds listed in Table IV-5. Spiked standards for most of the volatile organics were analyzed. There was wide variability in the results. Most chemicals varied by about 20 to 30 percent from the true value. No standards were run for the compounds listed in Table IV-5.

Table IV-4

DETECTION LIMITS OF VOLATILE ORGANIC COMPOUNDS

Compounds	Detection Limit (ppb)
chloromethane	0.1
bromomethane	0.1
dichlorodifluoromethane	0.1
vinyl chloride	0.1
chloroethane	0.1
dichloromethane	0.1
trichlorofluoromethane	0.1
1,1-dichloroethene	0.1
bromochloromethane	0.1
1,1-dichloroethane	0.1
trans-1,2-dichloroethene	0.1
chloroform	0.1
1,2-dichloroethane	0.1
1,1,1-trichloroethane	0.1
carbon tetrachloride	0.1
bromodichloromethane	0.1
1,2-dichloropropane	0.1
trans-1,3-dichloropropene	0.1
trichloroethene	0.1
benzene	0.1
dibromochloromethane	0.1
cis-1,3-dichloropropene	0.1
1,1,2-trichloroethane	0.1
tetrachloroethene	0.1
bromobenzene	0.1
toluene	0.1
chlorobenzene	0.1
ethylbenzene	0.1
p-xylene	0.1
o- and m-xylene	0.1
styrene	0.1
propyl benzene	0.1
p-chlorotoluene	0.1
m-dichlorobenzene	0.1
o-dichlorobenzene	0.1
methyl ethyl ketone(MEK)	0.1
tetrahydrofuran(THF)	0.1
cyclohexanone	0.1

Source: Montgomery (1980).

002904

Table IV-5

MINIMUM DETECTION LIMITS OF EXTRACTABLE COMPOUNDS

Compound	Detection Limit (ppb)	Compound	Detection Limit (ppb)
N-nitrosodimethylamine	2.5	4-chlorophenylphenylether	0.5
phenol	2.5	diethylphthalate	0.1
bis(2-chloroethyl)ether	2.5	2-methyl-4,6-dinitrophenol	10
2-chlorophenol	2.5	N-nitrosodiphenylamine	0.5
1,3-dichlorobenzene	0.1	1,2-diphenylhydrazine	2.5
1,4-dichlorobenzene	0.1	4-bromophenylphenylether	10
1,2-dichlorobenzene	0.1	hexachlorobenzene	0.5
bis(2-chloroisopropyl)ether	0.5	4-chloro-3-methyl-phenol	10
hexachloroethane	0.5	pentachlorophenol	5.0
N-nitrosodipropylamine	2.5	phenanthrene	0.5
nitrobenzene	0.5	anthracene	0.5
isophorone	2.5	dibutylphthalate	0.5
2-nitrophenol	10	fluoranthene	0.5
2,4-dimethylphenol	2.5	pyrene	0.5
bis(2-chloroethoxy)methane	0.5	butylbenzylphthalate	5.0
2,4-dichlorophenol	2.5	chrysene	1.0
1,2,4-trichlorophenol	2.5	benzo(a)anthracene	1.0
naphthalene	0.1	3,3'-dichlorobenzidene	10
hexachlorobutadiene	0.5	bis(2-ethylhexyl)phthalate	5.0
hexachlorocyclopentadiene	1.0	dioctylphthalate	0.5
2,4,6-trichlorophenol	2.5	benzo(b)fluoranthene	1.0
2-chloronaphthalene	0.1	benzo(k)fluoranthene	1.0
acenaphthylene	0.1	indeno(1,2,3-c,d)pyrene	1.0
dimethylphthalate	0.5	dibenzo(a,h)anthracene	1.0
2,6-dinitrotoluene	1.0	benzo(a)pyrene	1.0
acenaphthene	0.1	benzo(g,h,i)perylene	1.0
2,4-dinitrophenol	10	2,3,7,8-tetrachloro-dibenzo-p-dioxin	10
4-nitrophenol	2.5	fluorene	0.1
2,4-dinitrotoluene	1.0		

Source: Montgomery (1980).

002905

Static Tests--In these tests, tap water was placed in a plumbed system of CPVC (indoor) and PVC (outdoor) pipe after three void volumes were flushed through the system. The water was allowed to sit in the pipe without agitation for a dwell time of 2 weeks. The water was emptied and analyzed, and more water was added for dwell times of 1 to 3 days (consecutive static experiments).

The CPVC (indoor) systems were designed to test the effects of good and bad joints on pipe leaching. Two systems were set up with good joints and two with bad joints. Each type of system was tested wih initially hot and initially cold Pasadena tap water. The initial temperatures were not specified, and the hot and cold water samples were allowed to equilibrate at room temperature.

Leaching data for the cement solvents in these tests are listed in Table IV-6.

Table IV-6

LEACHING DATA FOR CPVC (INDOOR) TEST FOR 2-WEEK INITIAL DWELL

Solvent	Concentration* (ppm)			
	Good/Hot	Good/Cold	Bad/Hot	Bad/Hot
MEK	69(0.8)	59(1.7)	75(0.2)	115(2.8)
THF	197(8.8)	190(6.9)	199(2.7)	375(8.4)
Cyclohexanone	7(0.2)	10(0.2)	8.3(0.3)	13(0.3)
DMF	0.15(ND)	ND	0.12(ND)	0.17(ND)

*Numbers outside parentheses are for initial 2-week dwell time. Numbers inside parentheses are for a 3-day period after the initial 2-week dwell period.

ND = not detected.

Source: Montgomery (1980).

002906

Because of the large concentration of cement solvents in the 2-week dwell samples, these samples were diluted for analysis. As a consequence, other volatile organics present in the pipe water may have been diluted below their detection limits. The 2-week samples were also liquid/liquid extracted and analyzed for these other volatile organics. Unfortunately, because the controls for these 2-week dwell tests were not liquid/liquid extracted, these data are of little use.

For the 1- to 3-day leaching tests for CPVC (indoor), we focus attention on the 1-day leaching experiments for bad joint/cold water (Table IV-7). The concentrations in this case are slightly higher on average than the bad/hot, good/hot, or good/cold concentrations. This is not surprising because the bad joints had excess solvent cement applied (which would expand the pipe and increase diffusion rates in the pipe) and because the initial temperature difference between the hot and cold water would be a minor perturbation over the period of a day relative to the uncertainty of the measurements.

As shown in Table IV-7, chloroform, dichloromethane, carbon tetrachloride, tetrachloroethene, trichloroethene, and toluene were found to have significantly higher concentrations in the test samples than in the controls. Chloroform was only marginally significant because the control values were greater than half the values of the sample concentrations. Moreover, of those chemicals, only carbon tetrachloride showed an expected decline in concentration with elapsed time. Data for the other systems (see Table IV-8) again do not show the expected reduction in leachate concentration with increasing elapsed time.

The PVC (outdoor) systems had good joints and the tests were run at ambient (16°-21°C) temperatures with unchlorinated Colorado river and State Project water. Because PVC is not being considered for expanded use with potable water, these data will be only briefly summarized. Moreover, we will not distinguish between Project water and Colorado water. It is unlikely that the difference in waters would significantly affect the leachability of pipes--a hypothesis that is confirmed by the data.

002907

For the initial 2-week dwell period, cement solvents (MEK, THF, cyclohexanone, and DMF) were found to leach into pipe water in significant amounts (comparable to those shown in Table IV-6); in subsequent 1- to 3-day dwell experiments, their concentrations diminished significantly. For the subsequent 1-day dwell tests, only dichloromethane and trichlorethene showed consistently higher concentrations in the samples than in the controls.

Kinetic Studies--In these tests, tap water was placed simultaneously in several tubes of pipe with no rinsing of the tube prior to use. The water was then allowed to sit in the tubes for times varying from 2 to 144 hours. After the specified dwell times, the pipes were emptied and the contents analyzed. The pipes then were refilled and allowed to stand for the same dwell time. Tables IV-9 and IV-10 summarize the data for Weld-On Primer and P711 Cement. Data for Fuseon 905 Primer and 916 Cement were also collected but showed a less consistent correlation with time.

Several observations can be made about the data listed in Table IV-9. First, the concentrations of cement solvents appear to approach limiting values after a 2- to 5-day dwell. Second, these values are (in general) lower in the refill dwell experiments. Conversely, the concentrations of non-cement organics did not increase as a function of dwell time nor did these concentrations decrease during the refill dwell experiment.

Thus, the data for the cement solvents appear to follow the model suggested by equations (4-6) and (4-8): the concentration approaches equilibrium relatively quickly, and the concentration diminishes during successive equilibrium dwell periods. It would have been useful to run replicate experiments and, in particular, to perform additional refill experiments to test this model more rigorously.

Conversely, the data for non-cement solvents do not conform to any simple kinetic model. The measured values may be so small that they fall within the uncertainty limits, or noise, of the analytical methods. Chloroform was detected below the levels found in raw-water blanks.

002908

Table IV-7

CPVC (INDOOR) DATA FOR 1-DAY DWELL STATIC TESTS
BAD JOINTS/COLD WATER
(Concentrations in PPB)

Chemical*	Concentration (ppb) After 360 Hours	After 384 Hours	After 480 Hours	In Initial Water
Dichloromethane	9.2	11	8	0.5
Chloroform	23	23	21	13
Carbon tetrachloride	7.1	6.4	4.6	0.4
Dichlorobromomethane	4.1	5.9	8.5	10
Dibromochloromethane	2.9	4.9	6.8	7.8
Trichloroethene	1.1	1.1	1.6	0.7
Tetrachloroethene	3.8	3.3	3.8	<0.1
Bromoform	0.4	1.2	1.2	1.8
Benzene	0.1	< 0.1	< 0.1	0.3
Toluene	0.7	0.6	0.5	0.1
Ethylbenzene	< 0.1	< 0.1	< 0.1	<0.1
p-Xylene	< 0.1	0.3	< 0.1	<0.1
o,m-Xylene	< 0.1	< 0.1	< 0.1	<0.1
Dibutyl phthalate	24	4.9	12	11
Diethyl hexyl phthalate	ND	226	246	ND

Note: ND = not detected.

*Underlined chemicals were detected in all samples at significantly higher concentrations than those found in initial water controls.

002909

Table IV-8

CPVC (INDOOR) DATA: CHEMICALS WITH SIGNIFICANT CONCENTRATIONS IN 1-DAY STATIC LEACHING

Chemical	Good/Hot	Good/Cold	Bad/Hot	Bad/Cold
Chloroform*	X	X	X	X
Dichloromethane	X	X	X	X
Carbon tetrachloride	X	X	X	X
Tetrachloroethene	X	X	X	X
Toluene	X	X	X	X
Trichloroethene	X	X	X	X
Dibutylphthalate+	X		X	

*Marginal: samples within a factor of 2 of controls.

+Doubtful values for reasons explained later in text.

Source: Montgomery (1980).

002910

Simulation Tests--As stated earlier, these tests were designed to simulate typical residential use of a potable-water plumbing system. A system similar to the design of the CPVC (indoor) system was set up and, after three void volume rinses, attached to a Pasadena tap-water supply. The flow of water was operated by a solenoid valve according to the following daily cycle:

- Twelve-hour dwell. One void volume sample.
- Ten-minutes flow (11.4 L min^{-1})/50-minute dwell cycle for 12 hours. One void volume sample after fifth hour.

In Table IV-11, we list those chemicals that showed consistently higher concentrations in the 12-hour dwell samples than in the raw-water blanks. Chloroform was detected at levels below that detected in raw-water blanks.

Summary Analysis of Montgomery Report--In this subsection the quality of the measurements and the usefulness of the data collected by Montgomery Consulting Engineers will be reviewed according to evaluation criteria listed in Table IV-2.

Sample handling in all tests was described in detail and appeared satisfactory to obtain representative samples and prevent sampling losses. The high concentrations of cement solvents (three orders of magnitude higher than the other chemicals) may have masked the presence of other trace volatile organics. As stated previously, some of the 2-week static samples had to be diluted to analyze for the cement solvents, this process may have diluted other volatile organics below their detection limit.

The sensitivity of the analytical methods was excellent for the volatile organics (0.1 ppb for all chemicals in Table IV-4 except for the cement solvents, which had detection limits of 1.0 ppb). The sensitivity of the analytical methods for nonvolatile organics (see Table IV-5) was not nearly as good, and thus some of these chemicals may have been present in the pipe water at potentially hazardous levels below their levels of detectability. Standards were run for many of the volatile organics in Table IV-4. However, for the other volatile organics, and all of the

002911

Table IV-9

CONCENTRATIONS OF CEMENT SOLVENTS IN WELD-ON P70 PRIMER AND P711 CEMENT AS A FUNCTION OF DWELL TIME
Concentrations in mg·L^{-1}

Chemical	Concentrations (ppm) After 2 Hours	After 4 Hours	After 8 Hours	After 24 Hours	After 48 Hours	After 120 Hours	After 240 Hours
MEK	0.2(0.1)*	0.3(0.1)	0.58	0.7(0.4)	1.5(0.4)	2.2(0.5)	2.3
THF	1.0(0.5)	1.4(0.6)	2.9	2.7(1.9)	7.8(2.0)	5.6(2.4)	4.2
Cyclohexanone	0.1(0.7)	0.15(0.1)	0.2	0.1(1.9)	1.2(0.3)	1.9(0.1)	0.5
DMF	3.1(1.9)	1.2(0.7)	4.9	16(8.3)	11(7.1)	31(5.6)	7.1

*Data outside parentheses are for initial dwell. Data inside parentheses are for refill dwell.

Source: Montgomery (1980).

002912

Table IV-10

CONCENTRATIONS OF NON-CEMENT SOLVENT ORGANICS
IN WELD-ON KINETIC CELLS

Chemical	Concentrations (ppb) After 2 Hours	After 4 Hours	After 24 Hours	After 46 Hours	After 120 Hours
Dichloromethane	0.3(0.3)*	0.3(1.5)	6.4(0.1)	0.5(2.0)	6.0(32)
Chloroform	18(19)	15(18)	10(11)	14(11)	11(16)
Carbon tetrachloride	0.6(1.4)	1.2(0.9)	0.4(0.7)	0.4(1.0)	0.5(0.9)
Dichlorobromomethane	9.6(6.2)	9.7(11)	6.6(9.5)	4.5(8.1)	7.1(12)
Trichloroethene	1.5(1.6)	1.6(1.3)	1.0(1.6)	0.8(1.6)	1.5(1.6)
Benzene	0.2(0.2)	0.2(0.2)	0.1(T)	0.5(0.1)	0.2(ND)
Dibromochloromethane	6.5(7.8)	7.7(9.8)	4.5(7.6)	4.8(5.5)	4.5(9.3)
Bromoform	0.9(1.4)	1.6(1.9)	0.8(1.5)	0.8(1.5)	0.6(1.8)
Tetrachloroethene	0.1(0.2)	0.2(0.2)	0.1(0.1)	0.1(0.2)	0.2(0.2)
Toluene	0.1(0.1)	0.3(0.3)	1.0(0.2)	0.8(0.3)	2.8(0.2)
Chlorobenzene	ND(ND)	ND(ND)	ND(ND)	ND(ND)	ND(ND)
Ethylbenzene	T(T)	T(T)	0.1(T)	T(T)	0.2(T)
p-Xylene	T(T)	T(T)	0.2(T)	0.1(T)	0.3(0.2)
o,m-Xylene	T(T)	T(T)	0.1(T)	T(T)	0.2(T)
Dibutylphthalate	11(9.3)	7.6(7.3)	5.7(2.1)	ND(ND)	2.7(ND)
DEHP	ND(ND)	ND(ND)	ND(ND)	ND(ND)	ND(ND)
Phenol	33(ND)	ND(ND)	ND(ND)	ND(ND)	ND(ND)

*Data outside parentheses are for initial dwell. Data inside parentheses are for refill dwell.

Note: T = trace (< 0.1). ND = not detected.

Source: Montgomery (1980).

002913

nonvolatile organics listed in Table IV-5, standards were not run; therefore, the precision of the analytical method for these chemicals could not be determined.

No controls or blanks were analyzed by the liquid/liquid extraction GC/ECD method used for analysis of the volatiles in the 2-week dwell static tests; therefore, those data cannot be used in the assessment of water quality. For the remainder of the measurements, raw water fresh out of the tap and water held 2 weeks in glass containers in the dark were used as blanks. The 2-week control sample was presumably run to account for any chlorination reaction that may have occurred in the water during prolonged dwell times.

Replicate samples were taken for many of the measurements listed, but replicate experiments were not run. This lack of replication and the consequent inability to quantify the statistical validity of the data were major limitations of the study.

The test configurations were described in good detail for all tests and conformed reasonably well with typical home plumbing. The size of the pipe for the static and simulation tests was 3/4 inch, and the length of pipe per joint was 0.73 meters. Only 10 void volume rinses were run during the course of the static dwell tests--which is less than the number of rinses expected before initial use of a new plumbing system. The number of rinses and the number of void volumes of rinse water in the simulation test appear to simulate reasonably the rinsing history of a plumbing system during initial occupancy.

A limitation of the experimental design was a poor choice of experimental variables. The hot and cold static dwell tests were ill-defined because the initial temperatures of the water were not specified; moreover, the pipe water was allowed to equilibrate to room temperature. It is not surprising that this minor perturbation (lasting a few minutes to an hour) with respect to room temperature, did not significantly affect the results of tests lasting 1 to 3 days. Moreover,

002914

Table IV-11

SUMMARY OF SIMULATION STUDY 12-HOUR DWELL RESULTS

Chemical	Concentration (ppb) Blank	After 1 Day	After 5 Days	After 10 Days	After 30 Days
Dichloromethane	0.2	2.2	2.4	4.5	1.6
Carbon tetrachloride	ND	0.9	1.4	1.2	0.2
Trichloroethene	<0.1	2.1	2.0	1.2	<0.1
Bromoform	ND	1.8	2.4	1.9	3.5
Tetrachloroethane	ND	0.3	0.4	0.2	0.1
Toluene	0.1	0.4	0.2	0.3	0.2
MEK	ND	100	2	227	28
THF	ND	300	2.4	879	55
Cyclohexanone	ND	100	31	79	109

Note: ND = not detected.

Note that this list of chemicals is similar to that found for the static measurements: namely, low-molecular-weight chlorinated organics, toluene, and cement solvents. Note also that these concentrations do not appear to diminish as a function of elapsed time.

Source: Montgomery (1980).

002915

the choice of water type as a variable was odd because differences in composition or pH of water would be expected to have relatively little effect on the leachability of organics compared with metals.

For the static tests, no correlation of concentration with dwell time or elapsed time was observed for the low-molecular-weight halogenated organics that were found in significant amounts. The cement solvents, however, show a definite decrease in concentration during the first few rinses of the cemented pipe. The absolute magnitude of these concentrations is probably unrealistic, even for initial use of a plumbing system, because of the low number of void volume rinses.

For the kinetic tests, no significant correlations between dwell time and concentration could be deduced for the volatile organics. Conversely, the concentrations of the cement solvents appeared to increase with increasing dwell time up to a limiting equilibrium value. Moreover, these concentrations fell significantly during the refill dwell kinetic experiments.

Data compiled from the static and simulation tests indicate that the following organic chemicals were consistently found in significant concentrations in pipe water:

Cement Solvents	Volatile Organics
MEK	Dichloromethane
THF	Carbon tetrachloride
Cyclohexanone	Tetrachloroethene
DMF	Trichloroethene
	Toluene

The cement solvents were found in the ppm range, but the amounts found appear to diminish rapidly, as expected, with rinsing. The volatile organics were (except toluene) typically found in the pipe water in the 1 to 10 ppb range for systems that approximated normal initial use of plumbing systems. Toluene was typically detected under 1 ppb. Chloroform may leach from the pipe. However, the data are inconclusive. Two of the tests found

002916

chloroform at levels no different from those in controls (kinetic and simulation), but it was found at levels marginally significantly different from those in controls in the static tests. The concentrations of these volatile organics did not correlate well with dwell or elapsed times; therefore, long-term exposure to these chemicals cannot be inferred from the experimental data.

Finally, we note that the detected presence of phthalates in some of the leachate waters (see Table IV-10) was probably an experimental artifact. Phthalates are not used in the manufacture of these pipes or solvents; therefore, we conclude that their presence in the pipe water was due to leaching from the Tygon tubing used to fill the pipe system or to some other unknown, extraneous source.

ii. Montgomery Report for B.F. Goodrich on CPVC (1982)

James M. Montgomery Consulting Engineers, under a contract with B.F. Goodrich, performed water leaching tests on CPVC pipe systems designed to reproduce the static test conditions used in the Montgomery (1980) work for CDHS. The experiments were designed to obtain leaching data for 2-week dwell times with proper controls.* Cement solvent concentrations were not measured.

B.F. Goodrich (BFG) and an unspecified commercial (COM) CPVC pipe were assembled into triplicate pipe systems (six total). The systems were allowed to sit for 48 hours and then 10 void volumes of unchlorinated water were rinsed through each system. The systems were then filled with hot (49°C) water. After a 2-week dwell at room temperature, each system was emptied and the pipe water was distributed to small jars and analyzed. The

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*Recall that proper controls for the 2-week dwell static samples for volatile organics (non-cement solvents) were not run by Montgomery (1980).

002917

pipe systems were refilled with hot water and allowed to stand for 1 week before a second sampling and analysis.

The results are listed in Tables IV-12 and IV-13. Two pipe systems per pipe type were analyzed unless a large discrepancy between these systems necessitated a third measurement. The values listed are averages of duplicate samples for each pipe system. Only chemicals with concentrations significantly greater in pipe water than in controls are listed.

There were several minor problems with the analytical procedures used on these tests. First, the samples were spiked after distribution to the smaller jars; therefore, sampling losses (which may be significant for highly volatile chemicals) encountered during the emptying of the system could not be accounted for. Second, most of the base, neutral, and acid fractions (most of which were found in the solvent cement) were quantified relative to an internal standard. Moreover, many of the volatile organics were quantified relative to an internal standard. These nonvolatile and volatile compounds (mostly ketones) are listed in Table IV-14. There appears to be little difference between BFG and COM samples--which is reasonable because most of the chemicals were detected in an analysis of the solvent cement. Therefore, only data from the BFG No. 1, 2-week dwell test are listed in Table IV-14.

Because duplicate systems were used for all chemicals tested, a standard deviation between different pipe systems of the same pipe type could be calculated. The average percentage standard deviations for duplicate samples (for all detected samples) for the 2-week dwell tests were 9 percent for BFG and 17 percent for COM.

The data listed in Tables IV-12 and IV-13 would be representative only of concentrations found before initial occupancy. They show that low-molecular-weight organic chemicals (as indicated by Montgomery, 1980) dominate the list of possibly significant leachates. Unfortunately, little can be inferred from the data listed in Table IV-14 because absolute concentrations were not given. Because these leachates were almost

002918

Table IV-12

TWO-WEEK STATIC DWELL RESULTS
(Concentration in ppb)

Chemical	Two-Week Control	BFG 1	BFG 2	BFG 3	COM 1	COM 2	COM 3
Chloromethane	ND	2.1	1.7		1.8	2.9	
Dichloromethane	ND	2.7	3.5		2.8	2.8	
Chloroform	1.5+			44+			52+
Carbon tetrachloride*	ND	8	6.7		11	16	
1,1,2-Trichloroethane	ND	ND	ND		8.4	11	
1,1,2,2-Tetrachloroethane	ND	ND	ND		4.4	6.0	
Tetrachloroethene	0.3	0.2	0.2		12	17	
Benzene*	ND	0.4	0.4		0.3	0.4	
Toluene	ND	0.4	0.4		0.3	0.3	
3,5,5-Trimethyl-2-cyclohexen-1-one*	ND	4.5	3.4		1.2	4.2	
Hexachloroethene	ND	ND	ND		2.8	2.5	

Note: ND = not detected.

*Detected in analysis of solvent cements.

+Analyzed by liquid/liquid extraction with GC/electron capture detector. All other volatile organics analyzed by purge and trap and GC/MS.

Source: Montgomery (1982).

002919

Table IV-13

ONE-WEEK STATIC DWELL RESULTS
(Concentration in ppb)

Chemical	One-Week Control	BFG 1	BFG 2	BFG 3	COM 1	COM 2	COM 3
Chloromethane	ND	0.4	0.4		0.3	0.4	
Dichloromethane	0.3	32	24	0.8	15	16	1.1
Chloroform	1.3+			17+			23+
Carbon tetrachloride*	ND	2.4	2.2		7.3	11	
1,1,2-Trichloroethane	ND	ND	ND		2.1	3.9	
1,1,2,2-Tetrachloroethane	ND	ND	ND		1.1	2.2	
Tetrachloroethene	0.3	0.1	0.1		8.5	13	
Benzene*	ND	ND	ND		ND	ND	
Toluene	ND	ND	ND		ND	ND	
3,5,5-Trimethyl-2-cyclo hexen-1-one*							
Hexachloroethene	ND	0.3	0.3		1.0	0.9	
	ND	ND	ND		2.7	3.8	

Note: ND = not detected.

*Detected in analysis of solvent cements.

+Analyzed by liquid/liquid extraction with GC/electron capture detector. All other volatile organics analyzed by purge and trap and GC/MS.

Source: Montgomery (1982).

002920

Table IV-14

TWO-WEEK DWELL DATA FOR BFG No. 1 SAMPLES

Chemical	Concentration*
1-butene+	11
acetone+	40
furan+	7
2,5-dihydrofuran+	16
tetrahydrofuran+	24,000
3-methyl-2-butanone+	4
4-methyl-2-pentanone+	32
2-hexanone+	1
1,1,1,2-tetrachloroethane	6 (COM only)
5-methyl-2-hexanone+	160
4-heptanone+	3
3-methyl-1-butanol, acetate+	2
3-methyl-3-hexene-2-one+	4
2,2,4,4-tetramethyl-3-pentanone+	310
pentachloroethane	11 (COM only)
2,6-dimethyl-4-heptanone+	280
3,3,5-trimethylcyclohexanone	44
hexachloroethane	7 (COM only)
5-decanone+	1,100
2-methylcyclohexanol, acetate+	80
2-methyl-2-nonen-4-one+	100
2-methyl-5-decanone+	1,400
4-undecen-6-one+	30
2-heptanone+	2
2,6-dimethyl-3-heptanone	7
2-methyl-4-octanone	30
2-nonanone+	9
2-butanone (methyl ethyl ketone)	2 (1-week test only)
1-pentanol	1 (1-week test only)
7-methyl-4-heptanone	2 (1-week test COM only)
2-methylfuran	1 (1-week test only)
1-chlorobutane	1 (1-week test only)
pentanal	1 (1-week test only)
n,n-dimethylformamide+	140
5-methyl-3-hexen-2-one+	80
2-decanone+	110
5-methyl-2-(1-methylethyl) cyclohexanone+	380

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Table IV-14 (concluded)

Chemical	Concentration
2-ethylhexanol+	7 (COM only)
acetophenone	5 (COM only)
3,4-dimethyl-1-hexene	6 (COM and 1-week test only)
3-methyl-3-buten-2-one+	5 (1-week test only)
1,1,2,2-tetramethyl-cyclopropane	4 (1-week test only)

*Relative to an internal standard

+Detected in analysis of solvent cements.

Source: Montgomery (1982).

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universally found in the solvent cements, it is expected that their concentrations would diminish rapidly with time.

iii. Organotin Leaching from PVC and CPVC Pipe (Boethner et al., 1981)

This study was initiated to develop an analytical method for detecting organotin stabilizers in water. In the process, useful information on CPVC leachability was developed.

Experiments were set up to maximize leachate concentrations (pipe loop experiments) and to simulate residential plumbing system use (miniature pipe systems). The pipe loops of CPVC (with hot water, 72°C) and PVC (warm water, 37°C) were constructed to pump water continuously through a loop. Every 1 to 3 days, the systems were emptied and their water was analyzed. A new batch of water was then added and the process repeated. NSF (National Sanitation Foundation) pH 5 extractant water was used in these systems. The miniature pipe system was assembled by connecting a PVC pipe system to a tap and allowing water to be drawn out and analyzed after varying dwell times for a total of 2 weeks.

The concentrations of organotins found in CPVC pipe loop systems are summarized in Table IV-15.

Organotin analysis at levels down to 0.01 ppb utilized hydride derivation, followed by collection of the hydrides in liquid nitrogen, and detection of tin by atomic absorption spectrometry as the hydrides eluted from a warming cold trap. The exact organotin species from which these hydrides arose were not identified, although they appear to exist in ionic form in the extractant water. Dibutyltin-bis-isooctyl thioglycolate was stated to be the main stabilizer in the CPVC pipe--which is confirmed by the higher concentrations of (apparent) dibutyltin chloride in the pipe water.

Cement solvents (MEK, THF, and cyclohexanone) applied to the PVC pipe leached into the pipe water for 15 days of sampling using the miniature pipe system. The experimental protocol and data are not clearly presented, but

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Table IV-15

ORGANOTIN CONCENTRATIONS IN LEACHATES OF CPVC PIPE

Chemical	Concentration (ppb)						
	1(1)*	2(3)*	3(6)*	4(10)*	4(14)*	3(17)*	4(21)*
Dibutyltin dichloride	2.6	2.0	0.84	2.2	0.8	0.6	0.12
Butyltin trichloride	0.63	0.66	0.34	0.08	-	-	-
Trimethyltin chloride	0.30	<0.01	-	-	-	-	-
Dimethyltin dichloride	0.61	0.34	0.06	0.12	0.12	-	-

*Dwell days (elapsed days).

Source: Boethner et al. (1981).

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power function of time. The initially high concentrations of the solvents and their reduction with elapsed time are qualitatively consistent with the Montgomery (1980) results.

It is most interesting to note that the concentrations of the organotin leachates appeared to diminish in a biphasic manner with time. Whereas this behavior was most apparent with the PVC pipe systems, Table IV-15 shows that, for CPVC, the concentrations of all detected alkyl tin chlorides diminish initially with elapsed time but the concentrations of dibutyltin chloride and dimethyltin chloride increase during the 6- to 10-day elapsed time period and then diminish again.

This biphasic behavior (more pronounced for the PVC systems) suggests a two-compartment model for leaching in cement-joined pipes. The initial leaching of organotins occurs from areas of the pipe where solvent cement has not been applied. Assuming that the organotins are uniformly distributed in the pipe at the beginning of the experiment, material leaches from the pipe near the pipe/water interface initially, but the amount that enters the water per unit time diminishes rapidly as the surface concentration is depleted and diffusion in the pipe becomes rate-determining. In the areas where solvent cement has been applied, there is no organotin present initially; but within a few days, organotin species begin to diffuse through the cement/pipe surface layer into the water, and the leachate concentration correspondingly rises.

These data suggest a possible explanation for a lack of correlation between leachate concentrations of non-cement solvents and time that was observed in the 1980 Montgomery report. If solvent cements were applied in differing thickness to the joints of the test systems, it would be expected that the leaching of pipe constituents through the cement to the water would be retarded to varying degrees. Thus, while the leaching rate in one part of the system may have been diminishing, the leaching rate in another part of the system may have been increasing. For a plumbing system with several joints, the variability of the leaching rate with elapsed time over a period of several weeks may well have been sporadic, as observed.

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iv. B.F. Goodrich (1982)

B.F. Goodrich performed water leaching experiments on CPVC and PVC pipe with no joints. The purpose of the experiments was to determine whether leaching of chloroform or carbon tetrachloride was caused by the presence of solvent cement.

Two experiments were performed on PVC and CPVC pipe manufactured by B.F. Goodrich. One experiment used Milli-Q water; the other used tap water to determine any effect of residual chlorine on the possible contaminants. Both experiments involved filling the pipe with water, plugging it with Teflon, and analyzing samples after a 2-week dwell. Additional experiments were run with other pipe samples with dwell times varying from 1 to 14 days to determine diffusion coefficients of chloroform and carbon tetrachloride in CPVC pipe.

Chloroform was not found to leach from PVC or CPVC pipe at concentrations significantly different from those in the controls. However, carbon tetrachloride was found to leach from CPVC pipe at very low concentrations in the 2-week dwell experiments. The data collected for the 1- to 14-day samples were not sufficiently different from control values to calculate the diffusion coefficients of chloroform or carbon tetrachloride in the pipes.

The low or insignificant amounts of carbon tetrachloride and chloroform found to leach from PVC or CPVC in the absence of solvent cement indicates that leaching may be enhanced by the presence of solvent cements. However, the number of void volume rinses of the pipe before the experimental data were taken makes direct comparison with experiments where solvent cement was present only speculative. Moreover, no conclusions regarding the effect of residual chlorine on leachate concentration could be made because of the low concentrations of leachates.

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v. CAL Field Studies on CPVC Pipe (1980

Two field studies (Hospital study and Foster house study) on the concentrations of chemicals in water in new CPVC systems were performed by the California Analytical Laboratory (CAL, 1980). These studies were undertaken to determine the concentrations of chemicals leached into typical plumbing systems.

In both studies, the water stayed in the system without agitation for unknown dwell times before samples were taken. Stagnant samples and samples taken after a 0.5- to 5-minute running rinse were taken in both studies.

High levels (ppm) of cement solvents were detected in the initial effluent. After a 0.5- to 5-minute rinse these levels were generally less than the detection limit. After a subsequent 4-1/2 hour stagnation, the levels remained below the detection limit in the Hospital study. High levels remained longer at some sampling points in the Foster house study. Trace amounts of low-molecular-weight halogenated organics were detected in some samples (see Table IV-16)

The data from the Foster house study should be viewed cautiously. Although it is stated in the report by CAL (1980) that the house is partially plumbed in CPVC, a letter (6/10/80 to Leonardini) in the Administrative Record states that the type of plumbing was not determined.

Incomplete sampling description and insufficient quality assurance cast some doubt on the data for both studies. It can probably be assumed that the same sample-handling precautions stated in the house study were also used in the hospital study (sampling techniques were not stated in the hospital study). No spiking data were reported; therefore, sample-handling losses cannot be determined. The presence or absence of a head space was also not stated. Other inadequacies include a lack of information on resolution and replicates. (Some replicate water samples were taken, but replicates of the same sample were not.)

Table IV-16

CAL FIELD STUDY DATA ON CPVC PIPE (1980)
(Concentrations ppb)

Chemical	Hospital			Foster House		
	Control	Stand	Run	Control	Stand	Run
methylethylketone	<1000	19000	8700	<500	8000	<500
tetrahydrofuran	<1000	240000	160000	<500	92000	<1000
cyclohexanone	<5000	<5000	<5000		2700	
N,N-dimethylformamide	--	--	--		<5000	
vinyl chloride	ND	2.7	10	ND	ND	
chloroform *	60	14	8.7	74	140	
1,1,2-trichloro-2,2,1-trifluoroethane*						
carbon tetrachloride	ND	0.83	0.20	NA	14	
bromodichloromethane	4.0	1.2	0.72	20	16	
trichloroethene	ND	2.1	1.7	ND	2.5	
tetrachloroethene	ND	1.5	ND	ND	6.0	
diethylhexylphthalate				20	110	

Note: ND = not detected

*These two chemicals were not distinguishable analytically; the data opposite chloroform are for the sum of the concentrations.

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The pipe history and the test configuration and protocol were adequately described. However, the specific temperatures of the cold water samples in both studies were not given. These studies also lacked a statistical analysis for a determination of data precision.

vi. Miscellaneous Studies on PVC Pipe

Several laboratory and field studies on PVC pipe were also reviewed. These studies will be only briefly discussed because PVC is not currently being considered for expanded use in potable water plumbing.

Wang and Bricke (1979) studied water samples from an in-service PVC pipe with the objective of determining the persistence of cement solvent leaching into pipe water. The samples were taken from a 6-month-old and an 8-month-old system. Six months after installation, the amounts of MEK and THF leached out after an 8-hour stagnation were 600 ppb and 17,000 ppb, respectively. The amounts leached out at equilibrium (attained by 48 hours) was 4,500 ppb for MEK and 13,000 ppb for THF. Two months later, the concentrations had dropped by about half. The persistence of the solvents in the water is expected to be much longer than would be experienced in a typical home because of the large volume of the tested systems and their limited use.

Dressman and McFarren (1978) also performed a field study on PVC pipe to determine vinyl chloride diffusion from service pipes. Observed concentrations in running-water samples varied from 0.03 ppb (detection limit) for a pipe 9 years old to 1.4 ppb for pipe a 6 months old. However, these pipes were installed before the NSF standard on residual vinyl chloride monomer (VCM) was issued. This standard limits the concentration of VCM in the pipe to 10 ppm.

Dietz et al. (1979) performed laboratory extraction tests on organotin-stabilized PVC to determine the amount and temperature dependence of the leaching. These data have limited use, however, because of the lack of quality assurance.

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Three studies on lead stabilizer extraction from PVC were reviewed: two studies (Packham, 1971a; Packham, 1971b) of unplasticized PVC, which is allowed to contain lead stabilizers in European plumbing systems, and the third study (Gross et al., 1974) is on the leaching of lead from PVC pipe. NSF does not allow lead stabilizers in pipe that it monitors; therefore, these data are not relevant to this study.

vii. California Analytical Laboratory Studies on PB (1980-81)

CAL performed extraction experiments on blue PB pipe (12/31/80 letter to Leonardini), on gray and black PB pipe (3/18/81 letter to Leonardini), and on gray PB pipe (1/15/81 letter to Reid Associates). The objective of these experiments was to determine the contaminants of PB pipe. It was reasoned that if the impurities of the pipe were known, then the list of possible PB leachates could be identified.

All of the experiments involved the extraction of pipe shavings by either water or an organic solvent such as hexane or benzene. Organic extraction was performed at ambient temperature, and the water extractions were performed for 48 hours at ambient temperature for the blue pipe, and at 70°C for the gray pipe.

The results vary considerably, as shown in Table IV-17. The volatile organic values were corrected for recovery losses.

Few of the chemicals were detected in more than one sample of the same pipe type. Where chemicals were detected in more than one sample, the concentrations typically differed by a factor of 5.

These data are of poor quality for several reasons:

(1) The water was spiked before addition to the pipe shavings. The reason for spiking the water at this point is difficult to understand because of certain sorption of the spike standards on the pipe.

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(2) No data on the sensitivity, resolution, or precision of measurements are given. Blanks were measured for the data transmitted in the letter of 3/18/81.

viiii. Reports on PB Funded by Shell

A series of leaching studies on PB pipe were performed by several laboratories under contract to the Shell Chemical Company. Most of the studies were performed by the Radian Corporation. The Radian I report analyzed PB water leachates sent to Radian by Shell. Radian II-IV reports were conducted to repeat the pipe extraction experiments performed by California Analytical Laboratories to determine impurities in PB pipe. Radian V analyzed samples taken from a residential PB plumbing system in service for 1 year and the Radian DeLeeuw house study analyzed samples taken from a newly installed residential PB system.

In Radian I (1981), Shell cut up PB4127 pipe and soaked the fragments in water at 23°C and 82°C. No base, neutral, or acid fraction compounds were detected. Dichloromethane and THF were detected at concentrations (ppb) different from the controls as shown below:

	23°C		82°C	
	Control	Sample	Control	Sample
Dichloromethane	16	23	18	28
THF	36	63	29	72

This report suffers from serious limitations. First, the recovery of spiked samples ranged from 46 percent to 91 percent (lower-volatility chemicals showed a higher recovery). No spiking data for dichloromethane or THF were stated; therefore, it is presumed that the data listed above were not corrected for recovery efficiency. Second, the PB fragment size distribution was not given. Third, data were not statistically analyzed. The report has little useful information on PB leachability because of these reporting deficiencies.

The objective of the Radian II-IV studies was to determine the impurities in PB pipe. Most of this work was done on ground or shaved PB pipe to increase leachate concentration.

Table IV-17

IMPURITIES DETECTED IN PB PIPE SAMPLE EXTRACTIONS
(CAL, 1980-81)

Chemical	Type of Extraction*	Concentration (ppm) Blue	Gray	Black
dichloromethane	W		2	
2-iodobutane	W		8	
butene	W	0.1-1		
acetone	W	0.5-5.0	0.3	
diethylether	W	0.01-0.5		
methyl cyclopentane	W	0.1-1.0	6	
methyl cyclohexane	W	0.5-10	8	
2,3,3-trimethylhexane	W	0.5-5.0		
3-methyl hexane	W	1-10		
3-ethyl-3-methyl pentane	W	1-10		
5,5-dimethyl-2-hexene	W		2	
heptane	W	1-10	40	
2-ethyl-2-methyl 1-pentane	W		0.2	
2-octene	W		0.5	
hexane	W		50	
3,4-dimethyl-1-octene	W		2	
alkanes ($>C_{16}$)	O	100-1000(total)	235-2500+	500-2500
alkene (C_{18}-C_{19})	O	5000-50000		
butylated hydroxy-toluene	O	50-500	10-50	10-50
diethylhexyl phthalate	O	50-500	0.7->20	1.5-1.8

* Water extraction (W) or organic extraction (O).

\+ Compounds detected in more than one sample.

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Radian II (1981) included a 1-day hexane leaching experiment of ground samples, a 2-day water leaching of ground samples, and a 5-day water leaching of sectioned black PB pipe. Radian III (1981) analyzed Westpro Bluetube PB, which was also analyzed by CAL. Radian IV (1981) included a hexane extraction of Westpro Bluetube by four independent laboratories:

(1) West Coast Technical Service, Cerritos, CA

(2) Acurex Corporation, Mountain View, CA

(3) Systems Science and Software, La Jolla, CA

(4) TRW, Redondo Beach, CA.

These laboratories used an analytical protocol recommended by CAL.

In all studies (Radian II-IV), the concentrations detected were less than the stated detection limit. This discrepancy was not explained. Moreover, the concentrations of most leachates were found to be similar to control values. A substituted phenol was detected at concentrations greater than 100 ppb (Radian II). This component was believed to be a derivative of Irganox 1010. C_{10} - C_{30} alkanes were also detected at concentrations of less than 10 ppb.

The lack of information given on experimental precision and recovery efficiency limits the reliability of these data. The concentration of volatile organics found in the 2-day water leaching samples is probably too low because of sample head space. The determination of hexane extractants in the parts-per-thousand range is too insensitive to meet the objectives of the study. Moreover, a 10 ppb stated sensitivity for most of the volatile organics is inadequate where most leachates are expected to be in the 1 to 10 ppb range.

ix. Radian V and Radian DeLeeuw House Study (1981-82)

Field studies in a 1-year-old (Radian V) and a new (DeLeeuw) gray PB plumbing system were reported. Both studies report analyses of water samples taken after a 14-hour dwell and after a 10-second rinse. Hot and cold water samples were also taken.

In the Radian V (1981) study, derivatives of cyclohexene and cyclohexanol were detected at concentrations from 11 to 130 ppb; however,

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these values were similar to those found in the controls. Phthalate esters were detected at concentrations lower than the stated sensitivity limit (10 ppb); moreover, these concentrations were insignificantly different from those found in controls.

In the DeLeeuw study (1982), dibutyl phthalates were detected in the cold water samples and phthalate esters and diphenylamine were detected in hot water samples. Whereas none of these chemicals was detected in the controls, all concentrations were less than the stated detection limit; and dibutylphthalate, DEHP, and diphenylamine were determined to have come from the hot water heater.

In summary, slight concentrations of phthalate esters were found in both the Radian V and DeLeeuw studies, but these concentrations can be attributed to sources other than the PB pipe.

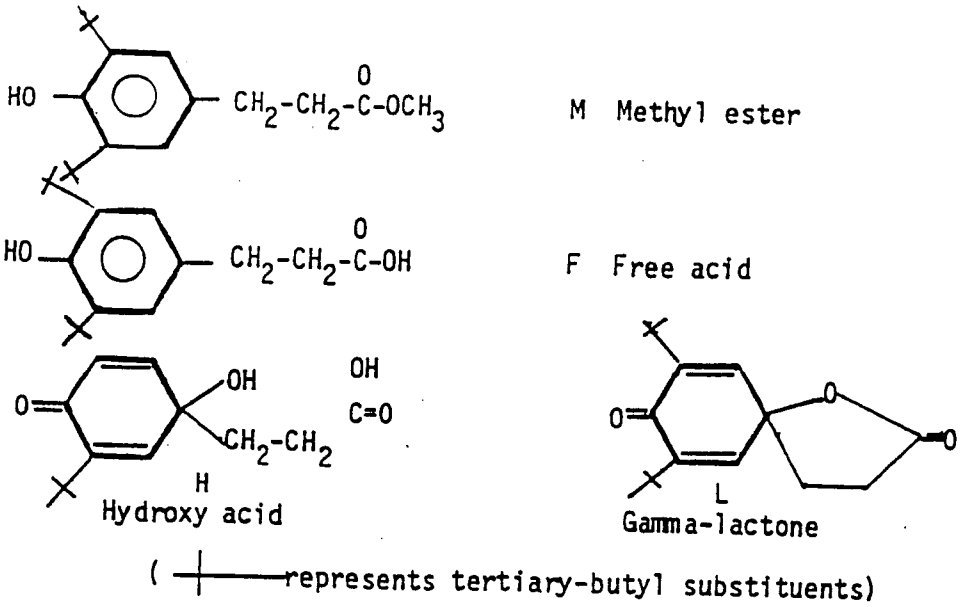
Mead CompuChem (1981), under contract to Shell Chemical Company, performed leaching studies on intact gray PB pipe. These tests were similar to the 5-day leaching experiments described in Radian II. A derivative of Irganox 1010 was the only leachate detected at concentrations (approximately 50 ppb) different from those in the controls. The experimental protocol was not reported in detail.

The East Bay Municipal Utility District (1981) sampled in-service black PB and water from PB service pipe that had been dormant for 4 months. One set of in-service samples was analyzed by the Environmental Research Laboratory (Montgomery Engineers); the other set of samples was analyzed by a CDHS laboratory.

No leachates were found in the in-service pipes or the dormant section of pipe at concentrations different from those of the controls. However, the sample procedure was not given and no spiking data were reported; therefore, these data should be viewed with caution.

Shell (1982) conducted research on the leaching of PB4127 in 5-day experiments at 82°C. Samples were taken every day to determine the leaching rates.

Irganox 1010 derivates were the only leachates detected. Quantitative results were reported only for leaching from PB resin nib. Proposed structures of the Irganox derivatives are shown below.



The leaching experiments showed an increase in concentration (ppb) as dwell time increased:

	1 Day	5 Days
free acid	2200	3000
hydroxy acid	2900	7500
gamma-lactone	800	1100

The quality of the reported data are uncertain for several reasons. First, no spikings were reported. Second, description of the sampling procedure was incomplete. Third, the sensitivity of the HPLC method was not stated. Finally, no data were reported for blanks for the pipe nib leaching.

3) Summary of Plastic Pipe Leaching Data

The Montgomery Report (1980) and Boethner et al. (1981) provided the most useful information on leaching from CPVC pipe.

Data collected from the Montgomery static and simulation tests indicated that pipe cement solvents (MEK, THF, cyclohexanone, and DMF) were

leached in ppm quantities, and that low-molecular-weight chlorinated organics (dichloromethane, carbon tetrachloride, tetrachloroethene, trichloroethene) were leached in the low (1-10) ppb concentration range, during initial dwell periods. The concentrations of cement solvents appeared to diminish with elapsed time, but the concentrations of the chlorinated organics did not appear to diminish with elapsed time. This lack of correlation with elapsed time may have been caused by the relative uncertainty of the measured values (which were typically within a factor of 5 of control values) and/or by the cumulative effect of leaching of these organics at different rates from areas covered or not covered with solvent cement.

The Boethner et al. (1981) report confirmed the findings of the Montgomery report on the leachability of cement solvents. High initial concentrations of these solvents were found in the pipe water--and these concentrations decreased with elapsed time. Boethner et al. also detected the presence of organotin leachates in CPVC pipe water. The concentrations of these leachates were initially in the 0.5 to 3 ppb concentration range for 1-day dwell periods, but fell rapidly to less than 0.1 ppb per day after 3 weeks elapsed time.

The 1982 Montgomery report indicated that low-molecular-weight chlorinated organics dominate the leachate composition of volatile organics from CPVC pipe, which is consistent with the 1980 Montgomery report. This report also indicated the need to analyze leachates (other than the dominant solvents) from the solvent cements.

Chloroform is a potential leachate. Montgomery (1980) shows concentrations of chloroform marginally different from concentrations in controls in static tests, and no different from controls in kinetic and simulations tests. The CAL (1980) hospital study detected chloroform at levels no different from levels in controls. Conversely, chloroform was detected at concentrations of approximately 50 ppb after a 2-week dwell (Montgomery, 1982). Also, the Foster house study (CAL, 1980) detected high levels (control 74 ppb, sample 140 ppb) for dwells of unknown period. These

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data are suspect, however, for reasons stated earlier. Based on the available data, no conclusion can be made regarding the leaching of chloroform. The availability of more data in this area is especially important.

The leachability studies of PB were generally lower in quality than those of CPVC. However, the Mead CompuChem (1981) and Shell (1982) studies indicated the presence of Irganox 1010 derivatives in leachate water.

c. Metal Pipe Leaching

The administrative record was reviewed for information on metal pipe leachability. Attention was focused on copper and galvanized steel pipes.

1) Rossum Metals Study (Appendix to Lappé Report, 1980)

This study was performed to determine:

- The range of metal concentration in potable water carried by in-service metal pipes.

- The possible range of metal concentrations in potable water carried by metal pipe (laboratory study).

A field study of metal concentrations in water from the kitchen faucet was undertaken to meet the first objective. Houses with copper and with galvanized steel pipe plumbing were sampled in the same and in different water distribution systems. Samples of the initial effluent after an 8-hour dwell (standing) were taken to represent the highest concentrations of metals for that system. After 38 liters were rinsed through the faucet, another sample was taken to represent concentrations of metals during periods of heaviest use (running). Table IV-19 lists data for one 8-year-old system with a water hardness of 190 ppm $CaCO_3$.

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Table IV-19

CONCENTRATIONS (PPB) OF METALS IN STANDING AND RUNNING WATER ($CaCO_3$ HARDNESS: 190 PPM IN AN 8-YEAR-OLD SYSTEM)

Leachate	Copper		Galvanized Steel	
	Standing	Running	Standing	Running
Lead	ND	--	10	--
Copper	250	40	50	40
Cadmium	ND	--	ND	--
Iron	ND	--	320	--
Zinc	60	20	770	280

Note: ND = not detected.

Source: Rossum (1980).

No chromium, arsenic, or mercury was observed in any system. In most of the galvanized steel systems tested, only zinc was detected. No correlation between the age of a system and leachate concentrations can be made from the data. Running samples were less concentrated than standing samples, as expected.

Copper systems, however, did exhibit a decrease in leachate concentration with an increase in system age. For most of the copper piping samples, only copper and zinc were detected. Because no controls were taken (water analyzed before entering the house), it is not possible to determine the percent of leachate detected that was generated from the household plumbing system.

The laboratory simulation study was performed with a copper and with a galvanized steel system. The system was connected to a laboratory faucet, and samples of 1-day dwell water were taken. The system was then rinsed with 19 void volumes. Moderately hard well water (pH 7.3, hardness $CaCO_3$ 279 ppm, Langlier index +0.06) and a slightly mineralized, corrosive surface

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water (pH 7.4, hardness $CaCO_3$ 20 ppm, Langlier index -2.53) were used in these tests.

As shown in Table IV-20, the concentrations of all metal leachates diminished with increasing elapsed time using moderately hard well water in both copper and galvanized steel systems.

Table IV-20

FIRST DAY AND TWENTY-FIRST DAY CONCENTRATIONS (PPB)
OF 1-DAY STATIC DWELL TESTS WITH MODERATELY HARD WATER

Leachate	Controls	Copper			Galvanized Steel		
		1st Day	8th Day	21st Day	1st Day	8th Day	21st Day
Lead	ND	400	10	ND	200	80	30
Copper	10	2,200	2,130	320	ND	20	ND
Cadmium	ND	ND	ND	ND	3	6	ND
Iron	ND	20	ND	ND	30	ND	ND
Zinc	20	550	250	10	6,700	5,900	4,200

Note: ND = not detected.

Source: Rossum (1980).

The more corrosive surface water was used with copper and domestic and imported galvanized steel pipe. The rate of decay in the amount leached was observed to be much slower with this type of water than with the less corrosive well water. These data are summarized in Table IV-21.

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Table IV-21

LABORATORY STUDIES OF METAL PIPE LEACHABILITY
USING CORROSIVE SURFACE WATER

	Elapsed Time (days)	Leachate Concentrations (ppb) Lead	Copper	Zinc
Control		ND	20	ND
Copper	1 - 10	430	720	80
	11 - 20	174	740	90
	391 - 400	45	1610	70
Galvanized steel (imported)	1 - 10	52	10	7130
	11 - 20	40	ND	7500
	391 - 400	15	20	4860
Galvanized steel (domestic)	1 - 10	62	10	3600
	11 - 20	56	10	2500
	391 - 400	5	40	3860

Note: ND = not detected.

Source: Rossum (1980).

Cadmium was detected in only one sample at 1 ppb. Whereas lead leachate concentration diminished with elapsed time, copper leachate concentration showed no correlation with elapsed time. Zinc showed no correlation with elapsed time in the copper or domestic galvanized steel pipe, but a decay of zinc concentrations from very high initial values was observed for the imported galvanized steel pipe.

Adequate quality control precautions were taken in the experiments. However, there is an inconsistency between the described testing protocol and data reported for the corrosive water tests. Samples were taken every day, yet only one value is reported for a 10-day interval.

The results of the laboratory tests qualitatively concur with those of the field study. However, the laboratory tests indicate that leaching rates

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for copper pipe/corrosive water systems decrease less rapidly than those for copper/noncorrosive systems.

2) Lyon and Lenihan Study (1977)

Lyon and Lenihan (1977) investigated lead leachate concentrations in potable water from copper plumbing with lead-based solder. This study was done to provide background information on lead leaching after high lead concentrations (4,300 ppb) were found in the drinking water of a new building plumbed in copper in Glasgow, Scotland.

Field and laboratory studies were performed. The field study was designed to determine the effect of dwell time on leachate concentration. The laboratory studies were designed to determine the effects on lead and copper leachate concentrations of:

- Dwell time and elapsed time
- Age and type (hard drawn or half hard) of copper tubing
- pH and hardness of water
- Quality of solder joints.

The field study involved the isolation of a portion of in-service copper plumbing in several buildings from which daily samples were taken for 5 days. Each system was rinsed for 15 minutes before the tests began and allowed to stand for 5 days. The isolated system was not topped off after 125-ml daily samples were taken. The water in all systems was corrosive (pH 6.3; hardness 10 ppm of $CaCO_3$).

Unfortunately, no controls were used; the precision of the measurements could not be estimated because replicates were not run; samples did not appear to represent the average concentration in the pipe because the water was not mixed prior to sampling; and the volume of water in the pipe decreased with successive samplings. Because of these experimental problems, these field data are of little use.

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The laboratory studies used a circulating system for measuring leachate concentration as a function of dwell time, and a static system where dwell time was fixed and other parameters were varied.

Several circulating systems were assembled. Three were made with hard drawn (thin wall) copper tube: one with poor solder joints, one with good solder joints, and one with compression fittings, which use no solder, as a blank. Two were made with half hard (thick wall) copper tube: one with good joints, another with compression fittings as a blank. Deionized water was circulated through each system for 4-1/2 hours, with samples taken every half hour. After 4-1/2 hours, the system was emptied and filled with new water. Each 4-1/2 hour dwell constituted a run. Six runs were made, and just before the sixth run, the system was cleaned with detergent to remove the flux.

No lead was detected after the second run in the blanks, so only runs 3 through 6 will be discussed here. The system with poorly made joints had higher levels of lead at the end of 4-1/2 hours (run 3, 790 ppb) than the one with good joints (run 3, 180 ppb). No significant difference was seen between the hard drawn (thin wall) and the half hard (thick wall) tubing. Copper levels at the end of run 3 were about the same for all systems (500 to 800 ppb), including the system with compression fillings (control).

The rate of lead and copper leaching remained fairly constant for runs 3 through 5 (see Table IV-22). After removal of the flux, the rate of lead leaching decreased by about an order of magnitude, but the rate of copper leaching temporarily increased by about a factor of 5. The rate of leaching for both copper and lead decreased slowly as dwell time increased during a run.

One experiment with the static systems was the determination of the concentration of lead as a function of elapsed time with tap water and deionized water. Also, the effects of poorly made joints and good joints were tested. The static tubes were assembled using hard drawn copper. The tubes were filled with water and allowed to sit for a 16-hour dwell time and

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Table IV-22

LEAD CONCENTRATIONS IN HARD DRAWN COPPER TUBING
WITH POOR SOLDER JOINTS
(Parts per Billion)

Dwell Time (hr)	Average Concentration*	Concentration Range*
0.5	207	170-230
1.0	307	280-320
1.5	373	320-400
2.0	453	390-490
2.5	517	450-580
3.0	556	500-650
3.5	600	510-700
4.0	633	520-730

* Runs 3 through 5, circulating systems. Lead was not detected in controls.

Source: Lyon and Lenihan (1977).

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then emptied and analyzed. The tubes were then filled again. After 8 hours, the tubes were emptied and the water discarded. The tubes were refilled and held for 16 hours. This process was repeated daily for 75 days.

There was no significant difference between leaching by tap water and by deionized water. Initially, bad joints leached more than good joints, but after 60 days the leaching rates were very similar. After 30 to 40 days the amount of lead leached in good joints decreased to a nearly constant level of 500 to 1500 ppb (10 to 30 µg/fitting). Leaching rates of bad joints decreased to approximately the same level (700 to 1000 ppb, 15-20 µg/fitting) in 60 days.

The effect of pH was studied by analyzing water of a certain pH after a 16-hour dwell time. An equation relating concentration and pH was derived from the data:

$$C_L = (8.76 \pm 1) \times 10^3 \exp(-(0.36 \pm 0.03)pH) \qquad (4\text{-}17)$$

where C_L is the lead concentration (ppb) in a 115-mL pipe with five fittings. The equation can be modified to give the amount of lead (µg) leached per fitting:

$$C_L' = (2.0 \pm 0.3) \times 10^2 \exp(-(0.36 \pm 0.03)pH) \qquad (4\text{-}18)$$

When the pH increases from 6 to 8, the leaching rate is halved.

In summary, several observations can be made about the usefulness of the Lyon and Lenihan study. The field study was inconclusive because quality assurance (no controls, sensitivity of measurements unknown, etc.) was poor. The laboratory tests with circulating water give a good measure of lead concentrations in lead-soldered copper pipes before initial occupancy. The static tests using tap water and deionized water indicate that the amounts of lead leachate in water decrease after 60 to 80 void volume rinses over a period of 30 to 40 days to be a constant value of 500 to 1,500 ppb (10 to 30 µg/fitting). Although the rinse volume is smaller

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than would be expected in typical home use, these values are probably good estimates of lead leachate concentrations during initial occupancy. Finally, laboratory static tests indicated that lead leachate concentrations increase as the pH decreases (water becomes more acidic).

3) NSF/EPA Collaborative Study on Metals in Drinking Water (1975)

Field samples were taken from houses of NSF employees in Ann Arbor, Michigan, with copper or galvanized steel plumbing. Ann Arbor has a moderately high pH. Samples were taken using initial effluent from the kitchen faucet in the morning (standing) and after the water had run continuously for 3 minutes (running). The water samples were analyzed for lead, copper, and cadmium. Table IV-23 lists the range of concentrations found in the study.

Table IV-23

CONCENTRATION RANGES OF METAL LEACHATES IN ANN ARBOR TAP WATER (Part per Billion)*

Leachate	Copper		Galvanized Steel	
	Standing	running	Standing	running
Lead	3.5 - 24	0.5 - 2.4	1.1 - 2.7	0.5 - 1.8
Copper	8 - 37	01.5 - 9	1 - 2	1 - 3
Cadmium	0.01 - 0.3	0.01 - 0.08	0.1 - 0.55	ND

*Data were quoted as parts per million, but a conversation with N. I. McClelland (1983) determined that this was a misprint.

Source: NSF/EPA (1975).

These data are very uncertain, however, because no blanks were taken and the uncertainty of the measured values is not given.

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4) Carroll County, Md., Health Department Study (1977)

In the spring of 1977, the Carroll County, Maryland, Health Department conducted a county-wide random sampling of drinking water from homes with private wells and copper plumbing with lead solder to determine the distribution of lead and copper leachates. Samples were taken in the morning before any water was used, and during normal use.

A majority (58 percent) of the samples had a water pH less than 6.0. Seventy-two percent of the samples where lead was found at concentrations greater than 50 ppb had a pH less than 6.0. The maximum lead concentration in the morning standing samples was 700 ppb; 76 percent of the standing samples had lead concentrations less than 50 ppb. The maximum concentration of lead in the running samples was 450 ppb; 95 percent of the running samples had concentrations less than 50 ppb. Copper was found at concentrations greater than 5,100 ppb in 35 percent of the standing samples and 3.5 percent of the running samples.

Unfortunately, controls were not measured, which makes quantification of the house plumbing leaching rates and comparison of leaching rates in different houses very uncertain.

5) Sharrett et al. Study (1982)

Sharrett et al. (1982) attempted to correlate concentrations of heavy metals in drinking water with metals concentrations in human tissue. Samples of drinking water were taken to provide representative concentration ranges for heavy metals. Samples of the initial effluent were taken after an overnight dwell. The running samples were collected after a 30- to 60-second rinse.

The copper concentration was determined to be significantly dependent upon the age of the copper plumbing system and the length of copper pipe in the house. Galvanized steel systems had copper concentrations generated from copper service lines leading to the meter.

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Lead concentrations were observed to diminish with the age of the system for both copper and galvanized steel systems (see Table IV-24). Copper concentrations in copper systems also diminished in houses older than 5 years.

Zinc and cadmium were said to have been found at concentrations an order of magnitude greater in galvanized steel pipe than in copper pipe, although no values were reported for zinc and cadmium in the latter. Zinc concentrations diminished slightly in older galvanized steel pipes.

Table IV-24

MEDIAN STANDING METAL LEACHATE CONCENTRATIONS IN PLUMBING SYSTEMS AS A FUNCTION OF AGE
(Parts per Billion)

	Age	Lead	Zinc	Cadmium	Copper
Copper	18 months	67			
	5 years	31			1347
	>5 years	4.4			653
Galvanized Steel	<30 years		830	0.5	
	>30 years		530	0.8	

Source: Sharrett et al. (1982).

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The following table lists the middle (50 percent) concentration ranges of all samples taken irrespective of the age of the system.

Table IV-25

MIDDLE (50 PERCENT) CONCENTRATION RANGES OF FIELD STUDY SAMPLES
(Parts per Billion)

Leachate	Copper		Galvanized Steel	
	Standing	Running	Standing	Running
Lead	2.9 - 15.3	0.7 - 5.9	1.7 - 8.6	0.8 - 3.5
Copper	456 - 1303	35 - 120	3.5 - 120	24 - 94
Cadmium	0.02 - 0.21	0.01 - 0.08	0.26 - 1.13	0.11 - 0.31
Zinc	29 - 241	5 - 85	323 - 1279	128 - 640

Source: Sharrett et al. (1982).

Copper concentrations depended on the water source. The Tolt River water (pH 6.0 and hardness 8 ppm $CaCO_3$) was found to be more corrosive than Cedar River water to copper systems. The copper concentrations found were about twice those for the Cedar River (pH 7.1 and hardness 8 ppm $CaCO_3$). In galvanized steel systems, the copper concentrations were only 50 percent higher with Tolt water than with Cedar water. Zinc also was found in higher concentrations in Tolt water. However, lead and cadmium were found in higher concentrations in Cedar water.

Very complete descriptions of the sampling procedure and analytical technique were given. Although replicates were taken, the results were not quoted. Also, no sensitivity limits were quoted. Again, as in other field studies reviewed here, no blanks were taken, so that the concentrations of metals leaching from the household plumbing could not be determined.

Nevertheless, these data do indicate that metal leachate concentrations decrease with the age of the pipe. The observed decay in leaching rate is

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generally faster with copper pipe than with galvanized steel. The concentrations found represent levels that would be found in highly corrosive waters.

6) NSF Study (1980)

The National Sanitation Foundation performed a study (NSF, 1980) on the leaching of metals and phenols from copper, galvanized steel, and PVC potable-water pipes. The metal pipes were tested under standard conditions that were formulated for testing leaching from plastic pipe.

Both the NSF extractant protocol and the British extractant protocol for plastic pipes were used for the metal and PVC pipes. The NSF protocol uses 5-inch sections of pipe in a beaker of extractant water so that the ratio of total inside and outside surface area to volume is 0.16 m^2/L. The pipe was allowed to sit in the water for 24 hours at 37°C. The water was then decanted off and analyzed. More water was added and the 24-hour extraction and analysis was repeated. The pipe was then extracted for 72 hours. In the British protocol 8-inch sections of 1-inch-diameter pipe with fittings were filled with 100 mL of extractant water. The pipes were sealed and rotated at 30 rpm for 1 hour, and the water was drained and analyzed. The process was repeated for 6 hours, and then for 24 hours. NSF pH 5 (100 ppm $CaCO_3$ hardness), and pH 11 standard extractant waters were used in these tests. The solder used in the copper pipes was 50/50 tin/lead solder. The systems were rinsed with distilled water before use.

All samples (copper, galvanized steel, and PVC pipe) had concentrations of antimony, arsenic (< 50 ppb), barium (<1,000 ppb), and cadmium (<10 ppb) below the maximum contaminant level (MCL). Detectable values below these levels were not reported. PVC pipe had no values leached above the MCL.

Because experiments with fittings more closely resemble use conditions, only these results are reported here. Concentration ranges for metal pipe leachates using the British test are listed in Table IV-26.

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Table IV-26

CONCENTRATION RANGES OF METAL LEACHATES USING THE BRITISH PROTOCOL
(Parts per Billion)

Leachate	Type of Pipe	pH 5			pH 11		
		1 Hour Elapsed, 1 Hour Dwell	7 Hours Elapsed, 6 Hours Dwell	31 Hours Elapsed, 24 Hours Dwell	1 Hour Elapsed, 1 Hour Dwell	7 Hours Elapsed, 6 Hours Dwell	31 Hours Elapsed, 24 Hours Dwell
Copper	Copper	2830-3080	2160-2270	1500-2650	1260-1340	1720-2100	580-1160
Lead	Copper	3200-3400	3600-4400	1400-1600	300-500	80-400	70-90
	Galvanized steel	<5-66	25-84	<5-38	10-500	440-700	990-1200
Iron	Galvanized steel	2010	4150	860	10	10	30
Selenium	Galvanized steel	5-8	15-17	5-7	<10	<10	<15
Tin	Copper	<5	43-74	90-98	500-800	600-1000	100-300
Zinc	Galvanized steel	11500-44000	40500-96000	47500-48000	1180-1300	1420-1730	3840-4160

Source: NSF (1980).

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Copper, lead (copper pipe only), iron, and zinc were all found at high levels in pH 5 extractant water. Lead (in galvanized steel pipe) and tin were found at higher levels in pH 11 extractant water.

The test protocol and experimental conditions were well described for these tests. However, the results are clearly not typical of concentrations that would be found in a house because of the unrealistically low and high pH extractant water used and because of the low amount of pretest rinsing.

7) Herrera Study (1982)

Herrera et al. (1982) studied the leaching of 95/5 tin/antimony solders for consideration as a possible alternative to 50/50 tin/lead solders now in use for copper plumbing. The alternative is being considered because of possible adverse health effects from lead leached from the solder. A theoretical analysis of the system based on half-reaction potentials (assuming electrochemical reactions only) was performed as well as laboratory and field tests. The laboratory studies were coupon leaching (tests) of the 95/5 solder connected to a copper plate (ratio of surface areas to volume unspecified). Field tests involved the sampling of various buildings at the University of Washington, which has been using 95/5 solder for 15 years. The water used was from the Cedar River and has pH 7 and hardness 20 ppm $CaCO_3$. This water is considered corrosive.

The coupon tests indicated that antimony leachate concentration increased slightly with dwell time, with most values less than 0.6 ppb but reaching up to 3.7 ppb in 96 hours). Lead leachate concentrations between 12 and 23 ppb were also found in these coupon tests. The lead could be an impurity in the tin/antimony solder, or in the copper pipe itself.

Antimony was detected only once above the detection limit in the field samples. Lead, copper, and zinc were found at varying concentrations in the field samples. However, only copper was consistently found in concentrations greater than those of the controls. These data are listed below in Table IV-27. The concentrations of lead leachate appear to be

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smaller than those found for systems using lead solder (Lyon and Lenihan, 1977).

8) Other Studies

A field test in one house, by Dunnigan and Blumenkranz (1982), was performed to test the hypothesis that less lead is leached into water from 95/5 tin/antimony solder than from 50/50 tin/lead solder.

A system plumbed in copper with 95/5 tin/antimony solder was assembled, filled with water, pressurized, and sealed off. Three months later, samples were taken from a point farthest from the service line inlet. The initial effluent (500 mL) was collected and distributed to small vials. Three 1-liter samples were then collected consecutively. A control was taken by sampling the system nearest to the service inlet after a 1-minute rinse. Mead CompuChem analyzed the samples.

Copper, tin, lead, zinc, and phenols were detected at high concentrations in the initial samples. The results of the three 1-liter consecutive samples were not reported. The reported data are summarized in Table IV-28.

The source of the organics is speculative because no controls were taken for these leachates. No replicate data were reported, so the precision of the sampling data cannot be determined. Most importantly, the system does not represent probable concentrations encountered in normal house use because of the lack of rinsing.

Wong and Berang (1976) studied the lead concentration in lead service pipes in Victoria, B.C., Canada, and in a simulated copper system with solders of various compositions. This study (Table IV-29) was performed to determine the lead contamination that people can be exposed to in drinking water. Field samples were taken directly from lead service pipe and from homes served by lead pipe.

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Table IV-27

CONCENTRATION OF METALS IN POTABLE WATER OF VARIOUS BUILDINGS WITH 95/5 TIN/ANTIMONY SOLDER
(Parts per Billion)

Age of Plumbing System (years)	Antimony		Lead		Copper		Zinc	
	Control	Sample	Control	Sample	Control	Sample	Control	Sample
13	<0.6	2.0	4.5	2.0	25	2500	10	19
13	<0.6	<0.6	3.5	30	30	470	15	40
13	<0.6	<0.6	4.5	1.5	35	750	350	40
9	<0.6	<0.6	<1.0	1.0	<10	1600	15	210
8	<0.6	<0.6	8.5	11.5	20	730	360	120
5	<0.6	<0.6	2	11.0	100	250	280	120
4	<0.6	<0.6	1.5	3.0	10	690	240	70
3	<0.6	<0.6	4.5	1.0	35	770	35	25

Source: Herrera et al. (1982).

Table IV-28

LEACHATE CONCENTRATIONS IN INITIAL EFFLUENT OF COPPER PLUMBING SYSTEM
(Parts per Billion)

Leachate	Control	Sample	Sensitivity
Copper	3200	1.2×10^6	100
Lead	ND	9000	200
Zinc	50	1000	20
Tin	ND	19800	10000
Phenols	--	2200	10
Chloroethane	--	27	10
Chloroform	--	17	10
Chloromethane	--	23	10
Dichloromethane	--	12	10

Note: ND = not detected.

Source: Dunnigan and Blumenkranz (1982).

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Simulated copper plumbing systems were also set up with solders of different compositions. Various water volumes were rinsed through the systems, and the water was allowed to dwell 1 hour before sampling.

Because the use of lead pipe for potable water has been discontinued, the field results will be only briefly reviewed. Both the samples at the service pipe and the samples at household taps showed a steady decrease in lead concentrations as the volume of rinse water increased.

In the simulated systems, the lead concentration decreased as the rinse volume increased. Also, the amount of lead leached decreased with the amount of lead in the solder.

The lack of any quality assurance data leads one to treat these results with caution. No descriptions of the sensitivity of detection, blanks, replicates, or sample handling are given.

There are also inadequacies in the description of the experimental conditions, such as the temperature of the water and the type of water used.

Table IV-29

LEAD CONCENTRATION IN SIMULATED COPPER PIPE SYSTEMS
(Parts per Billion)

Number of Void Volumes Rinsed	Tin/Lead Solder (50/50)	Tin/Lead Solder (60/40)	Tin/Antimony Solder (95/5)	Silver Solder	No Solder
41	1200	1100	3	2	1
620	150	130	2	2	2
6200	96	49	--	--	--
1300	34	25	1	1	1
78000	9	7	--	--	--

Source: Wong and Berang (1976).

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Nevertheless, these data indicate that the amount of lead leached from copper plumbing will decrease as the system is rinsed and as the amount of lead in the solder decreases.

9) Summary of Metal Pipe Leaching

Much of the work reviewed on metal pipe leaching included field studies in which metal leachate concentrations were given without identifying the source of the leachate. Because control measurements of leachate concentrations in water entering the house plumbing system were generally not taken, a comparison of leachate concentrations originating in household plastic and metal pipes cannot be made.

Nevertheless, some general comments can be made on metal pipe leaching. Copper and zinc are consistenly found in relatively high concentrations in both copper and galvanized steel pipe water. As expected, copper is the major leachate from copper pipe and zinc is the major leachate in galvanized pipe. The concentrations of these leachates generally diminish with the age of the pipe; however, this decay is diminished and leachate concentrations are highest if the water is corrosive (acidic pH).

Much of the reviewed work focused on lead leachates from lead solders. The measured concentrations of lead leachates varied over a wide range, depending on the age and quality of the solder joint, the composition of the solder, and the pH of the water. The field data given by the NSF/EPA study (Table IV-23) and by Sharrett et al. (Table IV-25) indicate that concentrations of lead appear to be in following range for systems that use lead solder:

Copper pipe: 0.5 - 20 ppb
Galvanized pipe: 0.5 - 10 ppb.

These concentrations could be higher for water with a pH less than 6 or for new houses (less than 5 years old). The data of Herrera et al. (1982) and

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Wong and Berang (1976) indicate that lead leachate concentrations diminish, as expected, when the percentage of lead in the solder decreases.

d. Pipe Permeation

Field studies (e.g., by Crum, 1981) and laboratory studies by Anlab (1982, 1983) and East Bay Municipal Utilities District (EBMUD, 1978) suggest that permeation of plastic pipe by low-molecular-weight organic solvents may contaminate drinking water.

EBMUD received several complaints of gasoline taste in water from PB service pipe. One report was traced to saturation of the fill around the service pipe with a mixture of gasoline and water. Another complaint was traced to the diffusion of butanethiol from a natural gas pipe through the PB pipe.

Laboratory studies by EBMUD (1978) were initiated in response to these complaints. Water was sealed in PB, PE, and PVC pipes and placed in gasoline-saturated vermiculite for 1 week to 2 months. Controls were run and found to contain no gasoline. Gasoline was found in the PB and PE pipe water after a 1-week dwell. No gasoline was found in the PVC pipe water after a 2-month dwell.

Anlab (1982) first approached this permeation problem by determining the concentration of various chemicals in PB, PE, and PVC pipe water after exposing the pipe to sand saturated with these chemicals for 1-week dwell periods. A copper pipe control was placed in the organic-saturated sand, and a plastic pipe control was submerged in tap water. The permeation of 1,2-dichloropropane, 1,1,1-trichloroethane, Chevron Super Unleaded gasoline, and Chlordane 8E (1 percent formulation) were tested; the data are listed in Table IV-30. Chlordane did not permeate any of the pipes.

Other chemicals, such as chloroform, THF, MEK, and toluene were found to increase in concentration in the water with permeation. These concentrations were variable.

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Table IV-30

PERMEANT CONCENTRATION AFTER 1-WEEK DWELL IN SATURATED SANDS
(Parts per Billion)

Permeant	Copper	PVC		PB		PE	
		Water		Water		Water	
	Control	Control	Sample	Control	Sample	Control	Sample
1,2-dichloropropane	ND	ND	0.98	20	310	ND	1800
1,1,1-trichloroethane	4.6	ND	2.2	ND	25000	ND	46000
gasoline	590	ND	ND	ND	78000	ND	120000

Note: ND = not detected.

Source: Anlab (1982).

Anlab (1983) also performed permeation experiments by immersing PVC, PB, and PE pipe in liquid 1,1-dichloroethene, 1,2-dichloroethane, trichloroethene, dinoseb, 2,4-D, chlordane, and lindane. Three-week dwell periods were used for the pesticide experiments; 1-week dwell periods were used with the other chemicals.

None of the pesticides was detected in the water above the concentrations found in the controls after the 3-week dwell. The low-molecular-weight chlorinated organics were detected in the water samples of PB and PE pipe, and the PVC pipe usually failed (by the loss of structural rigidity in the pipe joints) before 1 week had elapsed.

These data are not surprising. The larger molecules of the pesticides would be expected to diffuse much more slowly through a plastic pipe than the smaller, low-molecular-weight organics. Depending on the solubility of the organic in the pipe, the pipe would swell and the diffusion of all organic species in the pipe would substantially increase.

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The details of these experiments were not available for review. However, this lack of information is not critical because the experimental conditions were unrealistically severe: it is unlikely that an in-service pipe could be unknowingly exposed to a soil saturated with low-molecular-weight organics. Information on the permeation of plastic pipes subject to more realistic concentrations of low-molecular-weight organics in the soil, air, or soil water surrounding an in-service pipe would be more valuable. We can speculate that the permeant concentration in the pipe water will decrease very rapidly as its concentration in the soil decreases, because the diffusion of a soluble chemical in the pipe will be very sensitive to the concentration of the chemical in the pipe. The drop in pipe water concentration versus concentration in soil should be much greater than linear from highly contaminated soils to lightly contaminated ones.

e. Fluxes and Cutting Oils

Whereas the leaching of metals from solders has received much attention, little is known on the leaching of chemicals from fluxes or cutting oils.

Fluxes are mainly composed of a tree resin, tallow, ammonmium chloride, and zinc chloride. The chloride salts would be expected to be rinsed away quickly because of their high water solubility. Resin would be expected to be more persistent because of its low water solubility. Organic compounds may be generated during the heat of soldering that would also be persistent.

Cutting oils are mainly composed of surfactants (soaps and glycols). Other organic compounds can also be present in the oils, such as:

sodium nitrite

ethanol amines

organomercurials

quaternary ammonium compounds

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organophosphorous compounds

chlorophenols

chlorinated paraffins

The nitrites, amines, and quaternary ammonium compounds would be expected to rise away in a short time, because of their relatively high water solubility. The organometallics and the chlorinated organics would be expected to persist longer because of their low water solubility.

Based on the previous discussion, more tests need to be performed on metal pipes for the presence of organics and organometallics.

4. Summary

The objective of this review was to critically examine laboratory and field data on the concentrations of leachates in water exposed to CPVC, PB, copper, and galvanized steel pipes. In this section, we summarize significant data and the limitations of the work we reviewed. Later in this report we identify critical testing needs.

High concentrations (ppm) of cement solvents were found in water exposed to newly joined CPVC pipes. The concentration of these solvents in water rapidly diminished as expected with successive rinses, over a period of a few days, as the concentration of solvent in the surface layer diminished. Several low molecular weight chlorinated organics were also detected in significant concentrations in CPVC pipe water. However, these concentrations were very low (1 to 10 ppb) in new CPVC pipe and did not correlate with dwell time or elapsed time. Organotins were also detected in CPVC pipe water during initial leaching, but their concentrations were small and rapidly diminished to less than 0.1 ppb with successive rinsing.

Of the pipe systems studied, the leachability of CPVC is the most difficult to assess because of the number and type of possible leachates in a CPVC system and because of the use of solvent cement to join CPVC pipe. Table III-3 shows that the list of additives to CPVC is much greater than

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the list of additives of PB. Moreover, leaching data indicate that the predominant leachates generated from CPVC pipe are low-molecular-weight chlorinated organics. The origin of the chemicals is often difficult to determine because of their common background presence in chlorinated water.

The use of cement solvents in CPVC pipe systems makes the interpretation of leaching data very difficult in two ways. First, the constituents of the solvents add to the number of potential leachates in CPVC pipe water. Second, and most importantly, application of solvent cement significantly and irreproducibly alters the leachability of the pipe. Residual chemicals in the parts of the pipe where solvent cement has been applied will leach into the water at different rates than from virgin pipe. These rates will depend on the amount of solvent cement applied and will change significantly as the solvent leaches out of the joint during initial rinsing. The heterogeneous and dynamic leaching behavior expected for solvent-joined CPVC pipe, particularly during the first few weeks after the solvent has been applied, is probably a principal cause of the lack of correlation of leachate concentrations of CPVC with dwell or elapsed time.

In contrast to CPVC, PB pipe is composed almost entirely of polymer resin with very few additives, and no solvent cement is needed to join the pipe. Thus, only a few leachates, at low concentrations are expected in PB pipe water and indeed only Irganox 1010 derivatives have been detected at significant concentrations in studies to date.

As expected, the principal leachates in copper and galvanized steel pipe are copper and zinc salts. Our review focused on lead concentrations in metal pipe systems, however, because of the high toxicity of lead. Lead concentrations were found to be high in pipe systems where lead solder was used. Several studies (Herrera, et al., 1982 and Wong and Berrang, 1976) indicated that lead concentration diminished as expected, as the percentage of lead in the solder decreased. Moreover, field studies (Sharrett, et al., 1982) indicated that lead concentrations diminished with the age of the pipe system, as expected. In contrast to plastic pipe leaching, the composition and in particular, the pH of the pipe water significantly affects metal pipe

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leaching. Slightly acidic water (pH 5 to 7) significantly increases leachate concentrations of all metals, including lead.

Most of the data reviewed for metal pipe leaching was gathered in field studies. Because lead leachability depends on the amount and type of solder used, the age of the joint, and the composition of the water, it is difficult to succinctly summarize these data. In general, it can be expected that lead concentrations in water will be well below the MCL of 50 ppb for pipe systems older than two years. Not enough data exist however, on new pipe systems, where lead concentrations may be significantly higher than 50 ppb, to adequately assess chronic exposure. Moreover, a major limitation of most field studies of lead concentrations on potable water has been the absence of information on lead concentrations in water entering residential plumbing systems. This lack of information, of course, makes direct comparison of water quality hazards associated with plastic and metal residential plumbing very uncertain.

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B. Impacts on Public Health*

1. Introduction

One of the most controversial aspects of this Environmental Review is the extent to which the use of plastic pipes for plumbing may contaminate the water supply and thereby affect human health. This is not a question that is easily resolved. The chemicals of concern have been shown to be toxic to humans or animals at concentrations higher than those measured or estimated to be in water that has passed through plastic pipes. It is uncertain whether such toxic effects occur with lower levels of exposure that may persist over extended periods of time. How this issue is evaluated depends largely on whether the toxic effect is thought to be governed by a threshold.

A "threshold" represents a dose or level of exposure below which a given toxic effect is not observed. Most toxicological processes are thought to display threshold behavior: the principal exceptions to this observation include chemical effects on genes and chromosomes and cancer. It has been argued, however, that certain classes of chemical carcinogens act by mechanisms that effectively include thresholds (see, e.g., Stott et al, 1981).

Chemical toxicity may result from acute and chronic exposures. Acute exposure occurs over a short period of time (e.g., during one day), whereas chronic exposure is extended over a longer time (months to years). Acute exposure may result in immediate toxic effects. Chemicals that leach from

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*Potential human health impacts fall into three categories: (1) effects due to contamination of the water supply by plumbing pipe leachates or by exogenous chemicals permeating pipe from the outside; (2) effects due to exposure to chemicals used to install pipes; and (3) effects due to exposure to pipe combustion products. This section concerns only the first of these.

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both plastic and metal plumbing pipes can display acute toxic effects. However, these effects are typicially characterized by thresholds substantially above the concentrations found or expected in drinking water. Therefore, acute toxic effects would not be considered to constitute a significant hazard to public health. Acute exposures may also result in toxic effects that may not be manifest for months or years. Such delayed toxicity may be similar to that produced by chronic exposure to lower doses of the same agent(s). The health effects of particular concern in this respect include gene mutations, chromosome damage (to germ cells and nongerm or somatic cells), and cancer.

In cases where these health effects are attributable to a chemical exposure, threshold levels may not be ascertainable. A sufficient "target" for such effects may consist of the genetic material of one cell, which would make an effective toxic dose indistinguishable from zero. If the damage is not lethal and remains unrepaired, the affected cell's progeny may give rise to disease. For example, there is evidence that damage to a single cell or, in some cases, even a single DNA base-pair can result in cancer (Fialkow, 1974; J. Amer. Med. Assoc., 1982). Thus, there is legitimate concern that low doses of certain chemicals may cause chronic health effects.

In attempting to assess potential chronic health effects attributable to chemicals in the water supply, it should be borne in mind that there are sources of contamination of drinking water other than plastic plumbing pipes. For example, surface waters and ground waters serving as sources of drinking water have been extensively polluted by industrial and agricultural organic chemicals (NAS, 1977; Council on Environmental Quality, 1981a). Other contaminants may include: heavy metals from corrosion of distribution system and plumbing pipes, asbestos fibers from asbestos/concrete distribution pipe, organic leachates from plastic pipe used in water distribution systems; leachates from coal tar, asphalt, and other materials used to line water distribution pipes (NAS, 1982); and organic compounds, especially chloroform and other trihalomethanes, from disinfection of drinking water (NAS, 1979; Hoel and Crump, 1981). Recently a previously

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unrecognized potential source of organic compounds has been reported: permeation of plastic pipes by gasoline and other organic solvents (Ikesaki, 1983; Elliot, 1982). Plastic pipes used for plumbing constitute but one of several potential sources of contamination of the water supply. At the same time, it should be recognized that in evaluating the possible consequences of the use of such pipes, an assessment of risk must not be viewed as an isolated exercise, but rather as an analysis of risks incremental to those potentially posed by other sources of water contamination.

2. Approach

This section assesses, within the limits of current information, the nature and probability of risks of health effects due to contamination of the water supply by chemical leachates. It should be emphasized at the outset that such risk assessment is generally of a qualitative nature. Quantitative risk estimation methodologies have been extensively developed only for cancer risks, not for the other chronic health effects of interest. Potential effects on genes and chromosomes, particularly on germ cells, while of obvious importance, cannot yet be quantitatively estimated (Streisinger, 1983). There are many uncertainties involved in such risk assessment and these are identified whenever possible. Evaluation of potential public health risks was based on the following approach:

(1) Identification of chemicals of interest
(2) Exposure assessment
(3) Evaluation of literature on animal and human toxicity
(4) Identification of data gaps
(5) Selection of potentially hazardous chemicals
(6) Assessment of likelihood and magnitude of risks.

a. Identification of Chemicals of Interest

From the standpoint of public health, the chemicals of interest are substances known to be present in pipes (plastic and metal), in cements, primers, solders and fluxes, and which have been detected in water sampled

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according to appropriate protocols. The discussion in Chapter IV-A indicated that most experimental protocols have been deficient in design or analysis or both. Applying strict evaluative criteria to such protocols has reduced the number of chemicals of interest to relatively few, which have consistently been reported at levels greater than control values. These chemicals are listed in Table IV-30A. While a much longer list of chemical compounds was presented in the interim draft version of the public health section of this report (February 13, 1983), the draft list was based on a preliminary and less stringent evaluation of leaching data. The assessment of potential public health risks in the ERD is circumscribed by SRI's current analysis of the water quality experiments. Subsequent testing may warrant consideration of additional substances.

Other chemicals of potential interest are those that have been demonstrated to permeate plastic or metal pipe from the outside, which could contaminate domestic drinking water supplies. These substances are treated separately elsewhere in this chapter.

b. Exposure Assessment

An exposure assessment is a method for estimating quantities of a substance that humans are likely to ingest, inhale, or absorb through the skin. Necessarily based on multiple assumptions and approximations, an exposure assessment attempts to predict patterns of frequency and magnitude of human contact with the chemical(s) of interest.

In conducting the present analysis, the exposure assessments were not comprehensive, but consisted of identifying approximate concentrations of chemicals to be expected in drinking water. The results of such assessments were presented in Chapter IV-A.

c. Evaluation of Animal and Human Literature

Relevant epidemiologic, medical, and toxicological papers were identified by a review of the administrative record, a computerized

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TABLE IV-30A

CHEMICALS OF INTEREST FOR PUBLIC HEALTH ANALYSIS*

CPVC Pipe

Dichloromethane
Chloroform
Carbon tetrachloride
Trichloroethylene
Tetrachloroethylene
Toluene
Dibutyl tin
Tetrahydrofuran
Dimethylformamide
Cyclohexanone
Methyl ethyl ketone

Polybutylene Pipe

Tetrakis [methylene (3,5-di-t-butyl-4-hydroxyhydrocinnamate] and fragments thereof

PVC Pipe

Dichloromethane
Chloroform
Carbon tetrachloride
Dimethyl tin bis-isooctylthioglycolate
Trichloroethylene
Tetrahydrofuran
Dimethylformamide
Cyclohexanone
Toluene
Methyl ethyl ketone

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Table IV-30A (concluded)

Copper Pipe	
Cadmium	Tin
Nickel	Lead
Copper	Zinc

Galvanized Iron Pipe	
Cadmium	Iron
Nickel	Zinc
Copper	Lead
Selenium	

*Refer to chapter IV-A for documentation.

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literature search (MEDLINE, TOXLINE and RTECS) supplemented by a manual search, and by reference to standard texts. Most of the materials reviewed were secondary sources.

d. Identification of Data Gaps

In performing the tasks described above, important deficiencies in the data were identified. Data gaps with respect to the identities of leachates and their probable range of concentrations in water (exposure assessment) were described in Chapter IV-A. Inadequacies in medical and toxicologic literature are described in a later section of this chapter.

e. Selection of Potentially Hazardous Chemicals

From the list of chemicals of interest, several were chosen for further analysis on the basis of both toxicologic properties and probable human exposure via the water supply. Other chemicals were not chosen for such an evaluation because they were judged to pose minimal risks of chronic toxicity at predicted concentrations. Chemicals not considered for further analysis on this basis include iron, selenium, and toluene (Exhibit IV-1).

f. Assessment of Likelihood and Magnitude of Risks

As noted earlier, there is considerable uncertainty in estimating risks of chronic disease from low doses of chemicals. There are multiple sources of such uncertainty: (1) the identities and concentrations of chemical leachates over time in drinking water; (2) quantities of tap water actually consumed by individuals (exposure); (3) the nature of toxic effects of chemical ingestion (where the medical or toxicologic literature has significant gaps or where the studied routes of exposure are not oral); (4) the validity of extrapolating the probability of toxic reactions from high doses to low doses and from animals to humans; and (5) potential interactions among chemicals in drinking water that may result in additive, synergistic, potentiating, or antagonistic effects. How each of these areas of uncertainty has been handled is discussed briefly in the following

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Exhibit IV-1

JUSTIFICATION FOR CHEMICALS CONSIDERED TO POSE NEGLIGIBLE RISK

(1) Iron. The leaching studies reviewed earlier indicate that typical iron concentrations in water standing in galvanized steel pipe are less than 1 ppm (1 mg/liter). (See Tables IV-19, IV-20, and IV-26.) Even in the NSF study (1980), using pH 5 water--unrealistically low for California--the iron concentration in early samples would, if ingested by humans, contribute only a fraction of the daily dietary intake of this essential nutrient. The Recommended Daily Allowance for iron ranges from 10 mg for infants to 18 mg for teenage males and for females in their child-bearing years (Food and Nutrition Board, 1979). Furthermore, people have adequate homeostatic mechanisms to deal with this metal.

(2) Selenium. While selenium is toxic at high doses, it is an essential trace element. The recommended adequate and safe daily dietary intake ranges from 0.01 to 0.06 mg for infants to 0.05 to 0.2 mg for adults (Food and Nutrition Board, 1979). The NSF study (1980) (Table 4-26), using water at an unrealistic pH, found that levels in water standing in galvanized steel pipes were typically less than the MCL of 0.01 mg/liter (40 CFR 141.11[b]). Even if the concentration of selenium were consistently 0.01 mg/liter over the long term, this amount would constitute a small fraction of the daily dietary intake of this mineral (NAS, 1980).

(3) Toluene. Unlike iron and selenium, toluene plays no essential role in nutrition. It is clearly toxic to humans at high doses (Committee on Alkyl Benzene Derivatives, 1981). The concentrations of toluene detected in sampling protocols reviewed in Chapter IV-A were consistently less than 1 ppb (1 µg/liter). Such concentrations are 5 orders of magnitude (100,000 times) lower than the EPA ambient water quality criterion for toluene (14.3 mg/liter), which was established to protect human health against toxic effects not only from drinking water, but also from eating contaminated fish (45 Fed. Reg. 79340; November 28, 1980). More recently, EPA's Office of Drinking Water has calculated a chronic "Suggested No Adverse Response Level" (SNARL) of 343 ppb for toluene (EPA, 1982). SRI has recalculated this chronic SNARL to be 34.5 ppb, still nearly two orders of magnitude greater than the concentrations described in Chapter IV-A. EPA's Science Advisory Board has completed an extensive review of toluene's toxicologic properties and concluded that this substance cannot be currently considered mutagenic, carcinogenic, or teratogenic (McClellan, 1982). However, toluene is being tested for carcinogenicity under the auspices of the National Toxicology Program and may warrant more extensive discussion if that bioassay should prove to be positive.

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section on risk assessment. For the chemicals reviewed in this chapter, the analysis has followed the following sequence:

(1) Is there an applicable state or federal standard pertaining to the presence of the chemical of interest in the water supply? If so, the expected range of concentrations in the water supply has been compared with the relevant standard, assuming the latter has been calculated from chronic toxicity data.

(2) If there is no applicable standard, is there a "Suggested No Adverse Response Level" (SNARL) for chronic effects calculated by the National Academy of Sciences or the U.S. Environmental Protection Agency's Office of Drinking Water? If so, the expected range of concentrations in the water supply has been compared with such SNARL(s).

(3) If there is neither standard nor SNARL, are the data adequate to calculate a chronic SNARL? If so, such calculations have been done. If not, the risk assessment is qualitative only, except for solvent cements and carcinogens.

(4) In the case of the four solvent cements for which no chronic SNARLs or quantitative risk estimates have been calculated, a procedure devised by the Department of Health Services, based on occupational exposure limits, has been followed. In this procedure occupational exposure standards are used to calculate proposed acceptable concentrations and proposed maximum short-term acceptable concentrations. These values are compared to solvent concentrations in water carried by plastic pipes in order to estimate health risk.

(5) For recognized animal carcinogens, results of low-dose risk estimates calculated by EPA's Carcinogen Assessment Group using the multistage model of Crump and Watson (1979) are presented. A range of plausible risks were calculated under assumptions of different leachate concentrations.

3. Risk Assessment: Health Effects of Leachates

The risks of toxicity to consumers exposed to leachates in potable water depend on several factors:

(1) The toxic effects of such chemical leachates
(2) The doses at which such effects have been observed
(3) The concentrations of such leachates that have been found or can reasonably be expected to be found in drinking water, at different times in the life of the pipes
(4) The ratio of (2) and (3)
(5) Whether the toxic effects of interest are reversible or irreversible
(6) Whether the effects of exposure are likely to be cumulative, and if so, the cumulative dose.

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(7) Whether the toxic effects are thought to be governed by a threshold.

Risk estimation concerning potential health effects from exposure to chemicals has traditionally involved different methods for dealing with carcinogens and noncarcinogens, principally because carcinogenesis is postulated, at least for genotoxic agents, to be a nonthreshold process (NAS, 1977, 1980). For certain chemicals, mutagenesis or other genetic damage may also be considered a nonthreshold process, but genetic toxicology has not yet evolved to a point where human risks of genetic damage and potential disease can be predicted from the results of in vitro or in vivo assays positive for effects on DNA (Streisinger, 1983).

Noncarcinogenic effects are generally considered to display threshold behavior. Thus, the usual approach to assessing risks of chronic health effects from exposure to a chemical not known to be carcinogenic is to ascertain a "no-observed-effect-level" of long-term exposure and to apply an appropriate safety or uncertainty factor (NAS, 1980). Such calculations essentially involve linear extrapolation to levels of exposures below those where no adverse effects have been observed. Suggested-no-adverse-response-levels ("SNARLs") are the result of such estimates, and normal consumption of drinking water contaminated up to the SNARL should not result in toxicity to humans; however, total safety cannot be vouchsafed (NAS, 1980). Criticisms of such an approach have focused primarily on the choice of dose levels and on small sample sizes (so that the pertinent study may have inadequate statistical power to detect an effect). Another problem encountered with this approach is that there may be no adequate data from which to calculate a chronic SNARL. (See, e.g., evaluations for cyclohexanone, dimethylformamide, methyl ethyl ketone, and tetrahydrofuran.)

While this approach has potential shortcomings, SRI has utilized it for substances not known to be carcinogens because it does incorporate substantial safety factors and because it is utilized by regulatory agencies with responsibilities for protecting public health from contaminants in drinking water (e.g., EPA, California Department of Health Services) and by

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the National Academy of Sciences in its reports mandated by the Safe Drinking Water Act (see, e.g., NAS, 1977, 1980, 1982).

Risk estimation for carcinogens in drinking water is more complex. Neither the National Academy of Sciences nor EPA calculates SNARLs for substances demonstrated to be carcinogenic in animals or humans. The basis for this is that the toxicity of carcinogens may involve effects that are irreversible and self-propagating after the exposure has ceased. Furthermore, as noted earlier, carcinogenesis due to exogenous agents has been, and for regulatory purposes still is, considered to be a nonthreshold process. Therefore, to estimate incremental cancer risks from daily exposure to such agents, the general approach is to calculate plausible estimates of upper lifetime risks of 10^{-5}, 10^{-6}, and 10^{-7}. In other words, exposure levels are calculated that would correspond to an increase in an individual's lifetime risk of 10^{-5} (one in one hundred thousand), 10^{-6} (one in one million), and 10^{-7} (one in ten million). In general, such calculations are made using mathematical models that are based principally on the results of animal bioassays, although epidemiologic data are preferable when available. The models currently in use have been extensively reviewed by the California Department of Health Services (October 1982).

The scope and budget for this project did not permit an independent reevaluation of the risks posed by carcinogens in drinking water. In general, the calculations performed by EPA in developing its water quality criteria have been relied upon. These estimates were formulated using the linearized multistage model (Crump and Watson, 1979). For some carcinogens, notably those whose carcinogenicity is probably modulated by activated metabolites, this model may overstate risk (Hoel et al., 1983). However, regulatory agencies dealing with such a potentially serious outcome as cancer generally prefer to err on the side of conservatism. This preference in part explains the widespread use of the multistage model. The National Drinking Water Advisory Council has advocated that this model be used to set recommended MCLs for carcinogens (Neal, undated).

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In evaluating the risks posed by carcinogens, there is always a question of what constitutes a significant incremental risk of cancer. Federal agencies have in the past considered an individual risk level of 10^{-6} as a measure of acceptability of risk. This corresponds to one additional case of cancer occurring in a population of one million people. The California Department of Health Services has also recently proposed a 10^{-6} level as one measure of determining significant risk (December 1982). The choice of such a risk level is precautionary in nature, and is based on both the large degree of uncertainty involved in quantitative risk assessment and on the possibility of synergistic (and potentiating) interactions among carcinogens (and other chemicals not carcinogenic in themselves). Where the potentially exposed population is very large, even a risk level of 10^{-6} may lead to additional cases of cancer. At the federal level, the use of 10^{-6} as a target risk level may be changing. The National Drinking Water Advisory Council has recommended the use of 10^{-5} for at least some carcinogens, as has EPA in some cases (Neal, undated; Marshall, 1982). Although not formulated in official policy statements, California regulatory agencies have used a 10^{-6} target risk level for the general population.*

California's population in 1980 was about 24 million. In the early 21st century, it will probably exceed 30 million. If the projections of Section II-C hold true, by 2010, more than 8 million people could be drinking from plastic pipe. At that time, an average lifetime risk of 10^{-6}--or an annual risk of about 1.5×10^{-8}--would imply that one additional case of cancer might be expected about every 8 years in California. Some population groups (for example, people who move into newly

*The choice of 10^{-5}, 10^{-6}, or 10^{-7} as a target risk level could have a significant impact on the judgment as to the acceptability of pipes that may leach small quantities of carcinogens. Of these alternatives, 10^{-5} is least protective and 10^{-7} most protective of public health. Historically, however, 10^{-6} has been most commonly used by regulatory agencies. It should be recognized that these numbers can take on an unwarranted talismanic significance, whereas in actuality they represent crude approximations of plausible risk limits.

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plumbed houses in infancy) may be at higher risk, whereas others would be at lower risk.

a. Sources of Uncertainty in Risk Assessment

As noted earlier, there are several sources of uncertainty in assessing the risk of low level contamination of drinking water by plumbing pipe. The following paragraphs discuss the principal sources of uncertainty that are relevant to this document.

i. Leachate Concentrations Over Time--Critical variables in risk assessment are the identities and quantities of chemicals that people are likely to ingest over time. As is evident in Chapter IV-A, such information is not readily available from earlier sampling protocols, most of which have suffered from significant methodologic flaws. One can make predictions about the leaching behavior of certain substances; for example, for chemicals whose leaching into water is equilibrium-limited rather than diffusion-limited, concentrations should decline exponentially with increasing numbers of equilibrium dwell-time flushings. For other substances whose leaching behavior may be diffusion-limited or even more complex (see Chapter IV-A), such predictions cannot be made. In the absence of better data, such substances can be treated in at least two ways. One is a worst-case analysis, in which an estimated (high) concentration of the substance in the pipe is presumed to completely leach from the pipe at a constant rate for 20 years. Alternatively, one can assume a faster leaching rate and calculate the potential health risks for a shorter, but higher, level of exposure. Both of these approaches have been used here. Better, long-term leaching data would facilitate this analysis.

ii. Exposure--One does not know the quantities of tap water actually consumed by individuals; thus, simplifying assumptions have been necessary. For purposes of risk calculations, SRI has assumed that all of an individual's daily fluid intake has come from tap water. For adults, this quantity is assumed to be 2 liters/day and for infants and young children, 1 liter/day. One further assumption has been that oral ingestion is the only

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significant source of human exposure to chemical leachates. Potential absorption of some chemicals present at ppb quantities through intact skin (e.g., in hand-washing or bathing) has been historically assumed to be insignificant. (The validity of such an assumption may be altered by the results of an ongoing EPA investigation of this issue [Maibach, 1983].)

iii. The Nature of Chemical Effects--Risk assessment is subject to generic uncertainties due to an incomplete data base. For example, some chemical leachates have not been studied for carcinogenicity (e.g., methyl ethyl ketone) or the investigations for carcinogenicity have been inadequate (e.g., dimethyl tin bis isooctylthioglycolate). In cases such as these, the chemicals of interest have been treated as if they do not possess the capability of causing cancer. A substance may have been found to cause tumors in animals only when administered in a form or route different from that to be expected in drinking water (e.g., intratesticular injection of zinc in roosters). Unless the route of exposure is oral (including gavage) or by inhalation, no quantitative cancer risk assessment has been undertaken. It should be noted that chemicals demonstrated to be carcinogenic (or toxic in some other respect) by one route of exposure may or may not possess this capability if exposure takes place by another route (Tobin et al., 1982; Theiss, 1982).

iv. Low-Dose and Interspecies Extrapolation--Extrapolating the occurrence of toxic effects from high to low doses and from animals to humans are fundamental concepts in toxicology. These procedures assume a similarity of biological effects (at low doses and in humans) that has generated substantial controversy, particularly with respect to risk estimates for carcinogens acting through "epigenetic" mechanisms (see, e.g., Stott et al., 1981; Hoel et al., 1983; California Department of Health Services, October 1982; Munro and Krewski, 1981; NIEHS, 1976). It is beyond the scope of this document to present an extensive discussion of these issues. Suffice it to say that such extrapolations are necessary for quantitative risk assessment, even though there are major uncertainties involved in performing such calculations.

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v. Chemical Interations--Chemical leachates may interact with each other and with other chemicals in drinking water or food in ways that may result in additive, synergistic, potentiating, or antagonistic effects on toxicity. Examples of all of these types of interactions are known to occur but, in general, such information is not available for the variety of interactions that chemical leachates might take part in. The area of greatest potential concern in this respect is carcinogenesis. In the absence of information to the contrary, SRI has treated all such effects (where quantifiable) as if they were additive (California Department of Health Services, October 1982).

b. Background Information--Health Effects

i. Effects on Genes and Chromosomes--Chemicals that can affect the structure of genetic material are classified as mutagens (causing mutations--changes in DNA sequences) or clastogens (causing disruption of chromosomal architecture). Genetic effects may be passed on to an affected cell's progeny, and may result in cancer (non-germ cell mutations) or reduced fertility or birth defects (affected cells are germ cells). Many, but not all, chemicals shown to cause mutations in short-term in vitro assays are recognized carcinogens (McCann and Ames, 1977; Ames, 1979; Rosenkranz and Poirier, 1979). As noted previously, recent work indicates that in some cases, changing a single DNA base-pair (the basic building block of genes) may be sufficient to cause cancer (Anonymous, 1982). Others believe that, since many tumors display disturbed chromosomal structures, clastogenic effects are more important in the development of cancer (Cairns, 1981). In any case, damage to genetic material is likely to be deleterious. However, the state-of-the-art of genetic toxicology is not yet at a stage where short-term tests for genotoxicity can be used to quantitatively predict human genetic risk (Streisinger, 1983; Bartsch et al., 1982).

ii. Cancer--Of the chronic diseases at issue in this Environmental Review, cancer seems to be the source of greatest concern. One out of four persons in California will develop cancer, which is the second leading cause

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of death in California and the United States. Cancer is not one disease, but rather a group of diseases of multiple causes, all characterized by an uncontrolled proliferation of cells which can lead to the death of the host. Despite billions of dollars spent on cancer research during the past decade, the causal and developmental mechanisms of cancer remain obscure.

The development of cancer in a particular individual depends on both internal and external factors. The former include genetic constitution, general health, age, sex, race, nutrition, hormones and competence of the immune system. External factors include exposure to carcinogens--cancer-causing agents--either voluntarily (e.g., cigarette smoking) or involuntarily (e.g., exposures in the workplace or general environment). The rest of this section will focus on the role of carcinogens in cancer causation. It should be borne in mind that the following discussion is an extreme simplication of a highly complex topic.

It has been estimated that up to 90 percent of all cancer is caused by "environmental" agents (Higgenson, 1976). The majority of cancer cases has been attributed to so-called voluntary "lifestyle" factors, such as cigarette smoking, diet, exposure to sunlight, and consumption of alcohol (Doll and Peto, 1980; Miller, 1981). Such estimates are controversial (Epstein, 1981), but even assuming that only a few percent of cancers are attributable to environmental contaminants, several thousand cancer cases per year in California may be attributable to such contaminants. Furthermore, dividing causes into lifestyle and nonlifestyle categories creates the appearance of greater certainty about the development of cancer than currently exists: people are exposed to many carcinogens and "promoters" (see below) in ambient air and water and the workplace, as well as through such "lifestyle" factors as smoking and high-fat diets.

There are several sources of evidence for identification of carcinogens: human studies, animal models, short-term tests, and structure-activity analyses. (The latter two sources are considered supportive evidence only, and cannot prove or disprove mammalian carcinogenicity.) Although epidemiologic investigations of human populations exposed to

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putative carcinogens provide the most direct evidence of carcinogenicity, a variety of usually unavoidable structural problems limits the utility of such studies. Such problems include small study population sizes, multiple potentially confounding exposures, fragmentary or nonexistent documentation of exposure to the agent(s) in question, difficulty in identifying an appropriate control or reference population, and an inability to detect increases in risk less than 50-100 percent. When good epidemiologic data are available, they clearly represent the best evidence. However, most commercial chemicals found to be carcinogenic in animals have not been and probably cannot be investigated by epidemiologic methods, because of the methodological and statistical limitations of such methods (Karstadt, 1981).

Evidence of a substance's ability to cause cancer in animals represents the next best level of evidence that such substance poses a risk of cancer to humans. All known human carcinogens, with the possible exception of arsenic, have been reported to be carcinogenic in one or more animal species (Tomatis, 1979; IARC, 1982b). For reasons noted above, the reverse cannot be demonstrated or disproved. Carcinogenicity can generally be demonstrated in more than one animal species under adequate experimental protocols (Ames et al., 1981). The strong correlations between studies of human and animal carcinogens have led every federal and California agency concerned with regulation of carcinogens, as well as national and international expert committees, to regard animal carcinogens as potential human carcinogens.

An in-depth exposition of current theories about causes and mechanisms of carcinogenesis is beyond the scope of this document: there are several recent articles and books on the subject (Farber, 1981; Yuspa and Harris, 1982; Berenblum, 1979; California Department of Health Services, 1982; Stott et al., 1981; Weisburger and Williams, 1981; Sontag, 1981; OTA, 1981; Becker, 1981).

The evolution of cancer is a gradual process thought to occur in multiple stages, some of which are irreversible and others probably reversible (Farber, 1981; Berenblum, 1979; Peto, 1977). The irreversible change involves an alteration of DNA, designated "initiation," which can be

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passed on to the cell's progeny. Initiated cells may then be subject to the action of "promoters" (also known as "modifiers" or "late stage carcinogens"), which may eventually result in the development of a tumor, although the mechanisms of action are not known. While some substances are known to have only promoter activity (e.g., phenobarbital), others may act as initiators as well as promoters and are known as "complete carcinogens." However, this well-accepted theory cannot explain the apparent complete carcinogenicity of chemicals that do not bind to or directly change DNA.

Whether a chemical or its metabolites can bind to and alter DNA--i.e., whether it is genotoxic--has been proposed as a basis for classification of carcinogens (Weisburger and Williams, 1981). Dividing carcinogens into genotoxic versus epigenetic or nongenotoxic categories may have major implications for risk assessment and regulation (Kolbye, 1982). Promoters have been designated to act by unknown epigenetic mechanisms, though there is evidence that they can affect DNA indirectly (Marx, 1983; Parke, 1982). There is by no means, however, a consensus among scientists and regulators about the appropriateness of such a classification scheme for regulatory purposes and, considering that this bifurcated approach has not been officially adopted by any agency, it would be premature to suggest that DCHD subscribe to this policy (see, e.g., Toddhunter, 1983; Weinstein, 1983, Albert, 1983).

iii. Effects on Reproduction--Exposure to chemical agents has been associated with a variety of adverse reproductive outcomes in humans, including reduced fertility, miscarriages, stillbirths, birth defects, low-birth-weight infants, and effects on later physical and mental development of children who initially appear normal (Council on Environmental Quality, 1981b). Most of the medical literature concerning chemical effects on reproduction has focused on birth defects rather than other types of reproductive impairment. Other outcomes have not been subject to as much study as the development of birth defects and will be given less emphasis here. The overall influence of identifiable causative factors in human birth defects has been estimated to include genetic damage (about 23-35 percent) and environmental agents of all kinds, including

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chemicals, radiation, drugs, alcohol, infections and so forth (about 7-11 percent). The remainder (about two-thirds) have no identified cause (Wilson, 1973).

Substances capable of causing physical defects in the embryo or fetus are called teratogens. Most chemicals identified as human teratogens have involved situations where there has been high-level maternal exposure to the agent(s) in question, usually in a medical, occupational or "lifestyle" (smoking, consumption of alcohol) setting. This does not mean that such effects (or other reproductive impairments) do not occur at lower doses or in other contexts. Rather, these have been situations when there has been well-documented exposure to the agents in question and the agents have been potent enough to be detected by epidemiologic methods. For chemicals in the general environment, documentation of such relatively "pure" exposures to putative teratogens is not available. In addition, the timing of exposure may affect the outcome as well. Table IV-30B lists possible effects according to the time of parental exposure.

Because of the difficulties in identifying teratogens by epidemiologic methods, there has been considerable safety testing in animal studies. It cannot be assumed that a positive or negative teratogenic response in animals will produce a similar response in humans. Interspecies variability in physiology, placental structure, gestational sequence, background incidence and susceptibility to chemical substances needs to be taken into account (U.S. Food and Drug Administration, 1980). Nevertheless, many recognized human teratogens have been reported to have similar effects in at least one animal species. Other adverse reproductive outcomes, such as spontaneous abortions and reduced fertility, have also been shown to occur in animal models (Council on Environmental Quality, 1981b). An adverse effect on reproduction in animals may therefore result in a similar effect in humans. However, because of the interspecies differences noted earlier, no single animal study can be said to be predictive of human outcomes. Because of these difficulties in extrapolating from animals to man, no methodology for low-dose risk assessment has been developed. Furthermore, with the exception of genetic damage to the germ cells, most adverse

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Table IV-30B

POTENTIAL CHEMICAL EFFECTS ON REPRODUCTION AND PERINATAL DEVELOPMENT

Before Conception	During Pregnancy	After Birth
Menstrual disorders	Maternal	Abnormal development due to chemicals transmitted in breast milk or brought home on parents' workclothes.
Male potency and libido	Enhanced toxicity	
Reduced fertility	Toxemia	
Sterility	Miscarriage	
Germ cell mutation	Fetal	
	Death	
	Malformation	
	Functional deficit	
	Biochemical change	
	Growth retardation	
	Mutations	
	Cancer	

Source: Adapted from Sullivan and Barlow, 1979.

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reproductive effects are thought to be governed by thresholds, so that very low doses (in the ppb range) would be unlikely to produce birth defects.

iv. Effects on the Nervous System--Chemicals capable of exerting toxic effects on the nervous system are known as neurotoxins. Such substances may affect the central nervous system (CNS), the peripheral nerves, or both. It is common for different regions of the nervous system and different cell types to display selective vulnerability to various neurotoxins. The effect may vary with the dose absorbed--for example, a single exposure to a high concentration of hexane produces giddiness, mild euphoria and narcosis, while repeated exposure to lower levels may produce toxic effects principally on the peripheral nerves (Spencer et al., 1980).

Neurotoxic effects of chemicals are usually characterized by a steep dose-response curve, the boundaries of which do not vary widely among individuals. Therefore persons exposed to low concentrations of neurotoxins are unlikely to develop "idiosyncratic" symptoms characteristic of damage seen at higher doses (Schaumberg et al., 1981). For this reason, where the drinking water concentration of chemical leachates is substantially lower than known neurotoxic levels, it is not anticipated that individuals will develop gross neurologic dysfunction.

However, subclinical disease of the nervous system may result from repeated exposure to low doses of neurotoxins, particularly to those capable of bioaccumulation. As an example of this phenomenon is the effect that chronic low level exposure to lead can have on the mental and behavioral development of children. Also to be considered is the possibility of potentiation of the effect of a subthreshold dose of a neurotoxin. For example, the weakly neurotoxic compound methyl ethyl ketone has been reported to potentiate the neurotoxic effect of n-hexane (Schaumberg et al., 1981). Such potentiating effects are of primary concern in the occupational setting.

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4. Evaluation of Specific Leachates

Summaries of the toxic effects of selected chemical leachates are presented in this section according to the following format:

Exposure
Absorption and Metabolism
Acute Toxicity*
Chronic Toxicity
Effects on Genes and Chromosomes
Cancer
Effects on Reproduction
Evaluation

The concentrations in pipe water listed under "Exposure" are in some cases different from those listed in the prior draft of the public health section because of the more rigorous scrutiny applied to leaching studies since the distribution of the earlier draft. More extensive discussions of the toxicities of these substances can be found in Appendix D. The evaluation for each of the chemicals includes relevant drinking water standards, SNARLs or their equivalents for substances not known to be carcinogens or for certain metals, certain forms of which are carcinogens, and plausible limits for 10^{-5} to 10^{-7} incremental lifetime cancer risks for carcinogens. In each evaluation, there is a judgment as to whether the substance is likely to pose a significant risk to health, given current knowledge. Such assessments are subject to change in response to results of further testing. A summary evaluation for each type of pipe is presented at the end of Chapter IV-B.

*Included only for substances of potential significance in occupational exposures: cyclohexanone, dimethylformamide, lead, methyl ethyl ketone, and tetrahydrofuran.

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5. Substances Associate with CPVC and PVC Pipes

a. Dimethylformamide

Exposure--NIOSH (1980) estimates that 69,000 workers in 25 major industries are exposed annually to dimethylformamide (DMF). OSHA (1981) has set a permissible workplace exposure limit of 10 ppm (8-hour time-weighted average), but workplace concentrations ranging from less than 10 ppm to more than 200 ppm have been reported. The exposures of plumbers to DMF while installing plastic pipe have ranged from "undetectable" to less than 0.5 ppm. Consumers may be exposed to DMF as contained in solvents, degreasers, and adhesives (NIOSH, 1981). In a study of organic solvents, DMF ranked twelfth out of 34 solvents on a consumer exposure index (1979). DMF has been detected in effluent from industrial sources and domestic sewage treatment plants. DMF is a contituent of adhesives for CPVC plastic pipe and has been found to leach into water carried by such pipe. Concentrations reported in Chapter IV-A ranged from "nondetectable" to 7.1 ppm.

Absorption and Metabolism--Dimethylformamide is effectively absorbed by the lungs, skin and gastrointestinal tract. When human subjects were exposed to 8 ppm DMF in air for 6 hours on 5 consecutive days, most of the absorbed dose was eliminated within 24 hours. DMF is metabolized by humans to N-methyl formamide (NMF) and formamide, two suspected teratogens (Maham, 1977; NIOSH, 1981). The presence of NMF in the urine is a sensitive indicator of exposure to DMF, even to concentrations lower than 10 ppm, the OSHA permissible exposure limit (Krivanek et al., 1978; Maxfield et al., 1975). Alcohol consumption can retard metabolism of DMF, and DMF can inhibit alcohol metabolism. Alcohol intolerance (a reaction similar to that induced by the drug "Antabuse") has been noted in workers exposed to DMF (Chivers, 1978). The interaction of DMF and alcohol indicates that they are probably metabolized by the same enzymes.

Acute Toxicity--Dimethylformamide is moderately irritating to the eyes, skin, and respiratory tract. Repeated contact with the liquid may defat the skin and cause dermatitis (Proctor and Hughes, 1978). Exposure to high

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concentrations can produce dizziness and headache (Wink, 1972). DMF is toxic to the liver and highly irritating to the gastrointestinal tract (Massman, 1956). Single doses administered to laboratory rats and hamsters have produced liver damage (Ungar et al., 1976; Mathew et al., 1980) and functional changes in the central nervous system (Weiss and Orzel, 1967).

Chronic Toxicity--Workers exposed to atmospheric concentrations of DMF of 20-35 ppm for 32 weeks complained of nausea, vomiting and abdominal pain; liver enlargement was detected in some cases (Proctor and Hughes, 1978). Several other cases of gastrointestinal disorders due to DMF exposure have been reported. No epidemiologic investigations of DMF-exposed populations have been reported.

DMF has produced liver and kidney damage and changes in cardiac function when administered to laboratory animals via inhalation, skin application, or oral intubation. Dogs, rabbits, guinea pigs, rats, and mice were exposed to 23 ppm DMF for 5 1/2 hours followed by a 1/2 hour exposure to 426 ppm for 58 weekdays. Functional effects on the liver, pancreas, spleen, kidneys, adrenals, and thymus glands of all animals were seen. Degenerative changes in the heart and cardiovascular function were seen in dogs (Clayton et al., 1963).

Effects on Genes and Chromosomes--No effects on genes and chromosomes in humans have been reported. DMF has been studied in several test systems designed to detect damage to genes and chromosomes. No damage was reported in nine out of ten tests. Recently DMF was tested in five additional tests under the National Toxicology Program; results were not available for review as this report was written.

Cancer--There have been no studies of the cancer-causing potential of DMF in humans. One study in rats reported increased incidence of liver tumors, but the study was poorly designed and results were not statistically significant. A 2-year study designed to detect the effect of long-term inhalation of DMF in rats and mice is currently being conducted, but results will not be available for at least a year.

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Many studies with tumor cell cultures have shown an "anticancer" effect; one test showed the ability of DMF to transform normal cells to malignant cells.

Effects on Reproduction--One undocumented report of increased incidence of abortion in Soviet female workers exposed to DMF was reviewed, but no careful investigations of the possible effects of DMF on human reproduction have been conducted.

DMF has been shown to cross the placenta to the fetal blood circulation in rats. DMF is metabolized in humans, rats, and dogs to two compounds that have caused malformations in offspring of female laboratory animals exposed during the gestation period. Results of animal tests are conflicting. In the majority of studies, DMF has not caused gross malformations, but some decrease in implantations, depression of fetal weights, and variations in development have been seen. The available data indicate that DMF does not cause serious birth defects, but most investigations have not been conducted with sufficiently large numbers of animals to permit certain conclusions.

Evaluation--There is no federal drinking water standard applicable to DMF. There are no adequate chronic toxicity data in animals or humans from which a chronic snarl can be calculated (NAS, 1982). In the absence of such data, no recommendation can be made for a concentration of DMF in drinking water that will ensure long-term safety. However, the California Department of Health Services has proposed both long- and short-term maximum acceptable concentrations of DMF in drinking water, derived from the OSHA permissible exposure limit (California Department of Health Services, 1980). The procedure, which is outlined below, results in the derivation of proposed maximum acceptable concentrations (PMACs) based on several absorption estimates and proposed short-term acceptable concentrations (PSTMACs).

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PROCEDURE FOR DERIVING PROPOSED MAXIMUM ACCEPTABLE CONCENTRATONS

1. Current or recommended PEL (TWA) (mg/m^3)

multiplied by

2. Volume of air inhaled by worker per work day (mg/day)

multiplied by

3. Work week (assume 40 hours) or 5 days

multiplied by

4. Retention factor

equals

5. Amount of substance absorbed by worker per week (mg)

This, divided by

6. Weight of worker (assume 70 kg)

equals

7. Dose on body weight basis (mg/kg)

8. Seven day week.

equals

9. Daily dose on body weight basis (mg/kg)

multiplied by

10. Child or newborn body weight

divided by

11. Safety factor (100)

equals

12. Proposed maximum dose for child or newborn (mg)

The dose, divided by

13. Volume of water consumed per day (assume one liter)

equals

14. Proposed maximum acceptable concentration in water (mg/l)

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CALCULATIONS FOR PELs (PMACs) FOR PLASTIC PIPE ADHESIVE SOLVENTS IN TAP WATER

	MEK	THF	CYCLO	DMF
1. OSHA PEL mg/m^3	590	590	200	30
2. x 9.6 m^3/d	566.4	566.4	1920	288
3. x 5 d/w	28320	28320	9600	1440
4. x 0.5 R (Retention)	14160	14160	4800	720
6. . 70 kg	202.3	202.3	68.6	10.3
8. . 7 d/w	28.9	28.9	9.8	1.5
10. x 25 kg	722.4	722.4	244.9	36.7
11. . 100 Safety Factor	7.22	7.22	2.44	0.367
13. . 0.2 L/d	36	36	12	1.8
14. PMAC (R = 0.5) mg/L	36	36	12	1.8
(R = 0.7) mg/L	50	50	17	2.5
(R = 0.3) mg/L	22	22	7	1.1
15. PSTMAC (R = 0.5) mg/L	360	360	120	3.6

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In order to account for potential additive effects, the Department proposed using a formula analogous to the ACGIH (1982) method for calculating workplace threshold limit values (TLVs) for mixed exposures:

$$\frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \frac{C_3}{TLV_3} = 1$$

where C = concentration of the compound in air and TLV = the respective threshold limit value. If the sum is less than or equal to one, the exposure is considered acceptable; if the sum is greater than one, the exposure is considered excessive. The same procedure can be followed substituting concentrations in water and PMACs for airborne concentrations and TLVs.

The procedure developed by the Department of Health Services is one of several semi-quantitative models that could be used to provide a rough estimate of risk in the absence of appropriate data from human or animal studies. The procedure has been followed in this report because it embodies several features that should be included in such a model: an indicator of toxicity (TLV or PEL), absorption estimates (R), a means by which acceptable concentrations of contaminants in water can be calculated for individuals of different weights with different daily water intakes, and a safety factor. The results produced by the model are probably conservative, which is appropriate given the lack of chronic toxicity data.

Using this method, the acceptable limits for DMF can be calculated as described below:

PMAC (R = 0.5) mg/L	1.8
(R = 0.7) mg/L	2.5
(R = 0.3) mg/L	1.1
PSTMAC (R = 0.5) mg/L	3.6,

where R = the portion of the inhaled dose that is absorbed.

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The data on leaching of DMF from plastic piping as presented in Chapter IV-A vary widely with test protocols. The static test with a 2-week dwell period showed a low concentration of DMF, with nondetectable levels in subsequent static tests (see Table IV-6). If these data were used to predict DMF exposure, concentrations in water after adequate flushing would be well below the calculated PMACs and PSTMAc. If, however, values from kinetic tests were used as predictors, concentrations higher than the PMAC and PSTMAC would result and a significant risk to public health might be incurred (see Table IV-9). It is impossible on the basis of the information available to decide which data are more appropriate for purposes of risk estimation. It is hoped that additional testing will resolve the dilemma.

b. Tetrahydrofuran

Exposure--NIOSH (1980) estimates that approximately 95,000 workers are exposed annually to tetrahydrofuran (THF). Both the current OSHA Permissible Exposure Limit and ACGIH Threshold Limit Value are an 8-hour time-weighted average of 200 ppm (OSHA, 1981; ACGIH, 1982). THF has good warning properties; its odor is detectable at 25-50 ppm, well below the recommendations for workplace exposures (du Pont, 1977). Tetrahydrofuran is a constituent of adhesives for use with plastic pipe. Concentrations ranging from trace amounts to 79 ppm were detected in the work environment of plumbers installing plastic pipe (Halts, 1980). Tetrahydrofuran has also been identified as a leachate from CPVC plastic pipe: concentrations reported in Chapter IV-A range from 2.7 ppm to 375 ppm.

Absorption and Metabolism--No information on the metabolism of THF was available. Because the compound is so volatile, most of an inhaled dose would be expected to be eliminated in the expired air.

Acute Toxicity--THF is a mild irritant of the eyes skin and mucus membranes; repeated contact with the skin may cause dermatitis. Exposure to concentrations above 200 ppm may produce nausea, dizziness, and headache but these symptoms are readily reversible in fresh air (AIHI, 1959). Two reports of injuries due to exposure to THF were reviewed but, in both cases,

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individuals had been exposed to other compounds and no causal connections with THF could be established. Gosselin et al. (1976) estimate that the lethal oral dose for humans is 50-500 mg/kg.

In laboratory animals, concentrations above 3,000 ppm produced upper respiratory tract irritation after exposures of 8 hours per day for 20 days. Concentrations of approximately 60,000 ppm were required to induce narcosis (sleep) in cats, rabbits, rats, and mice.

Chronic Toxicity--No chronic toxicity in humans or animals attributable to THF exposure has been reported. Dogs exposed to atmospheric concentrations of 336 ppm or 2,100 ppm for 6 hours per day, 5 days per week over a 12-week period exhibited decreased blood pressure, but no other effects were observed (du Pont, 1977). A prechronic (90-day) test of THF has recently been completed under the NCI/NTP carcinogenesis bioassay program. Results were requested but have not yet been received.

Effects on Genes and Chromosomes--No tests for effects on genes and chromosomes have been reported.

Cancer--No studies of cancer in humans populations exposed to THF have been reported. Although a prechronic test was conducted under the National Toxicology Program bioassay program, no chronic test has been scheduled. The rationale for this decision has not been published, but it is probable that results of the prechronic test did not suggest cancer-causing potential (Juodeika, 1983).

Effects on Reproduction--No effects of THF on human or animal reproduction have been reported.

Evaluation--There is no federal drinking water standard applicable to THF. There are no adequate chronic toxicity data in animals or humans from which a chronic snarl can be calculated (NAS, 1982). In the absence of such data, no recommendation can be made for a concentration of THF in drinking water that will ensure long-term safety. However, the California Department

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of Health Services has proposed both long- and short-term maximum acceptable concentrations of THF in drinking water, derived from OSHA permissible exposure limit (California Department of Health Services, 1980). The procedure which is outlined in the evaluation for DMF, results in the derivation of proposed maximum acceptable concentrations (PMACs) based on several absorption estimates and proposed short-term acceptable concentrations (PSTMACs).

In order to account for potential additive effects, the Department proposed using a formula analogous to the ACGIH (1982) method for calculating workplace threshold limit values (TLVs) for mixed exposures:

$$\frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \frac{C_3}{TLV_3} = 1$$

where C = concentration of the compound in air and TLV = the respective threshold limit value. If the sum is less than or equal to one, the exposure is considered acceptable; if the sum is greater than one, the exposure is considered excessive. The same procedure can be followed substituting concentrations in water and PMACs for airborne concentrations and TLVs.

The procedure developed by the Department of Health Services is one of several semi-quantitative model that could be used to provide a rough estimate of risk in the absence of appropriate data from human or animal studies. The procedure has been followed in this report because it embodies several features that should be included in such a model: an indicator of toxicity (TLV or PEL), absorption estimates (R), a means by which acceptable concentrations of contaminants in water can be calculated for individuals of different weights with different daily water intakes, and a safety factor. The results produced by the model are probably conservative, which is appropriate given the lack of chronic toxicity data.

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Using this method, the acceptable limits for THF can be calculated as described below:

PMAC (R = 0.5) mg/L	36
(R = 0.7) mg/L	50
(R = 0.3) mg/L	22
PSTMAC (R = 0.5) mg/L	360,

where R = the portion of the inhaled dose that is absorbed.

The data on leachability of THF from plastic piping as presented in Chapter IV-A (see Tables IV-6 and IV-9) indicate that all concentrations in water were below the PSTMAC, and only concentrations found in a static test after a 2-week dwell time exceeded any of the PMAC values. These results suggest that adequate flushing procedures prior to use would reduce THF concentrations in water from plastic plumbing pipe to levels that would probably not pose a significant risk to public health. Preliminary calculations using the leaching data in Chapter IV-A also suggest that excessive mixed exposures to the three solvents with similar biologic effects (MEK, THF, and cyclohexanone) would be improbable if adequate flushing were performed.

c. Cyclohexanone

Exposure--NIOSH (1980) estimates that approximately 10,000 workers are exposed annually to cyclohexanone. The current ACGIH-recommended workplace TLV is an 8-hour time-weighted average exposure of 25 ppm; the OSHA permissible exposure limit is an 8-hour time-weighted average concentration of 50 ppm. No cyclohexanone was detected in breathing-zone samples of plumbers installing plastic pipe (California Department of Health Services, 1980). Cyclohexanone is a component of cements for CPVC plastic pipe and leaches into the water carried through these systems. Concentrations reported in Chapter IV-A range from 0.2 ppm to 13.0 ppm.

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Absorption and Metabolism--Inhaled cyclohexanone may be excreted unchanged in the expired breath or reduced to cyclohexanol and glucuronidated in the liver. Cyclohexanol glucuronide is excreted in the urine; other metabolites may be eliminated in the feces (Greener et al., 1982).

Acute Toxicity--Cyclohexanone is considered to be moderately toxic by dermal, oral, and inhalation exposure. It has mild narcotic properties (Sax, 1979). At atmospheric concentrations equal to and greater than 75 ppm, it is irritating to the eyes and respiratory tract. Repeated skin contact may cause contact dermatitis, but absorption through the skin is not significant (Proctor and Hughes, 1978). Gupta et al. (1979) performed a series of acute toxicity tests with mice, rats, and guinea pigs. Dying animals exhibited signs of irritation of the intestines and other internal organs. Repeated doses produced cumulative effects in mice as indicated by a reduction in the dose required to cause death. The lowest median lethal oral dose of cyclohexanone reported for rats is 1,620 mg/kg; the lowest concentration reported to be lethal to rats is 2,000 ppm/4 hours (NIOSH, 1981).

Chronic Toxicity--No effects in humans or animals due to long-term exposure to cyclohexanone have been reported.

Effects on Genes and Chromosomes--No effects on genes and chromosomes were seen in five tests sponsored by the National Institute for Occupational Safety and Health (McGregor, 1980). One investigator reported positive (mutagenic) results in two tests in bacteria, but details of the assays were not provided.

Cancer--No studies of the cancer-causing potential of cyclohexanone in humans or laboratory animals have been completed. Cyclohexanone is currently being tested in a carcinogenesis bioassy under the direction of the National Toxicology Program. No results were available at the time of this writing.

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Effects on Reproduction--No data on the effects of cyclohexanone on reproduction have been reported.

Evaluation--There is no federal drinking water standard applicable to cyclohexanone. There are no adequate chronic toxicity data in animals or humans from which a chronic snarl can be calculated (NAS, 1982). In the absence of such data, no recommendation can be made for a concentration of cyclohexanone in drinking water that will ensure long-term safety. However, the California Department of Health Services has proposed both long- and short-term maximum acceptable concentrations of cyclohexanone in drinking water, derived from OSHA permissible exposure limit (California Department of Health Services, 1980). The procedure which is outlined in the evaluation for DMF, results in the derivation of proposed maximum acceptable concentrations (PMACs) based on several absorption estimates and proposed short-term acceptable concentrations (PSTMACs).

In order to account for potential additive effects, the Department proposed using a formula analogous to the ACGIH (1982) method for calculating workplace threshold limit values (TLVs) for mixed exposures:

$$\frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \frac{C_3}{TLV_3} = 1$$

where C = concentration of the compound in air and TLV = the respective threshold limit value. If the sum is less than or equal to one, the exposure is considered acceptable; if the sum is greater than one, the exposure is considered excessive. The same procedure can be followed substituting concentrations in water and PMACs for airborne concentrations and TLVs.

The procedure developed by the Department of Health Services is one of several semi-quantitative model that could be used to provide a rough estimate of risk in the absence of appropriate data from human or animal studies. The procedure has been followed in this report because it embodies several features that should be included in such a model: an indicator of

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toxicity (TLV or PEL), absorption estimates (R), a means by which acceptable concentrations of contaminants in water can be calculated for individuals of different weights with different daily water intakes, and a safety factor. The results produced by the model are probably conservative, which is appropriate given the lack of chronic toxicity data.

Using this method, the acceptable limits for cyclohexanone can be calculated to yield the following results:

PMAC (R = 0.5) mg/L	12
(R = 0.7) mg/L	17
(R = 0.3) mg/L	7
PSTMAC (R = 0.5) mg/L	120,

where R = the portion of the inhaled dose that is absorbed.

In the case of cyclohexanone, SRI has chosen to calculate PMACs and PSTMACs using the ACGIH TLV. This value is one-half the OSHA PEL and reflects current thought regarding the toxicity of the compound. Using the TLV of 25 ppm (100 mg/m^3) rather than the OSHA PEL of 50 ppm (500 mg/m^3) the values derived are as follows:

PMAC (R = 0.5) mg/L	6.0
(R = 0.7) mg/L	8.5
(R = 0.3) mg/L	3.5
PSTMAC (R = 0.5) mg/L	60.0

Using these more conservative values and examining the data on leachability of cyclohexanone presented in Chapter IV-A (see Tables IV-6 and IV-9), one still finds that no concentrations in water exceeded the PSTMAC and only concentrations found in a static test after a 2-week dwell time exceeded the lowest PMAC (3.5 mg/L).

The data on leachability of cyclohexanone from plastic pipe in Chapter IV-A indicate that all concentrations in water found after static or kinetic

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tests were below the PMACs and PSTMAC as calculated above. Adequate flushing procedures prior to use should thus reduce cyclohexanone concentrations in water from plastic pipe systems to levels that would not pose a significant risk to public health. Preliminary calculations using the leaching data in Chapter IV-A also suggest that excessive mixed exposures to the three solvents with similar biologic effects (MEK, THF, and cyclohexanone) would be improbable if adequate flushing were performed.

d. Methyl Ethyl Ketone

Exposure--NIOSH (1980) estimates that approximately 2.5 million U.S. workers are exposed annually to methyl ethyl ketone (MEK). The current ACGIH TLV and OSHA PEL are set at 200 ppm (8-hour time-weighted average) to prevent irritation (OSHA, 1981; ACGIH, 1982). The compound has good warning properties; its odor can be detected at 25 ppm, well below the maximum recommended workplace concentrations. MEK is a constituent of adhesives for plastic piping and has been detected in the air at plumbing installations in concentrations ranging from trace amounts to 34 ppm (California Department of Health Services, 1980). MEK leaches from CPVC plastic plumbing pipe: concentrations reported in Chapter IV-A range from 0.2 to 115 ppm.

Absorption and Metabolism--MEK is effectively absorbed by any route of administration and is readily eliminated unchanged in the breath, or in the urine in unchanged or metabolized form (Tado et al., 1972). Urinary metabolites are 2-butanol, 2-butanol glucuronide, 3-hydroxy-2-butanone, and 2,3-butanediol (Di Vincenzo et al., 1976). MEK may affect the metabolism of other compounds by stimulating the activity of liver enzymes (Traiger et al., 1975).

Acute Toxicity--MEK is slightly irritating to the nose and throat at concentrations of 100 ppm. Short-term exposure to 300 ppm was described as objectionable, and mild headache and throat irritation occurred. In sufficiently high concentrations, MEK can cause central nervous system depression and narcosis; in guinea pigs, inhalation of 10,000 ppm for 5 hours was required to cause narcosis (Proctor and Hughes, 1978).

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Chronic Toxicity--The most significant chronic effect of MEK is the potentiation of the neurological effects of other solvents. MEK can increase the damage to peripheral nerves caused by methyl butyl ketone and n-hexane. Animals exposed to methyl ethyl ketone only have shown no signs of neurologic injury. Sprague-Dawley rats exposed by inhalation of 800 ppm MEK for 6 hours per day, 5 days per week for 4 weeks had increased liver weights, indicating possible liver damage. No significant toxic effects were seen in Fischer-344 rats exposed to 1,250, 2,500, or 5,000 ppm MEK for 5 days per week over a 90-day period (CIIT, 1981).

Effects on Genes and Chromosomes--No studies of the effects of MEK on genes or chromosomes were reported.

Cancer--No carcinogenesis bioassays of MEK have been reported. The Chemical Industry Institute of Toxicology (1981) had planned liftime inhalation bioassays in rats and mice but cancelled plans when results of a 90-day study showed no significant toxic effects.

Effects on Reproduction--In two studies conducted in pregnant rats, no statistically significant increase in major malformations was seen in offspring. No effect on the number of implantations or early embryonic deaths was seen. At the 3,000 ppm exposure level, there was a significant increase in the number of offspring with skeletal variations and delayed ossification of the skull. These two phenomena occur spontaneously in control groups. They are not considered true teratogenic effects, but increases in occurrence may reflect toxicity of the compound.

Evaluation--There is no federal drinking water standard applicable to MEK. EPA has calculated 1-day and 10-day SNARLs for MEK of 7.5 mg/L and 0.75 mg/L, respectively. There are no adequate chronic toxicity data in animals or humans from which a chronic snarl can be calculated (NAS, 1982). In the absence of such data, no recommendation can be made for a concentration of MEK in drinking water that will ensure long-term safety. However, the California Department of Health Services has proposed both long- and short-term maximum acceptable concentrations of MEK in drinking

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water, derived from OSHA permissible exposure limit (California Department of Health Services, 1980). The procedure which is outlined in the evaluation for DMF, results in the derivation of proposed maximum acceptable concentrations (PMACs) based on several absorption estimates and proposed short-term acceptable concentrations (PSTMACs).

In order to account for potential additive effects, the Department proposed using a formula analogous to the ACGIH (1982) method for calculating workplace threshold limit values (TLVs) for mixed exposures:

$$\frac{C_1}{TLV_1} + \frac{C_2}{TLV_2} + \frac{C_3}{TLV_3} = 1$$

where C = concentration of the compound in air and TLV = the respective threshold limit value. If the sum is less than or equal to one, the exposure is considered acceptable; if the sum is greater than one, the exposure is considered excessive. The same procedure can be followed substituting concentrations in water and PMACs for airborne concentrations and TLVs.

The procedure developed by the Department of Health Services is one of several semi-quantitative model that could be used to provide a rough estimate of risk in the absence of appropriate data from human or animal studies. The procedure has been followed in this report because it embodies several features that should be included in such a model: an indicator of toxicity (TLV or PEL), absorption estimates (R), a means by which acceptable concentrations of contaminants in water can be calculated for individuals of different weights with different daily water intakes, and a safety factor. The results produced by the model are probably conservative, which is appropriate given the lack of chronic toxicity data.

Using this method, the acceptable limits for MEK can be calculated as described in the evaluation for DMF. The final values derived are as follows:

PMAC (R = 0.5) mg/L	36
(R = 0.7) mg/L	50
(R = 0.3) mg/L	22
PSTMAC (R = 0.5) mg/L	360,

where R = the portion of the inhaled dose that is absorbed.

The data on leachability of MEK from CPVC pipe presented in Chapter IV-A (see Tables IV-6 and IV-9) indicate that all concentrations in water were below the PSTMAC, and only the concentrations found in a static test after a 2-week dwell time exceeded any of the PMAC values. These results suggest that adequate flushing procedures prior to use would reduce MEK concentrations in water from plastic pipe to levels that would probably not pose a significant risk to public health. Preliminary calculations using the leaching data in Chapter IV-A also suggest that excessive mixed exposures to the three solvents with similar biologic effects (MEK, THF, and cyclohexanone) would be improbable if adequate flushing were performed.

e. Carbon Tetrachloride

Exposure--In Chapter IV-A, carbon tetrachloride was reported to have consistently been detected in CPVC and PVC pipe within a concentration range of nondetectible to 10 ppb. This chemical has been found in many raw water and finished water sources throughout the United States in concentrations of up to 5 ppb (IARC, 1979; NAS, 1977). It is not usually found in surface waters in California, and is infrequently detected in groundwater sources (Spath, 1983).

Absorption and Metabolism--Carbon tetrachloride is rapidly absorbed from the gastrointestinal tract, the lungs, or through injured skin, and is distributed to the liver, fatty tissues, brain, kidney, blood, and bone marrow. Absorption from the GI tract is augmented by the presence of fats and alcohol. Carbon tetrachloride is excreted principally through the lungs unchanged (about 85 percent of absorbed dose) and as carbon dioxide (10 percent) and other metabolites, which (in rabbits) include chloroform and

hexachloroethane (NAS, 1977). Highly reactive free-radical intermediates are thought to be responsible for carbon tetrachloride's toxicity. Such reactive metabolites can bind irreversibly, primarily to proteins and lipids in the liver, and may do the same in other tissues (IARC, 1979).

Chronic Toxicity--Chronic exposures to carbon tetrachloride causes liver and kidney damage in humans and animals. Symptoms in humans include nausea, vomiting, headache, drowsiness, and fatigue (NAS, 1977).

Effects on Genes and Chromosomes--Carbon tetrachloride was reportedly negative for mutagenic activity in several bacterial assays (IARC, 1979, 1982b; NAS, 1980). It is possible that the negative results may be due to inadequate experimental protocols. One report cited by IARC (1979) indicated that carbon tetrachloride could react with DNA of rodent cells under certain conditions (Rocchi et al., 1973). The International Agency for Research on Cancer considers that there is inadequate evidence of carbon tetrachloride's activity in short-term assays (1982b).

Cancer--In 1979 the International Agency for Research on Cancer reviewed the 11 bioassays involving oral, inhalational, intratracheal, subcutaneous, and intrarectal administration of carbon tetrachloride in several species (rats, mice, hamsters, trout). It was found to be carcinogenic to rats and mice, producing liver tumors in several strains of both species. In one experiment involving subcutaneous injection of carbon tetrachloride to rats, it produced mammary tumors (IARC, 1979).

There is no conclusive epidemiological evidence of cancer in humans exposed to carbon tetrachloride. However, there are several reports of liver cancer following carbon tetrachloride poisoning, and of an increased incidence of several type of malignancy at different sites in persons occupationally exposed to carbon tetrachloride (IARC, 1979, 1982b).

Effects on Reproduction--Carbon tetrachloride has been shown to be fetotoxic and fetolethal, but probably not teratogenic in rats and mice.

003001

Evaluation--The health effect of primary concern for carbon tetrachloride is cancer. There are no MCLs for carbon tetrachloride, although the EPA has recently listed a potential range of recommended MCLs for carbon tetrachloride of 5 to 500 ppb (47 Fed. Reg. 9357, March 4, 1982). This range is not based on potential cancer risk estimates presented for the water quality criteria for carbon tetrachloride (45 Fed. Reg. 79327, November 28, 1980). The upper limit cancer risk estimates (based on consumption of 2 liters of water per day and consumption of 6.5 grams fish and shellfish) are as follows:

Criteria (ppb)	Risk Level
4.0	10^{-5}
0.40	10^{-6}
0.04	10^{-7}

Subtracting the exposure attributable to fish consumption (approximately 6 percent), these values become:

Criteria (µg/liter)	Risk Level
4.3	10^{-5}
0.43	10^{-6}
0.043	10^{-7}

According to the analysis of leaching data in Chapter IV-A, carbon tetrachloride was found at concentrations in the range of approximately 1 to 10 ppb. Since the multistage model is linear at low doses, lifetime risks corresponding to consumption of water containing these concentrations can be calculated:

Concentration (ppb)	Lifetime Risk
1	2.4×10^{-6}
10	2.4×10^{-5}

These lifetime risks are based on a daily exposure to these concentrations for 70 years.

003002

For a shorter exposure period, the risks may decrease proportionately. If, for example, all the carbon tetrachloride in the pipes were to leach out at either of these concentrations in one year, the above risks are divided by 70:*

Concentration (ppb)	Risk for 1-Year Exposure
1	3.4×10^{-8}
10	3.4×10^{-7}

If an individual move into five new homes plumbed with CPVC pipe during his or her liftime, these would change to the following:

Concentration (ppb)	Risk Level
1	1.7×10^{-7}
10	1.7×10^{-6}

An alternative way to look at potential risks is to assume that the residual concentration of carbon tetrachloride in CPVC pipe leaches in its entirety into drinking water. Such risk calculations were made using the following assumptions:

Residual concentration in CPVC pipe = 50 ppm
Quantity of pipe = 20 lb
Quantity of water used per person from faucets = 20 gal/day (not necessarily for drinking)
Number of persons per family (national average) = 2 3/4

$$\frac{50 \text{ ppm} \times 20 \text{ lb} \times 454 \text{ g/lb}}{20 \text{ gal/person/day} \times 2\ 3/4 \text{ persons} \times 365 \text{ days} \times 3.78 \text{ liters/gal}} =$$

0.45 gm/76,000 liters = 5.9 ppb, if leaching occurs over one year.

*This procedure is obviously arbitrary, but is the one most commonly used for regulatory purposes (Thorslund, 1983).

003003

If the exposure occurs over one year, the risk estimate is approximately 2.0×10^{-7}. The result is the same if one assumes a 20 year leaching period and 20 years of exposure. Assuming that an individual may move into five new houses during his or her lifetime, the risk estimate becomes approximately 1×10^{-6}. Under the above assumptions, the plausible risk limit from exposure to carbon tetrachloride alone from CPVC pipe is at the commonly accepted threshold of regulatory significance.

f. Perchloroethylene

Exposure--NIOSH (1980) estimates that 1.6 million workers are exposed annually to perchloroethylene ("PERC," tetrachloroethylene). The OSHA Permissible Exposure Limit (PEL) for PERC is 100 ppm (8-hour time-weighted average concentration); the ACGIH recommends a workplace TLV (8-hour time-weighted average concentration) of 50 ppm (OSHA, 1981; ACGIH, 1982). Perchloroethylene may be formed in water as a result of chlorination. It has been detected in numerous domestic water supplies and industrial effluent (IARC, 1979). Perchloroethylene has been identified as a leachate in CPVC plastic plumbing pipe; concentrations reported in Chapter IV-A range from 1 to 10 ppb.

Absorption and Metabolism--Perchloroethylene is absorbed through the lungs, skin, and gastrointestinal (GI) tract; the presence of fats enhances GI absorption. Most of an inhaled dose of radiolabelled perchloroethylene is eliminated unchanged or as CO_2 in the expired breath. The remainder is metabolized slowly; elimination may require more than 7 days. The major urinary metabolite is trichloroacetic acid (Monster et al., 1979). Ethylene oxide, a suspected carcinogen, may be a metabolic intermediate (Henschler and Bonse, 1977).

Chronic Toxicity--Chronic exposure to perchloroethylene has caused impaired memory and other symptoms of central nervous system damage, abdominal pain, and damage to the peripheral nerves (IARC, 1979). Repeated exposure to PERC by inhalation has produced liver damage in rats, rabbits,

003004

and guinea pigs (Proctor and Hughes, 1978). Oral doses have produced liver and kidney damage in dogs and mice (Klaasen and Plaa, 1966, 1967).

Effects on Genes and Chromosomes--Conflicting results have been obtained in tests designed to detect damage to genes and chromosomes. IARC (1982b) considers that there is inadequate evidence of the genotoxic activity of perchloroethylene in short-term tests. PERC may be a very weak mutagen.

Cancer--Two epidemiologic investigations of dry cleaners occupationally exposed to PERC have been conducted. Both studies found excess deaths from various cancers in the exposed populations, but problems involving possible mixed exposures and incomplete follow-up present problems in interpretation of results. IARC (1982b) considers results to be inconclusive.

Perchloroethylene has been tested in three animal studies for carcinogenic potential. Sprague-Dawley rats exposed for 12 months by inhalation to 300 or 600 ppm perchloroethylene in air showed no increased tumor incidence over treated controls. Negative results were also obtained in a skin-painting study with mice (Van Duuren et al., 1979). In an NCI bioassay in which perchloroethylene was administered by gavage no increased tumor incidence was observed in rats, but hepatocellular carcinoma incidence was significantly increased in mice (NCI, 1977). IARC (1979) considers that the NCI bioassay results provide "limited evidence" of the carcinogenicity of perchloroethylene.

Effects on Reproduction--No teratogenic effects in offspring or other adverse reproductive outcomes were seen when pregnant rats and mice were exposed to perchloroethylene on Days 6-15 of gestation. Offspring of female rats exposed to 100 ppm or 900 ppm perchloroethylene during the gestation period were examined in a series of behavioral tests. No significant differences were noted between offspring of animals in the 100 ppm group and unexposed controls. Behavior of offspring from the 900 ppm group varied from controls but not in a consistent treatment-related manner. In a third experiment, female rats were exposed by inhalation to 1,000 ppm

003005

perchloroethylene throughout pregnancy. Maternal liver weights were increased, fetal body weights were decreased, and there were variations in soft and skeletal tissues, all indicating toxicity, but not teratogenic effects.

Evaluation--The health effect of primary concern for perchloroethylene is cancer. The State Department of Health Services maintains an action level for this chemical of 4 ppb. There are no MCLs for perchloroethylene, although the EPA has recently listed a potential range of recommended MCLs of 5 to 500 ppb (47 Fed. Reg. 9357, March 4, 1982). This range is not based on potential cancer risk estimates presented for the water quality criteria for perchloroethylene (45 Fed. Reg. 79340, November 28, 1980). The upper limit cancer risk estimates (based on consumption of 2 liters of water per day and consumption of 6.5 grams of fish and shellfish) are as follows:

Criteria (ppb)	Risk Level
8.0	10^{-5}
0.80	10^{-6}
0.08	10^{-7}

Subtracting the exposure attributable to fish and shellfish consumption (approximately 9 percent), these values become:

Criteria (ppb)	Risk Level
8.8	10^{-5}
0.88	10^{-6}
0.09	10^{-7}

According to the analysis of the leaching data in Chapter IV-A, perchloroethylene was found at concentrations ranging from approximately 1 to 10 ppb. Since the multistage model is linear at low doses, lifetime

003006

risks corresponding to consumption of water containing concentrations can be calculated:

Concentration (ppb)	Lifetime Risk
1	1.1×10^{-6}
10	1.1×10^{-5}

These lifetime risks are based on a daily exposure to these concentrations for 70 years. For a shorter exposure period, the risks may decrease proportionately. If, for example, all the perchloroethylene in the pipes were to leach out at either of these concentrations in one year, the above risks can be divided by 70:*

Concentration (ppb)	Risk for 1-Year Exposure
1	1.6×10^{-8}
10	1.6×10^{-7}.

If an individual moves into five new homes plumbed with CPVC pipe during his or her lifetime, these would change to the following:

Concentration (ppb)	Risk Level
1	8×10^{-8}
10	8×10^{-7}.

An alternative way to look at potential risks is to assume that the residual concentration of perchloride in CPVC pipe leaches in its entirety into drinking water. Such risk calculations were made using the following assumptions:

*This procedure is obviously arbitrary, but is the one most commonly used for regulatory purposes (Thorslund, 1983).

003007

Residual concentration in CPVC pipe = 50 ppm
Quantity of pipe = 20 lb
Quantity of water used per person from faucets = 20 gal/day (not necessarily for drinking)
Number of persons per family (national average) = 2 3/4

$$\frac{50 \text{ ppm} \times 20 \text{ lb} \times 454 \text{ g/lb}}{20 \text{ gal/person/day} \times 2\ 3/4 \text{ persons} \times 365 \text{ days} \times 3.78 \text{ liters/gal}} =$$

0.45 gm/76,000 liters = 5.9 ppb if leaching occurs over one year.

If the exposure occurs over one year, the risk estimate is approximately 9.6×10^{-8}. The result is the same if one assumes a 20-year leaching period and 20 years of exposure. Assuming that an individual may move into five new houses during his or her lifetime, the risk estimate becomes approximately 4.8×10^{-7}. Under the above assumptions, the plausible risk limit from exposure to perchloroethylene alone from CPVC pipe is somewhat lower than the commonly accepted threshold of regulatory significance.

g. Trichloroethylene

Exposure--NIOSH (1980) estimates that approximately 2.8 million workers are exposed annually to trichloroethylene. OSHA has set a permissible workplace exposure limit of 100 ppm (8-hour time-weighted average concentration); the ACGIH recommends a TLV of 50 ppm (8-hour time-weighted average) (OSHA, 1981; ACGIH, 1982). Trichloroethylene has been detected in finished drinking water supplies in concentrations of 0 to 0.5 ppb and in tap, lake, spring, and subterranean waters at 80 to 105 nanograms per liter (IARC, 1979). Trichloroethylene has been detected as a leachate from CPVC plastic pipe: concentrations reported in Chapter IV-A range from 1 to 10 ppb.

Absorption and Metabolism--Trichloroethylene is rapidly absorbed by the lungs; about 45 percent of an inhaled dose is excreted unchanged in the

003008

expired breath (IARC, 1979). The portion that is not exhaled is metabolized by the liver to trichloroethanol, trichloroacetic acid, trichloroethanol glucuronide, and chloral hydrate (Monster et al., 1976; Muller et al., 1974; Cole et al., 1975). Alcohol intolerance, a reaction similar to that seen in persons taking Antabuse, has been seen in exposed workers (Proctor and Hughes, 1977). This reaction suggests that trichloroethylene and alcohol are metabolized by the same enzymes. Several investigators have suggested that a reactive epoxide is formed when trichloroethylene is metabolized and that this epoxide, rather than the parent compound or other metabolites, is a carcinogen (Van Duuren and Banerjee, 1976; Henschler and Bonse, 1978).

Chronic Toxicity--Chronic exposure to trichloroethylene produces damage to the central nervous system and the liver. Double vision, changes in color perception, and loss of coordination and sense of smell have been reported. Trichloroethylene can penetrate the skin; repeated contact can cause dermatitis. Repeated immersion of the hands in the liquid reportedly caused paralysis of the fingers (Proctor and Hughes, 1978).

Effects on Genes and Chromosomes--Results of tests for mutagenicity and chromosomal aberrations are conflicting. However, positive results were seen in a sufficiently large number of tests to suggest that trichloroethylene is at least a weak mutagen that can adversely affect genes and chromosomes.

Cancer--Four epidemiological studies have failed to show an association between exposure to trichloroethylene and increased numbers of deaths from cancer. However, in at least two studies, sample sizes were too small and follow-up periods too short for result to be considered conclusive. The International Agency for Research on Cancer considers that the evidence for the carcinogenicity of trichloroethylene is limited (IARC, 1982b).

Three long-term studies of the cancer-causing potential of trichloroethylene have been performed with laboratory animals. In an inhalation study in which rats, mice, and hamsters were exposed to 0, 100, or 500 ppm trichloroethylene in air, a twofold increase in malignant

lymphomas was seen in the two dosed groups (Henschler et al., 1980). In an NCI bioassay, a significant increase in hepatocellular carcinoma incidence was seen in male and female mice, but not in rats administered high doses (549-2,339 mg/kg) by gastric intubation. Because the trichloroethylene used in the original bioassay was contaminated with epichlorohydrin (a carcinogen), a second bioassay using highly purified trichloroethylene was undertaken in 1980. Results reportedly corroborate the findings of the first bioassay (Juodeika, 1983).

Effects on Reproduction--Three tests of the effects of trichloroethylene on reproduction have been reported. No gross malformations were seen in the offspring of pregnant rats or mice exposed by inhalation during the organ-forming period of gestation. In one group of rabbits, an excess of hydrocephalus occurred (Beliles, 1982). No significant maternal toxicity, embryotoxicity, or postnatal effects were seen in female rats or offspring exposed during gestation to 1,800 ppm trichloroethylene (Dorfmueller et al., 1979).

Evaluation--The health effect of primary concern for trichloroethylene is cancer. The State Department of Health Services' action level for this chemical is 5 ppb. There are no MCLs for trichloroethylene, although the EPA has recently listed a potential range of recommended MCLs for trichloroethylene of 5 to 500 ppb (47 Fed. Reg. 9357, March 4, 1982). This range is not based on potential cancer risk estimates presented for the water quality criteria for trichloroethylene (45 Fed. Reg. 79341, November 28, 1980). The upper limit cancer risk estimates (based on consumption of 2 liters of water per day and consumption of 6.5 grams of fish and shellfish) are as follows:

Criteria (ppb)	Risk Level
27	10^{-5}
2.7	10^{-6}
0.27	10^{-7}

003010

Subtracting the exposure attributable to fish and shellfish consumption (approximately 6 percent), these values become:

Criteria (ppb)	Risk Level
27.8	10^{-5}
2.8	10^{-6}
0.28	10^{-7}

According to the analysis of leaching data in Chapter IV-A, trichloroethylene was found at concentrations in the range of approximately 1 to 10 ppb. Since the multistage model is linear at low doses, lifetime risks corresponding to consumption of water containing these concentrations can be easily calculated:

Concentration (ppb)	Lifetime Risk
1	3.6×10^{-7}
10	3.6×10^{-6}.

These lifetime risks are based on a daily exposure to these concentrations for 70 years. For a shorter exposure period, the risks may decrease proportionately. If, for example, all the trichloroethylene in the pipes were to leach out at either of these concentrations in one year, the above risks are divided by 70:*

Concentration (ppb)	Risk for 1-Year Exposure
1	5.1×10^{-9}
10	5.1×10^{-8}

*This procedure is obviously arbitrary, but is the one most commonly used for regulatory purposes (Thorslund, 1983).

003011

If an individual moves into five new homes plumbed with CPVC pipe during his or her lifetime, these would change to the following:

Concentration (ppb)	Risk Level
1	2.5×10^{-8}
10	2.5×10^{-7}.

An alternative way to look at potential risks is to assume that the residual concentration of trichloroethylene in CPVC pipe leaches in its entirety into drinking water. Such risk calculations were made using the following assumptions:

Residual concentration in CPVC pipe = 50 ppm
Quantity of pipe = 20 lb
Quantity of water used per person from faucets = 20 gal/day (not necessarily for drinking)
Number of persons per family (national average) = 2 3/4

$$\frac{50 \text{ ppm} \times 20 \text{ lb} \times 454 \text{ g/lb}}{20 \text{ gal/person/day} \times 2\ 3/4 \text{ persons} \times 365 \text{ days} \times 3.78 \text{ liters/gal}} =$$

0.45 gm/76,000 liters = 5.9 ppb if leaching occurs over one year.

If the exposure occurs over one year, the risk is approximately 3.0×10^{-8}. The result is the same if one assumes a 20-year leaching period and 20 years of exposure. Assuming that an individual may move into five new houses during his or her lifetime, the risk estimate becomes approximately 1.5×10^{-7}. Under the above assumptions, the plausible risk limit from exposure to trichloroethylene alone from CPVC pipe is below the commonly accepted threshold of regulatory significance.

h. Dichloromethane

Exposure--NIOSH (1980) estimates that approximately 2 million persons per year are occupationally exposed to dichloromethane (DCM). OSHA (1981)

003012

has set a Permissible Exposure Limit (PEL) of 500 ppm; the ACGIH TLV is 100 ppm (ACGIH, 1982).

Dichloromethane is formed during the chlorination of water. It has been found in 1 percent of raw and 8 percent of finished water supplies tested; the mean concentration in several samples of finished water was 1 mg/liter. Dichloromethane was found in 9 of 10 domestic water supplies at a mean concentration of 1.6 mg/liter (IARC, 1979). DCM is approved for use by the FDA in food-contact materials and is also permitted as a residue in coffee, hops, and various spices (USFDA, 1977). DCM has been identified as a leachate from CPVC plastic plumbing pipe; concentrations reported in Chapter IV-A range from "nondetectable" to 10 ppb.

Absorption and Metabolism--Dichloromethane is absorbed by the lungs, skin, and gastrointestinal tract. Both degree of absorption and metabolic pathway appear to vary with the magnitude of the dose. The major metabolites of dichloromethane are formaldehyde and carbon monoxide.

Chronic Toxicity--Long-term exposure to dichloromethane has caused damage to the liver, heart, and central nervous system. Two epidemiologic investigations found no increased deaths from cancer, heart disease, or any other cause. Liver damage has been seen in mice after a single lethal dose and after chronic inhalation of 5,000 ppm dichloromethane (IARC, 1979).

Effects on Genes and Chromosomes--Conflicting results have been obtained in several tests designed to detect adverse effects on genes and chromosomes. Dichlormethane was mutagenic in the bacterial test most commonly used as a screen to predict carcinogenicity (Simmon et al., 1977).

Cancer--Dichloromethane has been tested in three assays designed to detect cancer-causing potential. In the first study, an increase in tumors in male mice occurred but was not statistically significant. In the second study, rats and hamsters were exposed to dichloromethane by inhalation for 2 years. A significant increase in benign tumors in female rats and high-dose male rats was seen; lymphosarcomas were increased in female hamsters.

003013

Dichloromethane is currently being tested in an NTP-sponsored 2-year inhalation study; results will not be available for at least 1 year. In an NTP bioassay recently completed, the compound produced significant increases of liver cancers in mice; a decision whether to regard neoplastic nodules in rats as indicative of carcinogenic potential is pending.

Effects on Reproduction--Three studies of the effects of dichloromethane on reproduction in mice and rats have been reported; no effects on litter size, resorptions, or fetal development were seen.

Evaluation

The health effect of greatest potential significance is the recent finding of carcinogenicity. In the NTP bioassay, there were reportedly significant increases in hepatocellular carcinomas in mice of both sexes and neoplastic liver nodules in both male and female rats. Dichloromethane should be regarded as a potential carcinogen on the basis of this bioassay. However, the results of the bioassay were not received in sufficient time to permit a quantitative estimate of potential risks to humans.

j. Organic Tin Compounds

Exposure--Organic tin compounds are used as stabilizers in PVC and CPVC pipe. The specific compounds reportedly used as stabilizers include dimethyl and dibutyl tin bis isooctylthioglycolates. Both dimethyl and dibutyl tin were found in standing water samples from CPVC pipe as indicated in Table IV-15. Apparent contaminants of butyl tin and trimethyl tin were also found in quantities below one part per billion. All these substances were analyzed as chloride, rather than isooctylthioglycolate, derivatives. With the exception of dibutyl tin dichloride, the organotin compounds were no longer detectable after 14 days (sensitivity of analysis was 0.01 ppb).

Absorption and Metabolism--Dialkyl and trialkyl tins may be absorbed from the gastrointestinal tract, although the fraction absorbed differs among species. Most organotin compounds are poorly absorbed from the GI

003014

tract, except trimethyl-, triethyl-, and dimethyl tin (Kimbrough, 1976). Alkyl tin compounds are distributed to the liver and, in the case of trialkyl tins, to the central nervous sytem. After injection in animals, dibutyl tin concentrates in the liver, with smaller amounts in the kidney. Dibutyl tin is excreted unchanged in the bile (Barnes and Stoner, 1959).

Chronic Toxicity--There are few published data on chronic toxicity of organic tin compounds. Two studies by Seinen et al., (1977a,b) on weanling rodents indicate that dibutyl tin dichloride (but not dimethyl tin dichloride) can reversibly cause atrophy of the thymus and other immune system tissues at concentrations as low as 20 ppm in the diet for 2 weeks.

Effects on Genes and Chromosomes--Dibutyl tin dichloride was positive in one mammalian cell test for mutagens, but negative in a bacterial assay (Li et al., 1982). No information was available for dimethyl tin.

Cancer--Dibutyl tin diacetate caused a dose-related trend in the incidence of liver tumors in mice, but there was no significant increase in tumors in rats or mice in a NTP bioassay (NTP, 1979).

Dimethyl tin bis isooctylthioglycolate (75 percent) and monomethyl tin (25 percent) were tested for chronic toxicity in a protocol inadequate for carcinogenicity testing (Mosinger, undated). No tumors were reported in test animals. This evidence is inadequate to assess the carcinogenicity of dimethyl tin bis isooctylthioglycolate.

Effects on Reproduction--No information was available for dibutyl tin bis isooctylthioglycolate.

Dimethyl tin bis isooctylthioglycolate--one inadequate study was submitted in the record (Mosinger, undated). This study was negative for teratogenesis, but only 1 male and 5 female animals were treated.

Evaluation--There is no drinking water standard for organic tin compounds. There are no adequate data from which to calculate a chronic

003015

SNARL. However, in view of the leaching data reviewed in Chapter IV-A, these substances are unlikely to pose a significant risk to health. Trimethyl tin, clearly the most toxic of these compounds, was not detectable at 0.01 ppb sensitivity after 3 days and 2 flushes of the pipe. Butyl tin, probably the least toxic, was present initially at 0.63 ppb, which declined to nondetectable levels after 10 days and 4 flushes of the pipe. Dimethyl tin, present initially at 0.61 ppb, reached nondetectable levels after 10 days and 5 flushes. After 2 weeks of pipe use, there is not likely to be exposure to these substances.

Dibutyl tin, present initially at a concentration of 2.6 ppb, was still present after 21 days at a level of 0.12 ppb. The lowest experimental level of a toxic effect due to dibutyl tin observed was depression of immune function in weanling rats given 20 ppm in the diet for 2 weeks (Seinen et al., 1977a). It was formerly thought that 40 ppm in the diet represented a no-observable-effect level (NOEL) for dibutyl tin dichloride (DBTC), based on a 90-day feeding study (Gaunt et al., 1968). However, immune function had not been assessed. The work of Seinen et al. showed that the dietary NOEL for DBTC in rats must be less than 20 ppm (1977a). Without specification of a NOEL, however, no chronic SNARL can be calculated for DBTC.

However, the atrophic effect on the thymus caused by DBTC was reported to be completely reversible after cessation of exposure (Seinen et al., 1977a). Thus, assuming that pipes will be flushed several times prior to occupancy, it is likely that occupants will be exposed only to DBTC, and then in concentrations below one part per billion for a relatively short period of time. This also assumes, however, that the concentration of DBTC in the water continues to decline as is evidenced in Table IV-15, and that there is no significant breakdown of the pipe in the future which might allow further leaching of this stabilizer into the drinking water.

The above evaluation assumes that none of these organic tin compounds is a carcinogen, although none has been adequately tested for this property.

003016

6. Substances Associated with Polybutylene Pipe: Irganox

a. Exposure

No workplace exposure limits or recommendations for Irganox have been issued. As described in Chapter IV-A, Irganox and Irganox derivatives have been identified as leachates from polybutylene piping systems at concentrations up to 50 ppb and 11 ppm, respectively.

b. Absorption and Metabolism

In studies in rats with radiolabelled Irganox, no measurable radioactivity was found in the urine, expired air, blood, liver, or kidney. The only significant activity (80-84 percent) was found in the feces. These results suggest that most of the Irganox passes through the gastrointestinal tract without being absorbed or metabolized (Ciba-Geigy, 1982).

c. Chronic Toxicity

Irganox was fed to rats in dietary concentrations of 1,000, 3,000, and 10,000 ppm for 104 weeks. No observable effects were seen at any concentrations. The "no-observable-effect-level" was estimated to be 446-547 mg/kg/day.

d. Effects on Genes and Chromosomes

Irganox did not adversely affect genes or chromosomes in a series of tests in mice, bacteria, and cell cultures.

e. Cancer

When Irganox was fed to Sprague-Dawley rats in dietary concentrations of 1,000, 3,000, or 10,000 ppm in the diet for 104 weeks, no significant increases in tumor incidence were seen at any concentration. No

003017

treatment-related increases in tumors were seen in mice fed Irganox in the diet at levels of 100, 300, or 1,000 ppm.

f. Effects on Reproduction

Two studies designed to detect adverse effects on reproduction have been conducted with Irganox. Pregnant mice and rats were given oral doses of 150 mg/kg body weight daily from Day 6 through Day 15 of gestation. No adverse effects were seen in rat pups. At the highest dose level in mice, slight retardation in development, as indicated by an increase in incomplete ossification of ribs, was seen in offspring (Ciba-Geigy, 1982).

g. Evaluation

There is no drinking water standard applicable to Irganox. Neither EPA nor the NAS has published a chronic SNARL for this compound. There are no appropriate human data from which a SNARL can be calculated. However, the chronic animal study described earlier, the no-observed-adverse-effect level was estimated to be approximately 500 mg/kg. A chronic SNARL can be calculated as follows, assuming a safety factor of 1,000 and assuming that total exposure to this substance is through drinking water:

$$(500\text{mg/kg} \times 10\text{ kg})/(1{,}000 \times 1\text{ liter}) = 5.0\text{ mg/liter} = 5{,}000\text{ ppb}$$

where 10 kg represents the weight of a child, 1,000 represents a safety factor, and 1 liter the daily consumption of fluid by a child weighing 10 kg.

It appears that the concentration of Irganox detected in standing water in new polybutylene pipe--i.e., 50 ppb, would not pose a significant chronic hazard. This assumes that Irganox is not a carcinogen and does not possess significant reproductive toxicity.

The toxicologic significance of the Irganox derivatives detected in one 5-day PB leaching study at about 11 ppm is unknown. One cannot infer from the study the magnitude of the concentrations of these derivatives over

003018

time. A preliminary analysis of the structures of these compounds indicated that they are probably of minor toxicologic significance. No empirical data on the toxicity of these derivatives, however, could be located. At this stage, given the lack of information about leaching kinetics and toxicity, no estimate of risk for such compounds has been attempted.

7. Substances Associated with Metal PipeLead

a. Lead

Exposure--In California, lead solder used to join copper or galvanized metal pipes is probably the commonest source of lead in drinking water. Lead levels decrease with pipe age, but according to data presented in Chapter IV-A, water lead concentrations in newly plumbed homes may exceed the current MCL of 50 ppb. In national surveys, lead has been found in raw and finished waters at concentrations ranging from nondetectable to 140 ppb (NAS, 1977). Of nearly 2,600 samples of tap water from 969 water systems, the average lead concentration was 13.1 ppb, the maximum of 64 ppb, and in only 1.4 percent of samples did lead exceed 50 ppb.

Higher concentrations occur in areas with soft water, such as Seattle, or where lead service pipes are used. Using the average figure of 13 ppb, the NAS noted that lead intake from drinking water is 10 percent or less of that from the diet. The daily dietary intake of lead in food has been estimated to be 300 mg for men and about 100-150 mg for women and children (NAS, 1977). In urban areas, airborne lead may substantially contribute to lead absorption. Other sources of exposure, particularly for children, include lead in dirt and paint chips.

Absorption and Metabolism--Absorption of lead from the gastrointestinal tract varies with the age of the individual, the chemical form of the lead, and the dietary levels of iron, calcium, fats, and proteins. Children absorb a much higher percentage of dietary lead (about 40 percent) than do adults (about 8-10 percent) (Hammond and Beliles, 1980; IARC, 1980). Lead is rapidly transferred to bone, a cumulative process that occurs throughout

003019

life. Lead in other tissues rises during childhood and adolescence, and reaches a steady state by early adulthood (Hammond and Beliles, 1980). Adults excrete lead primarily in the urine, but also in feces, sweat, and breast milk, and through deposition in the hair and nails. In infants the principal route of excretion is gastrointestinal.

Chronic Toxicity--Low level lead exposure can lead to toxic effects on the nervous system, the kidney, the blood-forming system, and the gastrointestinal tract, with a variety of systemic symptoms. The hematologic and CNS effects of lead are considered most critical. Recent investigations using psychometric and behavioral tests have indicated that subtle effects may take place in children with blood lead levels of 50 µg/100 ml blood. Reports cited by the National Academy of Sciences (1977, 1982) suggest that tap-water lead may raise blood lead concentrations to a range where CNS effects may occur. However, an analysis reported by the EPA indicates that blood lead levels increase as the cube root of water lead concentrations (EPA, 1980c).

Effects on Genes and Chromosomes--There is mixed evidence regarding lead's potential genetic effects in various short-term assays. Some compounds, e.g., lead chloride and lead acetate, are negative in some tests and positive in others. Multiple studies of chromosomes of people occupationally exposed to lead have produced contradictory results. The International Agency for Research on Cancer considers evidence of lead's activity in short-term tests to be inadequate (IARC, 1982b).

Cancer--Some lead salts (lead acetate, lead subacetate, and lead phosphate) are clearly carcinogenic in animals. However, the nature of the animal experiments is such that potential human risks cannot be calculated (NAS, 1982). Epidemiologic studies of lead-exposed workers have been judged inadequate evidence of lead's carcinogenicity in humans (IARC, 1982b).

Effects on Reproduction--Lead has clearly been implicated as fetotoxic, fetolethal, and teratogenic in animals. Menstrual disorders, impaired fertility, miscarriages, and stillbirths have been reported in women

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suffering from lead intoxication. The offspring of pregnancies in which there was maternal lead poisoning have had retarded intrauterine and postnatal growth, as well as neurological damage (Gerber et al., 1980). Sperm abnormalities have been reported in men occupationally exposed to lead who have had substantially elevated blood lead levels.

Evaluation--The current MCL for lead is 0.050 mg/liter (50 ppb) (40 CFR 141.11[b]). Recent work indicates that this level may not protect children from neurological effects. On the basis of potential CNS and hematologic effects on the fetus and growing children, the National Academy of Sciences concluded that, "The present limit of 50 µg/liter may not, in view of other sources of environmental exposure, provide a sufficient margin of safety...Although further studies will be necessary to arrive at a reasonable limit, it is suggested that the limit be lowered...(but because of the limitations of current data) this committee cannot now suggest a lower lead standard" (NAS, 1982).

To the extent that the sampling data cited in Chapter IV-A of this report represent levels found in households with new copper pipe joined with lead solder, there may be a significant risk of neurologic damage to fetuses, infants, and young children, particularly in view of other sources of exposure. Lead leachates from older plumbing systems (> 2 years) are well below the current MCL and are unlikely to pose a significant risk. In the current state of knowledge, the extent of the risk to this population cannot be quantitatively assessed. More reliable leaching data from new copper systems are needed. The use of alternative solders should also be explored. If tin/antimony or tin/silver solder were used instead, however, lead leachate concentrations and the associated risks would be substantially lower and probably negligible.

b. Copper

Exposure--In Chapter IV-A, different concentrations of copper leachates were reported in experiments of variable correspondence to realistic conditions. In in-service pipes, the copper concentration was reported to

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be 250 ppb in standing water, while in new pipes, an initial leachate concentration of 2,200 ppb declined to 320 ppb by Day 21. Corrosive water produced leachates in laboratory studies of up to 1,610 ppb after a year. Copper was not detected in new galvanized pipe except using corrosive water, which generated maximum concentrations of 40 ppb. Other studies showed that concentrations are typically likely to be substantially less than 1 ppm, particularly in running samples. Under unusual conditions, e.g., prolonged standing or extremes of pH, the concentrations can exceed 1 ppm.

Copper is an essential nutrient, and is found in many foods. For example, pepper contains 53 ppm and oysters up to 1,500 ppm of copper (Venugopal and Luckey, 1978; Doull et al., 1980). The average adult dietary intake is 4 to 5 mg/day (Butler and Daniel, 1973).

Absorption and Metabolism--About 30 percent of dietary copper is absorbed from the gastrointestinal tract: the fraction absorbed depends on the chemical form (salt or metal complex, water solubility) and on the presence of other substances--leucine increases absorption, while various ions of molybdenum, sulfur, iron and zinc decrease absorption (Venugopal and Luckey, 1978). Copper is transported throughout the body, and is found in high concentrations in liver, brain, kidney, and muscles. A 70-kg adult body contains between 80 and 150 mg copper. Fetal copper concentrations are ten times those of adults (Venugopal and Luckey, 1978).

Copper is excreted principally in bile along with unabsorbed dietary copper. Small amounts are excreted in urine and perspiration. Balanced against biliary excretion, net copper absorption in the GI tract is about 5 percent. (Venugopal and Luckey, 1978).

Control of copper absorption, distribution, and excretion is achieved primarily by the liver, but also by carrier proteins in blood (albumin and ceruloplasmin), and cells of the intestinal lining. Hereditary defects in copper metabolism produce diseases characterized by progressive damage to the liver, CNS, and other organs. These include Indian childhood cirrhosis and Mencke's kinky hair syndrome, which are generally fatal in childhood;

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persons with Wilson's disease can typically live a normal life when treated with penicillamine (Scheinberg, 1981; Vaughan et al., 1979; Lefkowitch et al, 1982).

Chronic Toxicity--With the exception of persons with the hereditary disorders (Wilson's disease, Mencke's syndrome, Indian childhood cirrhosis) noted above, chronic copper poisoning from exessive ingestion is rare, and is not thought to result in disease in normal individuals (Gosselin et al., 1976; Doull et al, 1980; NAS, 1977). Tissue levels of copper do not increase with age (in adults), although blood levels do (Doull et al, 1980). The significance of the increase is unknown.

Effects on Genes and Chromosomes--Evidence of copper's effect on genetic material is inadequate, although copper may have mutagenic potential.

Cancer--Copper salts injected into roosters' testes cause testicular tumors. Copper has not been thoroughly tested by other routes in animals. Epidemiologic evidence is inconclusive. Overall, evidence for carcinogenicity is weak.

Effects on Reproduction--There is little evidence that excess copper has any effect on reproduction in animals or humans (EPA, 1980d).

Evaluation--The current ambient water quality criterion with respect to human health effects is 1 mg/liter (1 ppm). This level was set only with respect to undesirable taste and odor qualities, however, since the EPA believed that health data were inadequate to specify a protective level (45 Fed. Reg. 79331; November 28, 1980). Under typical conditions of use, copper in drinking water from copper pipes contributes a fraction of normal dietary intake.

As noted, copper is an essential nutrient for which people have evolved adequate homeostatic mechanisms that handle occasional excesses and deficiencies. While the metal can be toxic at high doses, SRI concurs with

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the assessment of the National Academy of Sciences that, "the potential for toxicity (from copper in drinking water at observed levels) is virtually nonexistent for humans" (NAS, 1977).

c. Zinc

Exposure--Data presented in Chapter IV-A indicate that typical concentrations of zinc are higher in galvanized steel pipe than in copper pipe and are less than 1 ppm in standing water in 8-year-old galvanized systems and up to 7 ppm in static tests of new pipes (Tables 4-19, 4-20, and 4-21). Zinc is commonly found in drinking water, particularly in areas of soft, acidic water. In water supplies of low pH, zinc concentrations have exceeded 5 mg/l (NAS, 1977). Excluding some industrial operations, the principal source of zinc exposure for the general population is food. Zinc is present in all animal and plant tissues, and is found in high concentrations in meat, fish, dairy products, grains, nuts, and legumes. Average daily intake of this metal is between 8 and 15 mg/day (Venugopal and Luckey, 1978). Recommended Daily Dietary Allowances for zinc are 3 to 5 mg for infants, 10 mg for children 1 to 10 years, and 15 mg for older children and adults (National Research Council, 1979).

Absorption and Metabolism--Zinc is an essential nutrient, required for DNA and protein synthesis and for the activity of numerous intracellular enzymes. Absorption of zinc from the GI tract is variable, depending on the amount in the diet, but averages about 50 percent. A diet high in calcium, phosphate, and copper can decrease zinc absorption, as can some chelating agents.

Zinc is distributed to all tissues, with high concentrations in muscle, skin, bone, liver, kidney, pancreas, eye, and the male reproductive system. Excretion occurs principally in feces, with contributions from unabsorbed dietary zinc, bile, pancreatic, and other GI secretions. Lesser amounts are excreted in urine, sweat, and breast milk (Venugopal and Luckey, 1978). Zinc absorption, metabolism and excretion are governed by an efficient homeostatic mechanism.

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Chronic Toxicity--Repeated low-dose ingestion of zinc is essential to sustain life, and an effective homeostatic mechanism virtually assures that temporary exposures to concentrations moderately greater than what is necessary will not result in toxicity. Concentrations of up to 0.25 percent (or 2,500 ppm) in the diet have not caused toxicity in rats. Above this dietary level one finds growth retardation, anemia and abnormal bone formation (Hammond and Beliles, 1980). There has been a report of zinc poisoning in two adults from extended consumption of water from galvanized pipes with zinc concentrations of 40 mg/liter. Symptoms consisted of nausea, loss of appetite, muscular pain and stiffness, and irritability (NAS, 1977).

Effects on Genes and Chromosomes--The National Academy of Sciences (1977) concluded that there are no data to suggest that zinc is mutagenic in animals or humans. The NIOSH Registry of Toxic Effects of Chemical Substances (1981) reports no positive results for zinc in tests of mutagenesis.

Cancer--Zinc injected into the testicles of rats and roosters has produced testicular tumors, an effect ascribed in part to hormonal factors and the high levels of zinc already present in the testes (Hammond and Beliles, 1980). Zinc has not been found to be carcinogenic by other routes of exposure (Sunderman, 1971).

Effects on Reproduction--Zinc at 4000 ppm (0.4 percent) in the diet of pregnant rats was reported to cause increased resorption and fetal death (Schlicker and Cox, 1968). Zinc injection or feeding at doses ranging from 15 to 50 mg/rat per day reportedly resulted in infertility and reduced testicular size (Venugopal and Luckey, 1978).

Evaluation--There are no federal drinking water standards for zinc. EPA has recommended an ambient water criterion for this metal of 5 mg/liter (5 ppm), based on considerations of taste and odor qualities (45 Fed. Reg. 79341; November 28, 1980). While zinc does produce chronic toxic effects at high doses (e.g., several thousand ppm in the diet), it is unlikely to

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present a significant risk of chronic toxicity in drinking water from either copper or galvanized iron pipe. It is essential for human nutrition, and homeostatic controls have evolved to regulate absorption and excretion. Zinc levels in drinking water are a small fraction of those in food. In general, zinc deficiency is a more serious health problem than zinc toxicity. The National Academy of Sciences recently concluded that, "[t]he possibility of detrimental health effects arising from zinc consumed in food and drinking water is extremely remote" (1980).

d. Tin

Exposure--The leaching studies reviewed in Chapter IV-A report tin concentrations only for new copper pipe (Tables IV-26 and IV-28). Neither study can be viewed as establishing realistic leaching conditions. In the NSF study (1980), the highest reported concentration of tin (in static samples in pH 11 water) was 1,000 ppb or 1 mg/liter after 6 hours, which declined to a maximum of 300 ppb after 24 hours. The study of Dunnigan and Blumenkranz (1983), involving a 3-month static sample in a new house in which 95/5 tin/antimony solder was used, reported a concentration of 19,800 ppb or 19.8 ppm.

Since tin is rarely included in large-scale surveys of water systems, there is little basis for comparison. The concentrations reported in Chapter IV-A, however, are substantially above those noted by The National Academy of Sciences (1977). Tin has been found in public water supplies at concentrations up to 2.2 ppb and in natural sources at concentrations up to 30 ppb. The principal sources of tin exposure, however, are canned foods and drinks, which generally contain less than 100 mg/kg (100 ppm), but have been reported to contain in excess of 1,000 mg/kg (1,000 ppm) after extended storage in unlacquered cans or if the product has been stored in an open can for several days (NAS, 1977). Some foods naturally contain tin, (e.g., asparagus and dried peas contain about 9 ppm), with tin content dependent on the concentration of tin in the soil. Stannous chloride is used extensively in processing fruits and vegatables (Venugopal and Luckey, 1978). Some toothpastes also contain tin in the form of stannous fluoride.

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There are varying estimates of the average daily intake of tin, ranging from 1 mg to 30 mg (NAS, 1977).

Absorption and Metabolism--Tin is poorly absorbed from the GI tract, and hence most of what is ingested is excreted in feces (Venugopal and Luckey, 1978). Absorbed tin can be found mainly in the liver, lungs, and kidneys with trace quantities in other tissues (NAS, 1977; Hammond and Beliles, 1980).

Chronic Toxicity--There are a variety of chronic effects from oral ingestion of tin salts when high doses (at least 0.3Δ of the diet) are used. Deleterious effects on growth and development, the liver, the blood, the GI system and the male reproductive system have been reported. With lifetime consumption of tin at 5 ppm in drinking water, mice and rats reportedly had mild liver and kidney changes (Venugopal and Luckey, 1978). Whether the latter finding can be extrapolated to a human context is questionable, however, since this level of consumption is approximately the average human daily exposure in food.

Effects Genes and Chromosomes--No information was available.

Cancer--While Venugopal and Luckey report that orally ingested tin salts are carcinogenic, the accuracy of this observation is in doubt (Venugopal and Luckey, 1978; Furst and Radding, 1979). A recent bioassay of stannous chloride conducted under the auspices of the National Toxicology Program was negative (NTP, 1982).

Effects on Reproduction--No information was available.

Evaluation--There is no drinking water standard for tin in the United States or in most other countries. There is no water quality criterion for tin. This is due in part to the lack of a reliable rapid method for determining the low concentrations in water (NAS, 1977). Of greater significance are: (1) the relatively marginal contribution of waterborne tin to the average daily intake in food; (2) inorganic tin's poor

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gastrointestinal absorption and its consequent low oral toxicity. Furthermore, there is evidence that tin is an essential micronutrient, at least in animals (NAS, 1977). While tin concentrations in static testing of new pipe may reach as much as 20 ppm, these are unlikely to pose a hazard, particularly in copper pipe, where passivation would cause tin levels (e.g., if tin/antimony solder were used) to decline.

e. Cadium

Exposure--In the sampling data described in Chapter IV-A, the highest concentration of cadmium reported was in new galvanized pipe at 3 ppb (Table IV-20). All other values reported in a variety of tests were less than 1 ppb. These values are consistent with the trace amounts found in surveys reported by the National Academy of Sciences (1977). The greatest contribution is in food. Cadmium is found in trace amounts in plants and marine organisms. Common sources of exposure are shellfish, liver and kidneys, wheat, rice, leafy vegetables, and cigarette smoke. The average dietary intake of cadmium has been estimated to range from 40 to 215 µg/day (Venugopal and Luckey, 1978; Friberg et al., 1974; NAS, 1977). Breast milk and cow's milk are important sources of exposure for infants. Based on a national community water supply survey, the contribution of drinking water to the average daily adult intake is thought to be about 3 to 4 µg/day (Ryan et al., 1982).

Absorption and Metabolism--Cadmium is poorly absorbed from the gastrointestinal tract: thus, most ingested cadmium is excreted in feces. The percentage absorbed varies from 0.5 to 12 percent in various animal species (Hammond and Beliles, 1980). Limited human evidence indicates that about 5 to 7 percent is absorbed. (Rahola et al., 1972; NAS, 1980) Younger animals absorb a greater fraction of ingested cadmium than do older ones. Cadmium absorption is enhanced by a dietary deficiency of calcium, vitamin D, iron, zinc, copper or protein. Inhaled cadmium is more efficiently absorbed: 50 percent or more present in cigarette smoke or metal fumes is absorbed (Ryan et al., 1982).

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Absorbed cadmium is widely distributed throughout the body, concentrating preferentially in the kidney and liver. The metal accumulates in the body (at least up to age 50), with a biologic half-life estimated to range from several months to 47 years (Ryan et al., 1982). At birth the body burden of cadmium has been estimated to be 1 nanogram, which increases to 15-50 mg by age 50 (NAS, 1977). Excretion of absorbed cadmium is thought to occur principally in the urine, although other routes have not been well investigated (Hammond and Beliles, 1980). As noted above, cadmium appears in breast milk.

Chronic Toxicity--Chronic human exposure to cadmium has resulted in damage to the kidneys, lungs, bones, and cardiovascular system (NAS, 1980; Klaasen, 1980).

Effects on Genes and Chromosomes--There is conflicting evidence as to whether or not cadmium has genotoxic effects in short-term assays and whether it can cause chromosomal aberrations in people exposed to cadmium. The International Agency for Research on Cancer regards existing data as inadequate (IARC, 1982b).

Cancer--Cadmium compounds injected in rodents are carcinogenic. One feeding study involving 50 ppm of cadmium chloride in rats' diet did not cause an increased incidence of tumors. Epidemiologic evidence suggests that occupational cadmium exposure may increase the risk of lung cancer and prostate cancer. However, the evidence here is conflicting (IARC, 1982b).

Effects on Reproduction--Various cadmium compounds administered by injection to animals have been demonstrated to be fetotoxic, fetolethal, and teratogenic. Cadmium in drinking water at 10 ppm has been reported to be teratogenic to mice. Acute exposure of experimental animals to levels of cadmium far in excess of typical human intake can cause damage to male and femal gonads. Such effects have not been reported in humans.

Evaluation--The current MCL for cadmium is 0.010 mg/liter or 10 ppb (40 CFR 141.11[b]). The National Academy of Sciences has calculated a chronic

SNARL for cadmium of 0.005 mg/liter (NAS, 1980). The NAS utilized 70 kg as the average weight of persons exposed. Using a young child's weight instead of 70 kg, and assuming consumption of one rather than two liters per day, this SNARL can be adjusted as follows:

0.005 mg/liter x 10kg/70kg x 2 liter/1 liter = .0014 mg/liter

According to the sampling data summarized in Chapter IV-A, typical cadmium concentrations are less than both the NAS's and SRI's adjusted SNARLs. Even the extreme value of 3 ppb in new galvanized pipe (Table IV-20) is lower than the NAS's chronic SNARL and the MCL. In view of these low values and the observation that cadmium consumption in drinking water is but a fraction of that in food, it appears that under typical use conditions, cadmium in drinking water does not present a significant risk to human health.

Antimony

Exposure--Antimony was not extensively tested for in the sampling protocols in the administrative record. However, it could leach into water if tin/antimony solder rather than lead were used to join metal pipes, although the theoretical likelihood of such leaching is small (Herrera et al., 1982). Very limited evidence would appear to support the hypothesis of minimal leaching. (Dunnigan and Blumenkranz, 1982) There is no current drinking water standard for antimony.

Antimony exposure occurs principally in industry and by administration of some pharmaceutical products. Average human daily intake from all sources has been estimated to be 100 µg (NAS, 1980).

Absorption and Metabolism--Antimony metal occurs in +3 (trivalent) and +5 (pentavalent) oxidation states, which are distributed and metabolized differently. Trivalent antimony has a greater affinity for red blood cells than pentavalent compounds, which are found at higher levels in plasma. Antimony is poorly absorbed from the GI tract, and tends to cause vomiting. Thus, when given medicinally, antimony is administered by injection or

intravenously. Intravenously administered antimony concentrates in the liver, thyroid, and heart. Trivalent antimony is excreted primarily in feces, while the pentavalent form is excreted principally in the urine (NAS, 1980).

Chronic Toxicity--Chronically administered antimony compounds have been reported to cause anemia, heary muscle degeneration, and other symptoms in animals. The lowest no-observed-effect-level has been reported to be 0.0025 mg/kg for guinea pigs fed antimony for 6 months (Arzamastsev, 1964). In industrial contexts, diseases of the lungs, skin, and GI tract have been reported (Hammond and Beliles, 1980).

Effects on Genes and Chromosomes--Evidence is inadequate to assess potential genetic effect of antimony.

Cancer--One drinking water study using mice was negative at 5 ppm, but this study was inadequate by current standards. Epidemiologic evidence of occupational cancer due to antimony is inconclusive.

Effects on Reproduction--Antimony metal has been reported to cause decreased fertility in one study involving rats. Female antimony workers in the USSR reportedly had a variety of gynecologic problems and a greater incidence of miscarriage and premature delivery than a control group (NAS, 1980). There is insufficient evidence to assess potential reproductive effects of antimony.

Evaluation--There are no U.S. drinking water standards for antimony. A chronic SNARL can be calculated from the lowest no-observed-effect level of 0.0025 mg/kg in guinea pigs fed antimony trichloride for 6 months noted above:

$$\frac{0.0025 \text{ mg/kg} \times 70 \text{ kg}}{1000 \times 2 \text{ liters/day}} = 8.75 \times 10^{-5} \text{ mg/liter/day},$$

which is far below the estimated average daily intake of 100 µg/day from all

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sources. The usefulness of this SNARL as a guideline is therefore questionable. The Soviet drinking water standard is 0.05 mg/liter, or 50 ppb.

In view of the low probability of antimony leaching from soldered joints, the probable marginal contribution of waterborne antimony to the total daily intake of this metal, and the poor absorption of such compounds from the GI tract, it is unlikely that the antimony component of antimony/tin solder would pose a significant risk of toxicity.

7. Summary Evaluation of Substances Associated with Plastic and Metal Pipe

a. Polybutylene Pipe

From the perspective of public health, PB pipe appears initially to be more acceptable than CPVC in part because no solvents are used in joining the pipe and in part because no carcinogens have been detected as leachates. While leaching studies have not been as adequate, or thorough the results indicate that only Irganox and Irganox derivatives are present at levels above control levels. Irganox itself seems relatively nontoxic, principally because it does not appear to be absorbed. However, smaller Irganox derivatives, with unknown toxicity, are also present initially in concentrations of parts per million. The structures of these substances (shown in Chapter IV-A) do not provoke a high degree of toxicologic suspicion. The leaching kinetics of such substances are unknown. Should subsequent leaching studies demonstrate that they may be present in drinking water under conditions of initial occupancy, it would be desirable to conduct at least minimal short-term tests on these substances--e.g., Ames tests--before passing judgment on the acceptability of PB pipe.

If better-designed, more sensitive leaching studies confirm the results of earlier studies, and if Irganox derivatives are not likely to be present by the time a dwelling is occupied or such derivatives are found to be

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negative for genotoxicity, PB pipe would probably represent, from the standpoint of public health, an acceptable alternative to metal pipe for use in plumbing.

b. CPVC Pipe

From the standpoint of public health, the most significant concern about CPVC leachates is that several of them are recognized carcinogens. Individual low-dose risk calculations for carbon tetrachloride, perchloroethylene, and trichloroethylene (based on estimates developed by EPA's Carcinogen Assessment Group using the linearized multistage model) have been presented in the individual evaluations for these substances.

The individual risks from these substances can be summed to give a cumulative risk:

1) Assume 1 ppb concentration:

	Risk
Lifetime exposure	3.9×10^{-6}
1-year exposure	5.6×10^{-8}
Five 1-year exposures	2.8×10^{-7}

2) Assume 10 ppb concentration:

	Risk
Lifetime exposure	3.9×10^{-5}
1-year exposure	5.6×10^{-7}
Five 1-year exposures	2.8×10^{-6}

3) Assume 50 ppm residual concentrations of carbon tetrachloride, perchloroethylene, and trichloroethylene in CPVC pipe, and other leaching parameters described in the individual evaluations for these substances:

	Risk
1-year exposure	3.2×10^{-7}
Five 1-year exposures	1.6×10^{-6}

Thus, within the limitations of the linearized multistage model and of the assumptions noted here and in the separate evaluations for these substances, the estimate of the cumulative incremental lifetime risk from exposure to these chlorinated organic compounds is slightly above the commonly accepted threshold of regulatory significance.

A more sophisticated analysis for calculating the cumulative risk is as follows:

Risk (above background) = $1 - \exp(-q_1d_1 - q_2d_2 - q_3d_3)$, where q = carcinogenic potency factor calculated by EPA and d = concentration of the chemicals of interest

$q_1 = 0.08275\ (mg/kg/day)^{-1}$	carbon tetrachloride
$q_2 = 0.039776\ (mg/kg/day)^{-1}$	perchloroethylene
$q_3 = 0.0126\ (mg/kg/day)^{-1}$	trichloroethylene

Several scenarios are presented below.

1) $d_1 = d_2 = d_3 = 1$ ppb
for lifetime exposure, risk = 3.86×10^{-6}
for 1-year exposure, risk = 5.5×10^{-8}
for five 1-year exposures, risk = 2.75×10^{-7}

2) $d_1 = d_2 = d_3 = 10$ ppb
for lifetime exposure, risk = 3.86×10^{-5}
for 1-year exposure, risk = 5.5×10^{-7}
for five 1-year exposures, risk = 2.75×10^{-6}

3) $d_1 = d_2 = d_3 = 5.9$ ppb (assuming 50 ppm residual concentrations of these compounds in CPVC pipe)
for 1-year exposure, risk = 3.3×10^{-7}
for five 1-year exposures, risk = 1.65×10^{-6}

Not surprisingly, the potential risk estimates are in close agreement with simple addition of calculated risk.

It should be noted that these calculations do not take background levels of such substances in water supplies into account. For households supplied from surface water, the background levels of these compounds are generally nondetectable. These chlorinated organic chemicals have been

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detected in wells supplying drinking water in industrialized areas (particularly Los Angeles), but the average concentration for all of these chemicals combined is about 1 ppb (Spath, 1983). In any given instance, background groundwater contamination of drinking water supplies may augment the risk noted above. Generally the increased risk appears to be minor, but occasionally it may be significant.

Furthermore, the potential risk estimate does not take into account the recent finding that dichloromethane is carcinogenic. (No risk estimate was made for the latter substance because the raw data on tumor incidence were not available from the National Toxicology Program.) In addition, if there is any synergistic interaction among these chemicals, the cumulative risk may be underestimated by adding the upper risk limits of individual chemicals. Finally, because of the inadequacies of existing leaching data, it is unclear that these are the only carcinogens that may leach into drinking water from CPVC pipe or that the reported leachate concentrations are representative of values that would be obtained in real life situations.

On the other hand, the cumulative risk estimates (for these three chemicals) may be too high. For example, the carcinogenicity of perchloroethylene and carbon tetrachloride may be a high-dose phenomenon dependent upon cytotoxicity and saturation of primary metabolic pathways; if this is so, calculations made using the multistage model may overstate risk (see Stott et al., 1981; Hoel et al., 1983). Furthermore, calculations based on residual concentrations of chlorinated organic contaminants may have been greater than they are in reality. For example, there is evidence that residual concentrations of carbon tetrachloride in CPVC pipe are 25 ppm or less, not 50 ppm (Desrosiers and Dunnigan, 1982). Additional leaching studies may indicate that these concentrations or other potential carcinogens do not persist long enough to present a significant risk to occupants of buildings plumbed with CPVC pipe.

In summary, the current state of knowledge would indicate that, under the assumptions noted and within the limitations of the risk estimation model, the potential cumulative incremental cancer risk posed by leachates

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from CPVC pipe appears to be slightly in excess of 10^{-6}, a commonly accepted threshold of regulatory concern. This result, however, is based on specific assumptions that are subject to revision at the direction of DHCD and on the basis of further studies, which will permit more meaningful conclusions to be drawn.

For the solvent cements we have calculated proposed maximum allowable concentrations according to a procedure proposed by the California Department of Health Services. This procedure is probably conservative, but should not be viewed as a fully adequate substitute for (unavailable) chronic toxicity data. Ongoing NTP bioassays for DMF and cyclohexanone will provide important information. Of the four solvents found in plastic pipe cements, DMF presents the greatest noncarcinogenic health risk; further testing is needed to clarify the effects of DMF on the liver and reproduction.

c. Copper and Galvanized Steel Pipe

In view of the results of the leaching data and the current state of knowledge about the toxicity of leachates from both copper and galvanized steel pipes, there appears to be little likelihood of any significant health risk from either of these kinds of pipe, with the possible exception of lead leachates from lead/tin solder. While it is clear that in homes with plumbing older than 2 years, the concentrations of lead are below the current MCL, new homes may contain water lead levels in excess of 50 ppb. If, as has been suggested by the EPA, blood lead levels correlate with the cube root of drinking water lead concentrations, then concentrations below 50 ppb probably do not present a significant risk to the mental development of infants and young children, who are at highest risk for lead toxicity. However, the National Academy of Sciences (1982) has indicated that the 50 ppb level may not be protective, considering that children are also exposed to lead in food, air, and other environmental sources.

There is not enough information on the kinetics of lead leaching in newly plumbed systems to make a judgment about potential risks. It will be

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important to quantify the time-dependence of lead leaching from new plumbing. At the same time, it would be desirable to investigate alternative solders that could reduce the risks of lead exposure, such as tin/antimony and tin/silver solder. Since lead solder leaching is a problem in other parts of the country as well, the EPA has recently begun to explore potential impacts of using these alternatives (Lassovsky, 1983). The cumulative nature of lead intoxication indicates that alternative solders be seriously considered if leaching studies demonstrate persistent concentrations of lead above the MCL.

Finally, additional studies should also investigate the possibility of persistent leaching due to cutting oils, such as organometallics. Most components of cutting oils, while potentially toxic, are likely to be rinsed out during pre-occupancy flushings. The ingredients of metal fluxes would not be anticipated to pose significant risks of toxicity, although soldering may create substances of potential toxicologic concern.

8. Through-Permeation of Pipes

Pilot studies reported by Elliot (1982) and Ikesaki (1983) indicate that several low-molecular-weight organic solvents may permeate PB, PVC, and polyethylene pipes and thereby contaminate drinking water. In addition, gasoline was found to permeate PB and PE pipes (as well as the control copper pipe), but not PVC pipe. Some of the low-molecular-weight chlorinated organic compounds caused the PVC pipe to lose its structural integrity.

The significance of these findings from a public health standpoint cannot be evaluated at this time. Several compounds tested are recognized carcinogens that were found to permeate pipe and contaminate water at concentrations in excess of levels corresponding to upper bound incremental lifetime cancer risks of 10^{-6}. If similarly elevated concentrations of carcinogens were to be found in drinking water under more realistic experimental conditions, this would clearly present a significant risk to public health.

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Such an assessment would require investigation of the extent of permeability of such pipes at lower soil concentrations representative of, e.g., a gasoline spill, residential structure fumigation, or offsite migration from a hazardous waste site or chemical storage tank. In the absence of such data, it can be said only that contamination of drinking water through permeation of plumbing pipe may present a potentially serious problem. The magnitude of the problem is, in SRI's estimation, likely to prove greater for distribution pipes than for service lines.

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C. Worker Safety and Health

1. Introduction and Scope

The potential for harmful effects on those who work with pipes or piping materials must have a prominent place in any consideration of environmental impact. The major area of concern is the effect(s) on those who work most directly with the piping system--the plumbers and pipefitters who install and repair plumbing systems. For a variety of reasons--principally the difficulty of clearly defining the extent of exposure and the relatively small impact of any change of use patterns--the effects on those who work in industries remote from the actual installation will not be discussed in detail here.

2. Potential Occupational Health and Safety Impacts of Pipe Materials

Figures IV-6 and IV-7 are simplified schematics of the flow of metal and plastic pipes (and associated materials) through the economy from extraction of the raw materials to final disposal of the pipe at the end of its useful life. Obviously, the complexities of the actual distribution system cannot be fairly portrayed in this section of this assessment. (See Section III for a more complete discussion of the pathways followed by piping systems in the economy.) Further, even at this simplified level, the effects on occupational health and safety in areas far removed from the sale and installation of pipes cannot be accurately determined, but are probably negligible. The marginal increase or decrease in health effects in such industries as the extraction of coal, gas, or oil due to increased use of plastic pipe can be discussed but cannot be forecast. One can imagine a decrease in the demand for coal due to decreases in orders for cast iron pipe, accompanied by an increased demand for oil and natural gas as raw materials (and energy sources) in the production of the petrochemicals used as feedstocks for the production of the resins used to formulate plastics.

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Similarly, increased use of plastics would imply an increased demand for the solvents used to make cements. However, the increased (potential) exposures to workers in this industry might be balanced (overall) by the decreased exposure of workers in the companies producing solder and flux for use in copper pipes.

The occupational hazards associated with physical distribution of pipe and joining materials are unlikely to be measurably affected by the materials being distributed. One could suppose, for instance, that increased storage of the (flammable) cements might lead to an increase in fires in warehouses. However, one could also suppose that substitution of plastic pipe could lead to a decrease in the incidence of lifting injuries due to handling metal pipe or boxes of solder.

Thus, we concentrate on the installation, repair, and disposal activities at the bottom of Figures IV-6 and IV-7, paying principal attention to the plumbing trade. The effects that any change in the current patterns of use of pipe and associated materials will have on the expectation of injury or illness among plumbers will be of greatest interest.

3. Health and Safety Aspects of the Plumbing Trade--Effects of Pipe Materials

> Plumber: A workman who installs and repairs pipes and plumbing. [Middle English "plumber," from Old French "plommier," from Late Latin "plumbarius," lead worker, from Latin "plumbum," lead.] American Heritage Dictionary of the English Language, Houghton-Mifflin Company, Boston, Mass., 1981.

As can be seen from the definition above, the work of the plumber has traditionally involved work with one of the oldest systemic toxicants known--lead. The National Institute for Occupational Safety and Health (NIOSH, 1975) has stated in regard to plumbing, heating, and air conditioning contractors: "...[they] represent one of the oldest professional trades and one of the most hazardous occupations known to man.

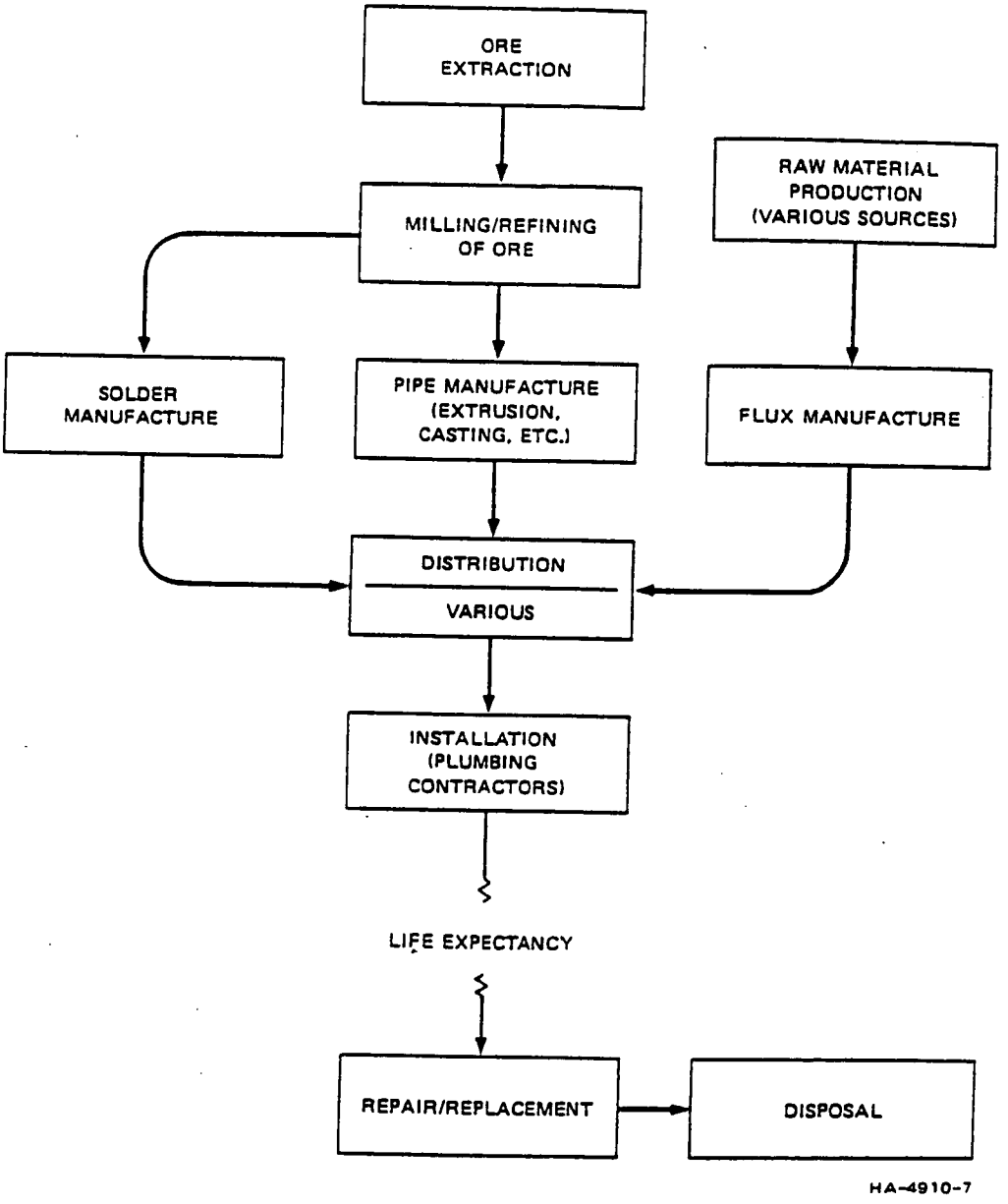

FIGURE IV-6 SIMPLIFIED SCHEME OF DISTRIBUTION OF METAL PIPE — OPPORTUNITIES FOR OCCUPATIONAL EXPOSURES

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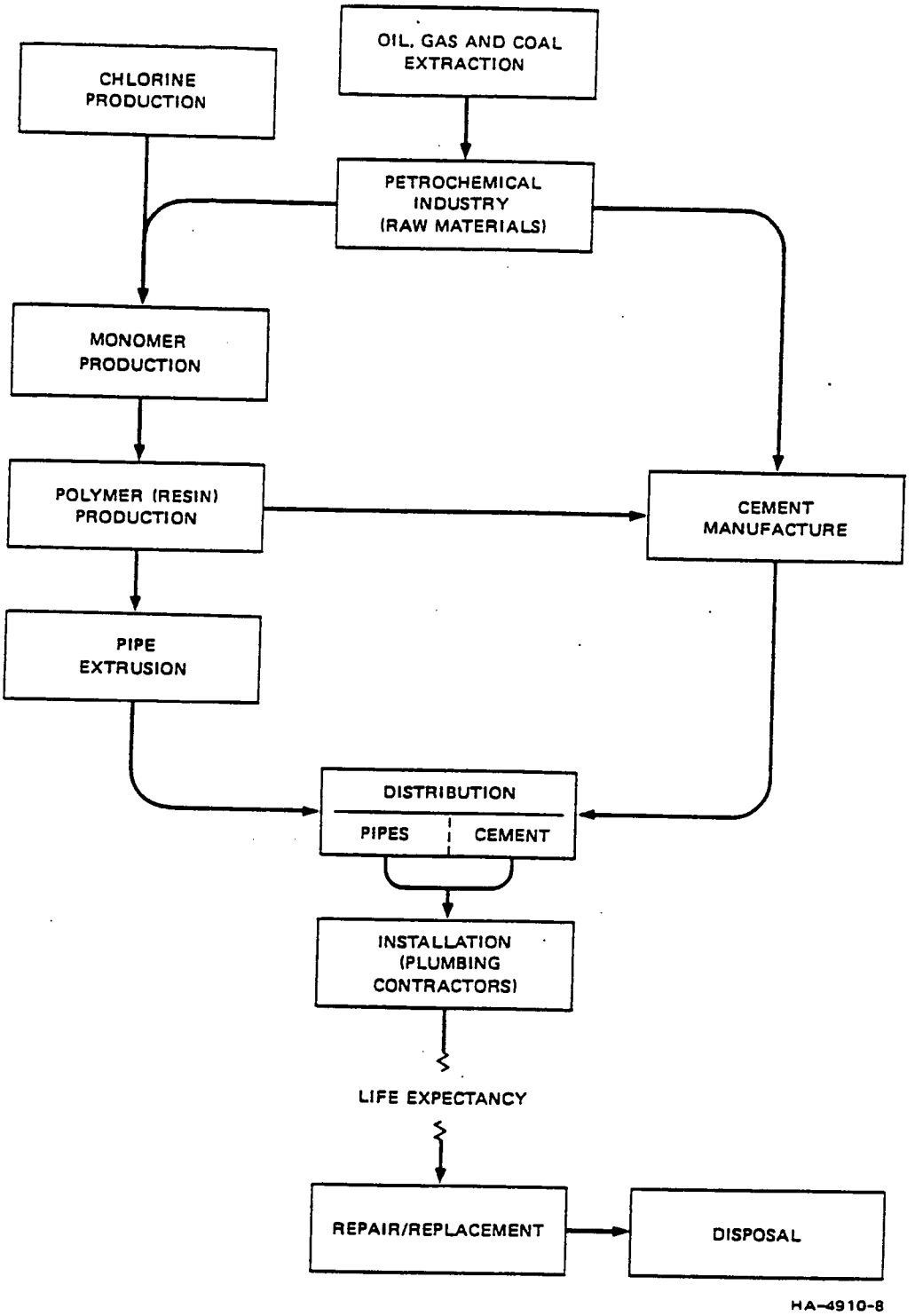

FIGURE IV-7 SIMPLIFIED SCHEME OF DISTRIBUTION OF PLASTIC PIPE — OPPORTUNITIES FOR OCCUPATIONAL EXPOSURES

The history of occupational injuries such as cave-in of excavations and illnesses from lead poisoning and dusts were some of the first to be documented in the written history of man..." Thus, concern about the health and safety of plumbers is not new--the current concern regarding health and safety aspects of plastic piping systems is simply the latest of many regarding potentially hazardous aspects of the plumbing trade. Thus, substitution of plastic pipe for metal pipe should not be viewed as the superimposition of a potentially hazardous material on a background of relatively low hazard. Rather, the existing piping systems in current use have substantial hazards, and the substitution must be viewed as an exchange of risk. The purpose of this section will be to discuss the nature of the competing risks involved, and to assess the relative advantage of substituting one for the other.

4. Function of the Plumber

The plumber's task is to provide piping and fixtures that will convey water and gas from the street mains into the building and deliver it to appropriate fixtures, and then to provide drain and vent piping to convey liquid wastes from the building to the street sewer main, and to vent gaseous waste from the system. Piping is usually laid in trenches to reach the building from the street, and then installed throughout the building by various means.

Before discussing the specifics of operations carried out to install plumbing, we will describe the materials used. One may consider four different services for which plumbing might be used in residential buildings: hot water, cold water, wastes, and gas (for fuel). (Specialty services such as distilled or chilled water are relatively uncommon.) Gas lines are not covered by the proposed action, and so will not be considered here. The other three services may make use of plastic piping. In California, plastic is currently most commonly used in drain, waste, and vent DWV piping.

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5. Plumbing Materials

The most common materials used for piping in current plumbing practice are the various plastics, cast iron, galvanized steel, and copper. In past years, a variety of other materials (including lead, bronze, and red brass) were used in addition to the current materials. Although some of these are still in use for the restoration of antique systems, it is now rare for plumbers to install (for instance) the lead pipes that were the cause of extensive lead exposure in past years.

The use of plastic pipe--the subject of this discussion--is not new. According to Babbit (1960), plastic pipe was available for use in the 1940s. The most common plastic pipe material used in the early years was polyethylene. No information on actual extent of use of plastic pipe in plumbing systems has been found, but we have obtained some information on the use of plastic conduit (for electrical wiring). In 1968, 9% of the conduit installed was plastic, while in 1980, 54% was plastic. Although this information is not definitive for the use of plastic pipe, it is indicative of acceptance of the plastics in construction materials. For the purposes of this report, it has been assumed that plastic piping was used sparingly until the mid-1960s, but with increasing frequency thereafter; it is probable that something on the order of half of the linear feet of plumbing materials used today is plastic. To discuss the materials used in a rational fashion, we have chosen to break down the discussion into two sections--water supply piping and DWV piping.

6. Exposures in Plumbing

a. Cutting

The only chemical exposures likely during pipe cutting are those to cutting oils in cutting and threading steel or iron pipe. Sawing is unlikely to produce respirable dust, since the hand sawing of metals is a

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slow-speed operation that will usually not produce fine dust. Of particular interest to this project is the probable lack of excessive exposure to plastic dust. The tubing cutter (see Figure IV-8) will turn off a cut "thread" of plastic, if any cutting scraps at all are seen. More commonly, it acts as a rolling knife, forcing through the plastic or copper pipe being cut, with no residual. In some cases (see Table IV-31) measurable dust concentrations have been found. Preliminary results from an as yet unpublished NIOSH study indicate that both respirable and total dust levels may be elevated when PVC pipe is cut with power tools, as would be expected.

b. Installation

It is in installation that the major potential for occupational exposure to chemicals occurs for plumbers. The installation will make use of all of the pipe joing methods previously listed, and the plumber may thus be exposed to solder and flux fumes when installing copper pipe, solvent

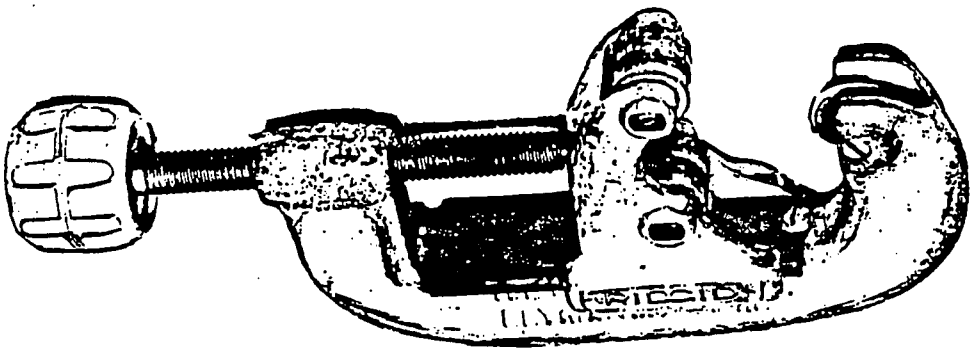

FIGURE IV-8 TUBING CUTTER

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Table IV-31

EXPOSURE DATA ON VCM, AN, AND ABS DUST

Plastic Pipe Operations

Exposure to AN:

Operation	8-Hour TWA (ppm)	Short-Term (ppm)
Prefabrication	0.00021	0.00028 0.00030
Roughing	0.0005	0.002
Topping Off	0.0005	0.002
Finishing	0.0003	0.00048 0.00059

Exposure to ABS dust:

Prefabrication	0.13 mg/M^3

PVC Plastic Pipe Operations

Exposure to VCM:

Roughing	0.007 0.003	0.047 0.010

Source: CDHS (1980a).

vapors when installing plastic pipe (except polybutylene and polyethylene), and lead fumes in the (rare) installation of bell and spigot or wiped joints. There will be, of course, ample opportunity for dermal exposure to all of the above.

c. New Construction

New construction may be categorized by two important variables affecting the potential chemical exposures of plumbers: the size of the job and the end use of the building under construction (commercial or residential). The size of the job, whether commercial or residential, is important because of the pace of the work. On a large enough job, the general contractor will have an on-site staff (superintendent and staff) who are charged with the responsibility for completing the work on-time and on-budget. While this is also true on small jobs, the economic penalties for late or noncompletion of a large job are substantial, and there will be constant visits from the general contractor's staff to assess the performance of the subcontractors (including the plumbing contractor) and to push them to complete the work as soon as possible. On a small job, there will be relatively greater flexibility, and the working plumbing foreman will have much greater latitude to determine the pace of work.

The end use of the building is important because it may (depending on the local jurisdiction) define the allowable plumbing fixtures and pipe type. In some localities, for instance, ABS is allowed for DWV in residential but not in commercial construction. There will usually be special code requirements for medical facilities, schools, and other institutional buildings.

Generally speaking, the plumbing contractor will begin work coincidentally with the final stages of framing of the building, but prior to the installation of electrical wiring or sheathing/subflooring. It is necessary to have the framing in place so that the fixtures can be placed properly in relation to floors and walls, but the plumbers need access to

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the joists and studs to drill holes for running pipes, and then need clear access to the pipe, fixtures, and fittings to make joints. Since wiring and piping will often run side-by-side, it is wise to avoid having the wiring in place while the plumbers are working, so that their torches (soldering copper pipe, for instance) will not accidentally melt the insulation on the wires.

Thus, plumbers will usually be working within the open framework of the building, and there will usually be substantial natural ventilation to remove any airborne contaminants. There may be times, however, when the plumbers are working in effectively enclosed spaces. If the building has a basement, then the plumbers may not get into the building until the subflooring has been installed on the first floor; they will then have to work close to the underside of the flooring. (In industrial construction, or in large commercial buildings of poured concrete, this will always be true, regardless of the level.) Second, even within a partially framed building, the plumbers will often be working in small spaces where air exchange is minimal. In addition, plumbing requires close attention to detail--particularly in making good joints. Thus, a plumber installing plastic or copper pipe will sometimes work with his nose close to the pipe (<u>especially</u> when working in enclosed spaces) in order to verify the soundness of joints. (See Figure IV-9 for typical soldering--although the piping is a specialized type--the Sovent system.)

As noted before, there may be prefabrication of substantial components of the plumbing, which will reduce the potential exposures of the installing plumbers. Perhaps more important, there will be specialization in large jobs that may act to substantially increase the exposures of some plumbers while reducing that of others. On a site where plastic is used, the journeyman or advanced apprentice usually doing the actual installation would have relatively intimate and constant contact with the cement throughout the day. This exposure would result not only from the vapor exposure as he cemented the joints, but also from the residual cement on his hands (or gloves) and clothing. A large job with the aforementioned time and cost pressures would accentuate this behavior, and it would not be

uncommon for a plumber to end the day with his coveralls coated with the cement. Installation of copper under the same conditions would also lead to potentially massive exposure to solder fumes. The exposure time-course could be characterized as relatively frequent peaks and valleys, superimposed on a background varying from "clean" to "dirty."

d. Remodeling/Replacement

Replacement of old plumbing with new (as in the remodelling of an old home or building and installation of new fixtures) involves a different set of exposure conditions. First, instead of the (relatively) open and unobstructed working conditions of new construction, the plumber will be faced with fitting pipe into existing wall and crawl spaces after the removal of old pipe. This implies much more enclosed conditions (with more potential for exposure to any airborne materials of concern), but also a slower pace of work (feet per hour). Such work is frequently done by a single plumber (almost always a journeyman), and thus the specialization mentioned above is not found. The exposure profile might be characterized by exaggerated peaks and valleys, with the valleys relatively prolonged.

7. Exposure Potential by Operation

The potentials for substantial exposures in the various plumbing operations are summarized in Table IV-32. Each operation that offers opportunities for exposure is discussed below.

a. Cutting Galvanized Steel Pipe

The major exposure here will be dermal exposure to any cutting oils used. When the work of cutting and threading the pipe is being performed by one plumber--usually a new apprentice working under instruction from an older apprentice or journeyman--there may be relatively constant exposure.

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.

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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 cements--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
Within the New Construction Segment	
Prefabrication	30%*
Installation	70
By Type of Service	
DWV	60%
Water	40

*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.

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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 Univeristy (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.

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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

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Table IV-34

ABS PLASTIC PIPE SOLVENT EXPOSURE MEASUREMENTS

Solvent: Cal/OSHA 8-hr. PEL Short-term Exposure Limit	MEK 200 ppm 300 ppm		THF 200 ppm 300 ppm		Cyclo 75 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)

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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

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Table IV-36

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

Location/Sample ID		Chemicals									
		VC	ACN	THF	MEK	Benzene	Hexane	Heptane	Toluene	Cyclo-Hexanone	Dimethyl-Formamide
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).

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Table IV-37

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

Condition	Chemicals									
	VC	ACN	THF	MEK	Benzene	Hexane	Heptane	Toluene	Cyclo-Hexanone	Dimethyl-Formamide
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).

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(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

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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.

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Table IV-38

ABS PLASTIC PIPE SOLVENT EXPOSURE MEASUREMENTS

Solvent: Cal/OSHA 8-hr. PEL Short-term Exposure Limit	MEK 200 ppm 300 ppm		THF 200 ppm 300 ppm		Cyclo 75 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)

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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

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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.

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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

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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

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

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

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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 milliliters 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).

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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.

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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

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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

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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.

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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

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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

Site	Occupational Group								
	Plasterers			Plumbers			Roofers		
	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++			

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

Source: Lassiter (1983)

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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*

Year	Plumbing, Heating, and Air Conditioning Contractors					Plumbers and Pipe Fitters		
	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			
1963	2,870	(80	200)	280	9.76			
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	3,894			228	5.86	2,668	194	7.27
1981	3,825			228	5.96	2,798	216	7.72

Not reported before 1977.

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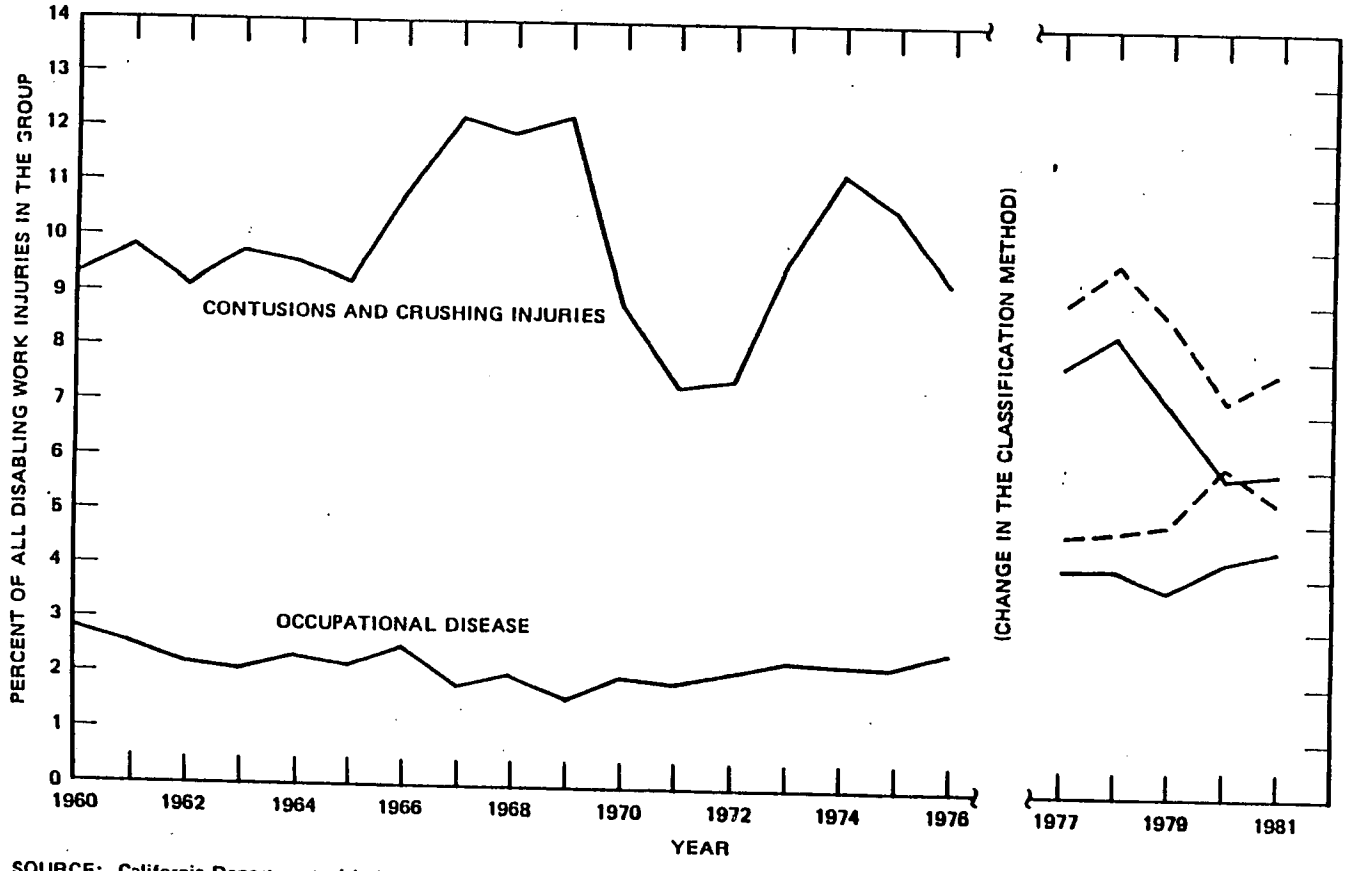
Table IV-42

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

Year	Plumbing, Heating, and Air Conditioning Contractors			Plumbers and Pipe Fitters		
	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		
1963	2,870	60	2.09	before 1977.		
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

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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

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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

Solvent	Glove Material					
	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-Tetrachloroethane	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	C	D	A
Phenol (10% Water)	B	A	B	A	B	C
Acetone	B	C	B	D	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.

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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.

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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.)

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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.

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"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 the provisions of the plumbing code as adopted or amended."

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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

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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

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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)

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(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.

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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 when all of the following conditions were satisfied:

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 was reduced when any of the following conditions existed:

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."

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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

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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.

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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.

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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

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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

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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

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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:

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- 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

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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.

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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

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(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).

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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

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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

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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.

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Table IV-44

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

	Variation with Oxygen Supply			Variation with Temperature					Variation with Heating Rate	
Compound	Air_3 (30 cm^3/min)	Air_3 (60 cm^3/min)	Air_3 (25 cm^3/min) + O_2 (cm^3/min) (21 cm^3/min)	25°C to 280°C	280°C to 350°C	35°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).

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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.

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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 tr simulate fire conditions--and attention paid to whether flames resulted--over those from classical laboratory techniques such as tube-furnace heating.

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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 Yields

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.

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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

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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.

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Still, the combustion product information needed to answer questions of environmental impact potential does ultimately entail estimates of toxicant concentrations and time histories outside 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.

If we assume that the fire in the room follows the prescribed ASTM E-119 test conditions, which are intended to be representative of a severe post-flashover room fire, three bits of information from the available literature permit some estimates. Data from B.F. Goodrich show temperature observed by thermocouples attached to plastic plumbing systems in a 1-hour fire-rated wall during an ASTM E-119 test. During the first 30 minutes, the temperatures for both ABS and PVC remained below 200°F, i.e., less than the boiling point of water, indicating that the heat flux is insufficient to cause any toxicant production.

Measurements of heat flux acting on test specimens during an E-119 test have been reported (Fong, 1975). Examination of this heat flux history reveals that the accumulated thermal insult to the wall is 4,297 Btu/ft^2. For a small room (e.g., 10 x 10 x 8 feet), the energy required to produce such heat fluxes during the first 20 minutes is 2.23 million Btu (assuming uniform heating of all the room walls, floor, and ceiling).

From the standard heats of combustion of PVC and wood*, it can be seen that 306 lb of PVC or 285 lb of wood would need to be in the room and to burn at 100% efficiency and heat transfer to cause the plastic pipe to reach 200°F. In practice, fuels do not burn with perfect efficiency; and with the enthalpy flow associated with the air flow required to maintain combustion, considerably more combustibles would be required to heat the room. For example, Fong (1975) found that the heat lost by the exhaust gases in the E-119 furnace ran about 50%. If this loss is applied to a good combustion efficiency of 80%, the PVC needed to be burned in the room would increase to about 760 lb (about 710 lb of wood).

Another example of the combustibles required is based on the fuel consumption rates in the E-119 furnace. From the energy consumption curves

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*PVC has a heat of combustion of about 7,500 Btu/lb. Wood has a heat combustion of about 8,000 Btu/lb.

in Fong (1975), the rate during the first 20 minutes averages about 8 x 10^6 Btu per hour. With wood's heat of combustion of about 8,000 Btu/lb, the fuel requirement at 100% burning efficiency becomes 1,000 lb of wood/hour. Assuming 80% efficiency and allowing for the surface area of our hypothetical room, the wood requirement becomes 455 lb for the first 20 minutes. Typical fuel loadings in noncommercial or industrial structures are in the range of 5 to 10 lb/ft^2 of floor area, so the estimated heating requirements would consume most of the available fuel before the pipes in the wall became involved. Such fires obviously would make the room untenable, and the escaping pyrolysis and combustion products would pollute the surrounding areas long before any contribution from the plastic pipe was significant. In this uniform-heating model, the fuel requirement to affect the pipes increases faster than the floor area; consequently, increasing the room size reduces the hazard.

In the above scenario, the thermal insult to the pipe in the wall is probably inadequate to generate a toxic threat from the pipe material. Certainly, its effect, if any, would be insignificant in relation to the smoke, heat, and toxic combustion products that would accompany the fire in the room.

c. Fire in Room with Some Plumbing Exposed or Concealed by Non-fire-resistive Construction

Calculations and rational assessments of many variations of this scenario have been performed, here and abroad (Hilado, Cumming, and Casey, 1978; Hilado and Hutlinger, 1983; Woolley, 1971; Van der Voort, 1972; Smith, 1973). The results can be summarized with the following statement: The combination of toxicants produced by the burning ensemble of room contents, furnishings, and materials of construction, utility, and aesthetics is far too complex and life threatening to warrant concern over the contribution of any one item, particularly a minor member of the collection of organic-based materials present, such as a few pounds of plastic plumbing compound among hundreds of pounds of other combustibles. Some (e.g., Smith, 1973), however, argue that the hazards can be so uniquely life threatening as to

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warrant special concern, to urge the course of "better safe than sorry." Smith ascribes to PVC a cause for special concern, namely, its high yield of HCl. He concludes: "Using reasonable assumptions for carbon monoxide production from cellulosic fuels, one may show that in a compartment in which the fuel load is 1% PVC and 99% cellulosic material there will be a relative hazard concentration of hydrogen chloride three times greater than that for carbon monoxide."

In the course of the study leading to this environmental review, we calculated a lower contribution from PVC. We assumed a fuel load of 200 lb DWV plastic and 18,800 lb wood*, that is, 1% mixed ABS and PVC combined with 99% cellulosic fuel, all burning at once. Drawing on data from an NBS study (Ives, 1972; Wagner, 1972), HCN concentrations from the ABS were inferred. Neglecting, for the moment, any effect of the HCl from the PVC, a the contribution of the plastic pipe materials would be less than 0.3%. However, if the plastic pipe components were about equally divided between ABS and PVC, we would expect between 10 and 15 pounds of HCl to be generated. This represents a serious toxicant load. As Smith notes: "When one considers that 3.5 grams of HCl in 1,000 cubic feet (about the volume of air in an average size room) produces a (physiologically dangerous) concentration of 100 ppm, the potential hazard is more apparent." By his rule of thumb, 10 to 15 pounds of HCl could poison the air of 1,500 rooms. But as Smith also notes, HCl has a fleeting existence as an airborne toxicant. He reckons its half-life at 10 minutes, but evidence reviewed by us during the course of this study indicates a process much more complex than a single-step, first-order decay--one in which aerosol concentrations strongly enhance the rate of HCl disappearance and in which surfaces located as much as a foot or more away from the airborne HCl provide a rapid sink for its removal. In other words, the thickness of the boundary layer for HCl loss to surfaces, which is a function of large-scale turbulence in

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*We doubled the DWV load from the estimates of Benjamin et al. (1982).

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fires, is appreciable in comparison to the dimensions of rooms. Taken together, these factors support the often remarked observation that HCl rapidly "plates out" and is quickly lost from the airborne toxicant pool, its concentration falling rapidly, not just with time but with distance from the source.

Viewed in terms of potency in animal toxicity studies, available test systems produce conflicting results regarding the toxicity of the combustion products of PVC and ABS relative to those of Douglas fir or red oak. ABS has been judged to be about equal to wood in toxicity by some authors and to be 10 times as toxic by others. PVC may be about as toxic as wood (as viewed by some authors) or 70 times more toxic. Since there is almost 100 times more wood than plastic pipe present (as part of construction), the contribution of the plastic to total toxicity could range from about 1% to about 40%--the latter if the toxicity of PVC is 70 times that of wood, as Alarie (1982) alleges. The contribution of PVC may be overstated in either case because the plastic will be fabricated, not in pellets as in some tests, and will burn less rapidly. Even with the higher estimate, however, persons would be more likely to succumb as a result of the burning of structural materials and room furnishings than as a result of toxicants contributed by plastic pipe.

d. Fire in Concealed Space Containing Plastic Plumbing

This scenario is thought to be far less likely than the others. It is, nevertheless, of special interest because it circumvents the two ameliorating characteristics of the previously discussed scenarios: (1) the heat load is not impeded by separations between pipe and fire, and (2) the combustion products are minimally affected or attenuated by the combustion products of other materials.

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Moreover, a particularly interesting feature of fire in such spaces is that combustion rates and, hence, toxicant release rates* are potentially limited by air supply; however, the resultant dilution of toxicant concentrations also decreases in proportion to the decreased rate of air supply. Thus, we might assume, for lack of pertinent information, a roughly constant concentration of each toxic species to be consistently present in the smoke issuing from the pipe chase, as long as sufficient pipe surface area is always available to ensure ventilation-controlled fire conditions. This constant level of concentration can be shown to be physiologically significant. Therefore, once again, we are led to an assay of the details of smoke movement, leakage from the confines of the pipe chase, and smoke dispersion patterns in each case of building design and fire event. Clearly, the best prospect for occupant safety is a reasonably gas-tight (and fire-resistive) chase enclosure designed to reduce to a prescribed minimum the air flow available to sustain a fire and the leakage of any combustion products into occupied spaces of the building.

4. Observed Effects of Smoke Toxicants

There is little in the literature from which to judge whether or not products of combustion or thermal degradation of plastic pipes in buildings has led directly to fire deaths or has contributed to them. Isolated reports exist (e.g., Haskell, 19__) that thermal degradation of pipes in buildings has compromised efforts to control and extinguish fires, but no clear-cut evidence shows a causal relationship with death of or injury to their occupants. There are reports that building fires develop faster today than in past years and produce smokes that are more obscuring and irritating to the respiratory tract or contain more gases such as HCN at toxic levels.

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*Assuming that rates of toxicant release are proportionate to heat release rates.

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Although there are sometimes statements attributing these developments to the increasing use of synthetic materials to replace traditionally used ones in building products and contents, other factors could be involved.

Data on the products of combustion in actual fire situations and knowledge of their physiological effects would aid greatly in assessing to what extent, if any, combustion of particular synthetics in the buildings is responsible. Only two studies (one in Boston and one in San Antonio) to identify and measure combustion products in real fires have been attempted; regrettably, the information falls far short of permitting any definitive conclusions (Benjamin et al., 1982).

In the absence of empirical information, indirect evidence to substantiate claims that plastics in buildings are increasing fire hazards and deaths may be sought. Because the fraction of building materials that is plastic has increased from 2% to 10% over the last 15 years or so, higher fatalities might be expected today than in the past if the use of plastics does increase fire hazards.

According to some sources, however, both the total number of fire deaths and deaths per capita have actually decreased over the last decade (C&EN, 1983). NFPA reports that total fire deaths have been decreasing since 1978. If this improvement is real, it is likely that the credit should go primarily to the increased use of low-cost residential smoke detectors and other building safeguards and the possible role of plastics is not ascertainable.

5. Toxicology of Smoke Toxins

The following analyses (1) examine animal studies or surveys that have as their aim the characterization of the potential for harm of smoke toxins from plastic pipe, and (2) evaluate information on the known combustion products and their thresholds for producing harm, in conjunction with postulated fire scenarios. We identify information gaps and uncertainties

and assumptions in the methods used that may influence confidence in our conclusions. We attempt to err in our analysis on the side of safety.

a. Perspective

The toxic effects of mixed combustion products on living organisms may be identified from epidemiologic or animal studies if such data are available. Alternatively, if identities of the constituents of gaseous products of combustion for the test materials and their rates of formation are known, theoretically one can use mathematical modeling together with the known toxicities of the constituents evolved to deduce the potential hazards of combinations of them.

Since all the data necessary for an accurate assessment of fire hazards under a reasonable range of circumstances do not exist for any of the types of pipe, inferences have to be made from what is known. As in the case of chronic effects from pipe leachates, epidemiological data for assessing hazards from plastics in fire situations are inadequate, forcing analysts to rely on animal toxicity data and combustion studies. The situation is complicated in this case, however, by the absence of generally accepted testing guidelines. Several groups have noted this deficiency, and there is active literature and laboratory research being conducted in attempts to resolve these problems (C&EN, 1983; NBS Workshop, 1983). None of them will be resolved by the due date of the plastic pipe EIR. Thus, the toxicity of the products of plastic pipe combustion for making projections of hazard in real fires must be viewed from the adequacy of both the test data and the methods used to evaluate it.

Although none of the available test methods is considered validated for this purpose, each being subject to various criticisms, data from them still can be used for semiquantitative estimates of risk and guidance on the likelihood that plastic pipes will or will not cause, or add significantly to, toxicity in real fires vis-a-vis other combustible materials present.

b. Fire Toxicity

To recapitulate and expand on the earlier discussion, fire produces toxic effects in a variety of ways. Toxic combustion products released from burning materials, oxygen depletion, or burns from direct contact with the fire can result in fatalities. Smoke, heat, and irritant gases can impair visibility, impede motor activity, or create fear leading to judgment errors that prevent escape and contribute to death (Autian, 1970; PRC, 1980).

There have been concerns expressed that, in addition to acute, potentially lethal effects of toxic gases, long-term irreversible effects, including cancer, may result from exposure to combustion products (Autian, 1970; PRC, 1980). Such effects might arise from exposure to one fire or to many, as in the case of fire fighters. Irritant gases could cause respiratory complications from injury to the respiratory tract, leading to residual effects in a significant fraction of fire victims, which persist long after the fire exposure and possibly result in permanent pulmonary injury. Also, little if anything is known of the effects of the absorbed gases on distant organs (those other than the lungs or surface areas), except in selected cases (PRC, 1980).

c. Causes of Fire Death and Injury

"Smoke" from thermal degradation and combustion of plastic pipes is composed of asphyxiants such as CO and HCN that affect oxygen transport or utilization; irritants such as HCl, aldehydes, and oxides (or epoxides) that cause respiratory tract injury; and other materials such as particulate matter that can obscure vision or burn the lungs if inhaled. Some components given off during degradation of PVC plastics, such as benzene and vinyl chloride, are known carcinogens; their oxidation products in the fire are likely to be of less concern.

CO Toxicity--CO is identified as a primary cause of fire death. When inhaled in sufficient quantities, it produces a condition termed anoxic

anoxia, which results from CO's rapid combination with O_2-carrying hemoglobin (Hb) in the blood to prevent O_2 transport from the lungs to the tissues and cellular CO_2 exchange and transport back to the lungs for expiration from the body (Caplan, 1982). Any O_2 remaining bound to the Hb is also retained more tightly in the presence of CO, magnifying the problem. Without O_2, tissues cannot perform their functions.

Because CO binds 200 to 250 times more tightly to Hb in blood than does oxygen, it is not easily displaced; thus, once a condition of low blood oxygen (anoxia) is induced, it can persist for a considerable time. Also, prolonged exposures may result in adverse or toxic effects at relatively low ambient air concentrations of CO because of this difficulty in eliminating it from the body (Table IV-45).

The body of an average adult male contains enough Hb to hold about 1 liter of O_2 (about a 4-minute supply). During rest, about 30% of the O_2 in arterial blood is used; however, during exertion, this may increase to 70% or 80%, thus reducing substantially the large reserve factor and decreasing the margin of safety. A man at rest can, therefore, tolerate a temporary 30% reduction of the O_2-carrying capacity of his blood with little effect, perhaps limited only to a headache. Under exertion, however, the O_2 supply to the brain and other tissues rapidly becomes inadequate, and fainting will usually result. Children are more vulnerable than adults because of a more active metabolism and relatively larger volume of respiration. A 5-year-old child has twice the cerebral blood flow rate and consumes 50% more O_2 per 100 grams of body weight per minute than does a 45-year-old adult.

HCN Toxicity--Without question, HCN is one of the most lethal substances known. The gas produces a type of anoxia referred to as histotoxic. The effects in man of various concentrations of HCN in the atmosphere are given in Table IV-46. Other sources indicate that between 300 and 350 ppm can cause death within 10 minutes (Terrill et al., 1978; PRC, 1980). The short-term exposure limit for HCN is 15 ppm.

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Table IV-45

CARBON MONOXIDE TOXICITY

Concentration in Air (Volume percent)	Response
0.01	Allowable for an exposure of several hours
0.04-0.05	Can be inhaled for 1 hour without appreciable effect
0.06-0.07	Causes a just noticeable effect after 1 hour exposure
0.10-0.12	Causes unpleasant but not dangerous symptoms after 1 hour exposure
0.15-0.20	Dangerous for exposure of 1 hour
0.40 and above	Fatal in exposure of less than 1 hour

Source: Caplan (1982).

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Table IV-46

EFFECTS OF VARIOUS CONCENTRATIONS OF HCN IN THE ATMOSPHERE

Atmospheric Concentration of HCN (ppm)	Remarks
10	Maximum permissible concentration
20	Slight symptoms after several hours
100	Very dangerous within 1 hour
200-400	Lethal within 30 minutes
2,000	Immediately lethal

Source: Caplan, 1982

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HCN is very fast acting, producing symptoms within minutes after inhalation of only milligram quantities. In general, a few breaths from a contaminated atmosphere or even a single breath may fell a man. Breathing may continue at greatly increased volume for a brief period, but death occurs almost immediately. In nonlethal situations, the symptoms of ordinary anoxia are seen more clearly. These include giddiness, headache, heart palpitations, difficult or irregular breathing, and ultimately unconsciousness. Death usually occurs within 1 hour but may be delayed up to 3 hours.

Irritants--The generally recognized irritants released from plastic pipes under conditions of thermal degradation or combustion are HCl, aldehydes, epoxides, and miscellaneous other gases.

Large quantities of HCl are released from burning PVC or CPVC, even below the temperatures at which the polymer chains break down. Levels of atmospheric HCl of 1,300 ppm or higher are reportedly lethal to animals and humans (NIOSH, 1980). Even short exposures at levels as low as 50 to 100 ppm provoke adverse physiological responses in humans (Tewarson, 1979). It has been shown that dilution of smoke evolving from burning PVC to a point where CO was not at lethal levels still caused delayed deaths in test animals. Under these conditions, pulmonary edema and hemorrhaging in the lungs of deceased animals were observed, implicating HCl as the causative agent. CPVC releases less HCl in fires because less hydrogen is available for coevolution with chlorine.

Aldehydes and oxides may be released from combustion products of plastic pipes. All aldehydes are irritants; some, such as acetaldehyde and paraldehyde, also have narcotic properties. No chronic ill effects are noted for these chemicals (Solomon, 1957), except for formaldehyde, which is a carcinogen in animals and could be in humans (Occupational and Health Reporter, 1983; Perera & Petito, 1982). Ethylene oxide can cause intense irritation of skin (blistering), mucous membranes, and lungs, including production of pulmonary edema, but it is also a systemic toxin. In high enough quantities, it can cause death from central nervous system depression

with respiratory arrest. If death occurs after several hours, the cause is pulmonary edema. If death is delayed for several days, liver and kidney damage may be the causative factors (Gosselin et al., 1976).

Other Gases--Benzene, styrene, and other aromatic compounds and their oxides appear in combustion products. Benzene is known to be carcinogenic; in humans it causes leukemia.

Nitriles are also present in some smokes, in addition to HCN. These show toxic effects similar to those produced by HCN.

Short-Term Exposure Limits--Short-term exposure limits (STEL) and acceptable maximum peak exposure data are published for a number of the more toxic components detected or possible in pyrolytic fumes from plastics. These are summarized here. Time-weighted (8-hour) average (TWA) exposure levels are included for cases where no other limits have been set (see Table IV-47).

d. Toxic Products from Metal Piping in Fires

The use of metal piping in the proposed applications is not completely risk-free with respect to fires. Small amounts of pipe joint compounds, such as litharge, a putty containing lead compounds, linseed oil, and clay, can be a source of lead in the atmosphere during fires. Assuming about one-quarter inch of thread is typically exposed, the quantities of pipe joint compound involved probably amount to no more than a few grams in any one building.

Polytetrafluoroethylene (Teflon) tape is also commonly used to seal metal pipe joints. This plastic caused delayed deaths in animal experiments (PRC, 1980). One laboratory found it to be 40 to 200 times more toxic than most of the other 10 synthetic and natural materials tested during the validation of the NBS toxicity screen (Benjamin et al., 1982). Although these results have been questioned, the possibility that relatively small

Table IV-47

SHORT-TERM EXPOSURE LIMITS
COMPARED WITH TIME-WEIGHTED AVERAGES

Compound	TWA* (ppm)	STEL* (ppm)	Acceptable Peak Exposure* Concentration (ppm)	Duration (minutes)
Acetic acid	10	15		
Acrolein	1.0	0.3	30-100+	10
Benzene	10		50	10
Carbon monoxide	50**			
Cresols	5			
Formaldehyde	2		10	30
Formic acid		5	1,500++	
Hydrogen chloride	5		500+	10
Hydrogen sulfide			50	10
Naphthalene	10	15		
Phenol	5	10		
Styrene	100		600	5
Sulfur dioxide	5	5		
Toluene	200		500	10

*From ACGIH (1982) unless otherwise specified.

+From Terrill et al. (1978).

**From Arena (1979).

++From Alarie (1982).

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changes in test conditions can make a big difference in the outcome was acknowledged (C&EN, 1983). A more probable source of combustion products from this plastic in fires, because of the larger amounts involved, are Teflon-coated kitchen utensils.

Sections of hot-water metal pipes and some types of plastic (especially PB) are encased in fiberglass or polyurethane tubing to reduce heat loss. Polyurethane (or other) tape with sticky backing may also be used for insulation in systems employing a circulating hot-water pump. Considering all other sources of polyurethane likely to be present in room furnishings, the contribution of burning insulation and tape to the total will probably be negligible.

6. Risk Assessment

Fires contain a variety of combustion products, most of which, in sufficient quantities, can produce death or impair health. Since the hazards to exposed individuals in a fire situation are likely to involve an interplay of several of these factors, predicting the causative agent or factor having the predominant impact on human health can be difficult. Epidemiological data from real fires are insufficient for concluding anything other than that CO is the major cause of fire death, and that HCN or other toxic gases may contribute to death to some currently unquantifiable extent, but certainly no more than 20%--and probably on the order of 10% or less, based on currently available information.

We take the following approaches to the problem in this section: (1) analysis of combustion products from each plastic pipe and modeling their rates of formation in various scenarios for comparison with known threshold exposure levels for them, and (2) animal toxicity studies that are reproducible and for which data on control natural products, such as Douglas fir, are available for reference. The shortcomings of such approaches have been alluded to earlier, but insofar as investigators have not yet identified a "right" way to test plastics for their toxic potential in fire

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situations and each test has relevance to some fire scenario, none really can be omitted from consideration at this time. However, these tests relate to short-term measured effects (such as irritancy, lethality, lung injury, etc.). No animal data address the question of whether pipe plastics might cause injury to distant organs or chronic effects such as cancer or, for that matter, whether smoke from Douglas fir or other natural products might do likewise. All that can be done in this regard is to compare data on yields of combustion products with threshold limit values (TLVs) to determine whether risks of harm to humans might exist.

In regard to PB pipe, the only test results we have found are those of Hilado and Huttlinger (1983), indicating that (based on observations of incapacitation and of death) such pipe was less toxic to mice than the same quantity of Douglas fir pyrolyzed under conditions of rising temperature without forced air flow. Such data suggest a low order of toxicity for this polymer compared with other building materials likely to be present in homes and furnishings. It would have been informative if the test had included experiments with forced air flow to see whether the availability of high oxygen levels might favor the generation of significant amounts of more toxic combustion products like acrolein and ethylene oxide; analytical data on the combustion products of PB pipe as a function of oxygen supply are also unavailable.

Although PB pipe or the homopolymer has not been tested in the method developed at the University of Pittsburgh, which tends to be more sensitive than others in regard to some plastics (Benjamin et al., 1982), PE was tested (Alarie, 1982). The authors classified PE as "more toxic than wood" but not markedly so. We would expect PB to show similar potency in this test. Considering (1) the very small amounts of PB, perhaps 10 to 20 pounds at most, that will be used in residences, fire-rated or non-fire-rated, relative to the total amounts of other combustible materials present, and (2) the use of the pipe to convey water, the likelihood that PB pipe would pose any fire toxicity health hazards appears to be exceedingly small, to the point of being unquantifiable.

Combustion tests on ABS pipe for DWV systems, either for identification and quantification of the products or for animal toxicity, are almost nonexistent. Rigby (1981) has identified acrolein and acidic gases from ABS to pose the greatest hazard, based on analytical determinations of the combustion products given off at 300° F in comparison with the TWA (8-hour time-weighted average exposure) values published for those products. His data are empirical, limited by expediency in some respects, and assume an independent but strictly additive factor for each volatile. His analysis suggests that combustion of ABS and PVC plastics would be of concern in confined spaces. Although this is probably true, the lack of data for natural products treated experimentally in the same way makes the data from this analysis unusable for the problem at hand.

Animal test data developed by Kimmerle (1976) in the DIN apparatus, data by Hilado (1977) in the NASA-USF test, and data reported by Levin et al. (1982) for the NBS test indicate that the quantity of ABS required to produce a measurable effect is within a factor of 2 (higher or lower depending on the test) of the quantity of wood required to produce the same effect. In contrast, ABS was appreciably (by an order of magnitude) more toxic to mice than was Douglas fir in the University of Pittsburgh test (Alarie/Anderson, 1981).

Of any of the toxicity tests used, the Alarie/Anderson (1981) data put ABS, compared with Douglas fir as the reference material, in the most unfavorable light. How real this assessment is is unclear since test results with their method disagree markedly with those of others in ranking the relative toxicity of many of the materials tested (e.g., based on LC_{50} values, Douglas fir in their test is approximately 2 to 3 times less toxic than it is in the NBS method, whereas sheep wool is 20 times more toxic).*

*This disagreement is not unique. Where any of the animal test methods in use have been compared with any others, agreement has been poor (Benjamin et al., 1982).

Nevertheless, to be conservative, we will assume that there may be some possible circumstances in which ABS will be more toxic than other combustible building materials present to the degree that the Alarie/Anderson data suggest. We will also assume as before that there will be 200 lb DWV plastic used for every 18,800 lb of wood in fire-rated construction, as there is in residences for purposes of this estimate. We assume further that, because of the particular use and location of the pipe in the building, for ABS to be consumed other materials will be burning simultaneously, let us say, in equal amounts. Thus, 200 lb of ABS, being 10 times more toxic than wood, is equivalent to 2,000 lb of wood in a smoldering fire. ABS in a DWV system would, under such circumstances, contribute 10% of the total fire load.

This example is strictly hypothetical but does suggest that, in some few cases, ABS combustion may make a contribution to the overall hazard from a fire. The estimates are not derived from studies with ABS pipe, and the findings of Anderson (see Appendix B) in the studies in progress at A. D. Little will indicate whether this estimate is too conservative or is realistic.

For PVC pipe, it seems fairly clear that the greatest hazard will result from stripping of HCl from the polymer. Rigby (1981) cites cyclization of the ethylene residues to benzene as also being of concern; he tested plasticized PVC samples. Studies with the pure homopolymer (Boettner et al., 1969) suggest that the ratio of benzene to HCl given off may vary from 0.2% to 0.7%, depending mainly on whether or not combustion is complete. If we accept the Acceptable Peak Exposure data as providing a truer assessment of the relative toxicity of combustion gases in fire than do TWA values, as Rigby used, the benzene is about 30 times more toxic than HCl. Multiplying this factor by its percentage relative to HCl indicates that, in smoldering fires, where PVC combustion may be important at lower temperatures (not all the PVC burns), benzene toxicity is still of less concern than HCl. For fire fighters entering a building in later stages of a fire, the above data and analysis suggest that this may not hold true, and exposure to benzene at these levels, if it occurs on one or more occasions,

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may be of as much or more concern than HCl, because of its known carcinogenicity.

On the basis of animal toxicity data on combustion products, as in the case of ABS, PVC polymer would probably be rated as comparable to wood. Again, the University of Pittsburgh test shows PVC to be about 10 times more toxic than Douglas fir and, using his factor of 7 for extrapolating from mice to humans, Alarie estimated the relative increase in hazard as closer to 70-fold.

Several factors should be recognized in considering the significance of this estimate for DWV pipe in real fires. First, DWV pipe was not tested; and, since differences in volume, surface area, or length, as well as weight, can influence test results, such testing is needed. Second, the 7-fold difference in PVC toxicity between mice and humans is based on smoke toxicity studies with a plasticized PVC sample and HCl, CO, and HCN gases in cannulated (to simulate breathing in humans) and noncannulated (breathing through nose only) mice. In these studies, the PVC sample and HCl, respectively, produced 7- and 9-fold lower LC_{50} values (that is, were much more lethal) to the former whereas HCN and CO were the same. Although CO is the primary cause of death from Douglas fir and HCN from wool, natural materials such as these were not tested in a similar manner, and such information would have been useful for verifying that the 7-fold factor in the extrapolations applies to Douglas fir (or other appropriate building material) as reference. Third, DWV pipe is not the only potential source of PVC combustion products in buildings. PVC is also used in floors, wallpaper, and electrical cable, among other things. All of these materials are far more likely than DWV pipe to be near a source of heat sufficient to initiate thermal degradation of PVC. Data were not available for estimating the extent to which PVC pipe in DWV applications might add to the range of total combustible PVC likely to be present in buildings. Certain kinds of PVC, such as electrical-grade material, are likely to be consumed earlier in fires. Fourth, the calculations by Alarie do not take into account possible differences in HCl-exposure levels from pyrolyzed PVC in real fires, where the much greater surface area of walls is likely to absorb appreciable

amounts of the gas (O'Mara, 1976) relative to animal toxicity studies involving glass exposure chambers with much smaller dimensions. Fifth, it is difficult to conceive of anyone's staying 10 to 15 minutes in a room in which smoke containing HCl, a highly irritating gas, would build up to lethal levels unless escape were physically or physiologically impossible. Escape would be attempted long before such levels were reached and would be relatively simple in 1- and 2-family residences (Benjamin et al., 1982). It may be that irritants can disorient and confuse humans, but only if they are engulfed in smoke or are unfamiliar with their surroundings. We need to know whether the HCl would alert occupants to problems sooner than such disorientation would occur. In fire-rated structures with proper ventilation, occupants are not likely to be exposed to the fumes before an actual fire breaks out.

These comments are not intended to disregard totally the possibility that PVC pipe combustion may make a significant contribution to fire toxicity under some conditions, as put forth by Alarie. Data on PVC pipe combustion toxicity now being developed may help delineate its potential hazard better. In fire-rated construction for which expanded use is being considered, if adequate safety factors are built into chase designs to protect occupants from PVC fumes, and if fire fighters use proper masks to remove HCl and benzene from the breathing atmosphere, the hazards are probably not appreciable but neither are they totally negligible. Thus, PVC pipe, like ABS pipe, compares less favorably with metal pipe, even galvanized steel with Teflon tape or white putty used in installation.

CPVC pipe appears to be less toxic than PVC pipe to mice in the one animal toxicity study reported. Considering this finding and the small quantities required for water supply lines, its use in this application should pose minimal concerns over fire toxicity hazards. For DWV pipe, involving much larger quantities, more test data are needed and are being acquired (Anderson, 1983). Our assessmert of relatively low risks from CPVC smoke toxicity in the proposed expected uses of plastic pipe should be reevaluated when test results are in hand.

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7. Countermeasures

Results to date suggest that, if indeed a unique toxicity problem exists, it will most likely be the result of evolution of HCl from PVC. It would be unwise to conclude, however, that problems with other toxicants are assuredly absent. Nor should the existence of a definite problem with HCl from PVC plumbing systems be regarded as demonstrated beyond doubt. It would probably be wise to take precautions regarding potential problems with PVC toxicity until further evidence indicates otherwise; in a similarly tentative vein, other concerns about toxic combustion products from plastic pipe formulations could be set aside until further evidence dictates a renewal of concern.

Countermeasures for HCl emissions naturally focus on reduced yields (and/or increased thermal stability) through changes in pipe-compound formulations, on methods for reducing the heat load in a fire situation, and on limiting the leakages of HCl from pipe chase enclosures. In the last case, the natural tendency for HCl to plate out of the gas/airborne phase suggests attractive approaches to mitigative techniques. To reduce heat loads on plumbing, isolation from other utilities could be effective. The plastics industry is constantly striving to improve products along the lines of the first suggestion above.

It is possible that metal pipe and fittings could be used on the living-quarters side of the plumbing system--in the bathrooms, kitchens, etc.--and be connected to a plastic-pipe plumbing system that is within the fire-resistive construction. This approach would eliminate possible direct fire exposure of the exposed or accessible PVC or CPVC pipe and fittings. This hybrid system should also be tested for its fire rating; beyond that, there is some question of heat conduction to the interior of the wall and smoke generation from the plastic-plumbing part of the system. There are other ways of using noncombustible parts for protection or as part of the system.

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The isolation approach has considerable merit. Isolation of plumbing from other utilities, particularly electric and gas, can minimize the chances of in-chase fires involving plastic-pipe elements. Increasing thermal insulation and limiting the air available makes this method especially attractive; it is fairly simple and straightforward to accomplish, and it is a desirable countermeasure from other fire safety standpoints as well.

In conventional construction, the dispersion of smoke into occupied spaces from concealed spaces is virtually impossible to predict because it is governed by myriad leaks whose number, location, and size are typically unknown. Nevertheless, the concentrations of leaked gas and smoke could be minimized by ventilation, and ventilation can be achieved without enhancing fire spread by venting through flame traps.

In principle, the countermeasure options should permit any desired degree of protection against toxic products to be achieved, and it should be the responsibility of pipe manufacturers and builders to develop and install countermeasures to an acceptable level of performance. Unfortunately, acceptable levels of toxic products have not been established for fire emergency situations, and there are no accepted performance tests available to certify the various countermeasures.

8. Conclusions

Although we have not been able to demonstrate without equivocation the existence of unique or special hazards due to the combustion products of plastic pipe, neither have we succeeded in ruling them out.

In a nonideal system where some countermeasures are required to achieve an acceptable level of performance, it is important to understand precisely the meaning of the proposed building code changes in order to evaluate their effect on the system's performance. In this respect, we have been concerned with the interpretation of the entries in the pipe use matrix of the request

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for proposals under "fire rated construction (exposed locations)," where no use of plastic pipe is permitted and none is proposed. A literal interpretation "that no plastic pipe or fittings shall extend into a room through or beyond the thermal insulation responsible for the fire rating" provides a well-defined case for evaluation of the fire threat and also simplifies the inspection and enforcement problem. However, if the interpretation prohibits plastic plumbing above false ceilings or passing through rooms but permits plastic connections through fire-rated walls to fixtures, the problem is complicated by the variety of installations that can be envisioned and the uncertainty in the amount of plastic introduced into the part of the building vulnerable to fire. For fire spread, the performance criteria approach circumvents this interpretation problem; but when evaluating the toxic hazard, the lack of accepted performance tests removes this approach as an option. In the three scenarios examined, the two dealing with fire-rated construction assumed the literal interpretation and did not try to estimate a toxic contribution from an uncertain amount of plastic pipe and fittings extending into the room. Consequently, and particularly in view of the current muteness of codes on the subject of smoke toxicity, we conclude that special precautions should be taken to minimize this potential for harm until the remaining uncertainties can be resolved. Clearly, further research is needed to identify the significant issues with confidence and, from these issues, to develop realistic test criteria. One hopes that such research will, in time, lead to revisions in the code to cover the safety aspects of combustion product emissions, not just to regulate plastic-pipe industries, but to provide a comprehensive and balanced control over all life-threatening materials introduced into the built environment.

As noted by the NFPA Committee on the Toxicity of the Products of Combustion (NFPA, 1982), the current tests for toxicity of products of combustion are inadequate for regulatory purposes. Several test methods appear to succeed in achieving realistic conditions for one or another of the stages (or modes) of fire behavior, but none can claim to cover the full range that the problem seems to demand. Certainly, validation against results measured in "real" fires representing an appropriate set of

practical scenarios would have to be a part of establishing any particular method as a standard. We may be years away from this knowledge.

In the meantime, it may be necessary to resort to conservative countermeasures (such as the Canadian device for closing off wall penetrations) or combined metal/plastic systems, and to test these countermeasures at full scale, with appropriate pressure differentials applied, in wall assemblies much as has been the practice typified by the ASTM E-119. Chemical analysis can be used to monitor the concentrations of known or expected toxicants, but it may be necessary to include animals to ensure that an unsuspected toxicant of life-threatening concern has not gone unnoticed by the nonbiological methods of atmospheric monitoring.

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F. Fiscal Impacts

The potential fiscal effects of expanded use of plastic plumbing pipe involve:

- Changes in the cost of housing
- Changes in the cost of providing public services
- Changes in employment.

Each of these is discussed in this section.

1. Effects on Cost of Housing

For a typical new single-family dwelling unit built under the current code, plumbing costs run about $600 for materials and $500 for labor. The materials cost calculations are based on a copper and PVC water supply system and ABS DWV system (see Tables II-3 and II-4). Labor costs are derived from NAHB (1981), General Construction Estimating Standards (1976-77), and Service Plumbing (1979). This total plumbing cost of $1,100--marked up 15% to cover builder's overhead and profit--represents about 1% of the 1983 median sales price of $115,400 for existing single-family homes in California (California Association of Realtors, 1983).

The materials substitutions that are likely to occur in response to the proposed changes to the code allowing expanded use of plastic plumbing materials would reduce per-unit materials costs by about $100 and labor costs by about $50. These calculations are based on the use of PB in place of copper for water supply inside the unit. Any other substitutions of newly permitted plastics for metals or other plastics would increase the

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plumbing costs.* Assuming that the entire construction cost saving of $150 plus 15% builder's markup is passed on to consumers, the median sales price of single-family homes in California would drop by 0.2%.

For multiple-family dwelling units greater than two stories in height, the proposed code change would reduce plumbing construction costs by a total (materials and labor) of $425 per unit. This saving derives primarily from the use of PB in place of copper for inside water supply and the use of ABS in place of no-hub cast iron for inside DWV systems. This estimate is somewhat high because to achieve the required 1-hour fire rating in buildings higher than two stories with plastic pipe would require some additional protection against horizontal fire spread, such as installing metal flanges around the plastic pipe where it penetrates the fire wall. Assuming a 15% markup for builder's overhead and profit and a 20-year life for the plumbing system, the $490 cost saving if passed on in its entirety to the renter, would lower the monthly rent on a unit by less than $3.

In addition to the construction or capital cost of a plumbing system reflected in the sales price or rent of a dwelling unit, there are annual maintenance costs and replacement costs that will be incurred by the homeowner over the life of the plumbing system. Metal plumbing systems are subject to corrosion, which leads to clogs, leaks, and ultimately replacement of the system. The present value of expenditures for repairs, corrosion treatment, and replacement of a metal plumbing system in a single-family dwelling over the last 10 years of the 30-year service life of the system has been estimated at about $700 (Journal AWWA, 1983). Comparable maintenance data are not available for plastic plumbing systems.

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* Materials costs for various plastics and metals are from Plumbing Suppliers Survey (1983); comparative labor hours are derived from NAHB (1981), Service Plumbing (1979), and General Construction Estimating Standards (1976-77); a.erage hourly wage rate (including fringe benefits) for plumbers in California is estimated at $27.00 (Adams, 1983).

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However, plastic plumbing used in public water systems has experienced failures, including cracks, splits, stress fractures, pinholes, and shear breaks requiring replacement of the system at costs ranging from $208,000 to $38.25 million per community (Leonardini, 1983).

The substitution of one plastic for another in response to the proposed code changes would not substantially affect maintenance or replacement costs for the system. Substitutions of plastic pipe for metal pipe would eliminate the costs of corrosion control to the homeowner. The present value of corrosion treatment costs for a completely metal system over a 10-year period is estimated at about $60 (Journal AWWA, 1983). Since plumbing systems in new dwelling units are typically a combination of metal and plastic, the savings due to substitution of plastic for metal would be somewhat less than this amount. There are no data that convincingly demonstrate that metal and plastic systems differ significantly in frequency of damage or failure, cost to repair, or service lives. The only generalizations that can be made are that maintenance costs are lower and service lives longer for plastics than metals in areas with corrosive water, and that improper installation appears to lead to pipe failures more frequently with plastics than metals. Plastics are also less subject to clogging than metals, but when clogged they are more susceptible to damage from snakes, de-rooters, and other mechanical cleaning devices and to damage from chemical cleaning products. The replacement cost of an all-plastic system installed under the proposed new code would be $150 less per single-family dwelling unit and $425 less per multifamily unit than the replacement cost for the combination metal and plastic system that would be installed under the current code.

In conclusion, the proposed code change allowing expanded uses of plastic plumbing materials would slightly reduce the life-cycle costs of the dwelling's plumbing system to a homeowner. The lower replacement cost, amounting to $150 for a single-family unit and $425 for a multifamily unit, would account for most of this saving. In addition, in areas with corrosive water, maintenance costs would be a maximum of $60 less. Based on a 20-year service life for both metal and plastic systems and 10% discount rate, the

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present value of the total life-cycle cost savings due to substitution of the newly approved plastics for metals would therefore amount to about $85 for a single-family unit and $140 for a multifamily unit.

2. Effects on the Costs of Public Service Provision

The expanded use of plastic plumbing materials in response to the proposed code change could affect the costs of providing public services and facilities in local jurisdictions that adopt the state code changes in two general ways. First, local administrative costs could be affected. Local jurisdictions, particularly those in areas with corrosive water, are likely to have to process fewer requests for variances from the current code to allow the use of plastics since most of these plastics would be permitted under the new code. Offsetting this saving would be the additional administrative costs to amend the local fire safety code and other relevant codes, where they exist, to include provisions specifying appropriate methods, procedures, and the like relating to the use of the newly permitted plastics. Building inspection costs might also increase if more attention must be given to proper installation with plastics.

The second category potentially affected would be the cost of providing public services. Expanded use of plastic plumbing materials in residences and commercial establishments would decrease the cost of corrosion in municipal water systems. Corrosion-related costs for the water distribution system in one municipality were estimated at $400,000 annually (Journal AWWA, 1980). Additional fire protection costs might somewhat offset the corrosion savings. However, because plastic pipes are not a source of ignition and would contribute insignificantly to fire spread and severity (see Section IV-D for a discussion of combustibility and fire spread), any additional local fire protection costs would be negligible.

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In summary, the expanded use of plastic plumbing materials would be likely to lower the costs of providing water service. The costs of providing other public services would not be affected, and the effects on local administrative costs would probably be offsetting.

3. Effects on Employment

The plumbing materials substitutions that are likely to result from the proposed code change allowing expanded uses of plastic plumbing materials would directly affect manufacturing and construction employment. Specifically, fabricators of metal and plastic pipe and fittings in the manufacturing sector and plumbers in the construction sector would be affected. In addition, the materials substitutions would indirectly affect other industries in the manufacturing sector, such as plastic-resin producers that provide the materials and services that are inputs to the pipe fabrication process. Finally, the materials substitution would, by affecting employment in pipe fabricating and supporting industries, affect employment in the service industries that provide goods and services such as food, clothing, and entertainment to their employees.

The changes in plastics use that are likely to result from the proposed code change break down roughly as follows:

- PB use would increase by 6.1 million pounds annually
- ABS use would increase by 5.7 million pounds annually
- PE use would decrease by 1.4 million pounds annually.

The PB and ABS use figures are high estimates because in some circumstances CPVC would be used instead of PB for water supply and CPVC and PVC would be used instead of ABS for DWV systems. However, because CPVC is much more expensive than the other plastics and PVC is not a traditional DWV material in California, we assume that their use would be so limited that it would not significantly affect the employment analysis.

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The net increase (i.e., PB and ABS increases less PE decrease) of 10.4 million pounds in use of plastics in California would represent about 0.4% of the total production of plastic pipe, tubes, and fittings in the United States in 1980 (PPI, 1980). Based on the total sales of $1,583 million for these products in 1980 (PPI, 1980) and a productivity of $98.3 million/thousand employees for workers in the plastics building and construction products industry (U.S. Census, July 1980), the 10.4-million-pound increase in plastic materials usage would directly create about 60 jobs nationwide in the fabrication of these products. Assuming an employment multiplier of 2 for the indirect and secondary effects, the additional plastics usage would also create an additional 120 jobs in the supporting manufacturing industries and service sector combined. Because of the number of assumptions on which the employment impact calculations are based, these estimates may be off by a factor of 2 to 3. Data on total production and sales of plastic plumbing materials in California are not available. However, because total 1982 employment in the production of miscellaneous plastics products numbered 482,000 (California EDD, 1983), any proportion of the estimated additional 60 jobs, created nationwide in this industry that were located in California even if underestimated by a factor of 3, would insignificantly affect state employment in this industry.

The effects of the total 11.8-million-pound change in plastics usage would, under our assumptions, affect the 1980 market shares (PPI, 1980) of specific plastics as follows:

Plastic	1980 Market Share	Market Share Under New Code
PVC	71%	70.88%
PE	23	22.75
ABS	5	5.19
CPVC	0.3	0.28
Others	0.7	0.89

Although the precision of these numbers is exaggerated by the number of significant figures shown, the changes in market share are clearly insignificant.

The increased use of plastics as discussed above would be likely to result in a decrease in the use of metal plumbing materials as follows:

- Copper usage would decrease by about 20.3 million pounds annually
- Cast iron usage would decrease by about 32.8 million pounds annually.

Total U.S. production in 1980 of cast iron pipe and fittings was 2,026.4 thousand tons (U.S. Census, June 1980). Comparable figures for copper are not available. Based on an average productivity of 122.5 thousand tons per thousand employees for workers manufacturing cast iron pipe and fittings (U.S. Census, June 1980), the total 53.1-million-pound decrease in metal plumbing materials usage would result in a direct loss of approximately 220 jobs nationwide in the production of these materials. Using a multiplier of 2 for indirect and secondary employment effects combined, an additional 440 jobs in the supporting manufacturing and service industries would be lost nationwide. Again, these employment impact estimates are subject to considerable uncertainty. However, because metal pipe manufacturing plays an insignificant role in California's economy,* virtually none of the estimated employment loss would be borne by the state.

The effects of the proposed code change and resulting plumbing materials substitutions on employment in the construction sector would be limited to effects on employment of plumbing contractors. Employment in other construction occupations, such as engineers and architects, developers, construction workers, and other special trade contractors (e.g., electricians), probably would not be affected because no significant change in the level of residential and commercial construction is expected to result from the proposed code change (see the Section IV-F-1 for a discussion of the effects of the proposed code change on the demand for housing in California).

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* In 1982, 0.079% (66,000 employees) of the total nonagricultural employees in California were employed in the fabrication of metal plumbing and heating products (California EDD, 1983).

Plumbing employment could potentially be affected in two ways. First, because plastic plumbing materials generally take less time to install than metal plumbing materials (see discussion in Section IV-F-1), the substitutions of plastics for metals that would be likely to occur under the proposed new code would increase the productivity of plumbers. However, because plastic-for-metal substitutions for the bulk of new residential and commercial construction would be limited to the inside water supply system and because substituting plastic for metal in this system would reduce installation time by about 20%, from a total installation time that accounts for about 45% of the time required to install an entire plumbing system (i.e., water supply and DWV inside and outside), the plastics-for- metals substitutions resulting from the proposed code change are not likely to increase plumber productivity substantially.

Second, because plastic plumbing materials are generally easier to install than metal materials, homeowners may be more likely to repair and replace their plumbing systems themselves and consequently may hire plumbers less frequently. In the United States in 1980, about 75% of expenditures on owner-occupied one-housing-unit properties for labor and materials for plumbing maintenance and repairs and construction improvements were payments by the owner to contractors (U.S. Census, 1981).* Let us assume that, under the proposed new code, homeowners will do the plumbing system repairs and improvements themselves about 75% instead of 25% of the time. If we further assume that repair and replacement work accounts for about 20% of a plumber's work, then the greater propensity of homeowners to do these plumbing jobs themselves could reduce a typical plumber's work by as much as 10%.

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* Since this percentage does not reflect the value of the homeowner's time spent doing plumbing jobs, it overestimates the actual percentage of jobs done by plumbing contractors.

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In conclusion, the employment effects of the expanded use of plastic plumbing materials would be as follows. The substitution of plastics for metals would be likely to create approximately 180 jobs nationwide in the industries fabricating plastic pipe and fittings and in supporting manufacturing and service industries. Offsetting this increase would probably be a loss of about 650 jobs nationwide in industries fabricating metal pipes and fittings and in supporting manufacturing and service industries. These estimates are probably uncertain by a factor of 2 to 3. Even accounting for this uncertainty, the effects of these estimated national employment changes on employment in California would be negligible. The materials substitutions are likely to have virtually no effect on employment in the construction sector in California, except perhaps for plumbing employment. A typical plumber's work may decrease by as much as 10%.

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G. Other Impacts

In addition to the major project areas discussed above, SRI investigated a wide range of other possible impacts. By a coarse prescreening process, we eliminated impacts that were judged as extremely minor or very unlikely to occur with expanded uses of plastic plumbing pipe. The remaining project areas discussed in this section are:

- Energy consumption
- Use of nonenergy resources
- Ecological effects of leachates
- Noise
- Pollution from shifts in production

1. Energy Consumption

The production of both plastics and metals is very energy intensive. Therefore, because a change from use of metals to plastics for plumbing systems could have a significant impact on energy consumption, this possibility was investigated. Only piping was considered; no attention was given to fittings. Also, all-metal and all-plastic plumbing systems were the only ones considered; the difference between these two cases would be larger than for most alternatives and thus would overstate the maximum.

a. Energy Consumed in Manufacturing Pipe

Table IV-48 shows the energy consumption per pound of pipe of each type of primary energy used to manufacture plastic (represented by PVC), cast iron, steel, and copper pipe. The indicated consumption includes the primary energy used to generate the electricity that is in turn used to manufacture the materials. For PVC, approximately one-fourth of the input energy is in the form of feedstock. The feedstock for plastics is

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Table IV-48

ENERGY CONSUMPTION FOR PRODUCING PIPE
(Thousands of Btu per Pound)

	PVC	Cast Iron	Steel	Copper
Natural gas	15	5	4	22
Petroleum	15	2	2	22
Coal	7	6	10	15
Hydro and nuclear	3	1	1	5
Total	40	14	17	64

Source: Bider et al. (1981), DHCD (1979), Battelle (1975).

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approximately 60% natural gas liquids and 40% petroleum. However, natural gas liquids are conventionally included in petroleum supplies because they are a substitute for petroleum in the production of liquid fuels. Natural gas liquids are counted here as petroleum.

b. Weight of Pipe for Typical House

The drain, waste, and vent (DWV) pipe used in plumbing systems was formerly largely cast iron, but ABS and other plastics have already been approved for some applications and are in widespread use. Table II-4 in Section II shows the derivation of the weight of plastic or cast iron DWV pipe for a moderately large house as used in this energy analysis. The water supply pipe is generally copper but may be galvanized steel. Table II-4 also shows the derivation of the weight of plastics, steel, or copper water supply pipe for such a house.

c. Energy Content of House Piping Systems

Table IV-49 compares the energy content of three alternative piping systems for a typical house: (1) plastics for both water supply and DWV systems, (2) steel for water supply and cast iron for DWV systems, and (3) copper for water supply and cast iron for DWV systems. The total energy consumption for each of the metal systems is nearly double that for the plastic system. However, the plastic piping uses over 60% more petroleum than the steel/cast-iron piping, and about 15% more than the copper/cast-iron piping. The differences in petroleum use are not very significant in relation to the inherent uncertainties in determining the petroleum consumption or weights of pipe.

d. Significance of Differences in Energy Content

The total energy saving of approximately 14×10^6 Btu/house (Table IV-52) for plastic piping compared with metal piping is equivalent to approximately 2 barrels of oil, while the increase in the petroleum consumption of 2.8×10^6 Btu compared with the steel/cast iron system is

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Table IV-49

ENERGY CONSUMPTION FOR PIPING SYSTEMS
FOR A MODERATELY LARGE HOUSE
(Millions of Btu)

	Petroleum	Total Energy
Plastic (PVC)	7.2	19.0
Steel water supply	0.9	8.0
Cast iron DWV	3.5	24.8
Total	4.4	32.8
Copper water supply	2.7	7.7
Cast iron DWV	3.5	24.8
Total	6.2	32.5

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equivalent to approximately 0.4 barrel of oil. Assuming construction of 90,000 houses per year and 60,000 units at one-half the savings (because substantially less pipe is used), the annual total energy saving is 1.7×10^{12} Btu, while the increase in petroleum consumption is 0.34×10^{12} Btu (50,000 barrels). For comparison, the annual total energy saving is about 0.14% of the residential energy use in California in 1979 ($1,246 \times 10^{12}$ Btu), and the increase in petroleum consumption is about 0.01% of total petroleum use ($3,623 \times 10^{12}$ Btu or 620 million barrels) (U.S. Department of Energy, 1981).

The California appliance efficiency standards, a relatively minor energy conservation measure, were estimated to save 24×10^{12} Btu per year by 1985 (California Energy Resources Conservation and Development Commission, 1977), over 10 times as much as the annual total energy saving associated with installing plastic pipe in new houses.

Examples of other minor energy convervation measures are: (1) added insulation for refrigerators--1.8×10^{6} Btu per year, or 36×10^{6} Btu over the life of the refrigerator; (2) adding one more inch of insulation to a gas water heater that already has an inch of insulation saves 4×10^{6} Btu per-year, or 40×10^{6} Btu over a 10-year life of the heater (Mathematica, 1975). Thus, the energy saving of 14×10^{6} Btu per house for plastic piping is a fraction of the savings expected from minor energy conservation measures.

This analysis indicates that the energy impacts of approving additional applications for plastic piping system are not significant.

2. Use of Nonenergy Resources

The strategic materials implications related to expanded applications of plastic pipe include increased petroleum consumption to produce the various plastics and the potential to reduce U.S. consumption of copper and

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zinc (the principal metal used in galvanizing steel pipe). The issues of total energy savings and additional petroleum consumption were discussed in the preceding section.

With regard to galvanized steel and copper pipe, the principal metals of concern are zinc and copper. Although the United States imports significant amounts of each and maintains a small copper stockpile, the U.S. reserves of both metals are large. Current U.S. reserves of copper are estimated at 90,000 tons, a 40-year supply at current consumption levels, and 51,000 tons of zinc, a 62-year supply (U.S. Department of the Interior, 1983). A number of zinc smelters have been closed because of the inability or lack of desire on the part of the operators to meet pollution control standards. Because copper pipe is considerably more expensive than galvanized steel pipe, the principal effect of increased use of plastic pipe would be incremental displacement of zinc and steel.

On the basis of this cursory investigation, there appear to be no significant strategic materials implications of more widespread use of plastic pipe.

3. Ecological Effects of the Leaching of Plastic Pipe Materials

The possibility that compounds leached from plastic pipes installed in dwellings might present a risk to the natural environment was considered. As described in Section IV-A, materials that do leach appear in the domestic water supply and wastewater pipes in very low concentrations. Generally, these concentrations and the cumulative amounts that could be released to the natural environment are very small compared with other known sources, especially because of the great dilution that would occur in water bodies. Therefore, the installation of additional plastic pipe in dwellings is very unlikely to be a significant threat to the natural environment. Likewise, because very few of the compounds are a health risk within the household plumbing (see Section IV-B), the large dilution that would occur in water

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bodies greatly reduces the human health risk from the presence of these materials in the environment. Thus, this consequence does not appear to be a concern and does not warrant further investigation.

4. Noise

Loud noise arising from the movement of water in plastic pipe has been mentioned in numerous anecdotal accounts. However, no empirical data related to the incidence of this apparent characteristic of plastic pipe or to the noise transmission properties of metal and plastic pipe were found. As in metal plumbing systems, some of this noise may be attributed to installations in which insufficient clearance has been allowed for thermal expansion and contraction of the pipe or between the pipe and wallboard.

This apparent characteristic of plastic pipe would be an annoyance, especially in the multifamily high-rise buildings that are fire-rated and would be affected by the changes in the DWV code. However, the noise levels do not reach decibel levels usually considered necessary for a significant impact.

5. Pollution from Production Shifts

Greater use of plastic pipe would lead to an increase in the manufacture of plastic pipe and plastic pipe materials and a decrease in the manufacture of metal pipe and materials. There would also be differences in the extraction and processing of raw materials for them. Because each of these activities has characteristic pollutant emissions, there would also be some shift in such pollutant emissions, both geographically and by pollutant type.

These shifts are very difficult to estimate but in any case can be judged to be of little concern in the decision to be made. Any decreases in production at existing plants would result in fewer emissions--presumably

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resulting in an improvement in environmental conditions. Increases in production at existing or new plants have the potential to degrade environmental conditions. However, all existing and new plants must have air quality, water quality, and other pollution control permits to operate, and one must presume that discharge limits are set to protect against a significant degradation of the environment.

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V CEQA SUMMARY

This chapter covers various information not presented earlier but required by the California Environmental Quality Act (CEQA) for Environmental Impact Reports. As this document is a preliminary environmental review, this section has not been fully developed. When the draft and final versions of the EIR are proposed, it is likely to expand and some of the findings will undoubtedly change or at least be stated more confidently.

A. Significant Unavoidable Environmental Impacts

For this preliminary environmental review of a very subtle and complex proposal, SRI chose to describe our current overall conclusions about the proposed plumbing code changes and our reasons for them, without making definitive findings of significance except where they were clearcut.

First, we discovered nothing to suggest that the issues discussed earlier as the prime ones are insignificant or that other issues are dominant. The only new issue of potential significance that surfaced was the permeation of buried plastic pipe by contaminants in soil and the resulting possible public health impacts. Although the possibility that such effects could occur from permeation of water supply lines from the meter to the house is plausible, any potential problem would also occur--probably in much greater proportion--from the public water distribution system. This problem should be re-examined when better understood and if found significant should influence state policies with respect to plastic use in both public and residential systems. With

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adequate education of building inspectors on the permeation issue, improper installation of plastic water service in contaminated soils should be rare.

As to public health impacts from chemicals leaching from water pipe into potable water, we find that significant impacts are possible but unproven, both for plastic pipes--especially the chlorinated varieties--and for metal ones, specifically copper systems. If the upper ranges of possible concentrations of leachates are regularly reached, the cumulative risks to public health may be high enough to be of concern by typical standards of acceptable risk, for example, a lifetime cancer risk of one in a million. The chemicals of concern are lead from the solder in copper pipes, possibly leading to neurologic disorders, and carbon tetrachloride, perchloroethylene, and trichloroethylene from plastic (especially PVC and CPVC) pipes, possibly resulting in cancer.

Two major considerations limit the significance of the findings. First, the status of information about long-term levels of leachates is exceedingly flimsy. Reasonable further testing could resolve at least part of the uncertainty (see Section VI). Second, the risk assessment procedure is moderately conservative. If risks still appear to be of concern after concentrations are better known, more attention would need to be devoted to assuring that the assessment procedure took into account detailed properties of the chemical. Finally, thorough initial flushing would effectively mitigate the effects of the rapidly leaching materials, especially the solvents used with plastic pipe. Overall, current information does not establish an environmental preference between copper and plastic pipe, with neither clearly likely to cause a great number of deaths or serious illnesses.

For worker safety and health, a similar situation exists. Both lead from solder fumes in installing copper pipe and solvents from installing ABS, PVC, and CPVC pipe could be hazardous if plumbers have high exposures by inhalation; dermal absorption could also be significant in the case of solvents. The diseases of concern for solder fumes are related to the lead exposure and are neurologic. The solvents may also cause nerve damage, and

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they may be involved in liver damage or reproductive problems as well. However, they are not implicated in cancer unless benzene is more common than thought. Unless the NIOSH report about to be released resolves the range of exposures satisfactorily, further testing would be useful before completing the EIR. Safety issues generally favor plastic over metal, which appears to lead to more burns (hot solder and especially flux) and strains and contusions (from heavier metal pipes). PB (like PE, although its uses are not proposed for change) poses little if any worker safety and health concern. Use of gloves, other protective equipment, ventilation, and simple care will significantly reduce any potential hazards from either plastic or metal pipe, but these practices have not achieved widespread acceptance among plumbers.

Fire safety is a very real concern with plastic DWV pipe; ABS is combustible, and PVC and CPVC will at least soften and slump in lines. If these plastics are installed as direct substitutes for metal, as they already are in non-fire-rated residences, they will degrade the fire resistance of structures. The gaskets in no-hub cast iron will also fail in fires and cause the pipe to fall, leaving fire passages. But the proposed code changes apply to fire-rated, fire-resistive construction that could retain its fire rating if appropriate installation procedures are developed and enforced. In such conditions, no degradation of fire resistance would occur. This issue thus turns on enforcement, not science. The potable water pipes, kept cooler by the water inside and of much lower mass, are not a significant fire safety issue.

As with fire safety, smoke toxicity is an issue in which plastic can only be less environmentally acceptable than metal. However, whether the difference is significant is less certain. Both ABS, which seems likely to contribute the majority of pipe mass in California, and the polyolefins PB and PE produce combustion products that are not highly toxic; few if any additional fatalities or serious injuries would be likely from their combustion. PVC and CPVC both produce significant quantities of hydrogen chloride vapor in fire environments, and this corrosive material could, under certain circumstances, make a difference in the probability of human

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survival in lines. The frequency of such occurrences is clouded by lack of a generally accepted test for smoke toxicity. This problem is currently being addressed both by the State of California Department of Industrial Relations and by the State of New York. We believe DHCD should pay close attention to results from those studies, but does not need to delay a decision solely on those grounds.

No other significant adverse impacts are likely to result from the expanded use of plastic plumbing pipe if relatively simple mitigation measures are taken. Plastic drain pipes may be slightly noisier than cast iron pipe. See the following section (V-B) for further elaboration.

Overall, the SRI study team sees little evidence that expanded use of plastic plumbing pipe would cause significantly greater environmental problems than the materials it would replace. Unfortunately, lack of evidence is not the same as lack of hazard. We believe it is especially important to gather more information on leaching of chemicals from both plastic and metal pipe systems into potable water and on the exposures of plumbers to material from plastic (ABS, PVC, CPVC) and metal (copper) plumbing systems.

Table V-1 summarizes our present assessment of our relative environmental concern about pipe systems. There we show our relative degrees of concern for different materials for each of the major areas of impacts. A high rating does not necessarily mean an impact that is significant in the sense of CEQA, but does mean that the material rated seems to us more likely to be environmentally harmful then other materials on that dimension. For example, the chlorinated plastics clearly are of highest concern for smoke toxicity, but may not pose any significantly higher impacts in the proposed new DWV uses (fire-resistive construction).

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Table V-1

RELATIVE DEGREE OF CONCERN REGARDING
POTENTIAL ENVIRONMENTAL IMPACTS*

Impact Area	Potable Water				Drain, Waste, and Vent			
	Plastic		Metal		Plastic		Metal	
	PB/PE	PVC/CPVC	Copper	Galv. Steel	ABS	PVC/CPVC	Copper/ Gal.Steel	Cast Iron
Public Health	3	4	3	3	0	0	0	0
Worker Safety	1	2	4	2	2	2	3+	5
Worker Health	0	3	4	2	4	4	3+	1
Fire Safety	3	2	0	0	5	4	0	2
Smoke Toxicity	1	3	0	0	3	5	0	0
Other Impacts	0	0	0	0	1	1	0	0

*Key: 0 - No concern
1 - Considerably less concern than average
2 - Less concern than average
3 - About average concern
4 - More concern than average
5 - Considerably more concern than average

Note: High relative concern does not necessarily imply high absolute concern; significance of ratings depends on mitigation measures taken.

+More for copper, less for galvanized.

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B. Insignificant Effects

The following environmental effects of expanded uses for plastic plumbing pipe may occur but are probably insignificant by any reasonable interpretation of CEQA:

- Plastic pipe systems may fail slightly more frequently than metal systems until a body of experience with installation errors has accumulated.
- Plastic pipe will consume slightly more petroleum than metal pipe, but slightly less energy overall.
- Plastic pipe will contribute a slightly different load of pollutants to public waste water treatment systems, but the direction of impact, let alone its magnitude, is uncertain.
- Plastic DWV pipe will be slightly noisier than metal systems if installed so as to contact wall surfaces; this may be more significant than otherwise in the multifamily, fire-rated construction that is affected in the DWV code changes.
- Plastic DWV pipe could be damaged by pipe cleaning equipment, but because of its resistance to corrosion, the frequency of such cleaning should be low.
- Plastic pipe will slightly decrease the life-cycle cost of plumbing and therefore of housing, but not enough to change demand patterns or growth.
- Small shifts in employment from metal pipe manufacturing to plastic pipe manufacturing will occur.
- A small reduction in the work of plumbers will occur, mostly as a result of repair and renovation work by do-it-yourselfers.

C. Effects of Alternative Actions

In addition to the proposed project, e.g., the proposed change to the 1982 Uniform Plumbing Code (UPC) allowing certain new uses of plastic plumbing pipe as described in the Project Description, this environmental review has examined the potential effects of alternatives to the proposed project on the quality of the natural and human environment. The eventual EIR will consider alternatives as well as the project itself to provide a

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baseline for evaluating the significance of the impacts and to provide possible alternative courses of action should the proposed project create significant adverse impacts that cannot be successfully mitigated. With this goal in mind, the alternatives we have selected for analysis are no changes to the state code, partial approval of plastic pipe use, and complete rejection of all plastic pipe (that is, reversal of earlier provisions allowing certain uses of plastic pipe).

Under the no-action alternative, there would be no changes in the state code regarding the use of plastic plumbing pipe. All currently approved uses for plastic pipe would continue to be permitted and no new uses of plastic pipe would be allowed. None of the impacts attributable to the use of plastic pipe in expanded applications would be observed; any public health and worker safety and health effects of currently allowed plastic and metal piping systems would persist.

The partial approval alternative would amend the state code to permit certain new uses of plastic pipe, but not all of the new uses proposed under the project. Counting cold and hot water supply in a given application as one new use, the proposed project would change the code to permit 11 new uses of plastic pipe (i.e., 1 new use for ABS pipe, 3 for PB pipe, 1 for PVC pipe, and 6 for CPVC pipe). Considering all the possible combinations of these uses, over 2,000 partial approval alternatives are possible.

Our analyses of the environmental consequences of the proposed project have guided our selection of the subset of the partial approval alternatives to be considered in the EIR. That is, we define the partial approval alternative(s) to permit those new uses of plastic plumbing pipe that are least likely to have significant adverse effects on the quality of the natural and human environment. At present, the only partial alternative that seems reasonably certain to meet this requirement is to allow PB for hot and cold water supply both outside buildings and inside buildings that are not fire-rated or within the fire-resistive construction of fire-rated buildings. No other new uses of plastic pipe would be allowed. Parenthetically, there seems little reason to prohibit PB in exposed

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locations of fire-rated buildings as long as the penetrations of fire-resistant construction are designed to maintain the rating of that construction. The state of information on the impacts of this alternative is generally the same as on those of the metal water pipe currently allowed for these two uses. Although PB will certainly burn and metal will not, the additional risk of fire spread appears minimal, as does that of smoke toxicity. Leachates from PB have not been shown to be risk-free, but neither have those from copper or galvanized steel. Of the two plastic alternatives, PB is somewhat less likely to be a public health hazard than CPVC, although the relative ratings of PB, CPVC, copper, and galvanized steel will not be clear without further testing (see Section VI). PB is clearly a preferred material, from the worker safety and health viewpoint, compared both with metal systems and with plastics that require cementing.

Under the option of disallowing currently allowed uses of plastic pipe, any impacts of these materials would disappear and those of metal systems reappear. The possibility of permeation of water supply piping by organic contaminants would decrease to the extent that PVC and PE supply lines would be replaced by metal with impermeable joints (but even metal pipe joints can be permeable). Leachates from PVC and PB would be replaced by those from copper, with no clear impact, positive or negative, on public health. The metal pipes would be somewhat more likely to corrode in soil than plastic (galvanized steel is not recommended for buried supply lines). Only small changes in worker safety and health would result from the changes in water supply piping.

Any major impacts of disallowing current uses of plastic pipe would be associated with the widespread use of ABS (and less widespread use of PVC) in DWV applications. Fire load and fire spread would be reduced in nonfire-rated construction. It is probable that few fatalities or little property damage would be avoided by this action, but both are possible benefits. Smoke toxins would also decrease somewhat, especially if PVC were replaced. The decrease in plumbers' exposures to solvent cements would be offset by increased work-related injuries from working with cast iron and, to some extent, with soldered joints in copper DWV. Whether the net effect

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on worker safety and health would be positive or negative is difficult to predict, given the current lack of information on plumbers' exposures.

Finally, the alternative that would disallow current uses of plastic would transfer some profits and jobs from the plastics to the metal pipe industries. Since large quantities of DWV are involved, these impacts would probably be greater than those for the prime project alternative of allowing expanded uses of plastic pipe. Houses could become more expensive, depending on the prices of cast iron and copper, but probably not enough to significantly affect the demand for housing.

In summary, the alternative of approving only the expanded uses of PB appears to pose fewer environmental risks than does the full proposed project given the state of current information. Because metal systems also pose some unique risks and may be comparable to plastic systems in other risk areas, we are not prepared to say that the no-project alternative or the alternative that would disallow current uses of plastic are environmentally preferable to the partial approval alternative, or even to the full proposed project.

D. Cumulative and Long-Term Implications

Increased use of plastic plumbing pipe can contribute to cumulative environmental impacts in two ways.

First, the sum of the environmental impacts of plastic pipe could be significant even when no one individual impact is deemed significant. In the case of plastic pipe, the most plausible example is for the various leachates that could each contribute to public health impacts. For example, no one leachate might reach the level of 10^{-6} lifetime risk for cancer, but the cumulative risk of all leachates acting together might exceed that level. Given the current uncertainties about the public health impacts, especially those concerning the long-term levels of leachates in drinking water, we are unable to determine whether the cumulative impact is

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significant. A similar situation is found with worker health impacts, where the risk of one solvent might be ingisgnificant, but that of two or more could be significant. For fire safety, the cumulative impact of all the proposed new uses for plastic pipe are likely to be dominated by the new DWV uses; the contribution of PW pipe is likely to be negligible. The same is true of smoke toxicity, except that the combined affect of HCl, CO, and other toxicants could be significant even when the effects of any one alone were not.

A second issue of cumulative impact is the question of whether the expanded use of plastic water pipe would add to the impacts of other similar actions and in total create a significant effect even though the use of plastic water pipe is not itself significant. We can consider two levels of cumulative impacts:

- Cumulative impact of expanded and existing use of plastic plumbing pipe.
- Contribution of plastic plumbing pipe to total use of plastic products.

As has been made clear earlier, the expanded uses of plastic pipe are in many ways rather small in comparison to existing approved use of plastic pipe. Most new California houses are already being plumbed with ABS DWV if they are not fire-rated; the addition of 10% (by weight) more plastic pipe as PB or (less likely) CPVC water pipe will be of little consequence for fire safety, especially as water piping is less sensitive. The increase for plastic pipe in fire-rated construction, of course, is total since no plastic is being used now; however, if ways of maintaining the rating are developed as required by code, little fire safety impact would be expected. Similarly, the cementing of plastic potable water pipe is probably much less of a problem for workers than the cementing of already approved ABS DWV. Thus, the greatest issue of cumulative impact involves public health impacts, in which plastic in residences can add to plastic in public utility distribution systems. We have no way of estimating the relative contribution of each to the total hazard, as the source of contaminants

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found in the water supply (controls) during leaching tests is not known. We doubt that the combined effects of distribution and residential piping would be significant if neither one alone were, but we cannot rule out that possibility. Similarly, permeation of plastic distribution pipes by toxic substances is more likely than it is for residential piping systems, but the significance of either, in terms of an overall risk assessment, will not be clear for a long time.

With regard to plastics in total, the expanded uses of plastic pipe will be a relatively small contribution in most respects. Plastics are by now endemic in our society. Most of the contaminants of PVC and CPVC that could be public health hazards will be ingested in much greater quantities from other PVC products such as food containers or, in the case of some of the chlorinated methanes, simply from waste products reaching the raw water supply. Those from PB and PE are similar to those from PE food contact materials. If plasticizers do contaminate plastic pipe, they will still do so at much lower levels than they do in any number of plasticized products to which people are regularly exposed, such as flexible vinyl upholstery (where they would yield inhalation rather than ingestion exposures). But equally clearly, plastic pipe does contribute to the total load of plastic-related hazards in California--for example, to the total of all combustible plastics in residences. The hazards from the total use of plastics are undoubtedly appreciable, even though nearly impossible to estimate. Whether or not they are greater or less than the hazards of the materials they replace is perhaps even more difficult to state. About all that can be said is that plastic pipe is not an unusually prominent or special case among plastics in general.

CEQA also requires an assessment of whether long-term environmental costs will be incurred as a result of short-term economic or other benefits. Certainly, any public health impacts of plastic pipe that do occur will probably be delayed for decades, as will some of the worker health or smoke toxicity impacts. However, for the purpose of determining the environmental consequences of the expanded uses of plastic pipe, those

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should be counted as current impacts, and not discounted in comparison with current benefits. We believe that, when it is viewed from this perspective, this CEQA issue is irrelevant to the decision at hand.

E. Significant Irreversible Changes

CEQA also requires an assessment of environmental changes or consumption of resources that would be permanent and irreversible. For example, the mining of a mountain is an essentially irreversible impact, whereas most air pollutants and their impacts would disappear once the source of pollution is removed.

In the case of the expanded use of plastic plumbing pipe, there would be a small permanent commitment of petroleum resources (but not other energy sources) to the manufacture of the pipe constituents. Total energy resources would be conserved to a slight degree. If any deaths occurred as a result of diseases caused by leachates or occupational exposures, or from fire or smoke toxicity, they would also be irreversible. If plastic pipe were later disapproved, the occurrence of new fatalities would gradually disappear. Some of the leachates from plastic pipe are mutagens and some mutations can be heritable. Thus, it is possible that a heritable--and more likely than not adverse--mutation could persist in the population as a result of drinking from plastic water pipes. Neither the specifics of the leachates in water from plastic pipe nor the overall state of the art of genetic risk assessment allows an evaluation of this possibility at present. If the impacts of plastic pipe eventually were judged unacceptable, it is possible that the metal pipe industry would have declined by that time to the point at which it would prove difficult to revive, but that possibility is also extremely speculative. Overall, we believe that the reversibility of the impacts is not as important an issue to resolve as the magnitude and significance of current impacts.

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F. Growth-Inducing Impacts

California's population is projected to increase from the 1980 total of 23.8 million people to 25.9 million by 1985 and to 27.9 million by 1990 (California Department of Finance, 1981). The proposed code change is not likely to significantly affect this forecast population growth for the following reasons. First, the reduction in the cost of housing construction that would result from use of the newly permitted plastics in place of currently approved plumbing materials is so small that it would have virtually no effect on the sales price or rent of dwelling units in the state. Therefore, there will be no change in the demand for housing and consequently no additional in-migration of residents who would be attracted by a drop in the price of housing. Second, the plumbing material substitutions that are likely to result from the proposed code change would not significantly affect employment opportunities in the state and so would not affect the in-migration and out-migration forecasts. Nor would either housing prices or employment opportunities significantly affect shifts in population from one part of California to another.

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VI TESTING NEEDS AND OTHER INFORMATION GAPS

A. Decisionmaking Under Uncertainty

An EIR, by its very nature, is an attempt to predict the environmental consequences of an action before that action is taken, and must necessarily be uncertain about those consequences even if the phenomena involved are well understood. Moreover, the underlying phenomena are ordinarily not completely understood, yet a decision on the action must still be taken even if the decision is against the action. Decisionmaking under uncertainty is thus the rule in actions wth potential environmental consequences; the decisionmaker must evaluate whether environmental consequences are more likely to be beneficial or adverse, and if adverse, whether the nonenvironmental benefits of the action will outweigh the adverse impacts. Moreover, the decision maker must consider--at least subjectively--the possibility that the impacts will prove significantly worse than seems most likely, and conclude whether the risks of those more adverse outcomes outweigh the nonenvironmental benefits.

Different attitudes about risk in decisionmaking will lead to different decisions with the same information. SRI does not propose a "correct" way to evaluate risk. Instead, we try to characterize, in this section, the degree of uncertainty about various "facts" and the significance of the uncertainties for the environmental consequences of expanded use for plastic plumbing pipe.

Our overall approach to "scoping" this environmental review entailed an iterative refinement of the depth of investigation. This approach was necessary to avoid spending great effort investigating potential impacts of trivial importance. To focus on the potentially most significant impacts, we first made "conservative" assumptions about both available data and

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interpretive techniques. For example, we used maximum observed concentrations in drinking water and a conservative dose-response relationship in determining whether a specific chemical is a threat to public health. If such an approach showed no problems, then it was not necessary to refine our estimates for more realistic concentrations and toxicological behavior. "Conservative" assumptions led to "reasonable" worst-case analysis, but not "very worst case." If impacts appeared to be possibly significant, we exerted more effort to make realistic estimates until either it was clear that the impact was or was not significant or it was clear that available information was not sufficient to make such a determination.

These residual uncertainties, or information gaps, are not unusual in the EIR process. At this stage of the environmental review, we can divide them into two categories:

- Uncertainties that are important to the decision and that can be significantly reduced by investigations that can be completed in a reasonable time (6 months) and at a reasonable cost; these are denoted as "testing needs."
- Other information gaps that, while potentially significant to the decision, are not subject to easy resolution and must be considered risks of the decision.

B. Testing Needs

At present, SRI sees critical testing needs in two areas:

- Characterization of long-term levels in drinking water of leachates from plastic pipes and initial levels of lead from metal pipes.
- Characterization of the exposures of plumbers to solvent cements and solder fumes.

These are by no means the only uncertainties limiting a complete evaluation of the environmental impacts of expanded use for plastic plumbing pipe. However, they constitute the two areas in which it is reasonable for DHCD to

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improve the base of knowledge through its own efforts in a reasonable time. Below we discuss these needs in more detail, but first we discuss some needs that we view as beyond DHCD's current responsibility or purview.

In the area of fire safety, there is substantial disagreement over the extent to which plastic pipe contributes to fire spread in terms of differences in injuries and property damage with and without plastic pipe. However, the point is virtually irrelevant if techniques can be developed to preserve the fire rating of construction that contains plastic pipe. Thus, we believe that it is necessary for pipe manufacturers and distributors to demonstrate the acceptability of plastic pipe systems complete with fire mitigation measures in standard fire rating tests such as the E-119; we do not believe it is necessary for DHCD to test arbitrary configurations for fire safety, presumably demonstrating only that some do and some do not pass the tests.

For smoke toxicity, we find that the evidence on the contribution of plastic pipe to illness and death from fire environments is at best weak and at worst contradictory. Thus, further testing of the smoke toxicity of plastic pipe is desirable to determine, in particular, the hazards of HCl from PVC. However, at present there is no generally accepted test for smoke toxicity, and specific pipe testing would not significantly clarify the issue. When the California and New York state studies are complete, it may be possible to reevaluate smoke toxicity as a factor in the acceptability of plastic pipe. In the meantime, the uncertainty over this issue should be treated as would any other risk.

Finally, much remains to be learned about public health other than leachate concentrations. Studies of the toxicity of the leachates should and will continue independent of any effort by DHCD. If any of the leachates prove significantly more or less toxic than anticipated, any decision regarding expanded uses of plastic pipe should be reexamined. Clarification of the question of the permeation of pipe by soil contaminants needs substantially better information, including:

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- Permeation experiments at realistic levels of external concentration and for simulated residential use patterns of the water inside the pipe over long time periods.
- Field observations of the distribution of levels of selected pollutants in the soils of California residential areas.

Because any problem that exists would probably be of more importance for water distribution lines, any such investigations should include water utility interests, and utility experience should be monitored for relevance to the residential permeation issue.

1. Leachate Concentrations

Because available data are sparse and of poor or uncertain quality, additional leaching data are needed to assess the long-term health effects of CPVC and PB plastic pipes and the chronic health effects of lead from metal plumbing systems.

For CPVC pipe systems, consecutive 1-day static dwell experiments should be run for at least 60 days to adequately observe the expected reduction in leachate concentration with elapsed time. Milli-Q or other highly purified, unchlorinated water should be used to minimize background concentrations of chlorinated organics. Replicate samples should be taken for every measurement to determine the precision of the analytical method. The solvent cements should be analyzed to isolate their potential contribution to the leachate population. Replicate systems of the same pipe should be tested but the leachability of these systems may vary considerably because of the difficulty of reproducibly joining pipe sections with solvent cement. Pipe samples from several manufacturers should also be tested.

Consecutive 1-day static dwell experiments should also be run for PB pipe systems for a sufficient period of time to estimate long-term leachate concentrations. Replicate systems of the same pipe and pipe from different

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manufacturers should be tested. Milli-Q water should be used and replicate samples should be analyzed to establish the precision of the measurements.

Laboratory and field studies should be run to determine lead concentrations in metal systems as a function of water pH and age of the system. Consecutive 1-day static dwell experiments should be run for lead-soldered copper and galvanized steel laboratoy systems for a period of at least 60 days using water with pH values ranging from 5 to 9. Copper systems with tin/antimony and tin/silver solders should also be studied to see the effectiveness of this mitigation technique. These short-term leaching data should be supplemented, if possible, with field data on new pipe systems (less than 2 years old) that use lead solder. The concentration of lead in the water entering the residential plumbing system should be measured to determine the contribution made by the lead in the residential plumbing system.

Laboratory test configurations for all plastic and metal systems should simulate residential plumbing. Strict attention must be given to quality assurance of the data, including a thorough statistical analysis of test results.

2. Plumbers' Exposures

A critical need in the evaluation of the hazards to plumbers of working with plastic and metal piping systems is characterization of the degree of exposure to solvent cements and solder fumes in typical plumbing situations. We need to know much more about both short-term peak exposures and longer term average exposures before a confident assessment can be made.

SRI believes that the measurement of exposures in the field with limited validation and calibration in the laboratory is the best design for

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answering the critical questions. The objectives should be to quantify inhalation and dermal exposures to solvent cement constituents and inhalation exposures to solder fumes.

The inhalation exposures of both kinds of hazards should be determined by measuring concentrations in the breathing zone of plumbers in ordinary job situations. Samplers attached to the plumbers themselves may be calibrated by sampling also with hand-held instruments operated by industrial hygiene professionals. Both short-term (15 minutes or 1 hour) and longer term (8-hour TWA) measurements should be taken, using either passive or active samplers, depending on the performance of the devices in laboratory calibration runs. The collected samples should be analyzed for unknowns as well as quantified for the contaminants suspected a priori.

Although some quantification of dermal exposures may be possible through gauze patch or glove collection techniques, the volatile solvents cannot be confidently measured in these ways. Thus, it will probably also be necessary to conduct biological sampling (for example, expired air, urine, or blood samples) in an attempt to measure absorbed doses. To measure the dermal contribution, an adjustment will be needed to account for the inhaled dose that can be inferred from the breathing zone concentrations and normal work-time breathing rates.

The measurements must be taken in all the representative plumbing situations--preassembly, in-trench installation, roughing, topping, and finishing, as well as replacement and repair--and must be adequately replicated.

Thus, the six major tasks for the worker health study are:

. Review previous efforts, including the NIOSH (1982) study just released and one about to be released.

- Determine the composition of solvent cements, solders, fluxes, and cutting oils.
- Determine the populations of plumbers at risk.

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- Design survey protocol.

  - Determine number of samples by type of work.
  - Specify work sites to be sampled.
  - Obtain cooperation.

- Design sample collection strategy.

  - Decide on materials and methods for air sampling.
  - Decide on materials and methods for biological sampling.
  - Decide on methods for chemical analyses.

- Calibrate as necessary in the laboratory.

  - Select among available methods.
  - Establish benchmarks.

- Conduct study according to design.

  - Obtain field samples.
  - Perform laboratory analysis.

- Analyze and report results.

Additional details on worker safety and health testing needs are presented in Appendix E.

C. Other Information Gaps

When we initiated this environmental review, we had assumed that the uncertainties we would find would be scientific in nature: How much of chemical X leached into water? To what extent is solvent Y toxic at levels found in the workplace? How much could plastic pipe contribute to the fuel load in residences? and so on. We were therefore somewhat surprised to discover that equally, if not more, important were uncertainties about human behavior: How will plumbers work with plastic pipe? What degree of skill can be expected from building inspectors? and the like. We discuss the scientific and behavioral uncertainties separately below.

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1. Gaps in the Scientific Information

Gaps in scientific knowledge for individual impact areas are discussed in some detail throughout Section IV. Here we merely summarize some of the major ones.

a. Water Quality

Most of the uncertainties have to do with concentration levels over time and will be investigated by the testing recommended above. However, uncertainties will remain about the influence of input water quality, quality of installation, unusual water use patterns, and the combined effects of leachates from the piping system and those in the input water.

b. Public Health

All the water quality uncertainties affect assessment of public health effects. In addition, there are many questions regarding individual variations in patterns of drinking water from the residential supply, the mobility of the population, whether or not infants are more or less likely to live in newly plumbed houes, and other influences on the pattern of exposure to leachates. More important are many open question regarding the toxicity of leachates. Although much biological testing has already been accomplished, not every leachate has been tested for every conceivable biological effect, nor will they ever be. The whole question of the safety of plastic versus metal pipe should be periodically re-examined as new data become available on the toxicity of the leachates and permeants.

c. Worker Safety and Health

A major uncertainty is the degree of worker exposure to potentially dangerous materials. The proposed testing will clarify this uncertainty

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greatly, but even then extremes of exposure will still be possible. As with public health, the toxicity of the workplace contaminants is incompletely understood, and will gradually be clarified as the art of toxicology develops. So far, no conclusive epidemiological investigation has been conducted to characterize past health problems in the plumbing trade, even though safety hazards are reasonably well understood. Such an investigation, particularly if it could isolate workers with relatively pure exposures to plastic and metal systems, would help to validate any estimate from the exposure/toxicity analysis.

d. Fire Safety

At present, we do not know much about the testing of fire-resistive construction with respect to vertical penetration of floor/ceiling units and the like. We need to understand much more about the value of various fire-blocking techniques to mitigate any fire-spread influence of plastic pipe.

e. Smoke Toxicity

The major issue in smoke toxicity evaluation is the lack of consensus on a valid test system for smoke toxicity. The complexity of predicting toxicity from experiments with individual smoke toxins prevents much confidence in results from such an exercise. Also needed are better data on observed levels of smoke toxicity in real fire situations. These are both questions that relate to the issue of plastics in buildings in general, not only to plastic pipe.

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f. Fiscal and Other Impacts

While there are relatively great uncertainties in these areas as well, the magnitude of probable impacts does not seem to justify much expenditure in resolving them.

2. Uncertainties About Human Behavior

There are two extreme ways to look at the behavioral aspects of expanded use of plastic plumbing pipe. One extreme is to hold that plastic pipe should be judged only on its intrinsic hazards, assuming that all precautions in its manufacture, installation, and use will be taken. In effect, this attitude implies that any impacts attributable to human error or misuse are the fault of the users, not of the pipe. At the opposite extreme is the position that every environmental impact associated with the most extreme misuse of plastic pipe is attributable to it, not to the abuser, and that the acceptability of the pipe should be assessed assuming the worst in human behavior. Whatever one's attitude toward this issue, however, it is reasonable to ask whether plastic pipe is less forgiving of human "errors" than the equivalent metal system is. If it is, then care in specifying and enforcing mitigation measures for human behavior will be important in allowing the expanded uses of plastic pipe.

The principal uncertainties about human behavior are classified by impact area and discussed below.

a. Water Quality

Leachate concentrations of some intentional constituents of pipe and solvent cements could have significant public health implications if plumbing systems are not flushed before use. Although use without flushing seems unlikely to be frequent, it is not impossible. (Flushing of metal pipes is also advisable.) Building inspectors should require evidence of

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flushing with at least 1,000 gallons of water before approval, and new owners should be encouraged to flush all lines again before use.

A second major uncertainty is the quality of installation. Poor solvent cement joints are known to produce more leachates than good ones. Plastic is probably somewhat less forgiving of error than metal. This factor will put additional pressure on building inspectors to assure quality. Do-it-yourselfers will find it easier to work with plastic and may or may not make more errors than professionals. They will surely be less likely to seek inspection.

More subtle concerns exist about unintentional contamination of pipe and cement. It is possible that either materials manufacturers or pipe and fittings manufacturers would experiment with unauthorized materials or that simple errors would introduce dangerous contaminants. Again, inspection procedures by NSF for potable water pipe will keep such incidents minimal but will not eliminante them. Plastic pipe would be less subject to such errors if NSF screened for certain organic contaminants as well as the present inorganic ones. It would seem reasonable to institute some extraction testing regime for metal pipe systems as well.

b. Public Health

The uncertainties pertaining to water quality also pertain to public health. In addition, the degree to which people drink the first water from the tap following a static period of concentration buildup is uncertain. It is untenable to assume that many people will deliberately avoid drinking the first water, but they will certainly not deliberately seek it. Other uncertainties surround the extent of tap water use in baby formulas and the use of water purifiers.

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c. Worker Safety and Health

Here the major behavioral uncertainties all have to do with the degree of care exercised by plumbers or do-it-yourselfers in installing plumbing, either of plastic or of metal. There are three major issues:

- How much guidance will be supplied by manufacturers, unions, and government regarding safe use?
- To what extent will contractors, plumbers unions, and occupational safety and health officials encourage or enforce safe practices?
- To what extent will plumbers and do-it-yourselfers follow the guidance given them?

Guidance is already available from manufacturers and generally appears in such forms as the installation standards in the UPC. However, labeling of materials at present (fluxes, solders, pipe joint compounds, solvent cements, primers, and so on) is at best variable, and guides to the do-it-yourselfer often overlook safety guidance. There is anecdotal evidence of time pressures militating against safe use. Most observers agree that many plumbers do not exercise maximum caution. What little evidence is available gives no clear signal whether plastic or metal pipe systems are more forgiving of worker error, although we would expect a less informed use with the newer plastics until experience had accumulated.

d. Fire Safety

As discussed at length in Section IV-D, the central issue for this proposed action is whether plastic pipe installed in "fire-resistive construction in fire-rated dwellings" will still meet the putative fire rating. There will be no substantial change in fire safety if "1-hour" fire walls plumbed with plastic indeed pass the fire rating test for longer than 1-hour. However, for this to occur:

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- Manufacturers and others will need to test and demonstrate safe methods of using plastic pipe in fire-resistive construction and describe them in terms implementable by plumbers and building inspectors.
- Plumbers must follow the guidance provided and not simply substitute plastic where metal was used safely.
- Building inspectors must exert somewhat greater diligence in assuring compliance with construction standards.

Plastic pipe is somewhat less tolerant of error than metal because of its own flammability. On the other hand, there are clearly many instances in which metal systems are installed in such a way as to compromise the fire ratings of structures.

e. Smoke Toxicity

We assume that people other than fire fighters would be no less able to avoid a toxic smoke hazard from plastic pipe than they would from ordinary smoke. People would have somewhat less time to escape the more toxic plastic smokes, but since the HCl from PVC and CPVC is offensive, even at low concentrations, there might be some tendency for people to escape earlier than they do in fires not involving the chlorinated resins.

Fire fighters are regularly equipped with breathing apparatus to mitigate exposures to toxic smoke. However, anecdotal evidence again suggests that the apparatus may not be used even in fires known to involve chlorinated plastics. Thus, the principal uncertainties are:

- Will fire departments provide further training on safety in combatting fire involving plastics?
- Will fire fighters heed the guidance?

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Since smoke toxicity is not a significant issue with metal pipe, plastic is definitely less forgiving of human error in this case.

f. Fiscal Impacts

As the fiscal impacts are likely to be small in any case, human behavior is less significant here. Taking care with plastic, especially with respect to fire safety, may narrow the cost advantages of plastic systems. Furthermore, carelessness in installation will reduce the life expectancy of both types of systems, perhaps slightly more so for plastic, and will thus reduce the life-cycle cost advantage of plastic in a different way.

g. Other Impacts

Again, these are relatively insignificant and human behavior will make little difference. Examples can be found even here:

- The issues affecting the water quality may have some implications for the quality of the water which the residential sewers eventually discharge.
- The impact of noisier plastic drain pipes will be more noticeable if care is not exercised to isolate the pipe acoustically, from wallboard.

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Appendix A

AUTHORS

This document is a combined effort of many SRI investigators, internal and external consultants, editors, and management review. The following attributions, therefore, indicate principal responsibilities rather than sole effort:

	Summary	Stephen L. Brown
I.	Introduction	Stephen L. Brown Michael C. McMillan
II.	Project Description	
	A. Proposed Code Change	Stephen L. Brown
	B. Projected Changes in Pipe Use	Therese A. Freeman
	C. Growth of Population Living in Dwellings with Plastic Water Pipe	Stephen L. Brown
	D. Other Major Assumptions	Stephen L. Brown
III.	Environmental Setting: Pipe and Fittings	
	A. Manufacture of Materials	Stephen L. Brown Eleanor M. Connolly H. Ernst Frey
	B. Manufacture of Pipe, Fitting, and Joining Materials	Stephen L. Brown Eleanor M. Connolly H. Ernst Frey
	C. Installation of Plumbing Systems	Douglas P. Fowler
	D. Use of Plumbing Systems	Stephen L. Brown
	E. Water Distribution and Waste Collection	Jack Van Zandt
IV.	Environmental Impacts and Mitigations	
	A. Water Quality	Thomas R. Podoll David Kelly
	B. Public Health	Michael J. Lipsett Ann Winship-Ball J. Wesley Clayton
	C. Worker Safety and Health	Douglas P. Fowler Ann Winship-Ball Samuel D. Kaplan
	D. Fire Safety	Jana Backovsky Raymond S. Alger Stanley B. Martin

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IV.	Environmental Impacts and Mitigations (Concluded)	
	E. Smoke and Combustion Product Toxicity	Charles A. Tyson Stanley B. Martin
	F. Fiscal Impacts	Therese A. Freeman Steven R. Pierce
	G. Other Impacts	Sidney J. Everett Richard L. Goen Steven R. Pierce
V.	CEQA Summary	Stephen L. Brown Therese A. Freeman Sidney J. Everett
VI.	Testing Needs and Other Information Gaps	Stephen L. Brown Entire team
VII.	Bibliography	Entire team
Appendices		
	A. Authors	Stephen L. Brown
	B. Organizations and Persons Consulted	Entire team
	C. Glossary of Terms and Abbreviations	Stephen L. Brown
	D. Detailed Toxicology of Substances Associated with Plastic and Metal Pipes	Michael J. Lipsett Ann Winship-Ball J. Wesley Clayton
	E. Details of Worker Safety and Health	Douglas P. Fowler
	F. Smoke Toxicity Details	Stanley B. Martin Charles A. Tyson

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Appendix B

ORGANIZATIONS AND PERSONS CONSULTED

The list below, while not exhaustive, shows the principal contacts made by SRI in getting information relevant to the environmental review. The first section shows contacts external to SRI; the second shows SRI personnel who were consulted but are not authors. In each case, we show the name of the person and organization represented, if known, and the general topic(s) of the discussion.

External Contacts	Topic(s)
Adams, Thomas R. Adams, Broadwell & Russell	Extent of Work in Various Activities by Plumbers; Average Hourly Wages
Alarie, Yves University of Pittsburgh	Request for Research Results on Smoke Toxicity
Anand, Vir U.S. Food and Drug Administration	Request for Unpublished Data on Organotins
Anderson, Rosalind Arthur D. Little, Inc.	Smoke Toxicity Testing
Barr, John Air Products and Chemicals, Inc.	Comments on and References for Public Health Draft
Beauchamp, Jr. Robert Chemical Industry Institute of Toxicology	Request for Information on Specific Chemical Leachates
Bellack, Errin Office of Drinking Water U.S. Environmental Protection Agency	Risk Assessment Issues

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Brown, Raymond J. Copper Development Association	Manufacture and Sales of Copper Pipe
Caplan, Yale H. Maryland Institute for Emergency Medical Service Systems	Reports of Increased Fire Deaths in Recent Years
Carns, Keith East Bay Municipal Utility District	Field Testing for Water Quality
Chernoff, Gerald University of California, San Diego	Thresholds for Teratogens
Cotruvo, Joseph Office of Drinking Water U.S. Environmental Protection Agency	Request for Information on Risk From Short-Term Exposures
Costello, _____ U.S. National Institute of Occupational Safety and Health	Request for Information on Smoke Toxicity
Craig, Douglas Litton Bionetics	Toxicity of DMF
Doull, John University of Kansas Medical Center	Request for Information on Lead
Dunnigan, Paula B. F. Goodrich Company	Technology and Economics of Plastic Pipe
Dyer, Dr. Robert Health Effects Research Laboratory U.S. Environmental Protection Agency (RTP)	Neurotoxicology of Organotin Compounds
Elmer, Jill Loctite Corporation	Composition of Pipe Joint Compounds
Flint, _____ Ciba-Geigy	Toxicity of Irganox 1010
Gaspar, Robert R & G Sloane Manufacturing Co.	Plastic Pipe Technology
Gorman, Richard U.S. National Institute of Occupational Safety and Health	Information on Exposures for Plumbers and Health Effects
Gralla, E. Toxigenics	Inhalation Toxicology of MEK

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Halperin, William U.S. National Institute of Occupational Safety and Health	Information on Exposures for Plumbers and Health Effects
Harwich, Nancy Security Pacific Bank	Amount and Value of Construction in California
Hilado, Carlos Product Safety Corporation	Smoke Toxicity Testing
Jackson, Richard California Department of Health Services	Existence of Thresholds for Teratogens
Jaeger, R. J. New York University	PVC Smoke Toxicity
Juodecka, Lois U.S. National Toxicology Program	Bioassay Status of Leachates
King, M. E. California Department of Housing and Community Development	Building Codes and Standards
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Appendix C

GLOSSARY OF TERMS AND ABBREVIATIONS

ABS	Acrylonitrile-butadiene-styrene plastic.
Additive effects	The combined biological effects of two or more substances are additive when equal to the sum of the effects of the substances acting alone.
Adverse reproductive outcome	Any of a variety of deleterious effects on reproduction, including impaired fertility, sterility, spontaneous abortion, stillbirth, birth defects, developmental retardation in offspring.
AN or ACN	Acrylonitrile.
Antagonistic effects	Two or more substances are antagonistic when the combined biological effects are less than the sum of the effects of the substances acting alone.
Btu	British thermal unit (a measure of heat energy).
CPVC	Chlorinated polyvinyl chloride.
Carcinogen	A chemical or physical agent that can cause cancer.
Central nervous system	The brain and spinal cord.
Chase	An enclosed space in walls or columns or between floor and ceiling in which piping is concealed.
Clastogen	A chemical or other agent that injures chromosomes or causes damage to chromosomal structure.
Cyclo	Cyclohexanone.
Dermal	Via the skin.
DHCD	California's Department of Housing and Community Development.
DMF	Dimethyl formamide.
DWV	Drain, waste, and vent.

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Dose	The quantity of a physical or chemical agent administered to a living system (typically an animal or human). The term may also refer to the amount of the agent that reaches the target organ, tissue, or cells; in this case it is usually referred to as the "target" dose or "effective" dose.
Dose-response curve	A diagrammatic representation of the intensity of biological response to different dose levels. A typical curve is S-shaped, showing responses of an individual organism or system or of a percentage of a population.
Dwell time	The time water stands in a pipe system between withdrawals.
Fittings	Plumbing items that join two or more pieces of pipe and enable changes in direction or branching.
Fixtures	The hardware (sinks, tubs, toilets, and so on) to which plumbing is attached.
Flashover	A phenomenon in which an entire room bursts into flame as a critical temperature is exceeded.
Flushing	Running numerous void volumes of water through a pipe to discharge any leached materials.
GI	Gastrointestinal.
HCl	Hydrochloric acid.
HCN	Hydrogen cyanide.
IAPMO	Internation Association of Plumbing and Mechanical Officials.
IARC	International Agency for Research on Cancer.
Idiosyncratic reaction	An unusual individual sensitivity or susceptibility to the effects of one or more substances.
Initiator	In theoretical carcinogenesis, an agent capable of directly affecting cellular DNA, "initiating" a cell, tissue, or organ for the evolution of a tumor.
LC_{50}	Median lethal concentration (i.e., the concentration level of an agent that is fatal for 50% of the population exposed to it).
LD_{50}	Median lethal dose.

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Leachates	Chemicals that move (leach) into water from plastic or metal pipes, fittings, and joining materials.
MCL	Maximum contaminant level.
MEK	Methyl ethyl ketone.
Monomer	The single molecules that are joined together to make a polymer.
Mutagen	A physical or chemical agent causing mutations in genetic material.
Mutation	A change in genetic material, typically involving a single gene. Mutations can be spontaneous or caused by a chemical or physical agent. Mutations affecting reproductive cells are called germ cell mutations; all others (in animals) are called somatic mutations. If a mutation is repaired or is fatal to a cell, it is not passed on to the cell's or organism's progeny: otherwise the change may become hereditary.
NSF	National Sanitation Foundation.
NTP	National Toxicology Program.
Neurotoxin	An agent that is capable of injuring nerve tissue.
PB	Polybutylene.
PE	Polyethylene.
PEL	Permissible exposure level.
Permeation	Movement of chemicals from outside a pipe through the pipe or its joints into water.
Peripheral nervous system	The nerves connecting the brain and spinal cord with the rest of the body. Sensory nerves transmit signals from receptors such as the eyes, nose, ears, mouth and skin, while in the other direction, motor nerves conduct impulses to the muscles, and autonomic nerves to the heart, glands, and other internal organs.
Polymer	A high-molecular-weight organic chemical consisting of a straight or branched chain of monomer units.
Potentiation	An agent can potentiate or augment the toxic effects of another agent even though the former does not cause such effects by itself.

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Primer	A material used to clean and presoften plastic pipe prior to solvent cementing.
Promoter	In theoretical carcinogenesis, an agent that promotes the appearance of a tumor in a tissue or organ whose DNA has been changed or "initiated." This represents a particular case of potentiation, in that a promoter cannot cause cancer by itself. However, some carcinogens have capabilities of both initiation and promotion.
PVC	Polyvinyl chloride.
Pyrolysis	Decomposition of a material under heat. Often used to refer to thermal breakdown without flame, especially in a low-oxygen environment.
SNARL	Suggested no adverse response level.
Solvent cement	A material consisting of one or more solvents and other materials that softens plastic pipe and allows it to be permanently joined.
Stabilizer	A chemical added to plastic formulations to prevent the polymer from breaking down under heat, ultraviolet radiation, or other attack.
STEL	Short-term exposure limit.
Synergistic effects	The combined biological effects of two or more agents are synergistic if they are greater than the sum of the effects of the agents acting alone.
Teratogen	A physical or chemical agent capable of causing physical defects in an embryo (birth defects).
Thermoplastic	A plastic material that softens when heated and hardens when cooled.
Thermoset plastic	A plastic material that hardens permanently after heating.
THF	Tetrahydrofuran.
Threshold	A dose or exposure level below which a particular toxic effect is not observed.
TLV	Threshold limit value.
TWA	Time-weighted average.

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Appendix D
DETAILED TOXICOLOGY OF SUBSTANCES
ASSOCIATED WITH PLASTIC AND METAL PIPES

Substances Associated with PVC Plastic Pipes

Dimethylformamide

Dimethylformamide (DMF), a common constituent of adhesives used for PVC piping, is a colorless liquid that is highly soluble in water and miscible with other organic solvents. It is used as a solvent in a wide variety of industrial processes, particularly in the production of acrylic fibers, vinyl-based polymers used in coatings and adhesives, and polyurethanes.

NIOSH (1980) estimates that in 1980, 69,000 workers in 25 major industries were exposed to DMF. Occupational exposure to DMF occurs primarily through inhalation or skin contact (Proctor and Hughes, 1978). The compound is effectively absorbed by the skin. Workplace airborne concentrations ranging from less than 10 ppm to more than 200 ppm have been reported (Lyle et al., 1979). Because levels are equal to or may exceed 10 ppm the OSHA Permissible Exposure Limit (OSHA, 1981) and ACGIH Threshold Limit Value (ACGIH, 1982), some workers are at risk of exposure to potentially harmful concentrations.

Consumers may also be exposed to dimethylformamide through inhalation and skin contact. The NIOSH Tradename Data Base lists 25 products containing 1 to 99 percent DMF, including coatings, adhesives, degreasers, paint strippers, deicing agents, and other compounds that may be used in the home in addition to the workplace (NIOSH, 1981). In a 1979 study of organic solvent use, DMF was ranked twelfth out of 34 solvents on the exposure index for consumers (Lee et al., 1979).

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Because DMF is stable in water at neutral pH (Eberling, 1980), the public may be exposed by drinking water containing the compound. DMF has been detected in the effluent from several industries and domestic sewage treatment plants (Shackelford and Keith, 1976) and is a leachate from plastic piping systems (Montgomery, 1980).

Absorption and Metabolism

DMF is absorbed through the skin and lungs as well as the gastrointestinal tract; free DMF appears in the blood and urine regardless of the route of administration. DMF is metabolized by humans, dogs, and rats to N-methylformamide (NMF) and formamide, two suspected teratogenic agents (Maham, 1977; Kimmerle and Eben, 1975a, 1975b). Maham (1977) has proposed a sequence for the metabolism of DMF that includes N-methyl-N-hydroxy-methyl formamide, formaldehyde, N-methyl formamide, formamide, ammonia, and formic acid. Not all steps have been empirically verified in animal species.

In humans exposed to approximately 8 ppm for 6 hours on 5 consecutive days, the majority of the absorbed dose was eliminated within 24 hours. The main urinary metabolite is N-methyl formamide (NMF); its presence in the urine is a sensitive indicator of exposure to DMF, even at levels lower than the current OSHA permissible inhalation exposure limit, 10 ppm (Krivanek et al., 1978; Maxfield et al., 1975). Unmetabolized DMF is also found in the urine after exposure. Toxic doses result in a higher concentration of DMF relative to NMF; essentially nontoxic doses produce the opposite result (Sanotskii et al., 1978). NMF is considered to be a more toxic compound than DMF.

Ethanol alters the rate of DMF metabolism in humans and animals; DMF may, in turn, alter ethanol metabolism, most likely by inhibition of acetaldehyde metabolism. Daily alcohol consumption retarded DMF metabolism in workers handling surface-treating agents containing the compound (Yonemoto and Suzuki, 1980). Prior administration of ethanol retarded DMF metabolism in four human volunteers exposed by inhalation and in beagle dogs

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exposed by inhalation before or after treatment with ethanol (Eben and Kimmerle, 1976). Mice pretreated with DMF and then given alcohol had significantly higher blood alcohol levels than ethanol-only controls (Sharkawi, 1980).

Acute Toxicity

DMF is moderately irritating to the skin, eyes and respiratory tract. Prolonged or repeated contact with the liquid may defat the skin and cause dermatitis (Proctor and Hughes, 1978). DMF also appears to lower the resistance of the skin to other compounds and to enhance absorption in a manner and degree similar to DMSO (Munro and Stoughton, 1965; Schulze, 1971). Although there is no experimental evidence that it is a skin sensitizer, exposed workers have reportedly experienced eczema, vitiligo, and delayed skin sensitivity (Bainova, 1975).

According to Gosselin et al. (1976), the probable lethal oral dose in humans ranges from 500 mg to 5,000 mg/kg. DMF is toxic to the liver and highly irritating to the gastrointestinal tract. In one incident workers exposed to concentrations ranging from < 20 ppm to 35 ppm for 32 weeks complained of nausea, vomiting and abdominal pain; liver enlargement was detected in some cases (Proctor and Hughes, 1978). In a second report, complaints of stomach disorders, headache, nausea and loss of appetite occurred among 24 workers exposed to an unknown concentration of DMF; several of these individuals, however, had reported stomach problems before exposure (Massman, 1956). Several other reports of gastrointestinal disorders resulting from exposure to DMF were reviewed, all describing similar symptoms. Employees exposed to DMF in a synthetic rubber plant reported frequent headaches and dizziness (Wink, 1972).

A Soviet investigator reported an increase in spontaneous abortions in women occupationally exposed to DMF (Schottek, 1972). The abstract reviewed contained insufficient information to permit a critical evaluation and interpretation of the findings, but Eastern European scientists often report

such events without addressing the questions of background incidence and documented exposure.

One of the potentially important aspects of DMF biological activity is its interaction with ethanol. Although some workers have noticed facial flushing after inhaling DMF vapors alone, the effect was especially pronounced when alcoholic beverages were taken coincidentally (a single glass of beer was sufficient to induce the reaction (Lyle et al., 1979). Alcohol intolerance (a reaction similar to that produced by Antabuse) has also been reported (Chivers, 1978).

A 10 mg dose applied to rabbit skin produced irritation 24 hours after treatment (NIOSH, 1981); 20 mg instilled in the rabbit eye was moderately irritating (E. I. DuPont, 1980).

Numerous studies of the acute toxicity of DMF have been performed. In range-finding experiments using cats, rabbits, and mice, the most prominent features of toxicity were liver and kidney damage. The cat and dog are the most sensitive laboratory species tested, with a median lethal oral dose (the dose estimated to kill half the animals tested) of approximately 500 mg/kg (Massman, 1956; NIOSH, 1981). Cats showed severe effects at inhalation exposures of 100 ppm (Massman, 1956). The compound is much less toxic to the rat, mouse, rabbit and guinea pig by all routes tested.

The major target organ of DMF is the liver. Single intraperitoneal injections of 0.5 ml/kg to 1.2 ml/kg have produced degenerative changes in the liver in hamsters (Ungar et al., 1976) and rats (Mathew et al., 1980). Neurological effects have also been reported. A single DMF dose of 2 ml/kg (intraperitoneal) or 5 ml/kg (oral) administered to rats caused cholinesterase depression; carbaryl-induced cholinesterase inhibition was also enhanced (Weiss and Orzel, 1967). White rats exposed by inhalation continously for 2 months to 0.5 or 10 mg/m^3 DMF in air exhibited significantly reduced cholinesterase levels and decreased coproporphyrin elimination in the liver (Odoshashvili, 1963). DMF had no direct effect on the central nervous system when administered intraperitoneally to mice in

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sublethal doses (0.75 to 3.2 g/kg). However, it lengthened the narcosis induced by hexobarbital, chloral, or urethane, and increased the duration of penetrazole-induced convulsions (Chanh et al., 1973).

Chronic Toxicity

DMF has produced liver damage in several species when applied to the skin, given orally, or administered in inhalation chambers. Kidney damage and changes in blood pressure and cardiac function have also been seen. Dogs, rabbits, guinea pigs, rats, and mice were exposed to air concentrations of 23 ppm DMF for 5-1/2 hours followed by a 1/2-hour exposure to 426 ppm for 58 weekdays. Functional effects on the liver, pancreas, spleen, kidneys, adrenals, and thymus of all animals were seen. Degenerative changes in the heart and cardiovascular effects, including decreased systolic blood pressure, were seen in dogs (Clayton et al., 1963).

Rats exposed to unspecified concentrations of DMF for 1/2 hour per day for 30 days exhibited hemorrhage and edema of the lung, hemorrhage and degeneration of the liver, and less severe changes in the kidney and heart. The degree of pathologic change was positively correlated with the concentration and duration of exposure (Cruz and Corpino, 1978; Cruz and Maccioni, 1978). Details of testing were not available in the English language summaries.

Effects on Genes and Chromosomes

The mutagenic potential of DMF has been studied in several test systems and the majority of results have been negative. Results in 6 of 7 Salmonella reversion assays have been negative (see section on carcinogenicity). The compound was also negative in an E. coli reversion assay (Vasil'eva, 1975), a transplacental host-mediated hamster cell culture system (Quarles et al., 1979), and an hepatocyte primary culture/DNA repair system (Williams and Laspia, 1979). Recently DMF was tested under the National Toxicology Program in the following assays: Drosophila sex-linked recessive lethal, rat dominant lethal, mouse sperm head morphology, rat bone

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marrow cytology, and in vitro unscheduled DNA synthesis in human fibroblasts. Results have been requested but have not been received.

Carcinogenicity

No results of standard bioassays or long term studies designed to determine the carcinogenic potential of DMF have been conducted, although an inhalation bioassay is now in progress at Litton Bionetics. The only report of induced carcinogenesis found in the literature is the work done in rats by Kommineni (1972). This study suffered from several design deficiencies, and results were not statistically significant. It is difficult to evaluate the biological significance of these results.

The short-term screen used most often to predict carcinogenicity is the Ames Salmonella assay in which positive "carcinogens" induce mutations in the bacteria; survival rates reflect mutation rates. DMF was negative (not mutagenic) in five of six batteries of Ames assays reported (Amlacher and Ziebarth, 1979; Commoner, 1976; Ong et al., 1980; Purchase et al., 1976; NTP, 1980; ICI Ltd, undated). Concentrations were not consistently reported, but included 100 µl/plate and $\leq$ 400 µl/plate. A test with four unspecified strains produced positive results at 200 µl/plate.

A large number of studies of DMF have concerned antitumorigenic effects, particularly differentiation of tumor cells (Avdalovec and Aden, 1978; Bendich et al., 1974; Borenfreund et al., 1975; Calabresi et al., 1979; Collins et al., 1978; Dexter et al., 1979; Dexter and Hager, 1980; Dexter et al., 1978; Fontana et al., 1980; Hager et al., 1980; Madhavan, 1972; Novogrodsky et al., 1980; Preisler, 1976; Santoro et al., 1978; Spilker, 1970). In one study, DMF treatment of cell cultures from a murine rhabdomyosarcoma induced morphologic differentiation and a marked reduction in the tumorigenicity of the sarcoma cells. Of 17 CE/J mice receiving injections of DMF-treated cells, 14 did not develop tumors after 6 months. All 21 mice receiving untreated sarcoma cells died of disease between 11 and 32 days after inoculation (Dexter, 1977).

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DMF may protect rats and mice from the tumorigenic action of dimethylinitrosamine through inhibition of its metabolism. This inhibition has been demonstrated *in vitro* using rat liver microsomes (Arcos et al., 1976) and *in vivo* using a radioactively labelled chemical to demonstrate reduced binding to liver protein in rats pretreated with DMF (Mirvish and Sidransky, 1971). In another study partially hepatectomized female rats were given an intraperitoneal injection of 6 to 9 mg/kg dimethylnitrosamine alone or in combination with DMF. One to two years later, animals treated with dimethylnitrosamine alone showed a high incidence of liver nodules and carcinomas. None of the rats receiving the combination treatment developed nodules or liver tumors (Craddock, 1971).

DMF has also exhibited effects associated with tumor induction or promotion (Argus et al., 1966; Blau and Epstein, 1979; Porter, 1979; Sato et al., 1975). The ability of DMF to induce cell transformation was tested in several systems. Positive results (transformations) were obtained with DMF in human peripheral lymphocytes (Koudela and Spazier, 1979); negative results were obtained with Syrian hamster embryo cells (Pienta, 1980) and Syrian hamster kidney fibroblasts (Purchase et al., 1976).

Effects on Reproduction

DMF is metabolized to formamide and N-methyl formamide, both of which have been identified by NIOSH as experimental teratogens (NIOSH, 1981). It is known to cross the placenta to the fetal blood circulation in the rat (Sheveleva et al., 1977). Many results of teratogenicity screens cannot be fully evaluated because dose levels were not reported (Scheufler, 1976; Schmidt, 1976) or because the administered dose produced maternal toxicity (Merkle and Zeller, 1980). In several studies, no teratogenic effects were reported (Gleich, 1974; Kimmerle and Machemer, 1975; Sheveleva et al., 1979; Thiersch, 1971).

DMF administered by gavage to groups of 10 pregnant rabbits on Days 6 through 18 of gestation caused a small decrease in fertility and growth retardation and malformations in fetuses, but the overall number of

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experimental animals was too small to produce statistically significant results (Merkle and Zeller, 1980). Inhalation exposure of rats to concentrations as great as 17 times the OSHA PEL (10 ppm) resulted in no biologically significant effect on reproductive outcome (Kimmerle and Machemer, 1975). At higher exposure levels however, the compound was embryotoxic and abortifacient (Sheveleva et al., 1979). Exposure to DMF in several fractions was more embryotoxic to rats than the same dose given in a single application (Stula and Krauss, 1977). Pregnant Sprague-Dawley rats (N = 19/group) were exposed for 6 hours per day on Days 6-15 of gestation to 0, 32, or 301 ppm DMF. Exposure to 32 ppm did not affect survival, fetal weight, or development. Exposure to 301 ppm caused slight depression of fetal weights and slight increases in normal ossification variations. No excess of soft tissue or skeletal abnormalities was observed, and therefore, the compound was not teratogenic under the conditions of the test (Keller and Lewis, 1981).

The studies reviewed suggest that DMF is embryotoxic and may also decrease fertilty. The available data do not indicate that it is teratogenic. Many data gaps exist, however, and most investigations have not been conducted with sufficient numbers of animals to ensure statistically significant results.

Tetrahydrofuran

Tetrahydrofuran (THF) is a solvent used in plastics and resins manufacture as well as in adhesives made for use with PVC and CPVC piping. It is miscible with water and other organic solvents. It has a vapor pressure of 143 mm Hg at 20°C and is quite volatile. The chief hazard associated with the use of THF is not its toxicity, but its flammability (duPont, 1977).

NIOSH (1980) estimates that approximately 95,000 workers are exposed annually to THF. Both the current OSHA Permissible Exposure Limit (OSHA,

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1981) and ACGIH Threshold Limit Value (ACGIH, 1982) are an 8-hour time-weighted average of 200 ppm.

Absorption and Metabolism

No information on the metabolism of THF was found. Because the compound is so volatile, most of an inhaled dose is likely to be eliminated unchanged in the expired air.

Acute Toxicity

No fatal human exposures were reported in the literature reviewed. THF is a mild irritant of the eyes and mucous memberanes. Exposure may defat the skin and cause dermatitis (duPont, 1977). Exposure to concentrations above the PEL may result in nausea, dizziness and headache, but these symptoms are readily reversible in fresh air (AIHA, 1959). THF has good warning properties; its odor is detectable at 25-50 ppm, levels well below the permissible exposure limit (duPont, 1977). Gosselin et al. give THF a toxicity rating of 4; the probably lethal human dose is estimated to be 50-500 mg/kg (Gosselin et al., 1976).

Two reports of injury potentially attributable to THF exposure were reviewed. In the first, a worker exposed to a mixture of THF and MEK experienced symptoms of peripheral neuropathy (Viader et al., 1975). In the second, a pipefitter exposed to THF, cyclohexanone, and acetone reported disturbed olfactory function (Emmet, 1976). In both cases exposures were mixed, and the cause of the disorders cannot be determined. No other systemic effects of exposure to THF were reported.

The lowest oral dose of THF lethal to the rat is 3,000 mg/kg; the lowest lethal concentration is 2,800 mg/m^3 for 2 hours (NIOSH, 1981). In cats, rabbits, rats and mice, concentrations of approximately 60,000 ppm were required to produce narcosis. Concentrations above 3,000 ppm produced upper respiratory tract irritation in animals exposed for 8 hours/day for 20 days. Cats and rabbits subjected to 30 6-hour exposures to 3,400 ppm THF in

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air exhibited no liver or kidney damage. Dogs exposed to concentrations of 336 ppm and 2,100 ppm for 6 hours per day, 5 days per week over a 12-week period exhibited decreased blood pressure, but no demonstrable pathology was present in the lungs, heart, liver, pancreas, kidneys or spleen (duPont, 1977).

Chronic Toxicity

No chronic effects attributed to THF have been reported. One study reported liver and kidney injury in animals exposed to 3,000 ppm, but these effects are believed to have been caused by the presence of contaminants in the test compound (Proctor and Hughes, 1978). THF supplied by Du Pont, the major producer in the U.S., is reported to be more than 99.9 percent pure. A prechronic test of THF has been completed under the NCI/NTP carcinogenesis bioassay program; it has not been scheduled for chronic testing (Juodeika, 1983). Results of the prechronic test have been requested but not received.

Cyclohexanone

Cyclohexanone, a cyclic 6-carbon ketone, is a colorless liquid with a peppermint-like odor. It is used widely in organic synthesis and as a solvent for various materials, including natural and synthetic resins. it is a common component of cements used with PVC and CPVC piping (Department of Housing and Community Development, 1983).

NIOSH (1980) estimates that approximately 10,000 workers are exposed annually to cyclohexanone. Cyclohexanone is considered to be moderately toxic by dermal, oral, and inhalation routes. It has mild narcotic properties (Sax, 1979). A pipefitter experienced olfactory disturbances after exposure to cyclohexanone, THF, and acetone (Emmet, 1976). The relationship between the disturbance and exposure to any one of the solvents could not be determined from the evidence presented. At an atmospheric concentration of 75 ppm, cyclohexanone is mildly irritating to the eyes and respiratory tract (NIOSH, 1981). Repeated skin contact may cause defatting of the skin and dermatitis, but absorption through the skin is insignificant

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(Proctor and Hughes, 1978). The current ACGIH TLV is set at 25 ppm (ACGIH, 1982); the OSHA PEL is 50 ppm (OSHA, 1981).

Absorption and Metabolism

Cyclohexanone is reduced to cyclohexanol, which is then glucuronidated in the liver (Elliot et al., 1959). Approximately 74-100 percent of administered cyclohexanone was converted to cyclohexanol and excreted in the urine as a glucuronide conjugate in less than 24 hours (Martis et al., 1980). In rats dosed intraperitoneally with cyclohexanone, urinary excretion constituted a minor pathway, with only 15-24 percent of the administered dose being excreted as the glucuronide and 1 percent excreted as cyclohexanone or cyclohexanol; no sulfate conjugates were detected. The authors suggest that the majority of the compound was excreted in the breath as the ketone or alcohol, or in the feces as a conjugate of cyclohexanol (Greener et al., 1982). Gupta et al. (1979) administered cyclohexanone and pentobarbital concurrently to mice. Because cyclohexanone did not increase pentobarbital-induced sleeping time, the authors concluded that the compound did not significantly affect the hepatic microsomal oxidation function responsible for pentobarbital metabolism.

Acute Toxicity

The lowest median lethal oral dose (LD_{50}) of cyclohexanone reported for rats is 1620 mg/kg; the lowest concentration lethal to rats exposed by inhalation is 2,000 ppm for 4 hours. The rabbit dermal LD_{50} is 1,000 mg/kg (NIOSH, 1981). Gupta et al. (1979) performed a series of acute toxicity tests with mice, rats, and guinea pigs using intraperitoneal or intragastric administration. Dying animals exhibited peritoneal and intestinal congestion, and signs of irritation. Repeated doses produced cumulative effects in mice as indicated by a significant reduction (approximately 90 percent) in the median lethal dose as the period of administration increased from one day to ten weeks.

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Cyclohexanone is irritating to the eyes and skin, the degree of irritation being a function of the applied concentration. In rabbits, a 12.4 percent cyclohexanone/cottonseed oil solution applied to the shaven back was only slightly irritating; a 99 percent solution was very irritating. Similar concentration-dependent results were obtained when various concentrations were instilled in the rabbit eye; a 2.5 percent solution was not irritating, whereas a 99 percent solution was very irritating (Gupta et al., 1979).

Greener et al. (1982) administered cyclohexanone intravenously to rats for 28 days at 0, 50, or 100 mg/kg. No toxic effcts were observed, but the number of animals per group (N = 10) was small. Rengstorff treated guinea pigs by dermal application or subcutaneous injection with 500 mg cyclohexanone three times weekly for 3 weeks. He observed cataract development in four of the twelve animals exposed. The details of the experiment were not available and therefore the significance of the result is difficult to evaluate (Rengstorff et al., 1972). The formation of corneal opacities is a response that is frequently seen in laboratory animals exposed to organic solvents. The effect is usually reversible, and no correlation between the development of opacities in laboratory animals and the formation of cataracts in humans has been established.

Chronic Effects

No long-term studies of the effects of cyclohexanone were reported in the literature.

Effects on Genes and Chromosomes

Cyclohexanone has been tested in a NIOSH-sponsored Tier II mutagenicity screening program (McGregor, 1980). No effects on genes or chromosomes were observed in any of the tests, which included the following:

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(1) Unscheduled DNA synthesis (UDS) assay in human diploid fibroblasts with exposures of 3 hours duration and concentrations of up to 9.48 mg/ml of culture medium.

(2) Dominant lethal test in male rats with exposure to atmospheres containing 50 ppm or 400 ppm cyclohexanone for 7 hours per day for 5 consecutive days.

(3) Sperm abnormality test in male mice using the same exposure conditions as in (2).

(4) Cytogenetic test in male and female rat bone marrow cells using the same exposure conditions as in (2) or a single exposure of 7 hours duration followed by sampling after 6 hours, 24 hours, and 48 hours.

(5) Sex-linked recessive lethal (SLRL) test in Drosophila melanogaster with exposure to atmospheres of 50 ppm for 7 hours or 400 ppm for 40 minutes.

Cyclohexanone was reported to be mutagenic in assays using B. subtilis and S. typhimurium; no details of the test protocol and methods were supplied (Massoud et al., 1980). No other data on mutagenic potential were located. The cytotoxicity of cyclohexanone was determined by Gupta et al. (1979); a medium containing 1.95×10^{-2} moles/liter inhibited the growth of mouse fibroblast cells by 50 percent. The composition of the medium was not reported.

Carcinogenicity

Cyclohexanone is currently being tested in an NTP/NCI bioassay (Juodeika, 1983). No results were available at the time of this writing. Only one report related to carcinogenicity was available for review. Massoud et al. (1980) reported that cyclohexanone was positive in both a forward mutation test using Bacillus subtilis and an Ames Salmonella assay.

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Details of the tests, including applied concentrations, incubation times, metabolic activation employed (if any), and number of forward mutants or revertants obtained were not supplied. In the Ames test, TA98 produced the greatest number of revertants, indicating a possible frame-shift mutation.

Effects on Reproduction

No data on teratogenicity or reproductive effects were available.

Methyl Ethyl Ketone

Methyl ethyl ketone (MEK) is a colorless liquid with an acetone-like odor. It is used extensively in industry in organic synthesis and as a solvent for plastics, inks, and coatings. It is found in variable concentrations in cements for plastic piping (Department of Housing and Community Development, 1983).

The National Institute for Occupational Safety and Health (1980) estimates that approximately 2.5 million U.S. workers are exposed annually to MEK. The current ACGIH TLV and OSHA PEL are set at 200 ppm to prevent irritation (ACGIH, 1982; OSHA, 1981). Because the odor of the compound can be recognized at 25 ppm, it may serve as a warning of potentially dangerous concentrations.

Absorption and Metabolism

MEK is effectively absorbed by any route of administration and is readily eliminated unchanged in the breath, and in the urine in unchanged or metabolized form (Tado et al., 1972). The dermal absorption of MEK was tested using absorption cells strapped to the arms of human volunteers. Fifteen minutes after the beginning of exposure, MEK was detected in the expired breath (Munies and Wurster, 1965).

Di Vincenzo et al. (1976) administered a single intraperitoneal dose of 450 mg/kg MEK to guinea pigs and examined the serum and urine for parent

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compound and metabolites. The serum half-life of MEK was approximately 270 minutes; all compound was cleared by 12 hours. Only 11 percent of the administered dose was accounted for in the urine. Urinary metabolites were 2-butanol, 3-hydroxy-2-butanone and 2,3-butanediol. Dietz and Traiger (1979) obtained similar results with rats given a single oral dose of 335 mg/kg MEK; serum levels peaked at 4 hours post administration. At the end of 12 hours, only 25 percent of the compound had been accounted for.

Rabbits exposed to MEK reduced the compound to 2-butanol; the main urinary metabolite was the glucuronic acid conjugate (Williams, 1959). Mice eliminated an intravenous dose primarily in the expired air; the remainder was eliminated as the glucuronide (De Castiglia et al., 1972). In dogs, 30-33 percent of a .3-.5/kg dose was eliminated in the expired air (Williams, 1959).

Although methyl ethyl ketone may affect the metabolism of other compounds, results of the studies reviewed were not entirely consistent. Toftgard et al. (1981) exposed rats to 800 ppm MEK in air for up to 14 hours per day over a 4 week period, then sacrificed the animals and used their livers in studies designed to detect effects on the microsomal enzyme system--the system used by the body to metabolize drugs and many other organic molecules. No change in enzyme levels was seen, but some P-450-dependent reactions were decreased. In studies with Wistar rats, Couri et al. (1977) found that continuous or intermittent exposure to 750 ppm MEK in air for 7 hours per day over a 7-day period decreased hexabarbital sleep time in male Wistar rats, presumably by increasing activity of liver enzymes. Traiger et al., (1975) reported that oral administration of a single dose of 1.87 ml MEK/kg body weight also increased liver microsomal enzyme activity in the rat.

Acute Toxicity

MEK is an irritant of the eyes, skin and mucous membranes at concentrations in air of 100 ppm and higher (NIOSH, 1981). Several workers exposed to concentrations of 300-600 ppm complained of numbness in the

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fingers and arms; one worker experienced numbness in the legs. Several developed dermatitis from contact with the liquid (Smith and Mayers, 1944). At sufficiently high concentrations, MEK will cause central nervous system depression; the severity of symptoms varies with the absorbed dose (Proctor and Hughes, 1978).

The median lethal oral dose for the rat is approximately 3,400 mg/kg, and the lowest lethal concentration is 2,000 ppm over a 4-hour period (NIOSH, 1981). The major effects of MEK appear to be irritation and central nervous system depression. Guinea pigs exposed to concentrations in air ranging from 10,000 ppm to 100,000 ppm for various durations up to 14 hours exhibited eye irritation, respiratory distress, changes in cardiac function, lack of coordination, and narcosis. Those animals sacrificed immediately after exposure had congested internal organs, indicating extreme irritation; these effects were not observed in animals sacrificed 4 or 8 days after exposure. Exposure for 30 minutes or more to 100,000 ppm produced reversible opacity of the cornea (Patty et al., 1935).

Inhalation of 1 percent, 2 percent and 5 percent concentrations of MEK produced CNS effects, including dose-dependent depression of body temperature, respiratory rate and heart rate (Specht et al., 1940). Increased levels of ornithine carbamyl transferase (OCT) and increased lipid content of the liver were observed in guinea pigs administered a single intraperitoneal dose of 2,000 mg MEK/kg body weight; these findings indicate liver damage (DiVincenzo and Krasavage, 1974).

Chronic Toxicity

No chronic systemic effects have been attributed to exposure to MEK. Although MEK in combination with other solvents has been associated with peripheral neuropathies, exposure to MEK alone has not produced these symptoms. Careful studies have documented peripheral neuropathies in workers exposed to MEK in mixtures with n-hexane or methyl n-butyl ketone; MEK enhances the neurotoxicity of these compounds (Allen et al., 1975), possibly by affecting microsomal enzyme activity (Couri et al., 1977). Case

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reports have attributed peripheral neuropathies to exposure to MEK in combination with acetone or toluene (Dyro, 1978) and tetrahydrofuran (Viader et al., 1975).

The most significant chronic effect of MEK exposure is the potentiation of other solvent-induced neuropathies. Rats exposed for 8 hours per day, 7 days per week over a period of 15 weeks to 1,100 ppm MEK and 8,900 ppm n-hexane or 10,000 ppm n-hexane alone developed peripheral neuropathies (muscular weakness of the limbs, etc.); rats exposed to 6,000 ppm MEK alone did not develop signs of neurotoxicity (Altenkirch et al., 1979). Rats exposed for 8 hours per day, 5 days per week over a 6 week period to 200 ppm methyl n-butyl ketone (MBK) and 2,000 ppm MEK developed peripheral neuropathies (Duckett et al., 1974). Rats exposed to 1,125 ppm MEK continuously for 5 months (Saida et al., 1976), exhibited no signs of neurologic injury. Sprague-Dawley rats exposed to 800 ppm MEK for 6 hours per day, 5 days per week for 4 weeks, had increased liver weights and liver weight/body weight ratios, indicating possible damage to the liver. The Chemical Industry Institute of Toxicology (1981) exposed Fischer-344 rats to concentrations of MEK in air of 1,250, 2,500, or 5,000 ppm. No significant toxic effects were seen, and a decision was made to cancel proposed lifetime inhalation toxicity studies. If new data indicate a need, the decision will be reconsidered.

Effects on Genes on Chromosomes

No results of tests for effects on genes and chromosomes were located.

Carcinogenicity

No results of tests for carcinogenicity were located.

Effects on Reproduction

Two tests for teratogenicity have been reported, and results are conflicting. Schewetz et al. (1974) exposed rats to 3,000 ppm for 7 hours

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per day on days 6 through 15 during the period of gestation and observed some increased in acaudia, imperforate anus, and brachygnathia. In addition, soft tissue abnormalities, and sternebral variants (not considered teratogenic) were increased, though not to the point of statistical significance. In order to clarify the significance of results, Deacon et al. (1981) of the same laboratory conducted a similar study using 25 pregnant rats per group and exposures of 400, 1,000 or 3,000 ppm MEK in air for 7 hours per day during days 6-15 of gestation. No increases in resorptions or preimplantation losses were observed. At 3,000 ppm, there was a significant increase in the number of animals with extra ribs, and ossification of the skull was delayed. No major malformations were seen .

Carbon Tetrachloride

Absorption and Metabolism

Carbon tetrachloride is rapidly absorbed from the gastrointestinal tract, the lungs, or through injured skin, and is distributed to the liver, fatty tissues, brain, kidney, blood, and bone marrow. Absorption from the GI tract is augmented by the presence of fats and alcohol. Carbon tetrachloride is excreted principally through the lungs unchanged (about 85 percent of absorbed dose) and as carbon dioxide (10 percent) and other metabolites, which (in rabbits) include chloroform and hexachloroethane (in rabbits) (NAS, 1977). Highly reactive free-radical intermediates are thought to be responsible for carbon tetrachloride's toxicity. Such reactive metabolites can bind irreversibly primarily to proteins and lipids in the liver, and may do the same in other tissues (IARC, 1979).

Acute Toxicity

In humans, high level exposure has led to severe liver damage and/or kidney failure (Klaassen, 1980b). Accidental poisonings with 14-20 ml have almost always been fatal: the lowest reported fatal dose is 1.5 ml (NAS, 1980; IARC, 1979). Inhaled carbon tetrachloride can cause CNS depression, fatal cardiac arrhythmias, and damage to the lungs (IARC, 1979).

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Chronic Toxicity

Chronic exposures to carbon tetrachloride cause liver and kidney damage in humans and animals. Symptoms in humans include nausea, vomiting, headache, drowsiness, and fatigue (NAS, 1977).

Effects on Genes and Chromosomes

Carbon tetrachloride was reportedly negative for mutagenic activity in several bacterial assays (IARC, 1979; NAS, 1980). However, it is possibility that these negative results may have been due to inadequate experimental protocols (EPA, 1982). One report cited by IARC (1979) indicated that carbon tetrachloride could react with DNA of rodent cells under certain conditions (Rocchi et al., 1973). The International Agency for Research on Cancer considers that there is inadequate evidence of carbon tetrachloride's activity in short-term assays (1982).

Carcinogenicity

In 1979, the International Agency for Research on Cancer renewed the 11 bioassays involving oral, inhalational, intratracheal, subcutaneous, and intrarectal administration of carbon tetrachloride in several species (rats, mice, hamsters, trout). It was found to be carcinogenic to rats and mice, producing liver tumors in several strains of both species. In one experiment involving subcutaneous injection of carbon tetrachloride to rats, it produced mammary tumors (IARC, 1979).

There is no conclusive epidemiological evidence of cancer in humans exposed to carbon tetrachloride. However, there are several case reports of liver cancer following carbon tetrachloride poisoning, and of excesses of other types of malignancy among persons occupationally exposed to carbon tetrachloride (IARC, 1979, 1982).

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Effects on Reproduction

Pregnant rats exposed to airborne concentrations of 1,800 and 6,300 mg/m^3 (300 and 1,000 ppm) of carbon tetrachloride for 7 hours per day on days 6-15 of gestation produced fetuses with retarded development (Schwetz et al., 1974). Carbon tetrachloride injected in mice at doses of 150 mg/mouse during the final part of pregnancy caused increased fetal mortality, due probably to fetal liver damage and injury to the placenta (Roschlau and Rodenkirchen, 1969). An earlier study reported no teratogenic effect of carbon tetrachloride administered to rats (Wilson, 1954, cited in NAS, 1977). In general, the available evidence is not adeaquate to assess whether carbon tetrachloride can cause teratogenic effects (EPA, 1982). It does, however, appear to be fetotoxic at high doses (such as those noted above). Furthermore, it appears to be capable ot causing testicular generation when injected intraperitoneally at very high doses (i.e., 4,800 mg/kg body weight in rats) (EPA, 1982).

Trichloroethylene

Trichloroethylene is a colorless liquid that is used as a degreaser, a chemical intermediate in organic synthesis and a solvent in various applications. It is highly volatile and is miscible with water and organic solvents. Pure trichloroethylene degrades readily to other toxic organic compounds (IARC, 1979). The stabilizers added to trichloroethylene, e.g., epichlorohydrin or amines, may affect its toxicity.

OSHA has set a PEL of 100 ppm (8-hour time-weighted average concentration with a ceiling of 200 ppm (OSHA, 1981). The ACGIH recommends a TLV of 50 ppm (8-hour time-weighted average) and a Short Term Exposure Limit (STEL) of 200 ppm (ACGIH, 1982).

The liver and the central nervous system are target organs for trichloroethylene; but the compound is reportedly less hepatotoxic than carbon tetrachloride or chloroform. Cats exposed to 20 ppm for 1.5 hours/day for 6 months developed lesions in the liver, kidney and spleen (IARC,

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1979). In other investigations, behavioral and histopathologic evidence of neurological damage was seen (Browning, 1965).

Absorption and Metabolism

Trichloroethylene is rapidly absorbed through the lung; about 45 percent of the inhaled dose is excreted unchanged in the expired breath (IARC, 1979). The portion that is not exhaled is metabolized by the hepatic mixed function oxidase system. Monster et al. (1976) exposed four male volunteers to 70 or 140 ppm trichloroethylene in air for 4-hour periods. Concentrations of the parent compound, trichloroethanol and trichloroacetic acid were determined in the blood. Exhaled air was analyzed for trichloroethylene and trichloroethanol and urine was examined for trichloroethanol and trichloroacetic acid. Total recovery was 67 percent. Ten percent was recovered unchanged in the expired breath; in the urine 39 percent was recovered as trichloroethanol and 18 percent was recovered as trichloroacetic acid. The major products of metabolism in dogs, rats, and humans are trichloroethanol (Astrand and Ovrum, 1976), trichloroacetic acid, and trichloroethanol glucuronide (Muller et al., 1974). Humans and rats also produce chloral hydrate (Cole et al., 1975).

Van Durren and Baneyee (1976) studied the *in vitro* microsomal metabolism of trichloroethylene and covalent binding to rat liver microsomal protein. They hypothesized that TCE is metabolized to its epoxide or other related reactive intermediates that bind to protein and are most likely involved in TCE carcinogenesis. Henschler and Bonse (1978) have also proposed the formation of a reactive epoxide by mixed function oxidases. Scott et al. (1982) studied pharmacokinetics and binding of TCE to macromolecules and DNA in male B6C3FI mice and Osborne Mendel rats *in vivo*. Mice metabolized more inhaled TCE to a metabolite that bind to monomolecules than did rats; liver damage and increased DNA synthesis in mice were noted after repeated doses (2,400 mg/kg/day for 3 days). Only a very low level of alkylation of DNA occurred, the authors suggested that the genotoxic potential of TCE was low, that tumorigenesis probably resulted from an

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epigenetic mechanism, and that TCE would be tumorigenic only upon chronic administration of high cytotoxic doses.

Acute Toxicity

Several fatal poisonings have occurred after ingestion of trichloroethylene; signs and symptoms of poisoning are usually those of central nervous system depression, gastrointestinal disturbance, and abnormalities in cardiac function (NAS, 1982). The lowest dose reported to cause inebriation in humans is approximately 300 mg/kg (NAS, 1982).

The median lethal dose of trichloroethylene in rats is 4920 mg/kg; the median lethal concentration is 5000 ppm. The compound is irritating to the rabbit eye and skin (NIOSH, 1981).

Chronic Toxicity

Chronic exposure to trichloroethylene produces damage to the central nervous system and the liver. Alcohol intolerance, similar to that seen in persons taking Antabuse (disulfiram) or exposed to dimethylformamide, has also been seen in exposed workers (Proctor and Hughes, 1977).

Carcinogenicity

Axelson et al. (1978) reported no statistically significant excesses of tumors associated with exposure to trichloroethylene in an epidemiological study of workers, but problems in the design and conduct of the study (e.g., small number of persons, short period of time since beginning of exposure) limit the usefulness of the results in assessing human risk. Tola et al. (1980) also studied a cohort of workers exposed to trichloroethylene. Both observed total mortality and cancer mortality rates were lower than expected; however, results cannot be considered conclusive because the cohort was young and follow-up has been too short to detect fatal cancers with a long latency period (more than 6-13 years). The cohort will be followed and data will be reanalyzed every 5 years. Studies by Malek et al.

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(1979) and Blair (1980) also failed to show an excess of cancers in workers exposed to trichloroethylene.

Trichloroethylene was tested by gavage in an NCI bioassay with Osborne Mendel rats and B6C3F1 mice. The time-weighted average daily doses administered over a period of up to 78 weeks were 1,169 and 2,339 mg/kg for male mice, 869 and 1,739 mg/kg for female mice, and 549 and 1,097 mg/kg for male and female rats. The compound produced hepatocellular carcinomas in both male and female mice, but not in rats (NCI, 1976). The International Agency for Research on Cancer considers that the results of this experiment provide "limited" evidence of the carcinogenicity of trichloroethylene (IARC, 1979). Henschler et al. (1980) exposed NMRI mice, WIST rats, and Syrian hamsters to 0, 100, or 500 ppm TCE for 6 hours per day, 5 days per week for 18 months in an inhalation study. Thirty animals of each sex were used for each dose level. Terminal sacrifice of mice and hamsters occurred at 30 months; surviving rats were maintained until 36 months. The only significant increase in tumor formation was observed in female mice, in which malignant lymphoma incidence was increased twofold in the 100 and 500 ppm groups. The authors suggested that this increase might be due to some effect of TCE on spontaneous rates of a virally induced condition. They conclude that TCE was not carcinogenic and that results of previous tests in which it was found to be carcinogenic were due to the presence of epoxides or other impurities.

The study appears to have been conducted carefully and survival was good. However, the number of animals per group was small, thus limiting the power of the assay. The positive result in female mice may or may not have been due to the action of TCE, but convincing negative evidence has not been presented.

Because the compound used in the original bioassay was contaminated by epichlorohydrin, a second bioassay was undertaken in 1980, using highly purified trichloroethylene. Results corroborate the findings of the first bioassay; the final report was scheduled to be published in late February, 1983, but had not been received as of this writing (Juodeika, 1983).

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Effects on Genes and Chromosomes

Results of tests for mutagenicity are conflicting. Trichloroethylene caused unscheduled DNA synthesis, spermhead abnormality in mice and weak or borderline responses in a host-mediated assay and Drosophila (Beliles, 1982). Positive results were also seen in tests with Escherichia coli, Salmonella typhimurum TA 100, and Saccharomyces cerevisiae (NIOSH, 1981). In a mouse host-mediated assay, trichloroethylene induced point mutations and gene conversion in yeast recovered from liver and kidney (IARC, 1982). Negative results were seen in Salmonella typhimurium, a bone marrow cytogenetics assay (IARC, 1979), and dominant lethal assays in rats and mice (IARC, 1982).

Effects on Reproduction

No adverse effects were seen in offspring of rats and mice exposed to 300 ppm trichloroethylene for 7 hours/day on Days 6-15 of gestation (Schwetz et al., 1975). No teratogenic effect, but decreased fetal weight and increased frequency of skeletal anomalies were seen in offspring of pregnant Wistar rats exposed to 100 ppm trichloroethylene in air for 4 hours daily from Days 8 to Day 21 of gestation. Female rats and rabbits were exposed to 0, 100, or 500 ppm trichloroethylene in air for 3 weeks before impregnation and up to 30 days post gestation. No adverse effects in offspring were seen in rats. In one group of rabbits, hydrocephalic fetuses were seen (Beliles, 1982).

Dorfmueller et al. (1979) exposed groups of 30 virgin female Long-Evans rats by inhalation to 1,800 ppm trichloroethylene in air in one of four treatment regimens:

(++)-TCE before mating and during pregnancy

(+-)-TCE before mating, filtered air during pregnancy

(-+)-Filtered air before mating, TCE during pregnancy

(--)-Filtered air before mating and during pregnancy.

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TCE with epichlorohydrin as a stabilizer was used. Exposures ended on Day 20 of gestation. On Day 21, 15/30 dams from each group were sacrificed, maternal and fetal liver enzymes were analyzed, and fetuses were examined. Remaining dams were allowed to litter and offspring were subjected to behavioral testing from Day 10 to Day 100 of life.

No significant treatment-related maternal toxicity or embryotoxicity were seen. Skeletal anomalies and displacement of the right ovary were seen in offspring of the (-+) group, but effect might have been strain-specific rather than treatment-related. No true effects were seen. Postnatal behavioral tests revealed no evidence of CNS damage in exposed offspring.

Perchloroethylene

Perchloroethylene (tetrachloroethylene) is a colorless liquid that is used as a dry-cleaning fluid, chemical intermediate, degreaser and as a solvent in various applications. In water it is practically insoluble; it decomposes slowly to trichloroacetic and hydrochloric acids. It is miscible with oils and organic solvents. Perchloroethylene is moderately volatile and has been found in the air of numerous U.S. cities. It may be formed in water as a result of chlorination. It has been detected in domestic water supplies and industrial effluent (IARC, 1979).

The OSHA Permissible Exposure Limit (PEL) for perchloroethylene is 100 ppm (8-hour time-weighted average concentration) with a ceiling of 200 ppm (OSHA, 1981). The ACGIH recommends a threshold limit value (8-hour time-weighted average concentration) of 50 ppm with a short term exposure limit of 200 ppm (ACGIH, 1982).

Absorption and Metabolism

Perchloroethylene is readily absorbed from the lung; gastrointestinal absorption is less complete, although the presence of fats may enhance absorption (Lamson et al., 1929). The compound is also absorbed through the skin (Hake and Stewart, 1977). Approximately 70 percent of the inhaled dose

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is excreted unchanged or as CO_2 in the expired breath by mice (Yllner, 1961) and rats (Pegg et al., 1978). In mice, urinary metabolites accounted for approximately 20 percent of the radioactive label and were identified as trichloroacetic acid, oxalic acid and dichloroacetic acid. A small percentage was excreted in feces. Induction of the microsomal oxidation system increased hepatotoxicity in rats (Moslen et al., 1977); ethylene oxide, a suspected carcinogen, may be a metabolic intermediate (Henschler and Bonse, 1977). Inhaled perchloroethylene is metabolized very slowly; its biologic half-life ($t_{1/2}$) in humans is 3-5 days, depending on length of exposure. The $t_{1/2}$ in persons exposed to 100 ppm for 8-hours (the OSHA permissible exposure limit) was estimated to be 71.5 hours (Guberan and Fernandez, 1974). Ogata et al. (1971) exposed male volunteers to 87 ppm perchloroethylene in air for 3 hours; after 67 hours, only 1.8 percent of the dose had been excreted in the urine as trichloroacetic acid; no information on concentrations in expired breath was available in the secondary source consulted. Monster et al. (1979) exposed human volunteers to 72-144 ppm perchloroethylene in air for 4-hour periods. Of the absorbed dose, eighty percent was eliminated unchanged in the exposed air; 2 percent was eliminated in the urine as trichloroacetic acid. Concentrations of perchloroethylene in the blood and exhaled air indicated that a long period of time is necessary before elimination is complete (more than 7 days) and therefore, repeated exposures could result in bioaccumulation.

Perchloroethylene in sufficiently high concentrations causes central nervous system depression, liver damage, eye and skin irritation, and pulmonary edema. Volunteers exposed to 100 ppm (the current OSHA PEL) for 7 hours experienced irritation of the eyes, nose and throat, headache, flushing of the face and neck, and lethargy and slurring of speech (Stewart, 1969). Exposure to 600 ppm for 10 minutes produced dizziness, lack of coordination, and numbness around the mouth. Exposures to 2,000 ppm produced mild CNS depression within 5 minutes (Von Oettingen, 1955).

The oral median lethal doses of perchloroethylene in rats and mice are approximately 13 g/kg (Smyth et al., 1969) and 7g/kg (Kohne, 1940), respectively. Acute exposures have produced dose-dependent symptoms of CNS

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depression. The inhalation LC50 (median letal concentration) in mice is 5,200 ppm/3 hours (Friberg et al., 1953).

Chronic Toxicity

Chronic exposure to perchloroethylene has caused impaired memory and other CNS symptoms, abdominal pain, and peripheral neuropathies (IARC, 1979; Proctor and Hughes, 1978). Liver and kidney damage have also been reported (Stewart, 1969). There are no published data concerning potential mutagenicity, or adverse reproductive outcomes in humans due to perchloroethylene exposure. Two epidemiologic investigations of dry cleaners, a proportional mortality study and a prospective cohort mortality study, found excess deaths from various cancers: lung, cervix, colon, skin, liver, and leukemia. However, in both studies, mixed exposures probably occurred and IARC (1982) considers results to be inconclusive.

Repeated exposure by inhalation to perchloroethylene has produced liver damage in rats, rabbits and guinea pigs (Proctor and Hughes, 1978). Oral doses have produced liver and kidney damage in dogs and mice (Klaasen and Plaa, 1966, 1967).

Carcinogenicity

Perchloroethylene was tested by gavage in an NCI bioassay in B6C3F1 mice and Osborne-Mendel rats (NCI, 1977). No increases in tumor incidence were observed in rats, but a significant increase in hepatocellular carcinoma incidence was observed in mice. The International Agency for Research on Cancer (1979) considered that these results provided "limited evidence of the carcinogenicity of tetrachloroethylene" (perchloroethylene). NCI/NTP has recently completed a second bioassay of perchloroethylene; the draft report has been requested but not received.

In a study reviewed by IARC, male and female Sprague-Dawley rats exposed by inhalation to 300 or 600 ppm perchloroethylene in air over a 12-month period showed no increased tumor incidence over untreated controls

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(Rampy et al., 1977). Schumann et al. investigated the pharmocokinetics and macromolecular interactions of perchloroethylene in Sprague-Dawley rats and B6C3F1 mice in an attempt to explain mechanistically the sensitivity of the mouse and resistance of the rat to perchloroethylene-induced hepatocellular carcinoma. Mice metabolized 8.5 and 1.6 more radiolabelled perchloroethylene than rats after a single inhalation exposure to 10 ppm or a single oral dose of 500 mg/kg, respectively. Greater irreversible binding to hepatic macromolecules also occurred in mice, but no binding to hepatic DNA was detected (the test was sensitive to 10-14.5 alkylations/10^6 nucleotides).

Hepatic DNA synthesis was increased twofold in mice after repeated oral administration of 500 or 1000 mg/kg/day, the approximate levels administered in the NCI gavage bioassay. No significant alterations in hepatic DNA synthesis were seen in rats.

The authors concluded that perchloroethylene induces tumors by cytotoxic mechanisms and that lowering exposure to a level below that at which tissues injury occurs should make tumor production unlikely in both animals and humans.

Effects on Genes and Chromosomes

There are conflicting results regarding the mutagenicity of perchloroethylene. Perchloroethylene caused spermhead abnormality in mice, positive results in host-mediated assay, and weak or borderline responses in tests for unscheduled DNA synthesis and bone marrow aberrations (Beliles, 1982). Positive results were seen in Ames Salmonella assay in strain TA 100 and in a host-mediated assay in mice using Salmonella TA 1950, TA 1951, and TA 1952 (Cerna and Kypenova, 1977). Negative results were seen in three screens using E. coli (Greim et al., 1975) and in a bone marrow cytogenetics assay (Cerna and Kypenova, 1977). IARC (1982) considers that there is inadequate evidence of activity in short-term tests.

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Effects on Reproduction

No teratogenicity or adverse reproductive outcomes were seen in offspring of rats or mice exposed by inhalation to 300 ppm perchloroethylene for 7 hours daily on Days 6-15 of gestation (Schwetz et al., 1975). Offspring of female Sprague-Dawley rats exposed to 900 ppm or 100 ppm perchloroethylene for 7 hours per day on Days 7-13 or 14-20 of gestation were examined in a series of behavioral tests. No significant differences were observed between offspring of animals exposed to 100 ppm perchloroethylene and control animals on any behavioral tests. Behavior of offspring of animals exposed to 900 ppm varied from controls but in no consistent pattern. Neurochemical analysis of brains of newborn and 21-day-old pups showed reduced levels of acetylcholine significantly different from offspring of controls. Dopamine levels of offspring of dams exposed to 900 ppm from days 7-13 of gestation were significantly lower than those of controls.

Dichloromethane

Dichloromethane (DCM, methylene chloride) is a large volume solvent used as a paint remover, degreaser, aerosol propellant and extractant; it is also used in the manufacture of plastics, photographic film, and textiles. It is approved for use by FDA in adhesives and in the production of polycarbonate resins intended for use in producing, manufacturing, packaging, processing, preparing and holding food (USFDA, 1977). It is also permitted as a residue in coffee, hops, and various spices. (USFDA, 1977). NIOSH (1980) estimates that approximately 2 million persons per year are occupationally exposed to dichloromethane. OSHA has set an 8-hour time-weighted-average permissible exposure limit (PEL) of 500 ppm (OSHA, 1981). The American Conference of Governmental Industrial Hygienists recommends an 8-hr threshold limit value (TLV) of 100 ppm (ACGIH, 1982).

Dichloromethane is formed during the chlorination of water; chloroform and carbon tetrachloride are also formed. DCM has been found in 1 percent of raw and 8 percent of finished water supplies tested. The mean

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concentration found in several samples of finished water was 1 µg/l. DCM was found in 9 of 10 domestic water supplies; the highest concentration detected was 1.6 µg/l. (IARC, 1979)

Absorption and Metabolism

Dichloromethane is absorbed by the lungs and the skin. Ninety-one percent, of a large radiolabelled intraperitoneal dose was eliminated unchanged via the lungs (DiVincenzo and Hamilton, 1975), 2 percent of the dose was eliminated as carbon monoxide, 3 percent as carbon dioxide, and 1 percent as an unidentified volatile compound; 1 percent of radioactivity was detected in urine and 2 percent remained in the carcass. Injection of a small dose (17 mg/kg) apparently resulted in much greater metabolism (Rodkey and Collison, 1977a, 1977b); 47 percent of radioactivity was recovered as carbon monoxide, 29 percent as carbon dioxide, and none was detected in the carcass. These results suggest that dichloromethane metabolism is saturable. Two metabolic pathways have been proposed for dischloromethane in rats. The first is mediated by microsomal mixed-function oxidases and results in the formation of carbon monoxide (Kubic and Anders, 1976). The second is mediated by cytosolic enzymes and is glutathione dependent; the major end products are formaldehyde and carbon dioxide. Formic acid may also be formed (Ahmed and Anders, 1976). In human volunteers exposed to 50-500 ppm for up to 7.5 hours for 5 consecutive days, most DCM was excreted unchanged in the expired breath (Peterson, 1978). Elimination continued for a substantial period beyond the termination of exposure, suggesting a degree of bioaccumulation, probably in lipid tissues (USEPA, 1980). Carboxyhemoglobin blood levels increased with dose up to approximately 10 percent saturation (Stewart and Hake, 1976). Such levels might increase cardiorespiratory stress (USEPA, 1980).

Acute Toxicity

Dichloromethane is a central nervous system depressant (NIOSH, 1976) and irritant of the eyes, skin, and mucous membranes. 2000 ppm did not cause dizziness, but a concentration of 7200 ppm caused numbness of the

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extremities after 8 minutes. CNS effects are reversible and the compound has been used as an anesthetic (USEPA, 1980). Skin contact can cause dermatitis (Sax, 1979). Occupation exposure has caused damage to both the CNS and the liver (Hanke et al., 1974; Weiss, 1976). Deaths have occurred after short-and long-term exposures (NIOSH, 1976); death is usually due to cardiac injury and heart failure (USEPA, 1980).

Friedlander et al (1978) conducted two epidemiologic investigations of males occupationally exposed to dichloromethane -- a proportional mortality study of 334 persons and a prospective cohort mortality study of 751 persons. No significant differences were noted in either study between observed and expected deaths from any type of malignancy, circulatory heart disease, ischemic heart disease, or any other cause. However, although both studies were well conducted and analyzed, the cohort studied was young and the follow-up period might not have been sufficiently long to detect even a moderate effect. Further follow-up is scheduled for consecutive 5-year periods.

The oral rat LD_{50} (median lethal does) for dichloromethane is 2136 mg/kg. The mouse inhalation LC_{50} (median lethal concentration) is 16,200 ppm or 56 g/m^3 (Svirbely et al., 1947). The lowest lethal concentration reported for guinea pigs is 5000 ppm/2 hours. Hepatotoxic effects were observed in mice after administration of single lethal doses (Gehring, 1968). Damage to the kidney has been seen in dogs (Klaassen and Plaa, 1967).

Effects on Genes and Chromosomes

Conflicting results have been obtained in various screens for mutagenesis. Positive results were obtained in the Ames test with Salmonella typhimurium strains TA98, TA100, and TA1535 with and without metabolic activation (Simmon et al., 1977; Kanada and Uyeta, 1978; Jongen et al., 1978; Snow et al., 1979; Green, 1980; Gocke et al., 1981). Positive results were also obtained in tests with yeast (Saccharomyces cerevisiae D-7), in a sister chromatid exchange assay with Chinese hamster cells (V79),

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in a cell transformation test using rat embryo cell line F1706, and in a sex-linked recessive lethal test with Drosophila melanogaster (Perry and Evans, 1975; USEPA, 1980; Jongen et al., 1981; Gocke et al., 1981). Dichloromethane has not produced genotoxic effects in the following assays: DNA synthesis in human and hamster cells, forward mutation in Chinese hamster cells, mitotic recombination in S. cerevisiae D-3, micronuclei production in NMRI mice.

Carcinogenicity

Dichloromethane is currently being in tested in rats and mice by gavage and inhalation exposure in National Toxicology Program carcinogenesis bioassays. The inhalation assay is in the chronic testing phase and no results will be available for approximately 1 year. The draft report of the gavage bioassay is scheduled for release in March or April of 1983. Rats and mice were administered 0, 500, or 1000 mg/kg DCM in corn oil by oral intubation. Significant increases of neoplastic liver nodules, adrenocortical adenomas, and pancreatic acinar cell adenomas were seen in rats. Significant increases in hepatocellular carcinomas and thyroid c-cell carcinomas were seen in mice. Pancreatic acinar cell adenomas in rats were apparently associated with the corn oil vehicle (Juodeika, 1983). The compound was originally judged to be carcinogenic in male and female animals of both species; the decision regarding carcinogenicity in rats, which was based on the elevated incidence of neoplastic liver nodules, may be revised (Mennear, 1983). Dow Chemical Company conducted a 2-year inhalation study with rats and hamsters exposed to 0, 500, 1500, and 3500 ppm DCM for 6 hours per day, 5 days per week. Preliminary reports indicated a significant increase in benign mammary tumors at all doses in female rats and at 3500 ppm in male rats (USEPA, 1980).

Theiss et al. (1977) conducted a pulmonary tumor assay in male strain A mice. Groups of 20 mice were injected intraperitoneally three times per week for 16 or 17 weeks with 0, 160, 400 or 800 mg/kg DCM. A significant increase in tumors was seen at the 160 ppm dose. Tumors were increased in the two higher dose groups but did not reach statistical significance as a

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result of poor survival; only 5/20 animals in the 400 ppm group and 12/20 in the 800 ppm group were examined for tumors.

The EPA Carcinogen Assessment Group states that there is "suggestive evidence" for the carcinogenicity of dichloromethane; this opinion is based on the results of mutagenicity screens as well as rodent tests. The International Agency for Research on Cancer (1982) considers that there is inadequate evidence for the carcinogenicity of DCM in animals and humans, and limited evidence for genotoxic activity in short-term tests. These judgments were made before preliminary results of the NTP bioassay were made available.

Effects on Reproduction

Schwetz et al. (1975) exposed pregnant rats and mice to 1250 ppm DCM in air for 7 hours daily on Days 6-15 of gestation. No treatment-related effects on litter size, resorptions, or fetal development were seen. Hardin and Manson (1980) exposed pregnant Long-Evans rats to 4,500 ppm DCM by inhalation and found no teratogenic effects.

Organic Tin Compounds

Absorption and Metabolism

Dialkyl and trialkyl tins may be absorbed from the gastrointestinal tract, although the fractional absorption differs among species. Most organotin compounds are poorly absorbed from the GI tract, except trimethyl-, triethyl-, and dimethyl tin (Kimbrough, 1976). Such alkyl tin compounds are distributed to the liver and, in the case of trialkyl tins, to the central nervous sytem. After injection in animals, dibutyl tin concentrates in the liver, with smaller amounts in the kidney. Dibutyl tin is excreted unchanged in the bile (Barnes and Stoner, 1959).

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Acute toxicity

There are few published data on isooctylthioglycolate derivates of organic tin compounds. The acute toxicity of these compounds, however, is reportedly similar to that of other dimethyl and dibutyl organotin derivatives (Barnes and Stoner, 1958, 1959). The following discussion is therefore based on experiments performed principally with dialkyl tin dichlorides or diacetates, or trimethyl tin chloride. There are major qualitative differences in the toxicity of dialkyl versus trialkyl tin derivatives.

The principal toxic effects of acute exposure to dialkyl tin componds are a generalized illness and, in the case of dibutyl tin, a severe, potentially fatal injury to the bile duct (Barnes and Stoner, 1958). Such bile duct lesions have been produced in rats and mice, but not rabbits, guinea pigs, cats, or hens (Barnes and Stoner, 1959). This phenomenon has reportedly been observed only in species in which the pancreatic and bile ducts follow a common course (Kimbrough, 1976). In humans, these ducts are separate.

Dimethyl tin salts, while also toxic to rodents, do not appear to cause bile duct lesions. Applied to the skin of rats and guinea pigs, there can be marked necrosis and scar formation. An oral no-observed-effect-level for a single dose of dimethyl tin dichloride to rats was reportedly 40 mg/kg, whereas for dibutyl tin dichloride such a level was 10 mg/kg, reflecting the latter compounds's greater oral toxicity (Barnes and Stoner, 1958).

Trialkyl tins, particularly triethyl and trimethyl tin, exert their principal toxic effects on the central nervous system, causing weakness, tremors, convulsions, paralysis, and death from respiratory failure.

Chronic Toxicity

There are very few chronic toxicity data on dimethyl or dibutyl tin bis isooctylthioglycolates. The Food and Drug Administration (FDA) recently

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approved the use of a mixture of dimethyl and monomethyl tin isooctyl mercaptoacetate (thioglycolate) as a stabilizer in PVC water pipe used in food processing plants (21 CFR 178; 46 Fed. Reg. 10461, Feb. 3, 1981). SRI requested documentation (by telephone and written request) supporting this regulation, but has not yet received anything from the FDA.

Dibutyl tin dichloride (DBTC), but not dimethyl tin dichloride, caused dose-related atrophy of lymphoid tissue (thymus and lymph nodes) in rats fed 50 and 150 ppm of this substance in their diets for 2 or 4 weeks (Seinen et al., 1977a). This was also observed in rats fed 20 ppm in their diet for 2 weeks. A no-observed-effect level was not determined. However, these effects on the thymus were reversible. Subsequent experiments indicated that DBTC selectively inhibits T-lymphocyte-dependent immune functions (Seinen et al., 1977b) in rats fed 50 or 150 ppm in the diet for 5 to 9 weeks or exposed prenatally, then postnatally, by gavage to doses of 1 to 3 mg/kg.

Effects on Genes and Chromosomes

Dibutyl tin dichloride was reported to be mutagenic in Chinese hamster ovary (CHO) cells, but not in the Ames test (Li et al., 1982). The concentration range in which mutagenicity was observed in CHO cells was at least 50 to 200 ppb.

Carcinogenicity

Dibutyl tin diacetate was tested for carcinogenicity using the standard protocol of the National Toxicology Program (NTP, 1979). Although there was a dose-related trend in liver tumor incidence in mice, there was no statistically significant increase in tumors in rats or mice of either sex. This assessment must be qualified in that more than one-third of the tissues from high-dose female rats were lost prior to examination.

A mixture of 75 percent dimethyl tin bis (isooctylthioglycolate) and 25 percent monomethyltin tris (isooctylthioglycolate) ("Advastab TM-181FS")

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was tested for chronic toxicity using a protocol that would not be acceptable for investigating carcinogenicity by current standards (Mosinger, undated). Twenty male and twenty female Wistar rats were fed ADVASTAB at 100 mg/kg in the diet. The author concluded that the absence of tumors in the experimental animals showed that "the product tested is not cancer-causing at the doses given." Since this test includes only one species, with less than half the number of experimental animals that are required to detect an increase of even 5 to 10 percent in tumor incidence, and a dose level that is not clearly the maximum tolerated dose (MTD), the author's generalized conclusion is unwarranted. The oral intake study of dimethyl/monoethyl tin isooctylthioglycolate is inadequate to assess the carcinogenicity of this mixture.

Effects on Reproduction

A mixture of 75 percent dimethyl tin isooctylthioglycolate and 25 percent monomethyl tin isooctylthioglycolate was tested for reproductive effects in Wistar rats. (Mosinger, undated) Little experimental data is provided, other than that 5 females and 1 male were treated. In view of the small sample size, the author's inference that "the product tested is not teratogenic," is not justified. Even without additional description of experimental protocol, this study is inadequate to assess the effects of the chemical mixture on reproduction.

Substances Associated with Polybutylene Plastic Pipe

Irganox 1010

Irganox 1010 is a hindered phenolic compound that is used as an antioxidant and stabilizer for various polymers. It is a constituent of polybutylene piping.

There is no OSHA PEL or ACGIH TLV for Irganox 1010. A repeated insult patch test was conducted on 50 human subjects according to the method of

Shelanski and Shelanski. No primary irritation or sensitization occurred (Ciba-Geigy, 1982). Based on animal testing, the compound would be considered nontoxic to slightly toxic in the Gosselin et al. (1976) rating system.

Absorption and Metabolism*

Radiolabelled (^{14}C) Irganox was administered to rats (dose and route unspecified) to determine gastrointestinal absorption and metabolic fate. Of the radioactive carbon, 1.5 percent was recovered in the expired breath, 0.5 to 1.0 percent was detected in the urine and unspecified "minute" quantities were found in the blood. The feces contained approximately 80 to 84 percent of the labelled species. In a second study of metabolic fate "no measurable radioactivity was found in the urine, expired air, blood, livers, or kidneys." The only significant activity was found in the feces (Ciba-Geigy, 1982).

Acute Toxicity

The acute oral LD_{50} in rats was not determined, but it is greater than 5,000 mg/kg. At this dose animals did not exhibit any signs of toxicity, and no gross pathology was detected at necropsy. Drake (1979) reported that the LD_{50} in mice also exceeded 5,000 mg/kg. Irganox in corn oil was administered by oral intubation to albino rats at doses of approximately 3,000, 4,000, 7,000, and 10,000 mg/kg. Treatment-related effects included hypoactivity and "ruffed" fur. No gross pathological changes were seen at necropsy. The acute dermal LD_{50} in rabbits is greater than 3,160 mg/kg, the highest level tested; at this level no observable effects occurred. Rats exposed to an airborne concentration of 46 mg/l for 1 hour showed no "significant" signs of irritation. There were

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* Because only two citations were obtained from a computerized literature search, virtually all of the following information was excerpted from toxicology data supplied by Ciba-Geigy Corporation.

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no treatment-related deaths, and at necropsy no pathological changes were detected. Rats and dogs were fed Irganox in the diet for 90 and 91 days, respectively. The no-observable-effect levels in the two species were the highest concentrations administered: 50,000 ppm in rats and 10,000 ppm in dogs (Ciba-Geigy, 1982).

Drake (1979) reported that Irganox 1010 was not irritating to rabbit skin. A mild and transitory effect was seen when the compound was applied to the rabbit eye. Irganox (dosage and route unspecified) did not produce sensitization in guinea pigs.

Chronic Toxicity

Irganox 1010 was fed to Sprague-Dawley CFY rats in dietary concentrations of 1,000, 3,000, and 10,000 ppm for 104 weeks. No observable effects were seen at any concentration. The "no-observable-effect level" was estimated to be 446-547 mg/kg day. No treatment-related increases in tumor incidence were seen in MAGF (SPF) mice fed 0, 100, 300, and 1,000 ppm Irganox 1010 in the diet for 24 months. These concentrations correspond to an approximate mean daily dose of 0, 11, 35, and 107 mg/kg for female animals and 12, 41, and 126 mg/kg for male animals (Ciba-Geigy, 1982).

Effects on Genes and Chromosomes

Irganox was reported to be nonmutagenic in a mouse dominant lethal assay at doses of 1,000 and 3,000 mg/kg. No significant increases in anomalies of interphase nuclei and no chromatid or chromosomal aberrations were detected in cytogenetic assays of the bone marrow of hamsters intubated on two consecutive days with 500, 1,000 or 2,000 mg/kg Irganox in corn oil. Geigy reported that "no evidence of the induction of point mutations by Irganox 1010 or by the metabolites formed as a result of microsomal activation was detectable in the strains of Salmonella typhimurium (TA 98, TA 100, TA 1535, TA 1537) used in the experiment" at concentrations ranging from 10 to 250 µg/0.1 ml without activation and from 5 to 100 µg/0.1 ml with activation (Ciba-Geigy, 1982). Wang and Smith (1980) also reported that

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Irganox was nonmutagenic in an Ames Salmonella test using strains TA 1535, TA 1537, TA 98, and TA 100 with and without metabolic activation.

Carcinogenicity

As noted above, 2-year feeding studies were conducted in Sprague-Dawley rats and MAGF mice. No treatment-related increases in tumor incidence were seen in animals of either species.

Irganox was nonmutagenic in an Ames Salmonella assay, a short-term test used to predict carcinogenicity (Wang and Smith, 1980).

Effects on Reproduction

Irganox was administered orally to pregnant rats at doses of 150, 500, and 1,000 mg/kg on days 6-15 of gestation; no embryotoxic or teratogenic effects were observed. Pregnant mice were dosed at the same levels according to the same schedule. No adverse effects were seen in offspring of dams dosed at 150 or 500 mg/kg. Delayed ossification of sternebrae was seen in offspring of females dosed at 1,000 mg/kg; no teratogenic effects were observed (Ciba-Geigy, 1982).

Substances Associated with Metal Pipes

Lead

Absorption and Metabolism

Absorption of lead from the gastrointestinal tract varies with the age of the individual, the chemical form of the lead, and the dietary levels of iron, calcium, fats, and proteins. Children absorb a much higher percentage of dietary lead (about 40 percent) than do adults (about 8-10 percent) (Hammond and Beliles, 1980; IARC, 1980). Lead is rapidly transferred to bone, a cumulative process that occurs throughout life. Lead in other

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tissues rises during childhood and adolescence, and reaches a steady state by early adulthood (Hammond and Beliles, 1980). Adults excrete lead primarily in the urine, but also in feces, sweat, and breast milk, and through deposition in the hair and nails. In infants the principal route of excretion is gastrointestinal.

Acute toxicity

Acute lead poisoning is uncommon. Symptoms and signs inlcude thirst, nausea, severe abdominal pain, diarrhea or constipation, muscle pain and weakness, tingling of the skin, anemia, and hemoglobin in the urine. The kidneys can be damaged and urinary output decreased. Death may occur in 1 or 2 days (Klaassen, 1980).

Chronic Toxicity

Chronic low-level exposure to inorganic lead can give rise to a variety of syndromes involving different organ systems (see below). Because of the cumulative nature of lead absorption in children, they (including unborn children) should be considered the most sensitive population. In evaluating the risk of lead in drinking water, it should be borne in mind that the average daily oral intake of lead (through food and water) is 120 to 350 µg, of which about 25 µg is aborbed by adults, while a greater amount is absorbed by children (Klaassen, 1980).

Several studies have provided suggestive evidence that tap-water lead levels are correlated with blood levels (NAS, 1977, 1982; EPA, 1980c). Lead concentrations greater than 50 µg/liter may, according to one study cited by the NAS, raise and sustain blood levels above 30 µg/100 ml of whole blood. An analysis discussed by EPA indicates that blood-lead levels approximate a cube root function of water-lead levels (EPA, 1980c). Other minerals in the water can affect the extent to which lead is absorbed. For example, increased calcium intake can interfere with lead absorption. Another study investigating the epidemiology of mental retardation in Glasgow, Scotland,

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suggested that tap-water lead concentrations greater than 100 µg/liter may raise the risk of childhood retardation (NAS, 1977).

Effects on Genes and Chromosomes

Whether lead affects genetic material depends in part on the nature of the lead compound being tested. Neither lead chloride nor lead acetate appears to induce mutations or similar effects in multiple bacterial tests (IARC, 1980). Lead chloride has interfered with the fidelity of DNA synthesis *in vitro*. Lead acetate transformed hamster cells, giving them the ability to produce tumors when injected into other rodents (IARC, 1980). Various *in vivo* and *in vitro* tests produced different kinds of chromosome damage, although there have been reports of negative results as well. Chromosomal abnormalities in humans have been reported in nine studies involving occupational exposure to lead. In six other studies no such effects were reported (IARC, 1980). Overall, because of differences in experimental protocols and in the quality of data, it cannot be said unequivocally that lead *per se* is mutagenic (Gerber et al., 1980).

Effects on Reproduction

Adverse effects of lead on reproduction have been known for centuries. Lead compounds used to be used to induce abortion. High levels of maternal exposure to lead are associated with menstrual disorders, impaired fertility, miscarriages and stillbirths (Gerber et al., 1980; Damstra, 1977). Several sperm abnormalities have been reported in men occupationally exposed to lead, with substantially elevated blood lead levels (IARC, 1980). Similar effects have been reported in rodents at lower blood leads (Damstra, 1977).

Numerous studies in animals implicate lead as a fetotoxic, fetolethal and teratogenic agent (see IARC, 1980). In addition to causing resorption (the rodent equivalent of miscarriage) and fetal deaths, high doses of lead have caused a variety of birth defects in different strains and species of experimental animals. Lead affected the development of the brain and

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nervous system, the eyes, the skeleton and tail, the teeth, and the gastrointestinal system (IARC, 1980). Also reported have been decreased birth weight, retardation, and lower post-natal survival (Damstra, 1977).

The offspring of human pregnancies during which the mother suffered lead intoxication have been observed to have retarded intrauterine and postnatal growth, and damage to the nervous sytem (Gerber et al., 1980). At high maternal doses, it is clear that lead can adversely effect the outcome of pregnancy; however, there is no published evidence that lead causes birth defects in humans at lower levels of exposure (EPA, 1980). While lead can be transferred to the fetus, the human placenta appears to act as a partial barrier to such transfer (Gerber, 1980).

Carcinogenicity

The International Agency for Research on Cancer reported three relevant epidemiologic studies on men occupationally exposed to lead. Each study was subject to different limitations, but none reported any excess cancer due to lead exposure (IARC, 1980).

At least 25 bioassays of lead compounds have been conducted. Reviewing this evidence, the International Agency for Research on Cancer concluded that, "[l]ead acetate, lead subacetate and lead phosphate are carcinogenic to rats and lead subacetate to mice. These compounds induced benign and malignant tumors of the kidney following oral or parenteral administration. Gliomas occurred in rats given lead acetate or lead subacetate parenterally or by the oral route" (IARC, 1980). The carcinogenicity of lead arsenate, lead carbonate, lead oxide, metallic lead, lead naphthenate, and lead nitrate could not be evaluated because of inadequate or insufficient data.

If one assumes that absorbed lead circulates in a dissociated ionic form, and that the lead ion induces the experimental tumors, then lead in drinking water may pose a risk of cancer to humans. However, the nature of

the animal experiments is such that the potential human risk cannot be calculated (NAS, 1982).

Other Chronic Toxicity

Chronic effects of lead exposure can be classified according the system affected: it is not uncommon for there to be some overlap. Except as otherwise noted, these effects only occur at high levels of exposure.

Central nervous system effects are common in children, and are often of insidious onset. Symptoms include clumsiness, irritability, insomnia, dizziness, falling, progressing to delirium, seizures, vomiting, coma, and death. The mortality rate is 25 percent. Nearly half of the survivors have a neurologic deficit (e.g., retardation, seizures, cerebral palsy) (Klaassen, 1980).

This severe form of lead poisoning is unlikely in children exposed to the lead levels described elsewhere in this report. Of greater concern are more subtle effects on the CNS in terms of mental deterioration. Symptoms and signs of low-level poisoning inlcude impaired learning, hyperactivity, loss of motor skills and sensory perception, aggressive behavior, and convulsions. Such effects are seen when blood lead levels exceed 60 µg/100 ml whole blood, though it may occur at lower levels (Klaassen, 1980). Indeed, the apparent threshold for CNS effects in children has been progressively lowered on the basis of the results of more recent studies (Landrigan et al., 1980; Needleman, 1980).

It has been estimated that there is a threshold of about 55-60 µg/100 ml whole blood with respect to effects on the CNS. The estimate has more recently been lowered to 50 µg/100 ml whole blood (NAS, 1977, 1982). Animal evidence suggests that adverse biochemical effects occur at blood lead concentrations below 30 µg/100 ml (Needleman, 1980; Averill and Needleman, 1980). Otherwise asymptomatic children have been reported to have subtle neurologic impairment (Landrigan et al., 1980; Needleman, 1980).

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Neuromuscular effects include "lead palsy." This syndrome of muscle weakness and fatigue is due to advanced chronic lead poisoning and is uncommon (Klaassen, 1980). It is not considered important for purposes of this Environmental Review.

Lead interferes with several biochemical steps in the synthesis of heme, a component of various oxygen-utilizing proteins (e.g., hemoglobin, myoglobin, cytochromes). Lead poisoning also causes anemia. The effect on heme synthesis is relatively easy to measure in the laboratory through analysis for heme precursors. The threshold blood-lead levels for accumulation of such precursors is below 20 µg/100 ml whole blood, or less than the average "normal" value for lead in blood (Piomelli, 1980). Lead's actions on heme synthesis has been considered the most sensitive effect in humans (NAS, 1977).

Two types of kidney injury have been reported in humans: reversible defects in reabsorption of certain nutrients and irreversible, progressive kidney failure usually found in persons with prolonged high-level lead exposure (Hammond and Beliles, 1980). Such kidney damage is not considered significant for the purposes of this Environmental Review.

Gastrointestinal effects are the most common syndrome of chronic lead intoxication among adults, and are characterized by loss of appetite, malaise, headache, constipation, and, in advanced cases, severe abdominal pain (Klaassen, 1980).

Copper

Absorption and Metabolism

About 30 percent of dietary copper is absorbed from the gastrointestinal tract. The fraction absorbed depends on the chemical form (salt or metal complex, water solubility) and on the presence of other substances (leucine increases absorption, while various ions of molybdenum, sulfur, iron and zinc decrease absorption) (Venugopal and Luckey, 1978).

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Copper is transported throughout the body, and is found in high concentrations in liver, brain, kidney, and muscles. A 70-kg adult body contains between 80 and 150 mg copper. Fetal copper concentrations are ten times those of adults (Venugopal and Luckey, 1978).

Copper is excreted principally in bile along with unabsorbed dietary copper. Small amounts are excreted in urine and perspiration. Balanced against biliary excretion, net copper absorption in the GI tract is about 5 percent (Venugopal and Luckey, 1978).

Control of copper absorption, distribution, and excretion is achieved primarily by the liver, but also by carrier proteins in blood (albumin and ceruloplasmin), and cells of the intestinal lining. Hereditary defects in copper metabolism produce diseases characterized by progressive damage to the liver, CNS, and other organs. These include Indian childhood cirrhosis and Mencke's kinky hair syndrome, which are generally fatal in childhood; persons with Wilson's disease can live a normal life when treated with penicillamine (Scheinberg, 1981; Vaughan et al., 1979; Lefkowitch et al., 1982).

Acute Toxicity

Acute ingestion of copper salts stimulates vomiting and, as a consequence, acute poisoning is usually not severe. If the metal is not removed by vomiting, however, copper poisoning results in injury to the liver, kidney and CNS (Gosselin et al., 1976). Exposure to copper has been reported to result in hemolytic anemia (destruction of red blood cells) similar to that seen in persons with glucose-6-phosphate dehydrogenase (G-6-PD) deficiency.

Signs and symptoms of copper poisoning include vomiting, burning pain in the mouth, esophagous and stomach, diarrhea, abdominal pain, bloody stools, headache, weak pulse, jaundice, decreased or absent urine output, convulsions, paralysis, and coma. Early deaths are due to shock, later ones to liver or kidney failure.

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Acute copper ingestion often occurs when acidic beverages have been stored or passed through containers made of copper. Copper toxicity increases with the water solubility of the salts.

Chronic Toxicity

With the exception of persons with the hereditary disorders (Wilson's disease, Mencke's syndrome, Indian childhood cirrhosis) noted above, chronic copper poisoning from exessive ingestion is rare, and is not thought to result in disease in normal individuals (Gosselin et al., 1976; Doull et al, 1980; NAS, 1977). Tissue levels of copper do not increase with age (in adults), although blood levels do (Doull et al., 1980). The significance of the latter is unknown.

Mutagenicity

Copper may have mutagenic potential in that it can diminish the fidelity of DNA synthesis (Sirover and Loeb, 1976). However, no other evidence of mutagenicity was found.

Carcinogenicity

Copper miners and smelter workers reportedly have a higher incidence of lung cancer than the general population (Newman et al., 1976; Agnese et al., 1959). However, the significance of this finding is vitiated by their concomitant exposure to arsenic, a recognized carcinogen (Furst and Radding, 1979).

Copper implanted or copper sulfide injected into animal tissues apparently does not cause tumors, whereas copper sulfate and copper chloride injected into roosters' testes have been reported to cause testicular tumors (teratomas) (Gilman and Ruckerbauer, 1962; Sunderman et al., 1974; Furst, 1971; Falin and Anissimora, 1940; Bresler et al., 1964). Copper has apparently not been tested for carcinogenicity by other routes. Copper has been reported to act as a possible promoter for rodent skin tumors induced

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by dimethylbenzanthracene (Furst, 1977). In summary, the evidence of carcinogenicity for copper is weak, at best.

Effects on Reproduction

There is little evidence of adverse reproductive effects of copper in humans of animals (EPA, 1980b).

Tin (Inorganic)

Absorption and Metabolism

Tin is poorly absorbed from the GI tract, and hence most of what is ingested is excreted in feces (Venugopal and Luckey, 1978). Absorbed tin can be found mainly in the liver, lungs, and kidneys with trace quantities in other tissues (NAS, 1977; Hammond and Beliles, 1980).

Acute Toxicity

Inorganic tin has very low oral toxicity, due principally to its poor intestinal absorption. No toxic effects were reported in rats fed inorganic tin compounds for 13 weeks at concentrations of 450-650 mg/kg of food. In humans, nausea, vomiting and diarrhea have been reported from consumption of various canned foods and drinks: e.g., fruit juices containing 1400 ppm, vodka punch containing 2,000 ppm, and canned salmon containing 650 ppm (NAS, 1977).

Chronic Toxicity

There are a variety of chronic effects from oral ingestion of tin salts when high doses (at least 0.3 percent of the diet) are used. Deleterious effects on growth and development, the liver, the blood, the GI system and the male reproductive system have been reported. With lifetime consumption of tin at 5 ppm in drinking water, mice and rats reportedly had mild liver and kidney changes (Venugopal and Luckey, 1978). Whether the latter finding

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can be extrapolated to a human context is questionable, however, since this level of consumption is approximately the average human daily exposure in food.

Effects on Genes and Chromosomes

No information was available.

Carcinogenicity

While Venugopal and Luckey report that orally ingested tin salts may be carcinogenic, the accuracy of this observation is in doubt (Venugopal and Luckey, 1978; Furst and Radding, 1979). A recent bioassay of stannous chloride conducted under the auspices of the National Toxicology Program was negative (NTP, 1982).

Effects on Reproduction

No information was available.

Cadmium

Absorption and Metabolism

Cadmium is poorly absorbed from the gastrointestinal tract. Thus, most ingested cadmium is excreted in feces. The percentage absorbed varies from 0.5 to 12 percent in various animal species (Hammond and Beliles, 1980). Limited human evidence indicates that about 5 to 7 percent is absorbed (Rahola et al., 1972; NAS, 1980). Younger animals absorb a greater fraction of ingested cadmium than do older ones. Cadmium absorption is enhanced by a dietary deficiency of calcium, vitamin D, iron, zinc, copper, or protein. Inhaled cadmium is more efficiently absorbed; 50 percent or more present in cigarette smoke or metal fumes is absorbed (Ryan et al., 1982).

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Absorbed cadmium is widely distributed throughout the body, concentrating preferentially in the kidney and liver. The metal accumulates in the body (at least up to age 50), with a biologic half-life estimated to range from several months to 47 years (Ryan et al., 1982). At birth the body burden of cadmium has been estimated to be 1 ng, which increases to 15-50 mg by age 50 (NAS, 1977). Excretion of absorbed cadmium is thought to occur principally in the urine, though other routes have not been well-investigated (Hammond and Beliles, 1980). As noted above, cadmium appears in breast milk.

Acute Toxicity

Acute toxic effects of ingested or inhaled cadmium are attributed to irritant effects. Cadmium is more toxic when inhaled, particularly if soluble salts of cadmium are involved. When ingested, symptoms of acute poisoning include nausea, vomiting, salivation, diarrhea, and cramps. The human oral LD_{50} has been estimated to range from 350 to 8900 mg (Hammond and Beliles, 1980). Death may occur from shock, renal or cardiopulmonary failure. Numerous health effects due to high-dose (0.5-1 mg cadmium/kg body weight) injections in animals are not generally observable when exposure is oral or by inhalation (Ryan et al., 1982).

Chronic Toxicity

Chronic cadmium exposure may result in damage to the kidney, lungs, bones, and cardiovascular system. The threshold for kidney damage is thought to be about 150 to 250 µg/gram of wet kidney tissue (NAS, 1980). Such injury may occur whether the route of exposure is oral or pulmonary. Damage to the lung occurs only with inhalation of cadmium (usually in an occupational context), and may result in emphysema and scarring of the lung. The bone disease attributable to cadmium exposure consists of softening of bones (osteomalacia), often with spontaneous multiple fractures. This affliction occurred mainly among middle-aged to elderly women in Japan who had eaten cadmium-contaminated rice. Epidemiologic

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investigations and some animal evidence indicates that cadmium exposure may play a role in the development of high blood pressure (Klaassen, 1980).

Effects on Genes and Chromosomes

Two dominant lethal mutation assays in mice using cadmium salts were negative (NAS, 1977). Results from studies of human cultured lymphocytes exposed to cadmium *in vitro* have been conflicting. Analyses of chromosomes of persons occupationally exposed to cadmium have reported a variety of structural anomalies in several studies cited by IARC (1976). Such chromosomal damage was not demonstrated in another study involving 5 workers and 4 patients with itai-itai disease (cadmium-induced osteomalacia) (Bui et al., 1975). Results from a variety of other tests have been mixed. A recent review of the literature concluded, "[T]here is no substantial evidence that human exposure to cadmium results in heritable genetic damage" (Ryan et al., 1982).

Carcinogenicity

The carcinogenicity of cadmium has been reviewed by the International Agency for Research on Cancer (1976, 1982b). Numerous studies cited in these reviews indicated that injected cadmium compounds produce local tumors in rats. Subcutaneous injections of $CdCl_2$ and $CdSo_4$ resulted in testicular tumors in rats and mice. There is only one adequate feeding study in animals in which rats fed up to 50 ppm of cadmium chloride in the diet did not show an increased incidence of tumors.

Epidemiologic evidence suggests that occupational exposure to cadmium oxide may increase the risk of prostate cancer and lung cancer (Kipling and Waterhouse, 1967; Lemen et al., 1976; Potts, 1975). However, because of small sample size and potentially confounding exposures to other substances, the carcinogenicity of cadmium in humans is not firmly established. Furthermore, a more recent study appears to indicate that occupational exposure to cadmium may not result in increased mortality from cancer for any site (Sorahan, 1981).

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Effects on Reproduction

Injected cadmium chloride causes birth defects in rats, mice, and hamsters. When $CdCl_2$ was administered to CD strain rats in doses of 4 to 12 mg/kg on Days 13 to 16 of gestation, there were dose-related increases of fetal deaths, of congenital anomalies such as cleft palate, club foot, small jaws, and small lungs, and a decrease in fetal weight (Chernoff, 1973). A variety of skeletal and neurological defects were produced in the offspring of mice given subcutaneous injections of $CdCl_2$ (0.33-0.35 mg/kg) on Day 7 of gestation (Ishizu et al., 1973). Cadmium sulfate administered intravenously (2 mg/kg) to hamsters on Day 8 of gestation increased fetal resorption and caused major facial malformations (Ferm and Carpenter, 1967). Cadmium at 10 ppm in drinking water was teratogenic to mice (Schroeder and Mitchner, 1971). Sheep fed 12-15 ppm cadmium and cadmium sulfate in the diet during Weeks 13 and 14 of gestation bore normal offspring, though goats fed 75 ppm $CdCl_2$ in the diet did not (Mills and Dalgarno, 1972; Anke et al., 1970). EPA (1980e) noted one report in which 0.1 ppm cadmium in rats' drinking water produced no reproductive effects.

There have been no adequate studies reported on potential reproductive effects in humans. The human placenta is relatively impermeable to cadmium, yet neonatal cadmium blood levels are about half of maternal levels (NAS, 1977; Ryan et al., 1982; EPA, 1980e).

Acute exposure to cadmium has been reported to cause damage to the gonads and sterility of both sexes of experimental animals, regardless of the route of exposure (Venugopal and Luckey, 1978). Such damage includes testicular atrophy, cessation of spermatogenesis, and testicular necrosis in males and vascular changes in the ovary resulting in female infertility. These effects have been observed at doses far in excess of the estimated human intake of cadmium, and have not been reported in humans (Venugopal and Luckey, 1978; Klaassen, 1980).

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Zinc

Absorption and Metabolism

Zinc is an essential nutrient, required for DNA and protein synthesis and for the activity of numerous intracellular enzymes. Absorption of zinc from the GI tract is variable, depending on the amount in the diet, but averages about 50 percent. A diet high in calcium, phosphate, and copper can decrease zinc absorption, as can some chelating agents.

Zinc is distributed to all tissues, with high concentrations in muscle, skin, bone, liver, kidney, pancreas, eye, and the male reproductive system. Excretion occurs principally in feces, with contributions from unabsorbed dietary zinc, bile, pancreatic, and other GI secretions. Lesser amounts are excreted in urine, sweat, and breast milk (Venugopal and Luckey, 1978). Zinc absorption, metabolism, and excretion are governed by an efficient homeostatic mechanism.

Acute Toxicity

Zinc has low acute toxicity and quantities normally ingested are far below those required for the occurrence of toxic effects. However, oral zinc intoxication from acidic food or beverages stored in galvanized cans has been reported. Symptoms include vomiting, diarrhea, fever and stomach cramps. (Some cases may be due to cadmium contamination.)

Chronic Toxicity

Repeated low-dose ingestion of zinc is essential to sustain life: an effective homeostatic mechanism virtually assures that temporary exposures to concentrations moderately greater than what is necessary will not result in toxicity. Concentrations of up to 0.25 percent (or 2,500 ppm) in the diet have not caused toxicity in rats. Above this dietary level one finds growth retardation, anemia, and abnormal bone formation (Hammond and Beliles, 1980). There has been a report of zinc poisoning in two adults

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from extended consumption of water from galvanized pipes with the zinc concentrations of 40 mg/liter. Symptoms consisted of nausea, loss of appetite, muscular pain and stiffness, and irritability (NAS, 1977).

Effects on Genes and Chromosomes

The National Academy of Sciences (1977) concludes that there are no data to suggest that zinc is mutagenic in animals or humans. The NIOSH Registry of Toxic Effects of Chemical Substances (1981) reports no positive results for zinc in tests of mutagenesis.

Carcinogenicity

Zinc injected into the testicles of rats and roosters has produced testicular tumors, an effect which has been ascribed in part to hormonal factors and the high levels of zinc already present in the testes (Hammond and Beliles, 1980). Zinc has not been found to be carcinogenic by other routes of exposure (Sunderman, 1971).

Effects on Reproduction

Zinc at 4000 ppm (0.4 percent) in the diet of pregnant rats was reported to cause increased resorption and fetal death (Schlicker and Cox, 1968). Zinc injection or feeding at doses ranging from 15 to 50 mg/rat per day reportedly resulted in infertility and reduced testicular size (Venugopal and Luckey, 1978). However there is little evidence that zinc excess in drinking water will result in reporductive effects. Zinc deficiency is more likely to produce adverse outcomes (NAS, 1977).

Antimony

Absorption and Metabolism

Antimony metal occurs in +3 (trivalent) and +5 (pentavalent) oxidation states, which are distributed and metabolized differently. Trivalent

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antimony has a greater affinity for red blood cells than pentavalent compounds, which are found at higher levels in plasma. Antimony is poorly absorbed from the GI tract, and tends to cause vomiting. Thus, when given medicinally, antimony is administered by injection or intravenously. Intraveneously administered, antimony concentrates in the liver, thyroid, and heart. Trivalent antimony is excreted primarily in feces, while the pentavalent form is excreted principally in the urine (NAS, 1980).

Acute Toxicity

Antimony is chemically similar to arsenic, and produces arsenic-like toxic symptoms. There are few reports of human toxicity, and most of these have originated in industrial or medicinal exposures. Symptoms of acute ingestion include vomiting, diarrhea, collapse, irregular breathing, and decreased temperature (Hammond and Beliles, 1980). Besides the GI tract, the skin, liver, lungs, and heart may be affected, with toxic effects on the heart potentially the most serious. Oral LD_{50}s for trivalent compounds are lower than for pentavalent ones--e.g., in rats the LD_{50} for antimony trichloride is 675 mg/kg, while that for antimony pentachloride is 1.115 g/kg (NAS, 1980).

Chronic Toxicity

The chronic toxic effects of antimony administration depend on which compound is being tested. Trivalent antimony chloride given to rats for 10 days at 135 mg/kg by gavage resulted in degeneration of the heart muscle. The same compound given to guinea pigs for 10 days at 12 and 20 mg/kg resulted in anemia. When fed to guinea pigs for 6 months at doses from 0.0025 to 2.5 mg/kg, the lowest dose produced no toxicity (Arzamastsev, 1964). A similar no-observed-effect level was found for antimony trioxide fed to rats at doses less than 2 g/rat per day (NAS, 1980).

Humans exposed chronically to antimony in industrial settings have developed respiratory symptoms, including pneumoconiosis, dermatitis, and GI

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symptoms. Confounding exposure to arsenic may contribute to industrial antimony disease (Hammond and Beliles, 1980).

Effects on Genes and Chromosomes

Human white blood cells were exposed to 2.3 nanomoles of antimony sodium tartrate *in vitro*. Of 100 examined for chromosomal changes, 12 were demonstrated to have aberrations (chromatid breaks). No conclusions were drawn (Paton and Allison, 1972).

Carcinogenicity

Epidemiologic evidence of occupational cancer due to antimony is inconclusive (NAS, 1980). Antimony potassium tartrate at 5 ppm in drinking water given to 76 mice for their lifetime reportedly showed no increased tumor incidence (Kanisawa and Schroeder, 1970). The lack of higher dose levels precludes making a judgement about the carcinogenicity of antimony.

Effects on Reproduction

Two Soviet studies cited by the National Academy of Sciences (1980) seem to indicate that antimony can produce adverse effects on reproduction. Female antimony workers were reported to have a greater incidence of miscarriage, premature deliveries, menstrual disorders, and gynecologic inflammation than did a nonexposed group. A study involving exposure of 30 pregnant rats to aerosolized antimony metal appeared to show decreased fertility relative to unexposed controls, but no teratogenic effects (NAS, 1980). There is not enough evidence to draw any reliable inferences about potential reproductive effects of antimony.

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Appendix E

DETAILS OF WORKER SAFETY AND HEALTH

General Testing Needs

The exposures of plumbers to solvent vapors, solder fumes, and other substances require better definition than is possible using currently available data. The existing studies for plastic pipe solvent cement (NIOSH, 1976; CDHS, 1980a; CDHS, 1980b; NIOSH, 1982) altogether have evaluated the exposures of fewer than 50 plumbers in a limited number of workplace environments (fewer than 10). The sampling that has been done has been performed using a variety of methods of uncertain comparability. Furthermore, there has been no attempt to define the systemic exposures of plumbers via dermal absorption, a potentially significant exposure route.

The situation with regard to the exposures of plumbers to other materials with which they work is even worse. SRI has not found a single study of the exposures of plumbers to solder fumes (including lead), although field observations indicate that those exposures may occasionally be severe.

Finally, the composition of the materials with which plumbers work is not at all certain. For instance, the presence or absence of DMF in cements will substantially affect its toxicity--especially its absorption through the intact skin. However, it is not clear which (if any) of the commercially available cements contain DMF. Benzene has also been found in air samples taken at a plumbing site (CDHS, 1980s), but its expected accompanying aromatic solvents (e.g., toluene) were not found. It is not clear whether benzene was present as a contaminant of the cement or whether it arose from another source. The constituents of cutting oils are

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important determinants of potential toxicity, but the composition of the specific cutting oils used in thread cutting (or cutting off) on metal pipes is not certain.

If the questions surrounding the expected introduction of plastic pipe into greater use are to be resolved, then some additional work is needed. This additional work should include a survey of the composition of the products available to the plumber, an environmental evaluation of the exposures of plumbers to the various contaminants found in their workplace, and a final health hazard evaluation of the total exposure profile.

In order to accomplish a valid assessment of the health hazards to plumbers associated with the use of plastic and metal piping one should attempt to:

I. Determine the extent of the information needed

   A. Determine the composition of the materials of interest

      1. Solvent cements

      2. Cutting oils

      3. Solders/fluxes

   B. Determine the population at risk

      1. Extent of use of specific materials from A. above

      2. Number of plumbers using each

      3. Number of plumbers performing specific tasks

   C. Complete the literature review--especially the NIOSH studies scheduled to be completed in the near future

II. Define the methods to be used

   A. Materials for which environmental sampling is to be performed

      1. Methods to be used

      2. Number of samples within each use/composition sample cell

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B. Materials for which biological sampling is to be performed

1. Methods to be used

a. Expired air sampling

b. Urine/blood sampling

c. Skin patches; gloves; other.

2. Number and type of samples to be taken within each defined cell

III. Determine the survey protocol

A. Define a geographical area within which adequate job sites will be available

B. Obtain the cooperation of relevant groups

1. Plumbers' union locals

2. Pipe manufacturers/cement manufacturers/trade associations

3. Associated General Contractors/Specialty contractors

C. Specify content of surveys to be performed (from I. and II. above)

IV. Perform study

V. Analyze data and report

Biological Monitoring Considerations

The potential for dermal absorption of the solvents used in plastic pipe cements is significant. It is notoriously difficult to determine such dermal exposure directly. Although the use of gauze patches on representative skin areas, or of specially prepared gloves may be useful in some circumstances (the patches and the gloves are subjected to chemical extraction with an appropriate solvent after exposure), these methods are unlikely to give satisfactory results in the solvent exposures. The major problem is that the substances of concern are volatile; the continued evaporation of these materials during the sampling period would make analysis of the patches fruitless unless they were changed very frequently,

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with consequent unacceptable disturbance of the workers being monitored. In addition, the potential for significant changes in the permeability of the skin to these materials (due to abrasion of the skin, defatting due to previous exposures, ambient temperatures and the like) is great. Thus it seems most reasonable to attempt to define the systemic exposures to these solvents due to dermal absorption by actually measuring systemic uptake. There are several methods available; the choice depends on the metabolic pathways followed by the material subsequent to intake. The least invasive method is to measure the compound of interest (or its metabolite if it is metabolized) in the expired air. Other possible methods (in decreasing order of desirability for field studies) are the collection of urine or blood, with subsequent analysis.

The solvents of major interest to us in this study are THF, cyclohexanone, MEK, and DMF. We have briefly evaluated the availability of rational biological methods for each of these solvents:

- THF--There exists no information on the metabolism of THF. It is very volatile and most probably is eliminated in expired breath.

- Cyclohexanone--Cyclohexanone is metabolized to cyclohexanol, which is presumably detectable in the expired breath. Cyclohexanol is glucuronidated in the liver (Elliot et al., 1959) or excreted unchanged. A certain percentage of cyclohexanone is undoubtedly excreted in the expired breath.

- MEK--MEK is metabolized to 2-butanol, 3-hydroxy-2-butanone and 2,3-butanediol. MEK and the first two metabolites are quite volatile and probably are excreted via the breath as well as the urine. Only 11 percent of an administered dose was accounted for in urine in metabolic tests with guinea pigs; similar results were found in rats (Di Vincenzo et al., 1976, Dietz and Traiger, 1979). The main urinary metabolite in rats was the glucuronide of 2-butanol. In dogs, 30-33 percent of an administered dose was eliminated in expired air. Humans exposed to MEK dermally eliminated the compound in the expired air, beginning 15 minutes after first contact. Within 2 hours, a steady-state elimination concentration of 6.5 micrograms/liter was achieved (Munies & Wurster, 1965). In general, ketones are not readily metabolized and may be eliminated unchanged in the expired air and to some extent in the urine (Opdyke, 1977).

- DMF--DMF is metabolized to N-methylformamide and formamide via microsomal oxidation in the liver and other organs with these

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enzymes. It can be detected in the blood of persons exposed, and DMF, monomethylformamide, and formamide can be detected in human urine after inhalation exposure. Formic acid and DMA (dimethylamine) are the hydrolysis products and they have not been detected in the urine or stomach contents of patients or experimental animals.

There is a linear relationship between DMF exposure and 24-hour monomethylformamide (MMF) excretion (Krivanek et al., 1978) in subjects exposed to 9 to 33 ppm for 6 hours daily on 15 consecutive days. No compound was present 48 hours after exposure (and very little after 24 hours). No increase in MMF was seen in urine after repeated doses. The mean value for the end-of-exposure sample (7 hour-sample) was 4.7 ug/ml or 436.8 ug total.

Conclusions

From the above considerations, it appears reasonable to assume that appropriate methods for the determination of total exposure to DMF, MEK, and cyclohexanone can be developed using the expired air samples. If DMF is of interest, urine samples could be taken. In any case, it would be most useful to attempt to define the constituents of solvent cements on job sites prior to taking samples so as to ensure use of appropriate methods and minimize disruption of work and invasion of worker privacy.

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Appendix F

SMOKE TOXICITY DETAILS

Summary of Smoke Toxins

Table F-1 provides a summary of the sources and physiologic effects of the principal combustion gases from synthetics and natural materials likely to be present in residences.

Evidence from Human Studies

In fires, approximately 96% of civilian deaths and 69% of injuries result from fires in residential occupancies (one- and two-family dwellings, apartments, hotels, motels, and all other) (NFPA statistics for 1977-1981). Of civilian fire deaths, 75% were accounted for by one- and two-family home fires alone. Where accidental ignitions alone were involved (not arson), 67% of the deaths were in fires where the material initially ignited was building contents (upholstered furniture, bedding, clothing, floor covering, rubbish, etc.). These kinds of material provide the bulk of the fire load in most buildings (NFPA, 1982). Addressing the problems of combustion hazards from such sources would result in a major reduction in the loss of life from fire, in the opinion of NFPA (1982).

As an alternative to sampling the atmosphere in fire environments for toxic gases, we can attempt to find out how much of which gases has been inhaled by fire victims. Several studies of this type have been done; none is free of criticism. In the United Kingdom, analysis of blood samples from eight fire fatalities have revealed 60 or more volatile components, including aromatic hydrocarbons, organic nitriles, and various other

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Table F-1

SOURCES AND PHYSIOLOGIC EFFECTS OF SELECTED THERMODECOMPOSITION GASES OTHER THAN CO AND CO_2

Sources of Thermodecomposition Gases*	Highlights of Physiologic Effects	Estimate of Short-term 10 Minute Lethal Concentration (ppm)
Hydrogen cyanide (HCN)		
From combustion of various products such as wool, silk, polyacrylonitrile, nylon, polyurethane, and paper, in varying amounts; flammable; difficult to analyze accurately	A rapidly fatal asphyxiant poison; toxicity suspected in some recent fires involving upholstery and fabrics but no definitive data	350
Nitrogen dioxide (NO_2) and other oxides of nitrogen		
Produced in small quantities from fabrics and in larger quantities from cellulose nitrate and celluloid (prepared from cellulose nitrate and camphor, in decreased use today)	Strong pulmonary irritant capable of causing immediate death as well as delayed injury; notorious from the 123 death in 1929 Cleveland Clinic fire caused by burning "nitrocellulose" x-ray films	≤ 200
Hydrogen chloride (HCl)		
From pyrolysis of some wire insulation materials such as polyvinyl chloride (PVC), also chlorinated acrylics and retardant-treated materials	Respiratory irritant; potential toxicity of HCl coated on particulate greater than that for an equivalent amount of gaseous HCl	≤ 500, if particulates are absent
Other halogen acid gases		
From combustion of fluorinated resins or films and some fire-retardant materials containing bromine	Respiratory irritant	HF ä 400 COF_2 ä 100 HBr ≤ 500

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Table F-1 (Concluded)

Sources of Thermodecomposition Gases*	Highlights of Physiologic Effects	Estimate of Short-term 10-Minute Lethal Concentration (ppm)
	Sulfur dioxide (SO_2)	
From compounds containing sulfur; the common oxidation product of such components in fires	A strong irritant, intolerable well below lethal concentrations	500
	Acrolein	
From pyrolysis of polyolefins and cellulosics at lower temperatures (400°C); significance, if any, in actual fires is undefined	Potent respiratory irritant	30-100

*All these gases can be lethal in sufficient concentration. In most common fire situations, these combustion gases would be expected to contribute to death rather than be primary causes of death.

Source: Terrill et al. (1978); PRC (1980).

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molecules, a few of which could not be identified (Anderson and Harland, 1980). In general, the blood from fire fatalities showed more complex patterns than that from healthy control or nonfire deaths. The significance of these stated differences is unclear at present, because in all cases the deaths could have been accounted for alone by the carboxyhemoglobin (COHb) levels in the blood. Cyanide levels were also elevated and may have contributed in an additive way, but blood specimens were not obtained until 24 to 72 hours after death, vitiating confidence in the quantitative values for this toxicant and other chemicals like the organic nitriles. Further, alcohol levels in the blood indicated that many of those dying in the fires were grossly intoxicated at the time of death. It may be noted that the amounts of acetonitrile quantified in the blood of three victims from domestic fires and two from a nursing home were comparable to cyanide concentrations, whereas propionitrile concentrations were at least an order of magnitude less. Neither of these nitriles is as toxic as hydrogen cyanide (NIOSH, 1982).

Postmortem analysis of blood specimens for HCN and other components has been done in other studies in attempts to ascertain the major causes of fire deaths. In a demographic study sponsored by the National Science Foundation, probably the most comprehensive and only systematic one of its kind, blood specimens were analyzed from 511 fire deaths in the state of Maryland over a 5-year period. Victims with more than 50% COHb, the level generally assumed to be lethal, represented 48% of the total (Benjamin et al., 1982). About 16% more of the victims with less than 50% COHb had preexisting cardiovascular disease and/or exposed to HCN. Low levels of CO, together with chemical irritants whose toxicity could not be assessed, were present in 10% of the specimens. The authors concluded that between 10% and 18% of the fire deaths did not appear to have materially involved CO or heat. Many of the latter deaths were delayed and involved lung injury or damage to the throat. In one case, that of a fire fighter who appeared to have recovered from the immediate effects of the fire but died later, extensive pulmonary hemorrhaging and edema were found at autopsy; the deceased also had arteriosclerosis.

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In a study of fire deaths in New York City, the primary cause was attributed to CO inhalation in 70% of those that succumbed (PRC, 1980). CO levels in fires usually rise rapidly, with concomitant changes in escape capability and rapid formation of COHb, causing death.

In some studies, attempts were made to evaluate whether blood levels of HCN might account for some portion of the deaths. The analyses were vitiated by the fact that, because HCN in blood is unstable, special sample handling and rapid acquisition of specimens following removal of the injured from fire areas are needed (PRC, 1980), and the matter of the magnitude of the contribution of cyanide to fire deaths is not resolved. Since nitrogen-containing polymers (e.g., polyurethane, polyacrylonitrile, wool, polyamides) may make up as much as 5% of the combustible materials in fires (PRC, 1980), some contribution from HCN to fire deaths is to be expected, but nowhere near that of CO.

Evidence from Animal Toxicity Studies

Methodologies--There are a variety of laboratory tests to evaluate the toxicity of combustion products in animals as a means to characterize the material's fire hazard, ostensibly under fire conditions. All have shortcomings that have been discussed critically elsewhere (Alarie, 1982; Benjamin et al., 1982; Caplan et al., 1982; Levin et al., 1982), and these sources may be consulted for details on the methods.

The test methods used do not duplicate room fires. They generate smoke by use of cup or tube furnaces and/or radiant heat under flaming or nonflaming conditions, either collecting the smoke over some fixed period of time for the animal exposure (static conditions) or passing an air stream through the furnace to the exposure chamber (dynamic conditions). Either fixed or slowly rising temperatures are used to heat the samples. Exposure chambers vary considerably. The test animals are almost invariably rats or mice, because of their economy in use and because a considerable amount of biological and toxicological information on them exists. A variety of

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physiological and biochemical measurements may be conveniently made on these animals, but lethality is invariably quantified, usually together with some additional parameters intended to assess the time required for incapacitation. Monitoring of CO (and sometimes HCl, HCN, and oxygen) levels and temperature in or near the chambers containing the animals, as well as measurements of respiratory rate, neurological response of motor performance or visual observations for effects, are done in some but not all tests.

The static arrangement is said to simulate, to some degree, exposure to a fire in or near the room of origin, in a situation of limited flow-through ventilation where smoke accumulates; the dynamic system simulates a steady-state burning with victims exposed to the moving smoke plume.

Although some attempts have been made to correlate small-scale laboratory tests with large-scale tests (Alarie et al., 1981; Alarie et al., 1983) the consensus of investigators in the field is that these test methods cannot be used at present with confidence for that purpose or for regulating materials based on test results (Workshop, 1983).

Their only present advantage is to serve as screens for detecting unusually toxic combustion materials or for guidance in the whole process of test development. To be useful for this purpose, any study should include use of suitable reference materials, such as Douglas fir. Dose-response curves are usually (but not always) obtained to aid in determining thresholds for the measured efect (Figure F-1 is an example).

Shortcomings of the toxicity screens usually stated are (1) questions of relevance to real fire situations; (2) limitations of animals, in particular rodents, for predicting human health hazards; (3) variability in toxicity results; and (4) the inability to incorporate toxicity data in the total hazard equation. Mathematical modeling for the last-named objective is still many years away. The tests in use measure time to incapacitation or some similar sublethal effect, as well as lethality, since smoke can be seen in a tenth of the total time that is required for it to reach toxic

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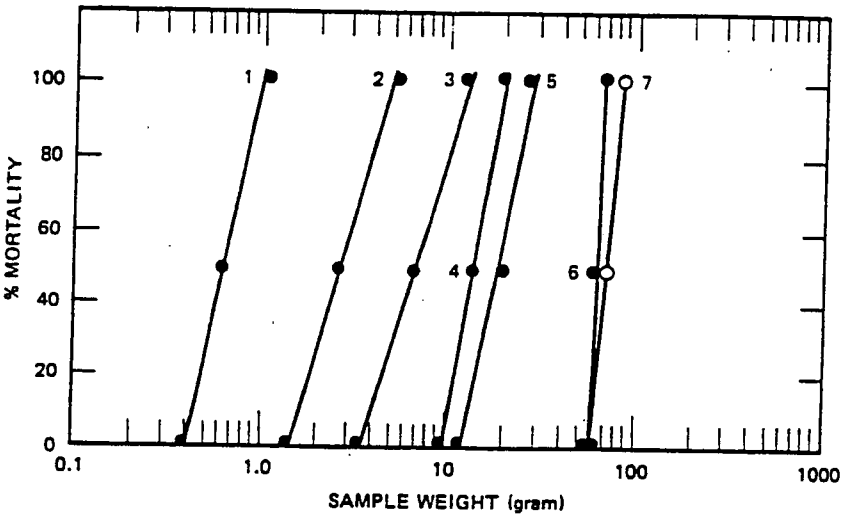
levels (Clarke, personal comment, Workshop, 1983) and these factors relate more to detection and time for escape. The time for escape is emphasized because to some it appears unrealistic to try to reduce fire load below some critical level; there is always too much combustible material, so escape time should be maximized (Packham, personal comment, Workshop, 1983).

Test Results on Intact Plastic Pipe--There are almost no published reports on the toxicity of gases generated from the plastic pipes under consideration here. There is much more information on the toxicity of gases evolved from the unformulated plastics themselves. For as comprehensive an assessment as possible, both types of studies are reviewed.

Hilado and Huttlinger (1983) compared the toxicity in Swiss-Webster young adult male mice of two samples of polybutylene pipe obtained from Shell Oil Company (Houston, TX) with that of a sample of Douglas fir. The method is referred to as the NASA-USF toxicity screen. Test conditions used were those of a rising temperature at 40°C/min from 200°C-800°C without forced air flow; a Lindberg horizontal tube furnace and quartz boat containing the sample are used for pyrolysis.

Time to incapacitation (staggering, convulsions, or collapse of the animal) and time to death were measured. Average times to death with the polybutylene pipe samples ranged from 21.5 to 24.4 minutes, compared with 16.8 to 18.6 minutes for Douglas fir. Similarly, average times for the three indices of incapacitation were greater for the polybutylene pipes than for Douglas fir.

Dr. Rosalind Anderson of A. D. Little, Inc. (Cambridge, MA) is currently testing three samples of PVC, CPVC, and ABS pipes for DWV uses from different suppliers in the so-called NBS (developed at the National Bureau of Standards) and Pittsburgh (developed in Dr. Alarie's laboratory at the University of Pittsburgh) tests. It is not expected that the results will be available before May 1, 1983.



1 polytetrafluoroethylene
2 urea-formaldehyde foam
3 phenol-formaldehyde foam
4 polyvinyl chloride (homopolymer)
5 flexible polyurethane foam
6 Douglas fir
7 fiber glass reinforced polyester

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FIGURE F-1 CONCENTRATION-RESPONSE CURVES OBTAINED WITH MICE FOR LETHALITY DURING 30 MINUTES OF EXPOSURE AND 10 MINUTES OF RECOVERY

Source: Anderson and Alarie (1978).

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Alarie and his colleagues (1982) at the University of Pittsburgh have studied the toxicity of three commercial samples of PVC and other plastics in their method, with mice as the test animal species. The PVC samples were designated as white PVC-coated cable for electrical applications and gray corrugated and solid PVC pipes; steel conduit served as the reference. All three PVC samples were classified as "more toxic than wood"; the two pipe formulations were classified "as fast acting as wood" and the coated cable "faster acting." Death of the mice was attributed to HCl release, with CO being a contributor to the toxicity. The steel conduit was almost totally inert toxicologically and, as could be anticipated, was classified as "better than wood" in this test.

All three samples gave off approximately the same amount of smoke to produce the LC_{50} values, or about 6 grams. The amount of HCl produced in the first 10 minutes of the exposure was trapped and quantified to be equivalent to an average exposure of about 6,400 ppm during that period. Using the data of Boethner et al. (1969) that 0.58 gram of HCl evolves from 1.0 gram of PVC consumed, an average of 8,550 ppm of HCl should have been produced. The amount found by Alarie is underestimated slightly, as he suspected, but still in the range. The difference may be due to plating of the acid on surfaces. Therefore, it may be reasonably concluded that an average HCl exposure of 6,400 ppm is sufficient to kill 50% of the test animals within 10 to 15 minutes.

Alarie (April 5, 1982) attempted to extrapolate the quantity of PVC solid pipe in his test that would fill an average room (8 x 10 x 12ft) with sufficient smoke to kill humans in about 10 to 15 minutes. Making certain assumptions that appear reasonable, he concluded that 2.35 pounds of the sample would be required. Noting that humans are likely to be more sensitive than mice in regard to the irritant effects of the HCl given off by PVC, he applied a conservative correction factor (derived from other studies with cannulated and noncannulated mice, conducted in his laboratory) and also used another line of argument to arrive at a figure of 0.34 to 0.62 pound being sufficient to produce adverse effects in humans. This would

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correspond to between 18 to 30 inches of solid pipe, or a somewhat longer piece of corrugated pipe.

Test Results on Unformulated Polymers--The thermal decomposition of PVC plastics in a tube furnace and the effects of the products on pulmonary function have been assessed using the guinea pig as an animal model (Jaeger et al., 1982). Pure PVC resin (from B.F. Goodrich Chemical), a technical-grade sample (whose composition was unknown but did include DEHP) and an electrical-grade PVC formulation were compared. CO levels in the atmosphere were quantified over the 30-minute exposure period.

The authors found that "death, while possibly hastened by exposure to CO, was usually delayed and was associated with substantial abnormalities in pulmonary mechanical function." There was, however, no correlation with known HCl release. The electrical-grade sample had a higher peak concentration and time-weighted average release of HCl than the technical-grade sample. Pure PVC released the most HCl, consistent with its greater chlorine content on a weight basis. The toxicity (lethality) of the three samples varied in the following order, however: pure PVC electrical-grade PVC technical-grade PVC. Irritant effects based on pulmonary function tests were similar with all three and were attributed in part to the HCl.

Petajan (1976) evaluated the toxicity of thermally degraded PVC foam in a "static box" with young adult male Long-Evans rats. Arterial blood COHb was increased to between 30% and 45% without death. Severe acidosis was also present, more than expected from the amount of COHb, which the author attributed to the animals' holding their breaths, since respiratory rate was also diminished during this period. After sacrifice, the rats were found to have increased pulmonary injury (severe bronchitis with edema and hemorrhaging).

Hilado (1983) has reported the following test results in the NASA-USF animal tests for generic plastics like those of interest here:

Sample	Time to Death (minutes)	LC50* (mg/l)
PVC	16.6 ± 0.33	--
ABS	17.1 ± 2.5	13.8
CPVC	22.2 ± 0.69	35.0

*PSC conditions.

Kimmerle (1976) evaluated the toxicity in rats of pyrolysis products of ABS and ABS foam relative to other thermoplastics and to spruce wood, using a furnace apparatus and test conditions standardized by the German government (DIN test). An equal volume of each material was burned. He concluded from the results shown in Table F-2 that the toxicity of pyrolyzed ABS foam could not be due to CO and HCN in the air because of the presence of lung damage, the low percentages of COHb levels, and delayed deaths. In the case of spruce wood, mortality was clearly due to the CO given off. Higher temperatures were required for mortality from combustion of ABS than of spruce wood.

ABS and PVC pellets of unspecified composition were tested in the NBS method using EC_{50} and LC_{50} values (Levin et al., 1982). EC_{50} is defined as the concentration (mass loading of material divided by exposure chamber volume) that was necessary to incapacitate 50% of the rats in the standard 30-minute exposure. LC_{50} is the most common measure of lethality and is the concentration necessary to cause 50% of the animal population to die in some fixed period, usually during the 30-minute exposure and a 14-day postexposure period.

Table F-2

TOXICITY OF THE PYROLYSIS PRODUCTS OF THERMOPLASTIC MATERIALS ON RATS
(Tests with Equal Volume: 300 by 10 by 5 mm)

Sample	Temp. (°C)	Concentration in Air CO (ppm)	Concentration in Air HCN (ppm)	COHb (%)	Number of Deaths Out of 20
ABS	350	150	100	5.8	0
	400	350	150	14.2	13
ABS foam	350	100	20	6.2	0
	400	100	100	7.3	2
Spruce wood	300	1,000	0	27.6	0
	350	7,500	0	72.7	19

Source: Kimmerle (1976).

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Data for flaming and nonflaming modes and for 440°C were obtained as given in Table F-3.* The lower the value, the less material is required to produce the effect in 50% of the test animals. Thus, ABS and PVC pellets show EC_{50} and LC_{50} values that are, in general, comparable to those for Douglas fir. That is, they produced combustion products with toxicity similar to that of Douglas fir. However, ABS (flaming mode) and PVC (nonflaming mode) did differ from the Douglas fir references in that there was significant mortality during the 14-day holding period after the exposure. If the PVC exposure was shortened from 30 minutes to 10 minutes at all three test temperatures, there was no incapacitation during the exposure and only one of three animals died during the 14-day postexposure period. At temperatures just below ignition (nonflaming mode), the relative release of CO for a comparable mass load factor was: Douglas fir | red oak | ABS and PVC. With HCN release, however, wool released about 2 times more HCN than ABS for the same mass load loading. These numbers suggest that toxicity of ABS and PVC is comparable to that of natural materials, but other gases or the smoke may contribute to their toxicity in addition to HCN and CO.

Additivity/Sensitivity--Animal test screens are almost entirely restricted to the evaluation of one material at a time. Actual fire situations are much more complex. Awareness of this dilemma has led to speculation on the possibility that synergistic effects may arise from more than one material burning or from combinations of toxic gases in the atmospheres that would be missed under screening conditions.

The early literature addressing this question yields conflicting results (Armstrong, 1976). Armstrong states that:

> Studies on binary mixtures can never be a completely adequate explanation of the physiological effects encountered in real fire

*The ignition temperatures for the ABS and PVC pellets, Douglas fir, red oak, and wool in the NBS furnaces were: 575, 600, 465, 480, and 650°C, respectively.

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Table F-3

TEST RESULTS WITH THE NBS METHOD

EC_{50} Values (mg/l)

Material	Number of Tests	Flaming	Nonflaming	440°C
ABS	= 3	11	17	15
PVC	= 2	12	9	14
Douglas fir	8	16	15	H
Red oak	3	42	24	H
Wool	4	27	17	25

LC_{50} Values (mg/l)

Material	Number of Tests	Flaming	Nonflaming	440°C
ABS	= 4	18	28	30
PVC	2	16	18	23
Douglas fir	8	36	23	H
Red oak	3	54	30	H
Wool	4	38	24	29

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situations. All fires, regardless of the material involved, are complex mechanisms involving thermal degradation and high-temperature free radical reactions. It is unlikely that two situations will ever exist in which the identical set of combustion products will be obtained. To assign synergistic properties to a given pair combination under synthetic mixture conditions may never do more than further confuse the issue, since it ignores the possible presence of unidentified components in the fire gases, whose lethality may be several orders of magnitude greater than either or both in the synthetic mixture. It also ignores the possible neutralizing effect of the two separately toxic components by addition or substitution reactions in the fire environment to form relatively innocuous products.

Before any realistic assessment of synergisms meaningful to the real fire situation can be made, it is essential that a great deal more knowledge must be obtained in these several areas.

Smith et al. (1976) attempted to resolve the question of synergism for CO and HCN using the pure gases. When rats were exposed to these gases at levels slightly below their 5-minute LC_{50} values, they were incapacitated or died in up to 50% shorter time than with either gas alone. The decrease in time and nature of the signs observed indicated that the effects of the two gases together were additive. When the gases were premixed at these exposure levels, the effect of the combination on the animals was greater, reminiscent of reports of synergism in the earlier literature in tests with rats and mice exposed to the mixtures in similar fashion (Caplan, 1982). Although conceivable, experimental demonstration of combined effects is still not unequivocal (PRC, 1980) and further research is required before the matter is resolved.

Additional Relevant Toxicity Information

Tewarson (1979) reviewed the literature on fire toxicity as part of the testing program on the effects of fire-exposed electrical wiring systems on escape potential from buildings. He cites a study of the concentrations of five products monitored by fire fighters during the first 15 minutes of 120 fires that occurred in Boston. HCl, CO, and benzene were detected in 92%, 37%, and 68% of the fires, respectively, at levels as high as 371, 4,800 and

62 ppm. These compare with the critical values for human escape listed in Table F-4.

The frequency of concentrations of HCl, CO, and benzene above the STEL values in the Boston fires were 37%, 11%, and 0.01%, respectively. HCl and CO, at the highest concentrations, exceeded the tentative critical values for human escape. No deaths were recorded in these fires, however, and the usefulness of the data obtained for the present evaluation has been questioned on other grounds (Benjamin et al., 1982). The physiological effects on humans of low HCl levels (less than or equal to 100 ppm) are listed in Table F-5, and those on animals in Table F-6.

Animals exposed to PVC fire products show a rapid fall in blood oxyhemoglobin without simultaneous rise in carboxyhemoglobin in initial phases, indicating effects of irritants (i.e., HCl, etc.). During exposure, significant decrease in blood pH occurs, which indicates metabolic acidosis. Animals that die have carbon particles in the respiratory tract and suffer corneal opacification. In studies on mice, other irritants in addition to HCl were considered to be responsible for depressions in respiratory rate.

Table F-4

TENTATIVE CRITICAL VALUES FOR HUMAN ESCAPE FROM FIRES AND SHORT-TERM EXPOSURE LIMIT

Compound	Tentative Critical Values for Human Escape (ppm)	STEL Values (ppm)*
HCl	50 to 100	5
Benzene	1,500 to 4,000	25
CO	1,500 to 4,000	400
CO_2	40,000 to 80,000	15,000
O_2	60,000 to 100,000	

*STEL value is defined by the Harvard School of Public Health as the highest level to which fire fighters may be exposed up to 15 minutes comtinuously without causing intolerable irritation, medical effects, or impairment of the ability to respond to emergencies. Data for acrolein and NO_2 not included.

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Table F-5

SUMMARY OF REPORTED PHYSIOLOGICAL EFFECTS OF INHALATION OF SMALL AMOUNTS (0-100 PPM) OF HCl BY HUMANS

HCl Concentration (ppm)	Effects
0.013	Odor perception
0.67-0.134	Odor threshold
0.67-0.134	Threshold for change in the rhythm and depth of respiratory movement
0.134	Threshold reflex effect on eye sensitivity to light
0.260	Threshold for olfactory sensation for the most sensitive persons
0.262	Threshold reflex effect on electrical activity of the cerebral cortex
0.273	Threshold reflex effect on eye sensitivity to light
0.335	Threshold effect on digito-vascular toxicity
0.402	Threshold reflect effect on optical chronaxie
1-5	Odor threshold
5	No organic damage
10	Irritation, work is undisturbed
35	Irritation of throat after short exposure
10-50	Work is difficult but possible
10-50	Does not prohibit work, but harmful to teeth, nose, mucosa of mouth, and face
50-100	No one can work
50-100	Work is impossible
	Intolerable in 60 minutes

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Table F-6

SUMMARY OF REPORTED PHYSIOLOGICAL EFFECTS OF INHALATION OF HCl BY ANIMALS

HCl Concentration (ppm)	Exposure Time (min.)	Species	Effect
17	10	Mice	Small ulcerations of the respiratory mucosa
30	10	Rabbits	Cessation of ciliary activity without recovery
60	5	Rabbits	Cessation of ciliary activity without recovery
128	10	Mice	Ulcerations of nasal mucosa
491	10	Mice	Moderate to marked polymorphonuclear leukocyte of the palpebral and global conjunctiva
670	120	Rabbits	Fatal in some cases
670	120	Guinea pigs	Fatal in some cases
712	10	Mice	Damage to underlying skeletal structures with necrosis of the skeletal cartilage
1,075	10	Mice	Necrosis of exposed cornea, marked polymorphonuclear infiltration of the eyelids
1,350	90	Cats	Severe irritation, dyspnea, and clouding of the cornea
1,350	90	Rabbits	Same as above
1,350	90	Guinea pigs	Same as above
1,949	10	Mice	Necrosis of exposed cornea, marked polymorphonuclear infiltration of the eyelids
3,071	10	Mice	Globes extensively damaged and weakened and spontaneous rupture of the globe occurred

Table F-6 (Concluded)

HCl Concentration (ppm)	Exposure Time (min.)	Species	Effect
3,400	90	Cats	Death after 2 to 6 days
3,400	90	Rabbits	Same as above
3,400	90	Guinea pigs	Same as above
4,300	30	Rabbits	Fatal in some cases due to laryngeal edema or rapidly developing pulmonary edema
4,300	30	Guinea pigs	Same as above
7,190	10	Mice	Massive damage to nose with necrosis of the mucosa, submucosa, cartilage, and underlying bone. The delicate naso and maxilloturbinate bone was totally destroyed
7,190	10	Mice	Death

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