ALASKA LEGISLATURE COMMITTEE FILES 1983 - 1984 8672

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Table III-27

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

	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	
Size	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

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*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

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

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*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.

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 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 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.

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

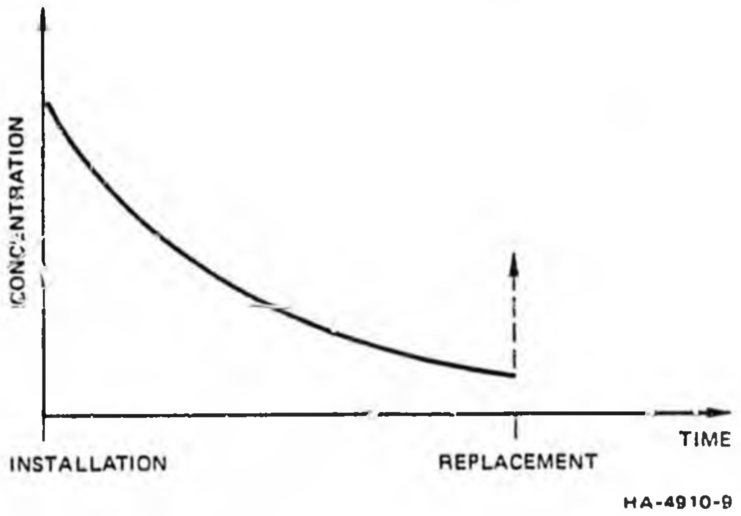


FIGURE IV-1 LONG-TERM PATTERN OF DECLINE IN CONCENTRATION

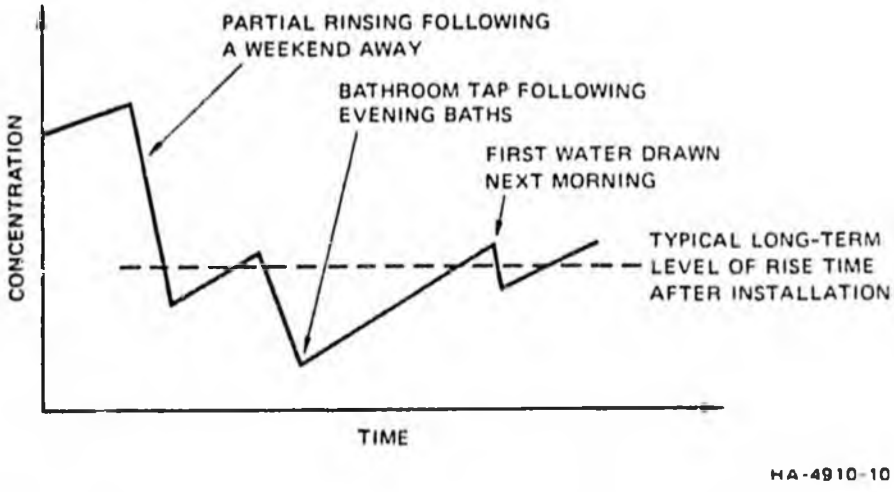


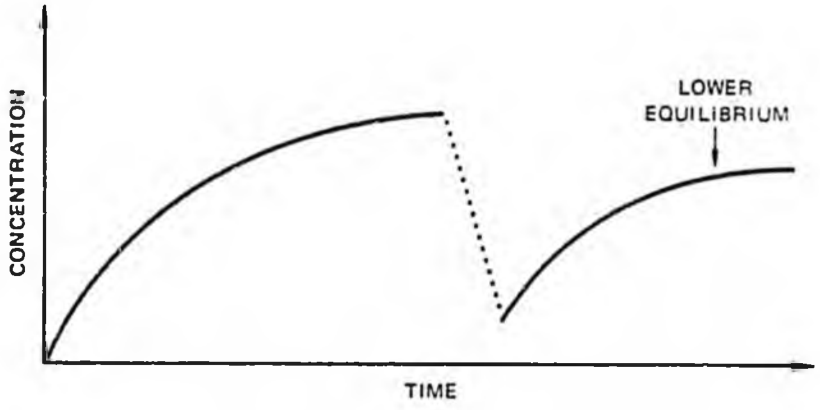
FIGURE IV-2 SHORT-TERM VARIATIONS IN CONCENTRATION plastic and water, and movement into water will be limited by equilibrium between the two, as indicated in Figure IV-3a. Other chemicals diffuse relatively slowly through the pipe matrix, and the buildup rate in water will be limited by this diffusion 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.

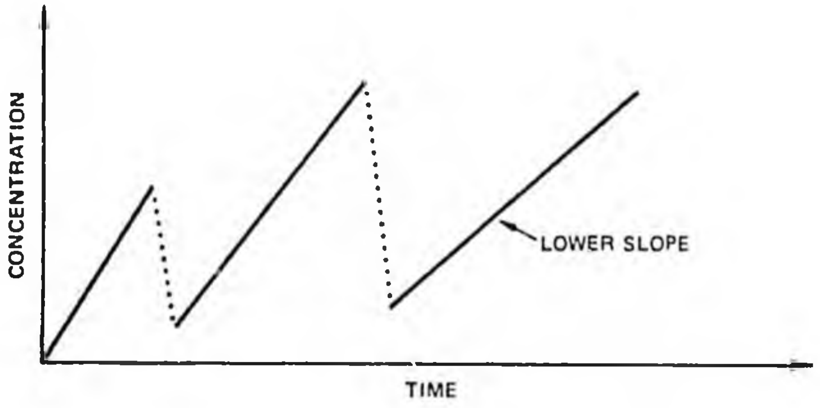
In both cases, concentrations after any given dwell times will eventually decline to negligible levels as the source of chemicals in the pipe is depleted or protected. If chemicals in the pipe break down to form other chemicals, the source strength for such chemicals may increase for a time before eventually 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.)



(a) EQUILIBRIUM-LIMITED



(b) DIFFUSION-LIMITED

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FIGURE IV-3 DIFFERENT BEHAVIORS OF LEACHING DURING DWELL PERIODS

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 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:

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

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

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:

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

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

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

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

where ϵ_n are the roots of the equations $J_o(x) = 0$ and $J_o(x)$ 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

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

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:

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

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:

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

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 η 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):

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

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

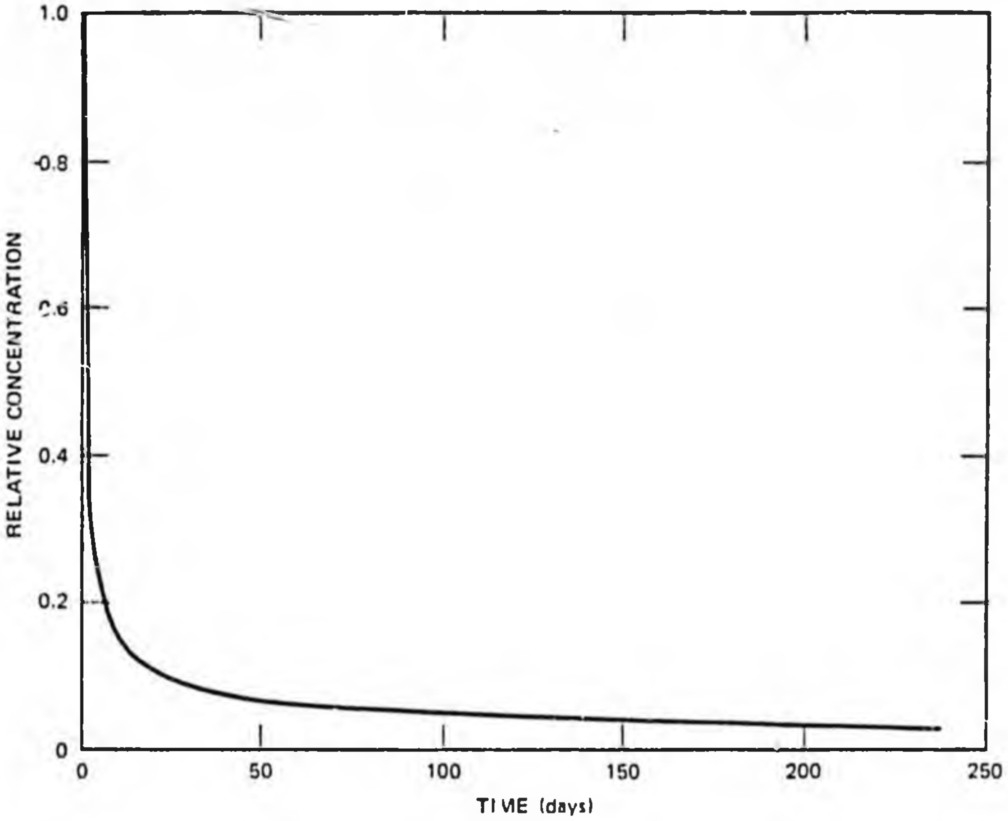

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FIGURE IV-4 CONCENTRATION VERSUS TIME PROFILE OF LEACHATE IN WATER ACCORDING TO EQUATION (4-16)

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

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

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

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

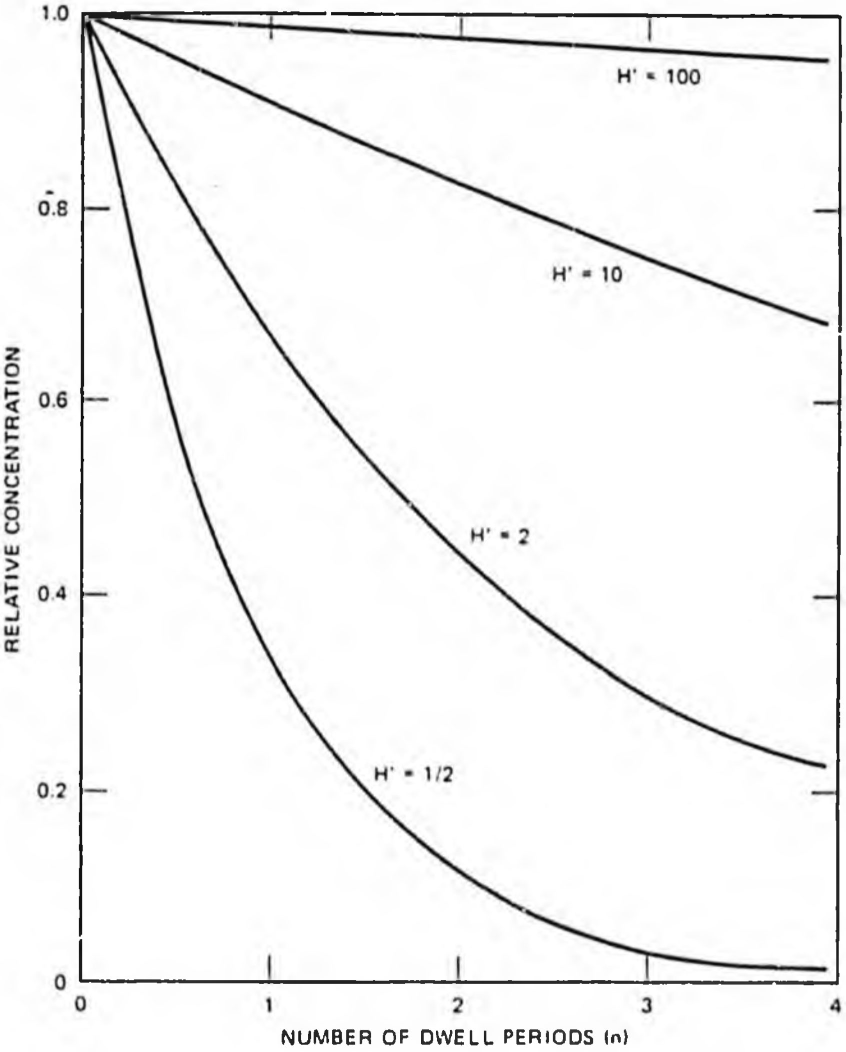

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FIGURE IV-5 CONCENTRATION OF LEACHATE IN WATER ACCORDING TO EQUATION (4-8)

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

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

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

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

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*Based on Table II-4

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).

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		
2,4-dinitrotoluene	1.0	fluorene	0.1

Source: Montgomery (1980).

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)

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*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).

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.

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 6-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.

Table IV-7

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

	Concentration (ppb)			
Chemical*	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.

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	

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

+Doubtful values for reasons explained later in text.

Source: Montgomery (1980).

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

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([illegible].1)	31(5.6)	7.1

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

Source: Montgomery (1980).

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)

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*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).

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,

Table IV-11

SUMMARY OF SIMULATION STUDY 12-HOUR DWELL RESULTS

	Concentration (ppb)				
Chemical	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).

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 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).

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

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-cyclo hexen-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 d
All other volatile organics analyzed by purge and trap and GC/MS.

Source: Montgomery (1982).

Table IV-13

ONE-WEEK STATIC DWELL RESULTS
(Concentration in ppb)

Chemical	One-Week Control	BFG			COM		
		1	2	3	1	2	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[*]	ND	0.3	0.3		1.0	0.9	
Hexachloroethene	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).

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

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)

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[*] Relative to an internal standard

[+] Detected in analysis of solvent cements.

Source: Montgomery (1982).

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

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	-	-

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*Dwell days (elapsed days).

Source: Boethner et al. (1981).

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.

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.

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.

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.

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) s 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.

(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

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

[+] Compounds detected in more than one sample.

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, 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.

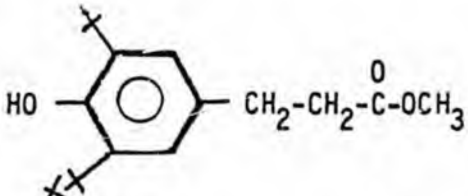
Mead CompuChem (1981), under contract to Shell Chemical Company, performed leaching studies on intact gray PB pipe. These tests were similar to the 5-day leaching experiments described in Radian II. A derivative of Irganox 1010 was the only leachate detected at concentrations (approximately 50 ppb) different 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.

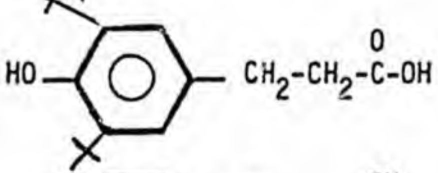
No leachates were found in the in-service pipes or the dormant section of pipe at concentrations different from those of the controls. However, the sample procedure was not given and no spiking data were reported; therefore, these data should be viewed with caution.

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.

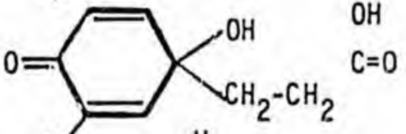
Irganox 1010 derivates were the only leachates detected. Quantitative results were reported only for leaching from PB resin nib. Proposed structures of the Irganox derivatives are shown below.



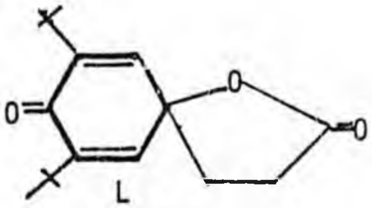
M Methyl ester



F Free acid



H
Hydroxy acid



L
Gamma-lactone

(┼ represents tertiary-butyl substituents)

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 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 $CaCO_3$.

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 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

		Copper			Galvanized Steel		
Leachate	Controls	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.

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 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.

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

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).

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:

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

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:

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

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 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)*

	Copper		Galvanized Steel	
Leachate	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

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*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.

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.

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).

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 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.

Table IV-26

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

		pH 5			pH 11		
Leachate	Type of Pipe	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).

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 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.

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	19000	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).

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).

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

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.

Table IV-30

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

		PVC		PB		PE	
		Water		Water		Water	
Permeant	Copper 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.

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

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 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 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.

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.

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 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