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If we assume that the fire in the room follows the prescribed ASTM E-119 test conditions, which are intended to be representative of a severe post-flashover room fire, three bits of information from the available literature permit some estimates. Data from B.F. Goodrich show temperature observed by thermocouples attached to plastic plumbing systems in a 1-hour fire-rated wall during an ASTM E-119 test. During the first 30 minutes, the temperatures for both ABS and PVC remained below 200°F, i.e., less than the boiling point of water, indicating that the heat flux is insufficient to cause any toxicant production.

Measurements of heat flux acting on test specimens during an E-119 test have been reported (Fong, 1975). Examination of this heat flux history reveals that the <u>accumulated</u> thermal insult to the wall is 4,297 Btu/ft^2. For a small room (e.g., 10 x 10 x 8 feet), the energy required to produce such heat fluxes during the first 20 minutes is 2.23 million Btu (assuming uniform heating of all the room walls, floor, and ceiling).

From the standard heats of combustion of PVC and wood*, it can be seen that 306 lb of PVC or 285 lb of wood would need to be in the room and to burn at 100% efficiency and heat transfer to cause the plastic pipe to reach 200°F. In practice, fuels do not burn with perfect efficiency; and with the enthalpy flow associated with the air flow required to maintain combustion, considerably more combustibles would be required to heat the room. For example, Fong (1975) found that the heat lost by the exhaust gases in the E-119 furnace ran about 50%. If this loss is applied to a good combustion efficiency of 80%, the PVC needed to be burned in the room would increase to about 760 lb (about 710 lb of wood).

Another example of the combustibles required is based on the fuel consumption rates in the E-119 furnace. From the energy consumption curves

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*PVC has a heat of combustion of about 7,500 Btu/lb. Wood has a heat combustion of about 8,000 Btu/lb.

in Fong (1975), the rate during the first 20 minutes averages about 8 x 10^6 Btu per hour. With wood's heat of combustion of about 8,000 Btu/lb, the fuel requirement at 100% burning efficiency becomes 1,000 lb of wood/hour. Assuming 80% efficiency and allowing for the surface area of our hypothetical room, the wood requirement becomes 455 lb for the first 20 minutes. Typical fuel loadings in noncommercial or industrial structures are in the range of 5 to 10 lb/ft^2 of floor area, so the estimated heating requirements would consume most of the available fuel before the pipes in the wall became involved. Such fires obviously would make the room untenable, and the escaping pyrolysis and combustion products would pollute the surrounding areas long before any contribution from the plastic pipe was significant. In this uniform-heating model, the fuel requirement to affect the pipes increases faster than the floor area; consequently, increasing the room size reduces the hazard.

In the above scenario, the thermal insult to the pipe in the wall is probably inadequate to generate a toxic threat from the pipe material. Certainly, its effect, if any, would be insignificant in relation to the smoke, heat, and toxic combustion products that would accompany the fire in the room.

c. Fire in Room with Some Plumbing Exposed or Concealed by Non-fire-resistive Construction

Calculations and rational assessments of many variations of this scenario have been performed, here and abroad (Hilado, Cumming, and Casey, 1978; Hilado and Hutlinger, 1983; Woolley, 1971; Van der Voort, 1972; Smith, 1973). The results can be summarized with the following statement: The combination of toxicants produced by the burning ensemble of room contents, furnishings, and materials of construction, utility, and aesthetics is far too complex and life threatening to warrant concern over the contribution of any one item, particularly a minor member of the collection of organic-based materials present, such as a few pounds of plastic plumbing compound among hundreds of pounds of other combustibles. Some (e.g., Smith, 1973), however, argue that the hazards can be so uniquely life threatening as to warrant special concern, to urge the course of "better safe than sorry." Smith ascribes to PVC a cause for special concern, namely, its high yield of HCl. He concludes: "Using reasonable assumptions for carbon monoxide production from cellulosic fuels, one may show that in a compartment in which the fuel load is 1% PVC and 99% cellulosic material there will be a relative hazard concentration of hydrogen chloride three times greater than that for carbon monoxide."

In the course of the study leading to this environmental review, we calculated a lower contribution from PVC. We assumed a fuel load of 200 lb DWV plastic and 18,800 lb wood*, that is, 1% mixed ABS and PVC combined with 99% cellulosic fuel, all burning at once. Drawing on data from an NBS study (Ives, 1972; Wagner, 1972), HCN concentrations from the ABS were inferred. Neglecting, for the moment, any effect of the HCl from the PVC, a the contribution of the plastic pipe materials would be less than 0.3%. However, if the plastic pipe components were about equally divided between ABS and PVC, we would expect between 10 and 15 pounds of HCl to be generated. This represents a serious toxicant load. As Smith notes: "When one considers that 3.5 grams of HCl in 1,000 cubic feet (about the volume of air in an average size room) produces a (physiologically dangerous) concentration of 100 ppm, the potential hazard is more apparent." By his rule of thumb, 10 to 15 pounds of HCl could poison the air of 1,500 rooms. But as Smith also notes, HCl has a fleeting existence as an airborne toxicant. He reckons its half-life at 10 minutes, but evidence reviewed by us during the course of this study indicates a process much more complex than a single-step, first-order decay--one in which aerosol concentrations strongly enhance the rate of HCl disappearance and in which surfaces located as much as a foot or more away from the airborne HCl provide a rapid sink for its removal. In other words, the thickness of the boundary layer for HCl loss to surfaces, which is a function of large-scale turbulence in

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*We doubled the DWV load from the estimates of Benjamin et al. (1982).

fires, is appreciable in comparison to the dimensions of rooms. Taken together, these factors support the often remarked observation that HCl rapidly "plates out" and is quickly lost from the airborne toxicant pool, its concentration falling rapidly, not just with time but with distance from the source.

Viewed in terms of potency in animal toxicity studies, available test systems produce conflicting results regarding the toxicity of the combustion products of PVC and ABS relative to those of Douglas fir or red oak. ABS has been judged to be about equal to wood in toxicity by some authors and to be 10 times as toxic by others. PVC may be about as toxic as wood (as viewed by some authors) or 70 times more toxic. Since there is almost 100 times more wood than plastic pipe present (as part of construction), the contribution of the plastic to total toxicity could range from about 1% to about 40%--the latter if the toxicity of PVC is 70 times that of wood, as Alarie (1982) alleges. The contribution of PVC may be overstated in either case because the plastic will be fabricated, not in pellets as in some tests, and will burn less rapidly. Even with the higher estimate, however, persons would be more likely to succumb as a result of the burning of structural materials and room furnishings than as a result of toxicants contributed by plastic pipe.

d. Fire in Concealed Space Containing Plastic Plumbing

This scenario is thought to be far less likely than the others. It is, nevertheless, of special interest because it circumvents the two ameliorating characteristics of the previously discussed scenarios: (1) the heat load is not impeded by separations between pipe and fire, and (2) the combustion products are minimally affected or attenuated by the combustion products of other materials.

Moreover, a particularly interesting feature of fire in such spaces is that combustion rates and, hence, toxicant release rates* are potentially limited by air supply; however, the resultant dilution of toxicant concentrations also decreases in proportion to the decreased rate of air supply. Thus, we might assume, for lack of pertinent information, a roughly constant concentration of each toxic species to be consistently present in the smoke issuing from the pipe chase, as long as sufficient pipe surface area is always available to ensure ventilation-controlled fire conditions. This constant level of concentration can be shown to be physiologically significant. Therefore, once again, we are led to an assay of the details of smoke movement, leakage from the confines of the pipe chase, and smoke dispersion patterns in each case of building design and fire event. Clearly, the best prospect for occupant safety is a reasonably gas-tight (and fire-resistive) chase enclosure designed to reduce to a prescribed minimum the air flow available to sustain a fire and the leakage of any combustion products into occupied spaces of the building.

4. Observed Effects of Smoke Toxicants

There is little in the literature from which to judge whether or not products of combustion or thermal degradation of plastic pipes in buildings has led directly to fire deaths or has contributed to them. Isolated reports exist (e.g., Haskell, 19__) that thermal degradation of pipes in buildings has compromised efforts to control and extinguish fires, but no clear-cut evidence shows a causal relationship with death of or injury to their occupants. There are reports that building fires develop faster today than in past years and produce smokes that are more obscuring and irritating to the respiratory tract or contain more gases such as HCN at toxic levels.

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*Assuming that rates of toxicant release are proportionate to heat release rates.

Although there are sometimes statements attributing these developments to the increasing use of synthetic materials to replace traditionally used ones in building products and contents, other factors could be involved.

Data on the products of combustion in actual fire situations and knowledge of their physiological effects would aid greatly in assessing to what extent, if any, combustion of particular synthetics in the buildings is responsible. Only two studies (one in Boston and one in San Antonio) to identify and measure combustion products in real fires have been attempted; regrettably, the information falls far short of permitting any definitive conclusions (Benjamin et al., 1982).

In the absence of empirical information, indirect evidence to substantiate claims that plastics in buildings are increasing fire hazards and deaths may be sought. Because the fraction of building materials that is plastic has increased from 2% to 10% over the last 15 years or so, higher fatalities might be expected today than in the past if the use of plastics does increase fire hazards.

According to some sources, however, both the total number of fire deaths and deaths per capita have actually decreased over the last decade (C&EN, 1983). NFPA reports that total fire deaths have been decreasing since 1978. If this improvement is real, it is likely that the credit should go primarily to the increased use of low-cost residential smoke detectors and other building safeguards and the possible role of plastics is not ascertainable.

5. Toxicology of Smoke Toxins

The following analyses (1) examine animal studies or surveys that have as their aim the characterization of the potential for harm of smoke toxins from plastic pipe, and (2) evaluate information on the known combustion products and their thresholds for producing harm, in conjunction with postulated fire scenarios. We identify information gaps and uncertainties and assumptions in the methods used that may influence confidence in our conclusions. We attempt to err in our analysis on the side of safety.

a. Perspective

The toxic effects of mixed combustion products on living organisms may be identified from epidemiologic or animal studies if such data are available. Alternatively, if identities of the constituents of gaseous products of combustion for the test materials and their rates of formation are known, theoretically one can use mathematical modeling together with the known toxicities of the constituents evolved to deduce the potential hazards of combinations of them.

Since all the data necessary for an accurate assessment of fire hazards under a reasonable range of circumstances do not exist for any of the types of pipe, inferences have to be made from what is known. As in the case of chronic effects from pipe leachates, epidemiological data for assessing hazards from plastics in fire situations are inadequate, forcing analysts to rely on animal toxicity data and combustion studies. The situation is complicated in this case, however, by the absence of generally accepted testing guidelines. Several groups have noted this deficiency, and there is active literature and laboratory research being conducted in attempts to resolve these problems (C&EN, 1983; NBS Workshop, 1983). None of them will be resolved by the due date of the plastic pipe EIR. Thus, the toxicity of the products of plastic pipe combustion for making projections of hazard in real fires must be viewed from the adequacy of both the test data and the methods used to evaluate it.

Although none of the available test methods is considered validated for this purpose, each being subject to various criticisms, data from them still can be used for semiquantitative estimates of risk and guidance on the likelihood that plastic pipes will or will not cause, or add significantly to, toxicity in real fires vis-a-vis other combustible materials present.

b. Fire Toxicity

To recapitulate and expand on the earlier discussion, fire produces toxic effects in a variety of ways. Toxic combustion products released from burning materials, oxygen depletion, or burns from direct contact with the fire can result in fatalities. Smoke, heat, and irritant gases can impair visibility, impede motor activity, or create fear leading to judgment errors that prevent escape and contribute to death (Autian, 1970; PRC, 1980).

There have been concerns expressed that, in addition to acute, potentially lethal effects of toxic gases, long-term irreversible effects, including cancer, may result from exposure to combustion products (Autian, 1970; PRC, 1980). Such effects might arise from exposure to one fire or to many, as in the case of fire fighters. Irritant gases could cause respiratory complications from injury to the respiratory tract, leading to residual effects in a significant fraction of fire victims, which persist long after the fire exposure and possibly result in permanent pulmonary injury. Also, little if anything is known of the effects of the absorbed gases on distant organs (those other than the lungs or surface areas), except in selected cases (PRC, 1980).

c. Causes of Fire Death and Injury

"Smoke" from thermal degradation and combustion of plastic pipes is composed of asphyxiants such as CO and HCN that affect oxygen transport or utilization; irritants such as HCl, aldehydes, and oxides (or epoxides) that cause respiratory tract injury; and other materials such as particulate matter that can obscure vision or burn the lungs if inhaled. Some components given off during degradation of PVC plastics, such as benzene and vinyl chloride, are known carcinogens; their oxidation products in the fire are likely to be of less concern.

CO Toxicity--CO is identified as a primary cause of fire death. When inhaled in sufficient quantities, it produces a condition termed anoxic anoxia, which results from CO's rapid combination with O_2-carrying hemoglobin (Hb) in the blood to prevent O_2 transport from the lungs to the tissues and cellular CO_2 exchange and transport back to the lungs for expiration from the body (Caplan, 1982). Any O_2 remaining bound to the Hb is also retained more tightly in the presence of CO, magnifying the problem. Without O_2, tissues cannot perform their functions.

Because CO binds 200 to 250 times more tightly to Hb in blood than does oxygen, it is not easily displaced; thus, once a condition of low blood oxygen (anoxia) is induced, it can persist for a considerable time. Also, prolonged exposures may result in adverse or toxic effects at relatively low ambient air concentrations of CO because of this difficulty in eliminating it from the body (Table IV-45).

The body of an average adult male contains enough Hb to hold about 1 liter of O_2 (about a 4-minute supply). During rest, about 30% of the O_2 in arterial blood is used; however, during exertion, this may increase to 70% or 80%, thus reducing substantially the large reserve factor and decreasing the margin of safety. A man at rest can, therefore, tolerate a temporary 30% reduction of the O_2-carrying capacity of his blood with little effect, perhaps limited only to a headache. Under exertion, however, the O_2 supply to the brain and other tissues rapidly becomes inadequate, and fainting will usually result. Children are more vulnerable than adults because of a more active metabolism and relatively larger volume of respiration. A 5-year-old child has twice the cerebral blood flow rate and consumes 50% more O_2 per 100 grams of body weight per minute than does a 45-year-old adult.

HCN Toxicity--Without question, HCN is one of the most lethal substances known. The gas produces a type of anoxia referred to as histotoxic. The effects in man of various concentrations of HCN in the atmosphere are given in Table IV-46. Other sources indicate that between 300 and 350 ppm can cause death within 10 minutes (Terrill et al., 1978; PRC, 1980). The short-term exposure limit for HCN is 15 ppm.

Table IV-45

CARBON MONOXIDE TOXICITY

Concentration in Air (Volume percent)	Response
0.01	Allowable for an exposure of several hours
0.04-0.05	Can be inhaled for 1 hour without appreciable effect
0.06-0.07	Causes a just noticeable effect after 1 hour exposure
0.10-0.12	Causes unpleasant but not dangerous symptoms after 1 hour exposure
0.15-0.20	Dangerous for exposure of 1 hour
0.40 and above	Fatal in exposure of less than 1 hour

Source: Caplan (1982).

Table IV-46

EFFECTS OF VARIOUS CONCENTRATIONS OF HCN IN THE ATMOSPHERE

Atmospheric Concentration of HCN (ppm)	Remarks
10	Maximum permissible concentration
20	Slight symptoms after several hours
100	Very dangerous within 1 hour
200-400	Lethal within 30 minutes
2,000	Immediately lethal

Source: Caplan, 1982

HCN is very fast acting, producing symptoms within minutes after inhalation of only milligram quantities. In general, a few breaths from a contaminated atmosphere or even a single breath may fell a man. Breathing may continue at greatly increased volume for a brief period, but death occurs almost immediately. In nonlethal situations, the symptoms of ordinary anoxia are seen more clearly. These include giddiness, headache, heart palpitations, difficult or irregular breathing, and ultimately unconsciousness. Death usually occurs within 1 hour but may be delayed up to 3 hours.

Irritants--The generally recognized irritants released from plastic pipes under conditions of thermal degradation or combustion are HCl, aldehydes, epoxides, and miscellaneous other gases.

Large quantities of HCl are released from burning PVC or CPVC, even below the temperatures at which the polymer chains break down. Levels of atmospheric HCl of 1,300 ppm or higher are reportedly lethal to animals and humans (NIOSH, 1980). Even short exposures at levels as low as 50 to 100 ppm provoke adverse physiological responses in humans (Tewarson, 1979). It has been shown that dilution of smoke evolving from burning PVC to a point where CO was not at lethal levels still caused delayed deaths in test animals. Under these conditions, pulmonary edema and hemorrhaging in the lungs of deceased animals were observed, implicating HCl as the causative agent. CPVC releases less HCl in fires because less hydrogen is available for coevolution with chlorine.

Aldehydes and oxides may be released from combustion products of plastic pipes. All aldehydes are irritants; some, such as acetaldehyde and paraldehyde, also have narcotic properties. No chronic ill effects are noted for these chemicals (Solomon, 1957), except for formaldehyde, which is a carcinogen in animals and could be in humans (Occupational and Health Reporter, 1983; Perera & Petito, 1982). Ethylene oxide can cause intense irritation of skin (blistering), mucous membranes, and lungs, including production of pulmonary edema, but it is also a systemic toxin. In high enough quantities, it can cause death from central nervous system depression with respiratory arrest. If death occurs after several hours, the cause is pulmonary edema. If death is delayed for several days, liver and kidney damage may be the causative factors (Gosselin et al., 1976).

Other Gases--Benzene, styrene, and other aromatic compounds and their oxides appear in combustion products. Benzene is known to be carcinogenic; in humans it causes leukemia.

Nitriles are also present in some smokes, in addition to HCN. These show toxic effects similar to those produced by HCN.

Short-Term Exposure Limits--Short-term exposure limits (STEL) and acceptable maximum peak exposure data are published for a number of the more toxic components detected or possible in pyrolytic fumes from plastics. These are summarized here. Time-weighted (8-hour) average (TWA) exposure levels are included for cases where no other limits have been set (see Table IV-47).

d. Toxic Products from Metal Piping in Fires

The use of metal piping in the proposed applications is not completely risk-free with respect to fires. Small amounts of pipe joint compounds, such as litharge, a putty containing lead compounds, linseed oil, and clay, can be a source of lead in the atmosphere during fires. Assuming about one-quarter inch of thread is typically exposed, the quantities of pipe joint compound involved probably amount to no more than a few grams in any one building.

Polytetrafluoroethylene (Teflon) tape is also commonly used to seal metal pipe joints. This plastic caused delayed deaths in animal experiments (PRC, 1980). One laboratory found it to be 40 to 200 times more toxic than most of the other 10 synthetic and natural materials tested during the validation of the NBS toxicity screen (Benjamin et al., 1982). Although these results have been questioned, the possibility that relatively small

Table IV-47

SHORT-TERM EXPOSURE LIMITS COMPARED WITH TIME-WEIGHTED AVERAGES

Compound	TWA[*] (ppm)	STEL[*] (ppm)	Acceptable Peak Exposure[*] Concentration (ppm)	Duration (minutes)
Acetic acid	10	15		
Acrolein	1.0	0.3	30-100[+]	10
Benzene	10		50	10
Carbon monoxide	50[**]			
Cresols	5			
Formaldehyde	2		10	30
Formic acid		5	1,500[++]	
Hydrogen chloride	5		500[+]	10
Hydrogen sulfide			50	10
Naphthalene	10	15		
Phenol	5	10		
Styrene	100		600	5
Sulfur dioxide	5	5		
Toluene	200		500	10

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[*] From ACGIH (1982) unless otherwise specified.

[+] From Terrill et al. (1978).

[**] From Arena (1979).

[++] From Alarie (1982).

changes in test conditions can make a big difference in the outcome was acknowledged (C&EN, 1983). A more probable source of combustion products from this plastic in fires, because of the larger amounts involved, are Teflon-coated kitchen utensils.

Sections of hot-water metal pipes and some types of plastic (especially PB) are encased in fiberglass or polyurethane tubing to reduce heat loss. Polyurethane (or other) tape with sticky backing may also be used for insulation in systems employing a circulating hot-water pump. Considering all other sources of polyurethane likely to be present in room furnishings, the contribution of burning insulation and tape to the total will probably be negligible.

6. Risk Assessment

Fires contain a variety of combustion products, most of which, in sufficient quantities, can produce death or impair health. Since the hazards to exposed individuals in a fire situation are likely to involve an interplay of several of these factors, predicting the causative agent or factor having the predominant impact on human health can be difficult. Epidemiological data from real fires are insufficient for concluding anything other than that CO is the major cause of fire death, and that HCN or other toxic gases may contribute to death to some currently unquantifiable extent, but certainly no more than 20%--and probably on the order of 10% or less, based on currently available information.

We take the following approaches to the problem in this section: (1) analysis of combustion products from each plastic pipe and modeling their rates of formation in various scenarios for comparison with known threshold exposure levels for them, and (2) animal toxicity studies that are reproducible and for which data on control natural products, such as Douglas fir, are available for reference. The shortcomings of such approaches have been alluded to earlier, but insofar as investigators have not yet identified a "right" way to test plastics for their toxic potential in fire situations and each test has relevance to some fire scenario, none really can be omitted from consideration at this time. However, these tests relate to short-term measured effects (such as irritancy, lethality, lung injury, etc.). No animal data address the question of whether pipe plastics might cause injury to distant organs or chronic effects such as cancer or, for that matter, whether smoke from Douglas fir or other natural products might do likewise. All that can be done in this regard is to compare data on yields of combustion products with threshold limit values (TLVs) to determine whether risks of harm to humans might exist.

In regard to PB pipe, the only test results we have found are those of Hilado and Huttlinger (1983), indicating that (based on observations of incapacitation and of death) such pipe was less toxic to mice than the same quantity of Douglas fir pyrolyzed under conditions of rising temperature without forced air flow. Such data suggest a low order of toxicity for this polymer compared with other building materials likely to be present in homes and furnishings. It would have been informative if the test had included experiments with forced air flow to see whether the availability of high oxygen levels might favor the generation of significant amounts of more toxic combustion products like acrolein and ethylene oxide; analytical data on the combustion products of PB pipe as a function of oxygen supply are also unavailable.

Although PB pipe or the homopolymer has not been tested in the method developed at the University of Pittsburgh, which tends to be more sensitive than others in regard to some plastics (Benjamin et al., 1982), PE was tested (Alarie, 1982). The authors classified PE as "more toxic than wood" but not markedly so. We would expect PB to show similar potency in this test. Considering (1) the very small amounts of PB, perhaps 10 to 20 pounds at most, that will be used in residences, fire-rated or non-fire-rated, relative to the total amounts of other combustible materials present, and (2) the use of the pipe to convey water, the likelihood that PB pipe would pose any fire toxicity health hazards appears to be exceedingly small, to the point of being unquantifiable.

Combustion tests on ABS pipe for DWV systems, either for identification and quantification of the products or for animal toxicity, are almost nonexistent. Rigby (1981) has identified acrolein and acidic gases from ABS to pose the greatest hazard, based on analytical determinations of the combustion products given off at 300° F in comparison with the TWA (8-hour time-weighted average exposure) values published for those products. His data are empirical, limited by expediency in some respects, and assume an independent but strictly additive factor for each volatile. His analysis suggests that combustion of ABS and PVC plastics would be of concern in confined spaces. Although this is probably true, the lack of data for natural products treated experimentally in the same way makes the data from this analysis unusable for the problem at hand.

Animal test data developed by Kimmerle (1976) in the DIN apparatus, data by Hilado (1977) in the NASA-USF test, and data reported by Levin et al. (1982) for the NBS test indicate that the quantity of ABS required to produce a measurable effect is within a factor of 2 (higher or lower depending on the test) of the quantity of wood required to produce the same effect. In contrast, ABS was appreciably (by an order of magnitude) more toxic to mice than was Douglas fir in the University of Pittsburgh test (Alarie/Anderson, 1981).

Of any of the toxicity tests used, the Alarie/Anderson (1981) data put ABS, compared with Douglas fir as the reference material, in the most unfavorable light. How real this assessment is is unclear since test results with their method disagree markedly with those of others in ranking the relative toxicity of many of the materials tested (e.g., based on LC_{50} values, Douglas fir in their test is approximately 2 to 3 times less toxic than it is in the NBS method, whereas sheep wool is 20 times more toxic).*

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*This disagreement is not unique. Where any of the animal test methods in use have been compared with any others, agreement has been poor (Benjamin et al., 1982).

Nevertheless, to be conservative, we will assume that there may be some possible circumstances in which ABS will be more toxic than other combustible building materials present to the degree that the Alarie/Anderson data suggest. We will also assume as before that there will be 200 lb DWV plastic used for every 18,800 lb of wood in fire-rated construction, as there is in residences for purposes of this estimate. We assume further that, because of the particular use and location of the pipe in the building, for ABS to be consumed other materials will be burning simultaneously, let us say, in equal amounts. Thus, 200 lb of ABS, being 10 times more toxic than wood, is equivalent to 2,000 lb of wood in a smoldering fire. ABS in a DWV system would, under such circumstances, contribute 10% of the total fire load.

This example is strictly hypothetical but does suggest that, in some few cases, ABS combustion may make a contribution to the overall hazard from a fire. The estimates are not derived from studies with ABS pipe, and the findings of Anderson (see Appendix B) in the studies in progress at A. D. Little will indicate whether this estimate is too conservative or is realistic.

For PVC pipe, it seems fairly clear that the greatest hazard will result from stripping of HCl from the polymer. Rigby (1981) cites cyclization of the ethylene residues to benzene as also being of concern; he tested plasticized PVC samples. Studies with the pure homopolymer (Boettner et al., 1969) suggest that the ratio of benzene to HCl given off may vary from 0.2% to 0.7%, depending mainly on whether or not combustion is complete. If we accept the Acceptable Peak Exposure data as providing a truer assessment of the relative toxicity of combustion gases in fire than do TWA values, as Rigby used, the benzene is about 30 times more toxic than HCl. Multiplying this factor by its percentage relative to HCl indicates that, in smoldering fires, where PVC combustion may be important at lower temperatures (not all the PVC burns), benzene toxicity is still of less concern than HCl. For fire fighters entering a building in later stages of a fire, the above data and analysis suggest that this may not hold true, and exposure to benzene at these levels, if it occurs on one or more occasions, may be of as much or more concern than HCl, because of its known carcinogenicity.

On the basis of animal toxicity data on combustion products, as in the case of ABS, PVC polymer would probably be rated as comparable to wood. Again, the University of Pittsburgh test shows PVC to be about 10 times more toxic than Douglas fir and, using his factor of 7 for extrapolating from mice to humans, Alarie estimated the relative increase in hazard as closer to 70-fold.

Several factors should be recognized in considering the significance of this estimate for DWV pipe in real fires. First, DWV pipe was not tested; and, since differences in volume, surface area, or length, as well as weight, can influence test results, such testing is needed. Second, the 7-fold difference in PVC toxicity between mice and humans is based on smoke toxicity studies with a plasticized PVC sample and HCl, CO, and HCN gases in cannulated (to simulate breathing in humans) and noncannulated (breathing through nose only) mice. In these studies, the PVC sample and HCl, respectively, produced 7- and 9-fold lower LC_{50} values (that is, were much more lethal) to the former whereas HCN and CO were the same. Although CO is the primary cause of death from Douglas fir and HCN from wool, natural materials such as these were not tested in a similar manner, and such information would have been useful for verifying that the 7-fold factor in the extrapolations applies to Douglas fir (or other appropriate building material) as reference. Third, DWV pipe is not the only potential source of PVC combustion products in buildings. PVC is also used in floors, wallpaper, and electrical cable, among other things. All of these materials are far more likely than DWV pipe to be near a source of heat sufficient to initiate thermal degradation of PVC. Data were not available for estimating the extent to which PVC pipe in DWV applications might add to the range of total combustible PVC likely to be present in buildings. Certain kinds of PVC, such as electrical-grade material, are likely to be consumed earlier in fires. Fourth, the calculations by Alarie do not take into account possible differences in HCl-exposure levels from pyrolyzed PVC in real fires, where the much greater surface area of walls is likely to absorb appreciable amounts of the gas (O'Mara, 1976) relative to animal toxicity studies involving glass exposure chambers with much smaller dimensions. Fifth, it is difficult to conceive of anyone's staying 10 to 15 minutes in a room in which smoke containing HCl, a highly irritating gas, would build up to lethal levels unless escape were physically or physiologically impossible. Escape would be attempted long before such levels were reached and would be relatively simple in 1- and 2-family residences (Benjamin et al., 1982). It may be that irritants can disorient and confuse humans, but only if they are engulfed in smoke or are unfamiliar with their surroundings. We need to know whether the HCl would alert occupants to problems sooner than such disorientation would occur. In fire-rated structures with proper ventilation, occupants are not likely to be exposed to the fumes before an actual fire breaks out.

These comments are not intended to disregard totally the possibility that PVC pipe combustion may make a significant contribution to fire toxicity under some conditions, as put forth by Alarie. Data on PVC pipe combustion toxicity now being developed may help delineate its potential hazard better. In fire-rated construction for which expanded use is being considered, if adequate safety factors are built into chase designs to protect occupants from PVC fumes, and if fire fighters use proper masks to remove HCl and benzene from the breathing atmosphere, the hazards are probably not appreciable but neither are they totally negligible. Thus, PVC pipe, like ABS pipe, compares less favorably with metal pipe, even galvanized steel with Teflon tape or white putty used in installation.

CPVC pipe appears to be less toxic than PVC pipe to mice in the one animal toxicity study reported. Considering this finding and the small quantities required for water supply lines, its use in this application should pose minimal concerns over fire toxicity hazards. For DWV pipe, involving much larger quantities, more test data are needed and are being acquired (Anderson, 1983). Our assessment of relatively low risks from CPVC smoke toxicity in the proposed expected uses of plastic pipe should be reevaluated when test results are in hand.

7. Countermeasures

Results to date suggest that, if indeed a unique toxicity problem exists, it will most likely be the result of evolution of HCl from PVC. It would be unwise to conclude, however, that problems with other toxicants are assuredly absent. Nor should the existence of a definite problem with HCl from PVC plumbing systems be regarded as demonstrated beyond doubt. It would probably be wise to take precautions regarding potential problems with PVC toxicity until further evidence indicates otherwise; in a similarly tentative vein, other concerns about toxic combustion products from plastic pipe formulations could be set aside until further evidence dictates a renewal of concern.

Countermeasures for HCl emissions naturally focus on reduced yields (and/or increased thermal stability) through changes in pipe-compound formulations, on methods for reducing the heat load in a fire situation, and on limiting the leakages of HCl from pipe chase enclosures. In the last case, the natural tendency for HCl to plate out of the gas/airborne phase suggests attractive approaches to mitigative techniques. To reduce heat loads on plumbing, isolation from other utilities could be effective. The plastics industry is constantly striving to improve products along the lines of the first suggestion above.

It is possible that metal pipe and fittings could be used on the living-quarters side of the plumbing system--in the bathrooms, kitchens, etc.--and be connected to a plastic-pipe plumbing system that is within the fire-resistive construction. This approach would eliminate possible direct fire exposure of the exposed or accessible PVC or CPVC pipe and fittings. This hybrid system should also be tested for its fire rating; beyond that, there is some question of heat conduction to the interior of the wall and smoke generation from the plastic-plumbing part of the system. There are other ways of using noncombustible parts for protection or as part of the system.

The isolation approach has considerable merit. Isolation of plumbing from other utilities, particularly electric and gas, can minimize the chances of in-chase fires involving plastic-pipe elements. Increasing thermal insulation and limiting the air available makes this method especially attractive; it is fairly simple and straightforward to accomplish, and it is a desirable countermeasure from other fire safety standpoints as well.

In conventional construction, the dispersion of smoke into occupied spaces from concealed spaces is virtually impossible to predict because it is governed by myriad leaks whose number, location, and size are typically unknown. Nevertheless, the concentrations of leaked gas and smoke could be minimized by ventilation, and ventilation can be achieved without enhancing fire spread by venting through flame traps.

In principle, the countermeasure options should permit any desired degree of protection against toxic products to be achieved, and it should be the responsibility of pipe manufacturers and builders to develop and install countermeasures to an acceptable level of performance. Unfortunately, acceptable levels of toxic products have not been established for fire emergency situations, and there are no accepted performance tests available to certify the various countermeasures.

8. Conclusions

Although we have not been able to demonstrate without equivocation the existence of unique or special hazards due to the combustion products of plastic pipe, neither have we succeeded in ruling them out.

In a nonideal system where some countermeasures are required to achieve an acceptable level of performance, it is important to understand precisely the meaning of the proposed building code changes in order to evaluate their effect on the system's performance. In this respect, we have been concerned with the interpretation of the entries in the pipe use matrix of the request for proposals under "fire rated construction (exposed locations)," where no use of plastic pipe is permitted and none is proposed. A literal interpretation "that no plastic pipe or fittings shall extend into a room through or beyond the thermal insulation responsible for the fire rating" provides a well-defined case for evaluation of the fire threat and also simplifies the inspection and enforcement problem. However, if the interpretation prohibits plastic plumbing above false ceilings or passing through rooms but permits plastic connections through fire-rated walls to fixtures, the problem is complicated by the variety of installations that can be envisioned and the uncertainty in the amount of plastic introduced into the part of the building vulnerable to fire. For fire spread, the performance criteria approach circumvents this interpretation problem; but when evaluating the toxic hazard, the lack of accepted performance tests removes this approach as an option. In the three scenarios examined, the two dealing with fire-rated construction assumed the literal interpretation and did not try to estimate a toxic contribution from an uncertain amount of plastic pipe and fittings extending into the room. Consequently, and particularly in view of the current muteness of codes on the subject of smoke toxicity, we conclude that special precautions should be taken to minimize this potential for harm until the remaining uncertainties can be resolved. Clearly, further research is needed to identify the significant issues with confidence and, from these issues, to develop realistic test criteria. One hopes that such research will, in time, lead to revisions in the code to cover the safety aspects of combustion product emissions, not just to regulate plastic-pipe industries, but to provide a comprehensive and balanced control over all life-threatening materials introduced into the built environment.

As noted by the NFPA Committee on the Toxicity of the Products of Combustion (NFPA, 1982), the current tests for toxicity of products of combustion are inadequate for regulatory purposes. Several test methods appear to succeed in achieving realistic conditions for one or another of the stages (or modes) of fire behavior, but none can claim to cover the full range that the problem seems to demand. Certainly, validation against results measured in "real" fires representing an appropriate set of practical scenarios would have to be a part of establishing any particular method as a standard. We may be years away from this knowledge.

In the meantime, it may be necessary to resort to conservative countermeasures (such as the Canadian device for closing off wall penetrations) or combined metal/plastic systems, and to test these countermeasures at full scale, with appropriate pressure differentials applied, in wall assemblies much as has been the practice typified by the ASTM E-119. Chemical analysis can be used to monitor the concentrations of known or expected toxicants, but it may be necessary to include animals to ensure that an unsuspected toxicant of life-threatening concern has not gone unnoticed by the nonbiological methods of atmospheric monitoring.

F. Fiscal Impacts

The potential fiscal effects of expanded use of plastic plumbing pipe involve:

- Changes in the cost of housing
- Changes in the cost of providing public services
- Changes in employment.

Each of these is discussed in this section.

1. Effects on Cost of Housing

For a typical new single-family dwelling unit built under the current code, plumbing costs run about $600 for materials and $500 for labor. The materials cost calculations are based on a copper and PVC water supply system and ABS DWV system (see Tables II-3 and II-4). Labor costs are derived from NAHB (1981), General Construction Estimating Standards (1976-77), and Service Plumbing (1979). This total plumbing cost of $1,100--marked up 15% to cover builder's overhead and profit--represents about 1% of the 1983 median sales price of $115,400 for existing single-family homes in California (California Association of Realtors, 1983).

The materials substitutions that are likely to occur in response to the proposed changes to the code allowing expanded use of plastic plumbing materials would reduce per-unit materials costs by about $100 and labor costs by about $50. These calculations are based on the use of PB in place of copper for water supply inside the unit. Any other substitutions of newly permitted plastics for metals or other plastics would increase the plumbing costs.* Assuming that the entire construction cost saving of $150 plus 15% builder's markup is passed on to consumers, the median sales price of single-family homes in California would drop by 0.2%.

For multiple-family dwelling units greater than two stories in height, the proposed code change would reduce plumbing construction costs by a total (materials and labor) of $425 per unit. This saving derives primarily from the use of PB in place of copper for inside water supply and the use of ABS in place of no-hub cast iron for inside DWV systems. This estimate is somewhat high because to achieve the required 1-hour fire rating in buildings higher than two stories with plastic pipe would require some additional protection against horizontal fire spread, such as installing metal flanges around the plastic pipe where it penetrates the fire wall. Assuming a 15% markup for builder's overhead and profit and a 20-year life for the plumbing system, the $490 cost saving if passed on in its entirety to the renter, would lower the monthly rent on a unit by less than $3.

In addition to the construction or capital cost of a plumbing system reflected in the sales price or rent of a dwelling unit, there are annual maintenance costs and replacement costs that will be incurred by the homeowner over the life of the plumbing system. Metal plumbing systems are subject to corrosion, which leads to clogs, leaks, and ultimately replacement of the system. The present value of expenditures for repairs, corrosion treatment, and replacement of a metal plumbing system in a single-family dwelling over the last 10 years of the 30-year service life of the system has been estimated at about $700 (Journal AWWA, 1983). Comparable maintenance data are not available for plastic plumbing systems.

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* Materials costs for various plastics and metals are from Plumbing Suppliers Survey (1983); comparative labor hours are derived from NAHB (1981), Service Plumbing (1979), and General Construction Estimating Standards (1976-77); average hourly wage rate (including fringe benefits) for plumbers in California is estimated at $27.00 (Adams, 1983).

However, plastic plumbing used in public water systems has experienced failures, including cracks, splits, stress fractures, pinholes, and shear breaks requiring replacement of the system at costs ranging from $208,000 to $38.25 million per community (Leonardini, 1983).

The substitution of one plastic for another in response to the proposed code changes would not substantially affect maintenance or replacement costs for the system. Substitutions of plastic pipe for metal pipe would eliminate the costs of corrosion control to the homeowner. The present value of corrosion treatment costs for a completely metal system over a 10-year period is estimated at about $60 (Journal AWWA, 1983). Since plumbing systems in new dwelling units are typically a combination of metal and plastic, the savings due to substitution of plastic for metal would be somewhat less than this amount. There are no data that convincingly demonstrate that metal and plastic systems differ significantly in frequency of damage or failure, cost to repair, or service lives. The only generalizations that can be made are that maintenance costs are lower and service lives longer for plastics than metals in areas with corrosive water, and that improper installation appears to lead to pipe failures more frequently with plastics than metals. Plastics are also less subject to clogging than metals, but when clogged they are more susceptible to damage from snakes, de-rooters, and other mechanical cleaning devices and to damage from chemical cleaning products. The replacement cost of an all-plastic system installed under the proposed new code would be $150 less per single-family dwelling unit and $425 less per multifamily unit than the replacement cost for the combination metal and plastic system that would be installed under the current code.

In conclusion, the proposed code change allowing expanded uses of plastic plumbing materials would slightly reduce the life-cycle costs of the dwelling's plumbing system to a homeowner. The lower replacement cost, amounting to $150 for a single-family unit and $425 for a multifamily unit, would account for most of this saving. In addition, in areas with corrosive water, maintenance costs would be a maximum of $60 less. Based on a 20-year service life for both metal and plastic systems and 10% discount rate, the present value of the total life-cycle cost savings due to substitution of the newly approved plastics for metals would therefore amount to about $85 for a single-family unit and $140 for a multifamily unit.

2. Effects on the Costs of Public Service Provision

The expanded use of plastic plumbing materials in response to the proposed code change could affect the costs of providing public services and facilities in local jurisdictions that adopt the state code changes in two general ways. First, local administrative costs could be affected. Local jurisdictions, particularly those in areas with corrosive water, are likely to have to process fewer requests for variances from the current code to allow the use of plastics since most of these plastics would be permitted under the new code. Offsetting this saving would be the additional administrative costs to amend the local fire safety code and other relevant codes, where they exist, to include provisions specifying appropriate methods, procedures, and the like relating to the use of the newly permitted plastics. Building inspection costs might also increase if more attention must be given to proper installation with plastics.

The second category potentially affected would be the cost of providing public services. Expanded use of plastic plumbing materials in residences and commercial establishments would decrease the cost of corrosion in municipal water systems. Corrosion-related costs for the water distribution system in one municipality were estimated at $400,000 annually (Journal AWWA, 1980). Additional fire protection costs might somewhat offset the corrosion savings. However, because plastic pipes are not a source of ignition and would contribute insignificantly to fire spread and severity (see Section IV-D for a discussion of combustibility and fire spread), any additional local fire protection costs would be negligible.

In summary, the expanded use of plastic plumbing materials would be likely to lower the costs of providing water service. The costs of providing other public services would not be affected, and the effects on local administrative costs would probably be offsetting.

3. Effects on Employment

The plumbing materials substitutions that are likely to result from the proposed code change allowing expanded uses of plastic plumbing materials would directly affect manufacturing and construction employment. Specifically, fabricators of metal and plastic pipe and fittings in the manufacturing sector and plumbers in the construction sector would be affected. In addition, the materials substitutions would indirectly affect other industries in the manufacturing sector, such as plastic-resin producers that provide the materials and services that are inputs to the pipe fabrication process. Finally, the materials substitution would, by affecting employment in pipe fabricating and supporting industries, affect employment in the service industries that provide goods and services such as food, clothing, and entertainment to their employees.

The changes in plastics use that are likely to result from the proposed code change break down roughly as follows:

- PB use would increase by 6.1 million pounds annually
- ABS use would increase by 5.7 million pounds annually
- PE use would decrease by 1.4 million pounds annually.

The PB and ABS use figures are high estimates because in some circumstances CPVC would be used instead of PB for water supply and CPVC and PVC would be used instead of ABS for DWV systems. However, because CPVC is much more expensive than the other plastics and PVC is not a traditional DWV material in California, we assume that their use would be so limited that it would not significantly affect the employment analysis.

The net increase (i.e., PB and ABS increases less PE decrease) of 10.4 million pounds in use of plastics in California would represent about 0.4% of the total production of plastic pipe, tubes, and fittings in the United States in 1980 (PPI, 1980). Based on the total sales of $1,583 million for these products in 1980 (PPI, 1980) and a productivity of $98.3 million/thousand employees for workers in the plastics building and construction products industry (U.S. Census, July 1980), the 10.4-million-pound increase in plastic materials usage would directly create about 60 jobs nationwide in the fabrication of these products. Assuming an employment multiplier of 2 for the indirect and secondary effects, the additional plastics usage would also create an additional 120 jobs in the supporting manufacturing industries and service sector combined. Because of the number of assumptions on which the employment impact calculations are based, these estimates may be off by a factor of 2 to 3. Data on total production and sales of plastic plumbing materials in California are not available. However, because total 1982 employment in the production of miscellaneous plastics products numbered 482,000 (California EDD, 1983), any proportion of the estimated additional 60 jobs, created nationwide in this industry that were located in California even if underestimated by a factor of 3, would insignificantly affect state employment in this industry.

The effects of the total 11.8-million-pound change in plastics usage would, under our assumptions, affect the 1980 market shares (PPI, 1980) of specific plastics as follows:

Plastic	1980 Market Share	Market Share Under New Code
PVC	71%	70.88%
PE	23	22.75
ABS	5	5.19
CPVC	0.3	0.28
Others	0.7	0.89

Although the precision of these numbers is exaggerated by the number of significant figures shown, the changes in market share are clearly insignificant.

The increased use of plastics as discussed above would be likely to result in a decrease in the use of metal plumbing materials as follows:

- Copper usage would decrease by about 20.3 million pounds annually
- Cast iron usage would decrease by about 32.8 million pounds annually.

Total U.S. production in 1980 of cast iron pipe and fittings was 2,026.4 thousand tons (U.S. Census, June 1980). Comparable figures for copper are not available. Based on an average productivity of 122.5 thousand tons per thousand employees for workers manufacturing cast iron pipe and fittings (U.S. Census, June 1980), the total 53.1-million-pound decrease in metal plumbing materials usage would result in a direct loss of approximately 220 jobs nationwide in the production of these materials. Using a multiplier of 2 for indirect and secondary employment effects combined, an additional 440 jobs in the supporting manufacturing and service industries would be lost nationwide. Again, these employment impact estimates are subject to considerable uncertainty. However, because metal pipe manufacturing plays an insignificant role in California's economy,* virtually none of the estimated employment loss would be borne by the state.

The effects of the proposed code change and resulting plumbing materials substitutions on employment in the construction sector would be limited to effects on employment of plumbing contractors. Employment in other construction occupations, such as engineers and architects, developers, construction workers, and other special trade contractors (e.g., electricians), probably would not be affected because no significant change in the level of residential and commercial construction is expected to result from the proposed code change (see the Section IV-F-1 for a discussion of the effects of the proposed code change on the demand for housing in California).

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* In 1982, 0.079% (56,000 employees) of the total nonagricultural employees in California were employed in the fabrication of metal plumbing and heating products (California EDD, 1983).

Plumbing employment could potentially be affected in two ways. First, because plastic plumbing materials generally take less time to install than metal plumbing materials (see discussion in Section IV-F-1), the substitutions of plastics for metals that would be likely to occur under the proposed new code would increase the productivity of plumbers. However, because plastic-for-metal substitutions for the bulk of new residential and commercial construction would be limited to the inside water supply system and because substituting plastic for metal in this system would reduce installation time by about 20%, from a total installation time that accounts for about 45% of the time required to install an entire plumbing system (i.e., water supply and DWV inside and outside), the plastics-for- metals substitutions resulting from the proposed code change are not likely to increase plumber productivity substantially.

Second, because plastic plumbing materials are generally easier to install than metal materials, homeowners may be more likely to repair and replace their plumbing systems themselves and consequently may hire plumbers less frequently. In the United States in 1980, about 75% of expenditures on owner-occupied one-housing-unit properties for labor and materials for plumbing maintenance and repairs and construction improvements were payments by the owner to contractors (U.S. Census, 1981).* Let us assume that, under the proposed new code, homeowners will do the plumbing system repairs and improvements themselves about 75% instead of 25% of the time. If we further assume that repair and replacement work accounts for about 20% of a plumber's work, then the greater propensity of homeowners to do these plumbing jobs themselves could reduce a typical plumber's work by as much as 10%.

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* Since this percentage does not reflect the value of the homeowner's time spent doing plumbing jobs, it overestimates the actual percentage of jobs done by plumbing contractors.

In conclusion, the employment effects of the expanded use of plastic plumbing materials would be as follows. The substitution of plastics for metals would be likely to create approximately 180 jobs nationwide in the industries fabricating plastic pipe and fittings and in supporting manufacturing and service industries. Offsetting this increase would probably be a loss of about 650 jobs nationwide in industries fabricating metal pipes and fittings and in supporting manufacturing and service industries. These estimates are probably uncertain by a factor of 2 to 3. Even accounting for this uncertainty, the effects of these estimated national employment changes on employment in California would be negligible. The materials substitutions are likely to have virtually no effect on employment in the construction sector in California, except perhaps for plumbing employment. A typical plumber's work may decrease by as much as 10%.

G. Other Impacts

In addition to the major project areas discussed above, SRI investigated a wide range of other possible impacts. By a coarse prescreening process, we eliminated impacts that were judged as extremely minor or very unlikely to occur with expanded uses of plastic plumbing pipe. The remaining project areas discussed in this section are:

- Energy consumption
- Use of nonenergy resources
- Ecological effects of leachates
- Noise
- Pollution from shifts in production

1. Energy Consumption

The production of both plastics and metals is very energy intensive. Therefore, because a change from use of metals to plastics for plumbing systems could have a significant impact on energy consumption, this possibility was investigated. Only piping was considered; no attention was given to fittings. Also, all-metal and all-plastic plumbing systems were the only ones considered; the difference between these two cases would be larger than for most alternatives and thus would overstate the maximum.

a. Energy Consumed in Manufacturing Pipe

Table IV-48 shows the energy consumption per pound of pipe of each type of primary energy used to manufacture plastic (represented by PVC), cast iron, steel, and copper pipe. The indicated consumption includes the primary energy used to generate the electricity that is in turn used to manufacture the materials. For PVC, approximately one-fourth of the input energy is in the form of feedstock. The feedstock for plastics is

Table IV-48

ENERGY CONSUMPTION FOR PRODUCING PIPE
(Thousands of Btu per Pound)

	PVC	Cast Iron	Steel	Copper
Natural gas	15	5	4	22
Petroleum	15	2	2	22
Coal	7	6	10	15
Hydro and nuclear	3	1	1	5
Total	40	14	17	64

Source: Bider et al. (1981), DHCD (1979), Battelle (1975).

approximately 60% natural gas liquids and 40% petroleum. However, natural gas liquids are conventionally included in petroleum supplies because they are a substitute for petroleum in the production of liquid fuels. Natural gas liquids are counted here as petroleum.

b. Weight of Pipe for Typical House

The drain, waste, and vent (DWV) pipe used in plumbing systems was formerly largely cast iron, but ABS and other plastics have already been approved for some applications and are in widespread use. Table II-4 in Section II shows the derivation of the weight of plastic or cast iron DWV pipe for a moderately large house as used in this energy analysis. The water supply pipe is generally copper but may be galvanized steel. Table II-4 also shows the derivation of the weight of plastics, steel, or copper water supply pipe for such a house.

c. Energy Content of House Piping Systems

Table IV-49 compares the energy content of three alternative piping systems for a typical house: (1) plastics for both water supply and DWV systems, (2) steel for water supply and cast iron for DWV systems, and (3) copper for water supply and cast iron for DWV systems. The total energy consumption for each of the metal systems is nearly double that for the plastic system. However, the plastic piping uses over 60% more petroleum than the steel/cast-iron piping, and about 15% more than the copper/cast-iron piping. The differences in petroleum use are not very significant in relation to the inherent uncertainties in determining the petroleum consumption or weights of pipe.

d. Significance of Differences in Energy Content

The total energy saving of approximately 14 x 10^6 Btu/house (Table IV-52) for plastic piping compared with metal piping is equivalent to approximately 2 barrels of oil, while the increase in the petroleum consumption of 2.8 x 10^6 Btu compared with the steel/cast iron system is

Table IV-49

ENERGY CONSUMPTION FOR PIPING SYSTEMS FOR A MODERATELY LARGE HOUSE
(Millions of Btu)

	Petroleum	Total Energy
Plastic (PVC)	7.2	19.0
Steel water supply	0.9	8.0
Cast iron DWV	3.5	24.8
Total	4.4	32.8
Copper water supply	2.7	7.7
Cast iron DWV	3.5	24.8
Total	6.2	32.5

equivalent to approximately 0.4 barrel of oil. Assuming construction of 90,000 houses per year and 60,000 units at one-half the savings (because substantially less pipe is used), the annual total energy saving is 1.7 x 10^{12} Btu, while the increase in petroleum consumption is 0.34 x 10^{12} Btu (50,000 barrels). For comparison, the annual total energy saving is about 0.14% of the residential energy use in California in 1979 (1,246 x 10^{12} Btu), and the increase in petroleum consumption is about 0.01% of total petroleum use (3,623 x 10^{12} Btu or 620 million barrels) (U.S. Department of Energy, 1981).

The California appliance efficiency standards, a relatively minor energy conservation measure, were estimated to save 24 x 10^{12} Btu per year by 1985 (California Energy Resources Conservation and Development Commission, 1977), over 10 times as much as the annual total energy saving associated with installing plastic pipe in new houses.

Examples of other minor energy convervation measures are: (1) added insulation for refrigerators--1.8 x 10^6 Btu per year, or 36 x 10^6 Btu over the life of the refrigerator; (2) adding one more inch of insulation to a gas water heater that already has an inch of insulation saves 4 x 10^6 Btu per-year, or 40 x 10^6 Btu over a 10-year life of the heater (Mathematica, 1975). Thus, the energy saving of 14 x 10^6 Btu per house for plastic piping is a fraction of the savings expected from minor energy conservation measures.

This analysis indicates that the energy impacts of approving additional applications for plastic piping system are not significant.

2. Use of Nonenergy Resources

The strategic materials implications related to expanded applications of plastic pipe include increased petroleum consumption to produce the various plastics and the potential to reduce U.S. consumption of copper and zinc (the principal metal used in galvanizing steel pipe). The issues of total energy savings and additional petroleum consumption were discussed in the preceding section.

With regard to galvanized steel and copper pipe, the principal metals of concern are zinc and copper. Although the United States imports significant amounts of each and maintains a small copper stockpile, the U.S. reserves of both metals are large. Current U.S. reserves of copper are estimated at 90,000 tons, a 40-year supply at current consumption levels, and 51,000 tons of zinc, a 62-year supply (U.S. Department of the Interior, 1983). A number of zinc smelters have been closed because of the inability or lack of desire on the part of the operators to meet pollution control standards. Because copper pipe is considerably more expensive than galvanized steel pipe, the principal effect of increased use of plastic pipe would be incremental displacement of zinc and steel.

On the basis of this cursory investigation, there appear to be no significant strategic materials implications of more widespread use of plastic pipe.

3. Ecological Effects of the Leaching of Plastic Pipe Materials

The possibility that compounds leached from plastic pipes installed in dwellings might present a risk to the natural environment was considered. As described in Section IV-A, materials that do leach appear in the domestic water supply and wastewater pipes in very low concentrations. Generally, these concentrations and the cumulative amounts that could be released to the natural environment are very small compared with other known sources, especially because of the great dilution that would occur in water bodies. Therefore, the installation of additional plastic pipe in dwellings is very unlikely to be a significant threat to the natural environment. Likewise, because very few of the compounds are a health risk within the household plumbing (see Section IV-B), the large dilution that would occur in water bodies greatly reduces the human health risk from the presence of these materials in the environment. Thus, this consequence does not appear to be a concern and does not warrant further investigation.

4. Noise

Loud noise arising from the movement of water in plastic pipe has been mentioned in numerous anecdotal accounts. However, no empirical data related to the incidence of this apparent characteristic of plastic pipe or to the noise transmission properties of metal and plastic pipe were found. As in metal plumbing systems, some of this noise may be attributed to installations in which insufficient clearance has been allowed for thermal expansion and contraction of the pipe or between the pipe and wallboard.

This apparent characteristic of plastic pipe would be an annoyance, especially in the multifamily high-rise buildings that are fire-rated and would be affected by the changes in the DWV code. However, the noise levels do not reach decibel levels usually considered necessary for a significant impact.

5. Pollution from Production Shifts

Greater use of plastic pipe would lead to an increase in the manufacture of plastic pipe and plastic pipe materials and a decrease in the manufacture of metal pipe and materials. There would also be differences in the extraction and processing of raw materials for them. Because each of these activities has characteristic pollutant emissions, there would also be some shift in such pollutant emissions, both geographically and by pollutant type.

These shifts are very difficult to estimate but in any case can be judged to be of little concern in the decision to be made. Any decreases in production at existing plants would result in fewer emissions--presumably resulting in an improvement in environmental conditions. Increases in production at existing or new plants have the potential to degrade environmental conditions. However, all existing and new plants must have air quality, water quality, and other pollution control permits to operate, and one must presume that discharge limits are set to protect against a significant degradation of the environment.

V CEQA SUMMARY

This chapter covers various information not presented earlier but required by the California Environmental Quality Act (CEQA) for Environmental Impact Reports. As this document is a preliminary environmental review, this section has not been fully developed. When the draft and final versions of the EIR are proposed, it is likely to expand and some of the findings will undoubtedly change or at least be stated more confidently.

A. Significant Unavoidable Environmental Impacts

For this preliminary environmental review of a very subtle and complex proposal, SRI chose to describe our current overall conclusions about the proposed plumbing code changes and our reasons for them, without making definitive findings of significance except where they were clearcut.

First, we discovered nothing to suggest that the issues discussed earlier as the prime ones are insignificant or that other issues are dominant. The only new issue of potential significance that surfaced was the permeation of buried plastic pipe by contaminants in soil and the resulting possible public health impacts. Although the possibility that such effects could occur from permeation of water supply lines from the meter to the house is plausible, any potential problem would also occur--probably in much greater proportion--from the public water distribution system. This problem should be re-examined when better understood and if found significant should influence state policies with respect to plastic use in both public and residential systems. With adequate education of building inspectors on the permeation issue, improper installation of plastic water service in contaminated soils should be rare.

As to public health impacts from chemicals leaching from water pipe into potable water, we find that significant impacts are possible but unproven, both for plastic pipes--especially the chlorinated varieties--and for metal ones, specifically copper systems. If the upper ranges of possible concentrations of leachates are regularly reached, the cumulative risks to public health may be high enough to be of concern by typical standards of acceptable risk, for example, a lifetime cancer risk of one in a million. The chemicals of concern are lead from the solder in copper pipes, possibly leading to neurologic disorders, and carbon tetrachloride, perchloroethylene, and trichloroethylene from plastic (especially PVC and CPVC) pipes, possibly resulting in cancer.

Two major considerations limit the significance of the findings. First, the status of information about long-term levels of leachates is exceedingly flimsy. Reasonable further testing could resolve at least part of the uncertainty (see Section VI). Second, the risk assessment procedure is moderately conservative. If risks still appear to be of concern after concentrations are better known, more attention would need to be devoted to assuring that the assessment procedure took into account detailed properties of the chemical. Finally, thorough initial flushing would effectively mitigate the effects of the rapidly leaching materials, especially the solvents used with plastic pipe. Overall, current information does not establish an environmental preference between copper and plastic pipe, with neither clearly likely to cause a great number of deaths or serious illnesses.

For worker safety and health, a similar situation exists. Both lead from solder fumes in installing copper pipe and solvents from installing ABS, PVC, and CPVC pipe could be hazardous if plumbers have high exposures by inhalation; dermal absorption could also be significant in the case of solvents. The diseases of concern for solder fumes are related to the lead exposure and are neurologic. The solvents may also cause nerve damage, and they may be involved in liver damage or reproductive problems as well. However, they are not implicated in cancer unless benzene is more common than thought. Unless the NIOSH report about to be released resolves the range of exposures satisfactorily, further testing would be useful before completing the EIR. Safety issues generally favor plastic over metal, which appears to lead to more burns (hot solder and especially flux) and strains and contusions (from heavier metal pipes). PB (like PE, although its uses are not proposed for change) poses little if any worker safety and health concern. Use of gloves, other protective equipment, ventilation, and simple care will significantly reduce any potential hazards from either plastic or metal pipe, but these practices have not achieved widespread acceptance among plumbers.

Fire safety is a very real concern with plastic DWV pipe; ABS is combustible, and PVC and CPVC will at least soften and slump in lines. If these plastics are installed as direct substitutes for metal, as they already are in non-fire-rated residences, they will degrade the fire resistance of structures. The gaskets in no-hub cast iron will also fail in fires and cause the pipe to fall, leaving fire passages. But the proposed code changes apply to fire-rated, fire-resistive construction that could retain its fire rating if appropriate installation procedures are developed and enforced. In such conditions, no degradation of fire resistance would occur. This issue thus turns on enforcement, not science. The potable water pipes, kept cooler by the water inside and of much lower mass, are not a significant fire safety issue.

As with fire safety, smoke toxicity is an issue in which plastic can only be less environmentally acceptable than metal. However, whether the difference is significant is less certain. Both ABS, which seems likely to contribute the majority of pipe mass in California, and the polyolefins PB and PE produce combustion products that are not highly toxic; few if any additional fatalities or serious injuries would be likely from their combustion. PVC and CPVC both produce significant quantities of hydrogen chloride vapor in fire environments, and this corrosive material could, under certain circumstances, make a difference in the probability of human survival in lines. The frequency of such occurrences is clouded by lack of a generally accepted test for smoke toxicity. This problem is currently being addressed both by the State of California Department of Industrial Relations and by the State of New York. We believe DHCD should pay close attention to results from those studies, but does not need to delay a decision solely on those grounds.

No other significant adverse impacts are likely to result from the expanded use of plastic plumbing pipe if relatively simple mitigation measures are taken. Plastic drain pipes may be slightly noisier than cast iron pipe. See the following section (V-B) for further elaboration.

Overall, the SRI study team sees little evidence that expanded use of plastic plumbing pipe would cause significantly greater environmental problems than the materials it would replace. Unfortunately, lack of evidence is not the same as lack of hazard. We believe it is especially important to gather more information on leaching of chemicals from both plastic and metal pipe systems into potable water and on the exposures of plumbers to material from plastic (ABS, PVC, CPVC) and metal (copper) plumbing systems.

Table V-1 summarizes our present assessment of our relative environmental concern about pipe systems. There we show our relative degrees of concern for different materials for each of the major areas of impacts. A high rating does not necessarily mean an impact that is significant in the sense of CEQA, but does mean that the material rated seems to us more likely to be environmentally harmful then other materials on that dimension. For example, the chlorinated plastics clearly are of highest concern for smoke toxicity, but may not pose any significantly higher impacts in the proposed new DWV uses (fire-resistive construction).

Table V-1

RELATIVE DEGREE OF CONCERN REGARDING POTENTIAL ENVIRONMENTAL IMPACTS[*]

	Potable Water				Drain, Waste, and Vent			
	Plastic		Metal		Plastic		Metal	
Impact Area	PB/PE	PVC/CPVC	Copper	Galv. Steel	ABS	PVC/CPVC	Copper/ Gal.Steel	Cast Iron
Public Health	3	4	3	3	0	0	0	0
Worker Safety	1	2	4	2	2	2	3[+]	5
Worker Health	0	3	4	2	4	4	3[+]	1
Fire Safety	3	2	0	0	5	4	0	2
Smoke Toxicity	1	3	0	0	3	5	0	0
Other Impacts	0	0	0	0	1	1	0	0

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[*] Key:
0 - No concern
1 - Considerably less concern than average
2 - Less concern than average
3 - About average concern
4 - More concern than average
5 - Considerably more concern than average

Note: High relative concern does not necessarily imply high absolute concern; significance of ratings depends on mitigation measures taken.

[+] More for copper, less for galvanized.

B. Insignificant Effects

The following environmental effects of expanded uses for plastic plumbing pipe may occur but are probably insignificant by any reasonable interpretation of CEQA:

- Plastic pipe systems may fail slightly more frequently than metal systems until a body of experience with installation errors has accumulated.
- Plastic pipe will consume slightly more petroleum than metal pipe, but slightly less energy overall.
- Plastic pipe will contribute a slightly different load of pollutants to public waste water treatment systems, but the direction of impact, let alone its magnitude, is uncertain.
- Plastic DWV pipe will be slightly noisier than metal systems if installed so as to contact wall surfaces; this may be more significant than otherwise in the multifamily, fire-rated construction that is affected in the DWV code changes.
- Plastic DWV pipe could be damaged by pipe cleaning equipment, but because of its resistance to corrosion, the frequency of such cleaning should be low.
- Plastic pipe will slightly decrease the life-cycle cost of plumbing and therefore of housing, but not enough to change demand patterns or growth.
- Small shifts in employment from metal pipe manufacturing to plastic pipe manufacturing will occur.
- A small reduction in the work of plumbers will occur, mostly as a result of repair and renovation work by do-it-yourselfers.

C. Effects of Alternative Actions

In addition to the proposed project, e.g., the proposed change to the 1982 Uniform Plumbing Code (UPC) allowing certain new uses of plastic plumbing pipe as described in the Project Description, this environmental review has examined the potential effects of alternatives to the proposed project on the quality of the natural and human environment. The eventual EIR will consider alternatives as well as the project itself to provide a baseline for evaluating the significance of the impacts and to provide possible alternative courses of action should the proposed project create significant adverse impacts that cannot be successfully mitigated. With this goal in mind, the alternatives we have selected for analysis are no changes to the state code, partial approval of plastic pipe use, and complete rejection of all plastic pipe (that is, reversal of earlier provisions allowing certain uses of plastic pipe).

Under the no-action alternative, there would be no changes in the state code regarding the use of plastic plumbing pipe. All currently approved uses for plastic pipe would continue to be permitted and no new uses of plastic pipe would be allowed. None of the impacts attributable to the use of plastic pipe in expanded applications would be observed; any public health and worker safety and health effects of currently allowed plastic and metal piping systems would persist.

The partial approval alternative would amend the state code to permit certain new uses of plastic pipe, but not all of the new uses proposed under the project. Counting cold and hot water supply in a given application as one new use, the proposed project would change the code to permit 11 new uses of plastic pipe (i.e., 1 new use for ABS pipe, 3 for PB pipe, 1 for PVC pipe, and 6 for CPVC pipe). Considering all the possible combinations of these uses, over 2,000 partial approval alternatives are possible.

Our analyses of the environmental consequences of the proposed project have guided our selection of the subset of the partial approval alternatives to be considered in the EIR. That is, we define the partial approval alternative(s) to permit those new uses of plastic plumbing pipe that are least likely to have significant adverse effects on the quality of the natural and human environment. At present, the only partial alternative that seems reasonably certain to meet this requirement is to allow PB for hot and cold water supply both outside buildings and inside buildings that are not fire-rated or within the fire-resistive construction of fire-rated buildings. No other new uses of plastic pipe would be allowed. Parenthetically, there seems little reason to prohibit PB in exposed locations of fire-rated buildings as long as the penetrations of fire-resistant construction are designed to maintain the rating of that construction. The state of information on the impacts of this alternative is generally the same as on those of the metal water pipe currently allowed for these two uses. Although PB will certainly burn and metal will not, the additional risk of fire spread appears minimal, as does that of smoke toxicity. Leachates from PB have not been shown to be risk-free, but neither have those from copper or galvanized steel. Of the two plastic alternatives, PB is somewhat less likely to be a public health hazard than CPVC, although the relative ratings of PB, CPVC, copper, and galvanized steel will not be clear without further testing (see Section VI). PB is clearly a preferred material, from the worker safety and health viewpoint, compared both with metal systems and with plastics that require cementing.

Under the option of disallowing currently allowed uses of plastic pipe, any impacts of these materials would disappear and those of metal systems reappear. The possibility of permeation of water supply piping by organic contaminants would decrease to the extent that PVC and PE supply lines would be replaced by metal with impermeable joints (but even metal pipe joints can be permeable). Leachates from PVC and PB would be replaced by those from copper, with no clear impact, positive or negative, on public health. The metal pipes would be somewhat more likely to corrode in soil than plastic (galvanized steel is not recommended for buried supply lines). Only small changes in worker safety and health would result from the changes in water supply piping.

Any major impacts of disallowing current uses of plastic pipe would be associated with the widespread use of ABS (and less widespread use of PVC) in DWV applications. Fire load and fire spread would be reduced in nonfire-rated construction. It is probable that few fatalities or little property damage would be avoided by this action, but both are possible benefits. Smoke toxins would also decrease somewhat, especially if PVC were replaced. The decrease in plumbers' exposures to solvent cements would be offset by increased work-related injuries from working with cast iron and, to some extent, with soldered joints in copper DWV. Whether the net effect on worker safety and health would be positive or negative is difficult to predict, given the current lack of information on plumbers' exposures.

Finally, the alternative that would disallow current uses of plastic would transfer some profits and jobs from the plastics to the metal pipe industries. Since large quantities of DWV are involved, these impacts would probably be greater than those for the prime project alternative of allowing expanded uses of plastic pipe. Houses could become more expensive, depending on the prices of cast iron and copper, but probably not enough to significantly affect the demand for housing.

In summary, the alternative of approving only the expanded uses of PB appears to pose fewer environmental risks than does the full proposed project given the state of current information. Because metal systems also pose some unique risks and may be comparable to plastic systems in other risk areas, we are not prepared to say that the no-project alternative or the alternative that would disallow current uses of plastic are environmentally preferable to the partial approval alternative, or even to the full proposed project.

D. Cumulative and Long-Term Implications

Increased use of plastic plumbing pipe can contribute to cumulative environmental impacts in two ways.

First, the sum of the environmental impacts of plastic pipe could be significant even when no one individual impact is deemed significant. In the case of plastic pipe, the most plausible example is for the various leachates that could each contribute to public health impacts. For example, no one leachate might reach the level of 10^{-6} lifetime risk for cancer, but the cumulative risk of all leachates acting together might exceed that level. Given the current uncertainties about the public health impacts, especially those concerning the long-term levels of leachates in drinking water, we are unable to determine whether the cumulative impact is significant. A similar situation is found with worker health impacts, where the risk of one solvent might be ingisgnificant, but that of two or more could be significant. For fire safety, the cumulative impact of all the proposed new uses for plastic pipe are likely to be dominated by the new DWV uses; the contribution of PW pipe is likely to be negligible. The same is true of smoke toxicity, except that the combined affect of HCl, CO, and other toxicants could be significant even when the effects of any one alone were not.

A second issue of cumulative impact is the question of whether the expanded use of plastic water pipe would add to the impacts of other similar actions and in total create a significant effect even though the use of plastic water pipe is not itself significant. We can consider two levels of cumulative impacts:

- Cumulative impact of expanded and existing use of plastic plumbing pipe.
- Contribution of plastic plumbing pipe to total use of plastic products.

As has been made clear earlier, the expanded uses of plastic pipe are in many ways rather small in comparison to existing approved use of plastic pipe. Most new California houses are already being plumbed with ABS DWV if they are not fire-rated; the addition of 10% (by weight) more plastic pipe as PB or (less likely) CPVC water pipe will be of little consequence for fire safety, especially as water piping is less sensitive. The increase for plastic pipe in fire-rated construction, of course, is total since no plastic is being used now; however, if ways of maintaining the rating are developed as required by code, little fire safety impact would be expected. Similarly, the cementing of plastic potable water pipe is probably much less of a problem for workers than the cementing of already approved ABS DWV. Thus, the greatest issue of cumulative impact involves public health impacts, in which plastic in residences can add to plastic in public utility distribution systems. We have no way of estimating the relative contribution of each to the total hazard, as the source of contaminants found in the water supply (controls) during leaching tests is not known. We doubt that the combined effects of distribution and residential piping would be significant if neither one alone were, but we cannot rule out that possibility. Similarly, permeation of plastic distribution pipes by toxic substances is more likely than it is for residential piping systems, but the significance of either, in terms of an overall risk assessment, will not be clear for a long time.

With regard to plastics in total, the expanded uses of plastic pipe will be a relatively small contribution in most respects. Plastics are by now endemic in our society. Most of the contaminants of PVC and CPVC that could be public health hazards will be ingested in much greater quantities from other PVC products such as food containers or, in the case of some of the chlorinated methanes, simply from waste products reaching the raw water supply. Those from PB and PE are similar to those from PE food contact materials. If plasticizers do contaminate plastic pipe, they will still do so at much lower levels than they do in any number of plasticized products to which people are regularly exposed, such as flexible vinyl upholstery (where they would yield inhalation rather than ingestion exposures). But equally clearly, plastic pipe does contribute to the total load of plastic-related hazards in California--for example, to the total of all combustible plastics in residences. The hazards from the total use of plastics are undoubtedly appreciable, even though nearly impossible to estimate. Whether or not they are greater or less than the hazards of the materials they replace is perhaps even more difficult to state. About all that can be said is that plastic pipe is not an unusually prominent or special case among plastics in general.

CEQA also requires an assessment of whether long-term environmental costs will be incurred as a result of short-term economic or other benefits. Certainly, any public health impacts of plastic pipe that do occur will probably be delayed for decades, as will some of the worker health or smoke toxicity impacts. However, for the purpose of determining the environmental consequences of the expanded uses of plastic pipe, those should be counted as current impacts, and not discounted in comparison with current benefits. We believe that, when it is viewed from this perspective, this CEQA issue is irrelevant to the decision at hand.

E. Significant Irreversible Changes

CEQA also requires an assessment of environmental changes or consumption of resources that would be permanent and irreversible. For example, the mining of a mountain is an essentially irreversible impact, whereas most air pollutants and their impacts would disappear once the source of pollution is removed.

In the case of the expanded use of plastic plumbing pipe, there would be a small permanent commitment of petroleum resources (but not other energy sources) to the manufacture of the pipe constituents. Total energy resources would be conserved to a slight degree. If any deaths occurred as a result of diseases caused by leachates or occupational exposures, or from fire or smoke toxicity, they would also be irreversible. If plastic pipe were later disapproved, the occurrence of new fatalities would gradually disappear. Some of the leachates from plastic pipe are mutagens and some mutations can be heritable. Thus, it is possible that a heritable--and more likely than not adverse--mutation could persist in the population as a result of drinking from plastic water pipes. Neither the specifics of the leachates in water from plastic pipe nor the overall state of the art of genetic risk assessment allows an evaluation of this possibility at present. If the impacts of plastic pipe eventually were judged unacceptable, it is possible that the metal pipe industry would have declined by that time to the point at which it would prove difficult to revive, but that possibility is also extremely speculative. Overall, we believe that the reversibility of the impacts is not as important an issue to resolve as the magnitude and significance of current impacts.

F. Growth-Inducing Impacts

California's population is projected to increase from the 1980 total of 23.8 million people to 25.9 million by 1985 and to 27.9 million by 1990 (California Department of Finance, 1981). The proposed code change is not likely to significantly affect this forecast population growth for the following reasons. First, the reduction in the cost of housing construction that would result from use of the newly permitted plastics in place of currently approved plumbing materials is so small that it would have virtually no effect on the sales price or rent of dwelling units in the state. Therefore, there will be no change in the demand for housing and consequently no additional in-migration of residents who would be attracted by a drop in the price of housing. Second, the plumbing material substitutions that are likely to result from the proposed code change would not significantly affect employment opportunities in the state and so would not affect the in-migration and out-migration forecasts. Nor would either housing prices or employment opportunities significantly affect shifts in population from one part of California to another.

VI TESTING NEEDS AND OTHER INFORMATION GAPS

A. Decisionmaking Under Uncertainty

An EIR, by its very nature, is an attempt to predict the environmental consequences of an action before that action is taken, and must necessarily be uncertain about those consequences even if the phenomena involved are well understood. Moreover, the underlying phenomena are ordinarily not completely understood, yet a decision on the action must still be taken even if the decision is against the action. Decisionmaking under uncertainty is thus the rule in actions wth potential environmental consequences; the decisionmaker must evaluate whether environmental consequences are more likely to be beneficial or adverse, and if adverse, whether the nonenvironmental benefits of the action will outweigh the adverse impacts. Moreover, the decision maker must consider--at least subjectively--the possibility that the impacts will prove significantly worse than seems most likely, and conclude whether the risks of those more adverse outcomes outweigh the nonenvironmental benefits.

Different attitudes about risk in decisionmaking will lead to different decisions with the same information. SRI does not propose a "correct" way to evaluate risk. Instead, we try to characterize, in this section, the degree of uncertainty about various "facts" and the significance of the uncertainties for the environmental consequences of expanded use for plastic plumbing pipe.

Our overall approach to "scoping" this environmental review entailed an iterative refinement of the depth of investigation. This approach was necessary to avoid spending great effort investigating potential impacts of trivial importance. To focus on the potentially most significant impacts, we first made "conservative" assumptions about both available data and interpretive techniques. For example, we used maximum observed concentrations in drinking water and a conservative dose-response relationship in determining whether a specific chemical is a threat to public health. If such an approach showed no problems, then it was not necessary to refine our estimates for more realistic concentrations and toxicological behavior. "Conservative" assumptions led to "reasonable" worst-case analysis, but not "very worst case." If impacts appeared to be possibly significant, we exerted more effort to make realistic estimates until either it was clear that the impact was or was not significant or it was clear that available information was not sufficient to make such a determination.

These residual uncertainties, or information gaps, are not unusual in the EIR process. At this stage of the environmental review, we can divide them into two categories:

- Uncertainties that are important to the decision and that can be significantly reduced by investigations that can be completed in a reasonable time (6 months) and at a reasonable cost; these are denoted as "testing needs."
- Other information gaps that, while potentially significant to the decision, are not subject to easy resolution and must be considered risks of the decision.

B. Testing Needs

At present, SRI sees critical testing needs in two areas:

- Characterization of long-term levels in drinking water of leachates from plastic pipes and initial levels of lead from metal pipes.
- Characterization of the exposures of plumbers to solvent cements and solder fumes.

These are by no means the only uncertainties limiting a complete evaluation of the environmental impacts of expanded use for plastic plumbing pipe. However, they constitute the two areas in which it is reasonable for DHCD to improve the base of knowledge through its own efforts in a reasonable time. Below we discuss these needs in more detail, but first we discuss some needs that we view as beyond DHCD's current responsibility or purview.

In the area of fire safety, there is substantial disagreement over the extent to which plastic pipe contributes to fire spread in terms of differences in injuries and property damage with and without plastic pipe. However, the point is virtually irrelevant if techniques can be developed to preserve the fire rating of construction that contains plastic pipe. Thus, we believe that it is necessary for pipe manufacturers and distributors to demonstrate the acceptability of plastic pipe systems complete with fire mitigation measures in standard fire rating tests such as the E-119; we do not believe it is necessary for DHCD to test arbitrary configurations for fire safety, presumably demonstrating only that some do and some do not pass the tests.

For smoke toxicity, we find that the evidence on the contribution of plastic pipe to illness and death from fire environments is at best weak and at worst contradictory. Thus, further testing of the smoke toxicity of plastic pipe is desirable to determine, in particular, the hazards of HCl from PVC. However, at present there is no generally accepted test for smoke toxicity, and specific pipe testing would not significantly clarify the issue. When the California and New York state studies are complete, it may be possible to reevaluate smoke toxicity as a factor in the acceptability of plastic pipe. In the meantime, the uncertainty over this issue should be treated as would any other risk.

Finally, much remains to be learned about public health other than leachate concentrations. Studies of the toxicity of the leachates should and will continue independent of any effort by DHCD. If any of the leachates prove significantly more or less toxic than anticipated, any decision regarding expanded uses of plastic pipe should be reexamined. Clarification of the question of the permeation of pipe by soil contaminants needs substantially better information, including:

- Permeation experiments at realistic levels of external concentration and for simulated residential use patterns of the water inside the pipe over long time periods.
- Field observations of the distribution of levels of selected pollutants in the soils of California residential areas.

Because any problem that exists would probably be of more importance for water distribution lines, any such investigations should include water utility interests, and utility experience should be monitored for relevance to the residential permeation issue.

1. Leachate Concentrations

Because available data are sparse and of poor or uncertain quality, additional leaching data are needed to assess the long-term health effects of CPVC and PB plastic pipes and the chronic health effects of lead from metal plumbing systems.

For CPVC pipe systems, consecutive 1-day static dwell experiments should be run for at least 60 days to adequately observe the expected reduction in leachate concentration with elapsed time. Milli-Q or other highly purified, unchlorinated water should be used to minimize background concentrations of chlorinated organics. Replicate samples should be taken for every measurement to determine the precision of the analytical method. The solvent cements should be analyzed to isolate their potential contribution to the leachate population. Replicate systems of the same pipe should be tested but the leachability of these systems may vary considerably because of the difficulty of reproducibly joining pipe sections with solvent cement. Pipe samples from several manufacturers should also be tested.

Consecutive 1-day static dwell experiments should also be run for PB pipe systems for a sufficient period of time to estimate long-term leachate concentrations. Replicate systems of the same pipe and pipe from different manufacturers should be tested. Milli-Q water should be used and replicate samples should be analyzed to establish the precision of the measurements.

Laboratory and field studies should be run to determine lead concentrations in metal systems as a function of water pH and age of the system. Consecutive 1-day static dwell experiments should be run for lead-soldered copper and galvanized steel laboratoy systems for a period of at least 60 days using water with pH values ranging from 5 to 9. Copper systems with tin/antimony and tin/silver solders should also be studied to see the effectiveness of this mitigation technique. These short-term leaching data should be supplemented, if possible, with field data on new pipe systems (less than 2 years old) that use lead solder. The concentration of lead in the water entering the residential plumbing system should be measured to determine the contribution made by the lead in the residential plumbing system.

Laboratory test configurations for all plastic and metal systems should simulate residential plumbing. Strict attention must be given to quality assurance of the data, including a thorough statistical analysis of test results.

2. Plumbers' Exposures

A critical need in the evaluation of the hazards to plumbers of working with plastic and metal piping systems is characterization of the degree of exposure to solvent cements and solder fumes in typical plumbing situations. We need to know much more about both short-term peak exposures and longer term average exposures before a confident assessment can be made.

SRI believes that the measurement of exposures in the field with limited validation and calibration in the laboratory is the best design for answering the critical questions. The objectives should be to quantify inhalation and dermal exposures to solvent cement constituents and inhalation exposures to solder fumes.

The inhalation exposures of both kinds of hazards should be determined by measuring concentrations in the breathing zone of plumbers in ordinary job situations. Samplers attached to the plumbers themselves may be calibrated by sampling also with hand-held instruments operated by industrial hygiene professionals. Both short-term (15 minutes or 1 hour) and longer term (8-hour TWA) measurements should be taken, using either passive or active samplers, depending on the performance of the devices in laboratory calibration runs. The collected samples should be analyzed for unknowns as well as quantified for the contaminants suspected a priori.

Although some quantification of dermal exposures may be possible through gauze patch or glove collection techniques, the volatile solvents cannot be confidently measured in these ways. Thus, it will probably also be necessary to conduct biological sampling (for example, expired air, urine, or blood samples) in an attempt to measure absorbed doses. To measure the dermal contribution, an adjustment will be needed to account for the inhaled dose that can be inferred from the breathing zone concentrations and normal work-time breathing rates.

The measurements must be taken in all the representative plumbing situations--preassembly, in-trench installation, roughing, topping, and finishing, as well as replacement and repair--and must be adequately replicated.

Thus, the six major tasks for the worker health study are:

- Review previous efforts, including the NIOSH (1982) study just released and one about to be released.
  - Determine the composition of solvent cements, solders, fluxes, and cutting oils.
  - Determine the populations of plumbers at risk.

- Design survey protocol.
    - Determine number of samples by type of work.
    - Specify work sites to be sampled.
    - Obtain cooperation.
- Design sample collection strategy.
    - Decide on materials and methods for air sampling.
    - Decide on materials and methods for biological sampling.
    - Decide on methods for chemical analyses.
- Calibrate as necessary in the laboratory.
    - Select among available methods.
    - Establish benchmarks.
- Conduct study according to design.
    - Obtain field samples.
    - Perform laboratory analysis.
- Analyze and report results.

Additional details on worker safety and health testing needs are presented in Appendix E.

C. Other Information Gaps

When we initiated this environmental review, we had assumed that the uncertainties we would find would be scientific in nature: How much of chemical X leached into water? To what extent is solvent Y toxic at levels found in the workplace? How much could plastic pipe contribute to the fuel load in residences? and so on. We were therefore somewhat surprised to discover that equally, if not more, important were uncertainties about human behavior: How will plumbers work with plastic pipe? What degree of skill can be expected from building inspectors? and the like. We discuss the scientific and behavioral uncertainties separately below.

1. Gaps in the Scientific Information

Gaps in scientific knowledge for individual impact areas are discussed in some detail throughout Section IV. Here we merely summarize some of the major ones.

a. Water Quality

Most of the uncertainties have to do with concentration levels over time and will be investigated by the testing recommended above. However, uncertainties will remain about the influence of input water quality, quality of installation, unusual water use patterns, and the combined effects of leachates from the piping system and those in the input water.

b. Public Health

All the water quality uncertainties affect assessment of public health effects. In addition, there are many questions regarding individual variations in patterns of drinking water from the residential supply, the mobility of the population, whether or not infants are more or less likely to live in newly plumbed houes, and other influences on the pattern of exposure to leachates. More important are many open question regarding the toxicity of leachates. Although much biological testing has already been accomplished, not every leachate has been tested for every conceivable biological effect, nor will they ever be. The whole question of the safety of plastic versus metal pipe should be periodically re-examined as new data become available on the toxicity of the leachates and permeants.

c. Worker Safety and Health

A major uncertainty is the degree of worker exposure to potentially dangerous materials. The proposed testing will clarify this uncertainty greatly, but even then extremes of exposure will still be possible. As with public health, the toxicity of the workplace contaminants is incompletely understood, and will gradually be clarified as the art of toxicology develops. So far, no conclusive epidemiological investigation has been conducted to characterize past health problems in the plumbing trade, even though safety hazards are reasonably well understood. Such an investigation, particularly if it could isolate workers with relatively pure exposures to plastic and metal systems, would help to validate any estimate from the exposure/toxicity analysis.

d. Fire Safety

At present, we do not know much about the testing of fire-resistive construction with respect to vertical penetration of floor/ceiling units and the like. We need to understand much more about the value of various fire-blocking techniques to mitigate any fire-spread influence of plastic pipe.

e. Smoke Toxicity

The major issue in smoke toxicity evaluation is the lack of consensus on a valid test system for smoke toxicity. The complexity of predicting toxicity from experiments with individual smoke toxins prevents much confidence in results from such an exercise. Also needed are better data on observed levels of smoke toxicity in real fire situations. These are both questions that relate to the issue of plastics in buildings in general, not only to plastic pipe.

f. Fiscal and Other Impacts

While there are relatively great uncertainties in these areas as well, the magnitude of probable impacts does not seem to justify much expenditure in resolving them.

2. Uncertainties About Human Behavior

There are two extreme ways to look at the behavioral aspects of expanded use of plastic plumbing pipe. One extreme is to hold that plastic pipe should be judged only on its intrinsic hazards, assuming that all precautions in its manufacture, installation, and use will be taken. In effect, this attitude implies that any impacts attributable to human error or misuse are the fault of the users, not of the pipe. At the opposite extreme is the position that every environmental impact associated with the most extreme misuse of plastic pipe is attributable to it, not to the abuser, and that the acceptability of the pipe should be assessed assuming the worst in human behavior. Whatever one's attitude toward this issue, however, it is reasonable to ask whether plastic pipe is less forgiving of human "errors" than the equivalent metal system is. If it is, then care in specifying and enforcing mitigation measures for human behavior will be important in allowing the expanded uses of plastic pipe.

The principal uncertainties about human behavior are classified by impact area and discussed below.

a. Water Quality

Leachate concentrations of some intentional constituents of pipe and solvent cements could have significant public health implications if plumbing systems are not flushed before use. Although use without flushing seems unlikely to be frequent, it is not impossible. (Flushing of metal pipes is also advisable.) Building inspectors should require evidence of flushing with at least 1,000 gallons of water before approval, and new owners should be encouraged to flush all lines again before use.

A second major uncertainty is the quality of installation. Poor solvent cement joints are known to produce more leachates than good ones. Plastic is probably somewhat less forgiving of error than metal. This factor will put additional pressure on building inspectors to assure quality. Do-it-yourselfers will find it easier to work with plastic and may or may not make more errors than professionals. They will surely be less likely to seek inspection.

More subtle concerns exist about unintentional contamination of pipe and cement. It is possible that either materials manufacturers or pipe and fittings manufacturers would experiment with unauthorized materials or that simple errors would introduce dangerous contaminants. Again, inspection procedures by NSF for potable water pipe will keep such incidents minimal but will not eliminante them. Plastic pipe would be less subject to such errors if NSF screened for certain organic contaminants as well as the present inorganic ones. It would seem reasonable to institute some extraction testing regime for metal pipe systems as well.

b. Public Health

The uncertainties pertaining to water quality also pertain to public health. In addition, the degree to which people drink the first water from the tap following a static period of concentration buildup is uncertain. It is untenable to assume that many people will deliberately avoid drinking the first water, but they will certainly not deliberately seek it. Other uncertainties surround the extent of tap water use in baby formulas and the use of water purifiers.

c. Worker Safety and Health

Here the major behavioral uncertainties all have to do with the degree of care exercised by plumbers or do-it-yourselfers in installing plumbing, either of plastic or of metal. There are three major issues:

- How much guidance will be supplied by manufacturers, unions, and government regarding safe use?
- To what extent will contractors, plumbers unions, and occupational safety and health officials encourage or enforce safe practices?
- To what extent will plumbers and do-it-yourselfers follow the guidance given them?

Guidance is already available from manufacturers and generally appears in such forms as the installation standards in the UPC. However, labeling of materials at present (fluxes, solders, pipe joint compounds, solvent cements, primers, and so on) is at best variable, and guides to the do-it-yourselfer often overlook safety guidance. There is anecdotal evidence of time pressures militating against safe use. Most observers agree that many plumbers do not exercise maximum caution. What little evidence is available gives no clear signal whether plastic or metal pipe systems are more forgiving of worker error, although we would expect a less informed use with the newer plastics until experience had accumulated.

d. Fire Safety

As discussed at length in Section IV-D, the central issue for this proposed action is whether plastic pipe installed in "fire-resistive construction in fire-rated dwellings" will still meet the putative fire rating. There will be no substantial change in fire safety if "1-hour" fire walls plumbed with plastic indeed pass the fire rating test for longer than 1-hour. However, for this to occur:

- Manufacturers and others will need to test and demonstrate safe methods of using plastic pipe in fire-resistive construction and describe them in terms implementable by plumbers and building inspectors.
- Plumbers must follow the guidance provided and not simply substitute plastic where metal was used safely.
- Building inspectors must exert somewhat greater diligence in assuring compliance with construction standards.

Plastic pipe is somewhat less tolerant of error than metal because of its own flammability. On the other hand, there are clearly many instances in which metal systems are installed in such a way as to compromise the fire ratings of structures.

e. Smoke Toxicity

We assume that people other than fire fighters would be no less able to avoid a toxic smoke hazard from plastic pipe than they would from ordinary smoke. People would have somewhat less time to escape the more toxic plastic smokes, but since the HCl from PVC and CPVC is offensive, even at low concentrations, there might be some tendency for people to escape earlier than they do in fires not involving the chlorinated resins.

Fire fighters are regularly equipped with breathing apparatus to mitigate exposures to toxic smoke. However, anecdotal evidence again suggests that the apparatus may not be used even in fires known to involve chlorinated plastics. Thus, the principal uncertainties are:

- Will fire departments provide further training on safety in combatting fire involving plastics?
- Will fire fighters heed the guidance?

Since smoke toxicity is not a significant issue with metal pipe, plastic is definitely less forgiving of human error in this case.

f. Fiscal Impacts

As the fiscal impacts are likely to be small in any case, human behavior is less significant here. Taking care with plastic, especially with respect to fire safety, may narrow the cost advantages of plastic systems. Furthermore, carelessness in installation will reduce the life expectancy of both types of systems, perhaps slightly more so for plastic, and will thus reduce the life-cycle cost advantage of plastic in a different way.

g. Other Impacts

Again, these are relatively insignificant and human behavior will make little difference. Examples can be found even here:

- The issues affecting the water quality may have some implications for the quality of the water which the residential sewers eventually discharge.
- The impact of noisier plastic drain pipes will be more noticeable if care is not exercised to isolate the pipe acoustically, from wallboard.

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