# Exposures from Polyvinyl Chloride (PVC)

## Introduction

Produced since the 1930s, polyvinyl chloride (PVC) was one of the first plastics to be manufactured. Today it is the second most commonly-used plastic in the world,[1] with an estimated 59 billion pounds produced globally in 2002. Plastic pipes and other construction materials account for the majority (75 percent) of PVC consumption in North America.[1] PVC is also used in a wide range of products, including kitchen flooring, shower curtains, wallpaper, children's toys, garden hoses, three-ring binders, credit cards, and food packaging. It is one of the only common plastics to contain chlorine. PVC is 56 percent chlorine by weight, and it is this ingredient that has raised questions about PVC's effect on human health.

While the carcinogenic risks posed to workers occupationally exposed to vinyl chloride during the production of PVC were recognized over twenty years ago,[2] it is only recently that attention has focused on other potential health consequences in the general population posed by PVC throughout its entire life cycle – from production, to use, to disposal. Two U.S. advocacy groups have recently published extensive reviews of research in this regard that provide more detailed discussion of the overall health and environmental dangers associated with PVC.[1, 3] The summary presented here is focused on the exposures and potential effects of PVC only as they may be relevant to breast cancer risk.

## Definitions and Sources of Exposure

PVC is a polymer made from vinyl chloride molecules. PVC products, however, are typically not the pure polymer itself, but contain a variety of additives and stabilizers that impart the desired qualities specific to the various uses of PVC. The most widely used of these are the phthalate plasticizers, used to soften and make the products more flexible, and metallic stabilizers used to extend the life of the products. Thus, in considering the potential breast cancer risks associated with PVCs, it is important to include a consideration of potential exposures to these additives.

Potential human exposures associated with PVCs vary throughout the life cycle of PVC (Table 1). Vinyl chloride exposures are primarily a concern associated with PVC production. Heavy metals and phthalates are of concern during the use and disposal of PVC products, while dioxins and other persistent organic pollutants are an exposure of concern throughout the entire life cycle of PVC. The extent of human exposures to each one of these compounds is described in more detail on the following pages. In addition to these compounds, there are a myriad of other chlorinated hydrocarbons released as by-products during PVC production and combustion, including hexachlorobenzene, chlorinated phenols, PCBs, hexachloroethane, hexachlorobutadiene, and carbon tetrachloride.[3] With the exception of PCBs, the relationship of these compounds to breast cancer risk has not been widely investigated. For a summary of the breast cancer evidence for PCBs, please see Section I, Chapter B.2, Persistent Organic Pollutants.

**Table 1. Potential Human Exposures to Hazardous Substances from the Production, Use and Disposal of PVCs.**

| **Compounds of Concern** | **Source of Exposure** | **Likely Extent of Human Exposures** |
|---|---|---|
| **From Production:** | | |
| Vinyl Chloride | • Environmental contamination from facilities that produce PVC and its feedstocks | • Minimal, except in small areas in close proximity to these facilities, where exposures could be quite high |
| | • Workers involved in PVC manufacturing | • Minimal due to industrial hygiene efforts to reduce exposures & the relatively small number of women likely to be employed in this industry |
| Mercury | • Used and released in some processes to make elemental chlorine | • May be high in some small areas/populations.<br>• Not likely to be widespread |
| Dioxins & Other Persistent Organic Pollutants | • Manufacturing by-products released into environment by facilities that produce PVC and its feedstocks; released into environment directly or via disposal of wastes. | • Universal due to these compounds' ability to persist and bioaccumulate |
| **From Use:** | | |

| | | |
|---|---|---|
| Phthalates | • Leach out of products during normal use | • May be fairly extensive; biomonitoring data of phthalates indicate widespread exposures but all sources have not been elucidated |
| Heavy Metals | • Leach out of consumer and building products during normal use | • Not known |
| Dioxins | • Produced during accidental building and vehicle fires | • Universal due to these compounds' ability to persist and bioaccumulate |
| **From Disposal:** | | |
| Phthalates | • Environmental contamination from landfill leachates | • Not known; biomonitoring data of phthalates indicate widespread exposures but not all sources have been elucidated |
| Heavy Metals | • Environmental contamination from landfill leachates, incinerator air emissions and ash | • Not known |
| Dioxins | • Environmental contamination from incinerator air emissions and ash | • Universal due to these compounds' ability to persist and bioaccumulate |

### *Vinyl Chloride*

Vinyl chloride was previously used as a refrigerant, an extraction solvent, and in aerosol propellants, including hairsprays, but these uses were banned in 1974.[4] Today, vinyl chloride is released into the environment primarily through effluents and emissions from vinyl chloride and PVC manufacturers.[5] Due to its high volatility, vinyl chloride does not appear to bioaccumulate in terrestrial or aquatic food chains.[6] Although vinyl chloride has been detected in air, water, soil, and food, levels are generally very low. The exceptions are areas in close proximity to hazardous waste or PVC manufacturing sites, where levels can be orders of magnitude higher than general ambient levels and have been found to exceed health-based standards.[5-7] Vinyl chloride has been detected at nearly 40 percent of the hazardous waste sites on the EPA's National Priorities List[5] and at 24 out of 251 California landfills tested in the 1990s.[6]

Workers involved in PVC manufacturing are primarily exposed to vinyl chloride through inhalation, but some dermal exposure may also occur.[5] The National Occupational Exposure Survey conducted by NIOSH in the early 1980s estimated that approximately 28,000 women were employed at manufacturing facilities where potential vinyl chloride exposures were likely.[8] These data probably do not adequately reflect exposures in today's workforce, but more recent occupational survey data on potential PVC exposures do not exist. Due to improvements in industrial hygiene efforts over the last 30 years, however, workers involved in PVC manufacturing today likely experience much lower levels of exposures than previous generations.[3]

Vinyl chloride is a Class A carcinogen because of its known effects on the liver, with other reported toxicities of the nervous system.[9] As is true for many environmental contaminants, the effect of this component of PVC on the development of mammary tissue or breast cancer risk is unknown. However, the fact that this compound can cause irreversible damage to the neonate deserves further attention to PVC's possible effects on reproductive tissues such as the breast.

### *Mercury*

There are currently three different processes used to extract the chlorine gas needed to produce PVC. The mercury process, the oldest and most energy-intensive, can result in substantial releases of mercury into the environment.[3] One estimate puts the annual release of mercury into the atmosphere from the production of PVC in the U.S. in the range of six to 26 tons.[7] The vast majority of mercury's effects on the brain/central nervous system are thought to derive from developmental exposures. The effects that it may have on the endocrine system are not known, but there is some evidence that mercury exposures are related to premature pregnancy loss. Mercury is discussed further in Section I, Chapter B.8, Metals. Fortunately, production of chlorine gas via the mercury process is being phased out.[3]

### *Dioxins*

Dioxins are associated with every part of the PVC life cycle. During production of feedstocks for PVC, they are produced and released directly to the environment or indirectly via hazardous wastes, which are disposed of in incinerators or landfills. Dioxins are also produced as by-products of incineration of other chemicals in the wastes from PVC production.[3] During use, dioxins are released into the air from the estimated one million annual accidental building and vehicle fires often laden with PVC-containing materials.[1] During disposal, dioxins are released into the air through incineration. With an estimated 500-600 million pounds of PVC burned in municipal incinerators each year,[1] this is a significant source of dioxin pollution. While there are many other sources of dioxins, it has been suggested that when the entire life cycle of the product is considered, PVC may be the largest single source of dioxin formation in this country.[3]

Dioxins are highly toxic, persistent, widely-dispersed and they bioaccumulate, making them of great concern to human health. Dioxin is a well-documented mammary developmental toxicant, having significant effects on mammary gland development and breast cancer risk in both animal models and in humans.[10] A more comprehensive discussion of the extent of human dioxin exposures and how they may relate to breast cancer appears in Section I, Chapter B.1, Air Pollutants, Fuels and Additives and in Section I, Chapter B.2, Persistent Organic Pollutants.

### *Phthalates*

With global production of at least three million metric tons annually,[11, 12] phthalates are a family of compounds with widespread and diverse use. By far their greatest use, however, is as a plasticizer to soften and impart flexibility to products made of PVC. Approximately 90 percent of phthalates produced are used in the PVC industry.[3] In the U.S., where 75 percent of PVC is used in building materials, phthalates are used to soften PVC products such as cabling, vinyl flooring, roofing membranes, and wall coverings.[3] Approximately 5.4 million tons of phthalates are used annually for this purpose, with an estimated 83 million tons of phthalates contained in the reservoir of building materials in existing structures worldwide.[3]

While there are several forms of phthalates in commercial use today, di-(2-ethylhexyl) phthalate (DEHP) is the most heavily-used phthalate, as it is the primary plasticizer of PVC.[13, 14] In addition to DEHP, di-isononyl phthalate (DiNP), benzyl-butyl phthalate (BBP) and Di-isodecyl phthalate (DiDP) are also used in PVC, although to a much lesser extent. Soft PVC can consist of up to 40 percent DEHP by weight.[15] Some products commonly made of soft PVC that contain phthalates include breast pumps and other medical devices (such as plastic tubing, syringes, and blood bags), toys, food storage and packaging materials, furniture, pool liners, home accessories (such as shower curtains, window blinds, and tablecloths), children's backpacks, and auto parts and interiors.

Because phthalates are not bound to the PVC polymers in which they are embedded, they readily migrate, or leach from the product into the surrounding media, including air, water, saliva, blood, IV solutions, and nutritional formulas. It has been reported that up to 50 percent of the phthalate content of a product can be released over the product's lifetime, depending on the circumstances of use.[14] While the release process is still not fully characterized, it does appear that phthalates can leach out of building products during normal use. Indoor air levels of phthalates are five to 20 times higher than ambient levels in outdoor air.[3]

In the U.S., environmental contamination with phthalates is well documented.[13, 14] PVC disposal is the largest source of phthalates in the solid waste stream.[1] Soil and water contamination tend to be greatest in areas of industrial use and waste disposal,[16] but widespread contamination has been documented even in areas as remote as Antarctica and in deep-sea jellyfish found at depths of more than 3,000 feet in the Atlantic Ocean.[14]

Potential pathways of human phthalate exposure include ingestion, inhalation, intravenous transfer, and skin absorption through either direct contact with consumer products or through general contamination of the ambient indoor and outdoor environment.[16-19] While for the general population, ingestion of contaminated food has been considered the major route of exposure, this conjecture is based on relatively little and outdated data.[17] A recent study of pregnant women reported correlations between personal air samples and urinary biomarkers of phthalate exposures, suggesting that inhalation may also be a route of substantial exposure for the general population.[13] Dermal absorption, especially of phthalates common in personal care products, may also provide a significant pathway of exposure, especially among women of reproductive age, who appear to have some of the highest urinary monobutyl phthalate levels in the U.S.[14, 16, 20]

While there is clear evidence of widespread human exposures to phthalates, a number of key data gaps remain with respect to fully elucidating the sources and pathways of human exposures. Recent data on phthalate exposures from dietary intake are lacking. Exposures from pharmaceuticals, herbal preparations, and nutritional supplements, some of which are intended for use during pregnancy, may be significant and are largely unexplored.[17] The degree to which inhalation and ingestion of ambient sources of phthalates in dust and air contribute to overall exposure also remains largely unknown. Among susceptible subpopulations such as premature infants, medical sources of phthalate exposures may be significant and need to be more fully characterized.

Regardless of the source, it is well documented that people in the general population are heavily exposed to phthalates. Virtually all people tested (85–100 percent depending on the study and the metabolites measured) have detectable markers of phthalate exposure in their urine or blood.[15, 16, 19, 20] Given that phthalates are rapidly metabolized and excreted,[15, 18, 19] the nearly universal detection of phthalate exposure is evidence for chronic, continuous exposures. Of particular concern with respect to breast cancer risk is the fact that women of reproductive age and young children appear to have some of the highest urine levels.[15, 16, 20]

While phthalate exposures appear to be nearly ubiquitous, body burden levels vary widely between people, and within people vary considerably by the predominant type of phthalate metabolite detected.[16, 20] It is unclear whether such variations are due to variations in exposure, individual differences in metabolic profiles, or differing toxicokinetics of the different types of phthalates. Many of the studies prior to 2004 measured diester and nonoxidative monoester metabolites, which are readily available in the air and may be detected due to contamination. Recent advances in our understanding of the differing toxicokinetics between the four major phthalates and the recent development of biomonitoring methods to measure secondary oxidized metabolites of the major phthalates,[15, 21] which have longer half-lives and are immune to the external contamination common in most earlier studies, provide a promising avenue for pursuing these issues. Elucidating the primary sources and routes of exposures to phthalates is a clear research priority.

### *Heavy Metals*

The other primary additives of concern are heavy metals, which are used as stabilizers in hard PVC materials to extend the life of the products.[3] While used in levels much lower than phthalates, heavy metals—including lead, cadmium, organotins, zinc, and magnesium—are commonly used as stabilizers in PVC building materials. The degree to which these metals leach out of the building materials and contaminate the indoor environment is largely unknown, but significant releases of lead have been documented from PVC window blinds and into water carried by PVC piping.[3] Following a 1996 Greenpeace study on serum lead levels in children, there was a global movement to remove lead from vinyl blinds.[22] During disposal of PVCs, the heavy metals persist in incinerator ash and landfills. The degree to which PVC waste contributes to overall environmental contamination and human exposures to these metals has not been evaluated, although it has been suggested that PVC serves as the major source of lead and cadmium in the municipal waste stream.[23]

## Critical Review of the Literature

Summarizing the evidence of an association between breast cancer risk and PVC exposures is complicated, given the numerous potential hazardous exposures originating from PVC, many of which are not unique to PVC. Also, there has been little research to determine the effects of these several compounds on endocrine disruption or developmental effects on reproductive tissues. Dioxin, a compound associated with PVC throughout its entire life cycle, is a known carcinogen and endocrine disruptor. A review of the potential breast cancer risks associated with dioxins and other persistent organic pollutants is contained in Section I, Chapter B.2 and will not be discussed here.

During the use of PVC products, the primary compounds of concern are the phthalates and heavy metals that can leach out of the polymer into the environment and into food and other products wrapped in PVC packaging. Phthalates are of particular concern for breast cancer, because of their well-documented endocrine-disrupting effects in animals and potential carcinogenic effects. A review of the literature on the health effects of phthalates is included in Section I, Chapter C, Compounds in Personal Care Products. Although a few metals are known to have endocrine disrupting effects,[24] virtually nothing is known about a potential relationship between metals and breast cancer; a review of the limited literature on this topic is presented in Section I, Chapter B.8.

The toxicity of vinyl chloride, released in the production of PVC, is well-characterized.[2, 5, 6, 25] In 1987, the International Agency for Research on Cancer (IARC) classified it as a Group 1 (known) human carcinogen,[25] based on a substantial body of animal and human studies. In animal studies, vinyl chloride has been shown to be mutagenic, carcinogenic, and have adverse reproductive and developmental effects.[5, 25, 26] Similarly, carcinogenic, reproductive, and developmental effects have been documented in epidemiologic studies of workers occupationally exposed to vinyl chloride.[2, 18, 25, 26] In animals, vinyl chloride exposures have been associated with an excess number of cancers, including those of the mammary gland.[6, 25] In humans, the evidence for carcinogenicity is strongest and most consistent for liver angiosarcoma, with more limited evidence for brain cancer, lung cancer, and lymphoma.[6] Due to the small numbers of women working in occupational settings with PVC exposures, it has not been possible to fully assess the risk of breast cancer associated with vinyl chloride exposures in women.

## Conclusions/Future Directions

In summary, the use of PVCs in building materials and consumer products grew dramatically in the latter half of the last century. While these materials are inexpensive and have some useful and convenient qualities, we are now discovering many of the hazards associated with these products. PVC production, use, and disposal result in myriad potentially harmful exposures to humans. PVC has contributed substantially to the contamination of our indoor and outdoor environments with a number of compounds that could be implicated in breast cancer incidence due to their carcinogenic and endocrine-disrupting potential. Vinyl chloride itself, although a known human carcinogen, is probably the least worrisome, because environmental contamination levels are generally low and direct exposures from use of PVC products are unlikely. More problematic are the by-products formed during PVC production and disposal and the migration of additives from the PVC during use and disposal. Phthalates, dioxins, and heavy metals top the list of priority compounds associated with PVC plastic. Please consult Section I, Chapters C, B.1, B.2, and B.8, respectively for a review of the evidence for the role of these compounds in breast cancer etiology.

Elucidation of the portion of the human body burden levels of these compounds that is attributable to the PVC life cycle is a necessary step towards reducing such exposures. Research aimed at investigating the risk of breast cancer associated with PVC plastics focusing on these individual compounds—considering the toxicokinetic properties of each, the probable timing of exposures in relationship to critical periods of breast and brain development, and the latency of breast cancer—could be fruitful. Alternatively, given the complex mix of potential endocrine disruptors and carcinogens produced in the PVC life cycle, examining potential breast cancer risks in communities living near industrial sources of these exposures may allow for a more comprehensive evaluation of breast cancer risks associated with all exposures originating from PVCs. Given the nearly universal exposure to some of these compounds among people living in the U.S., epidemiologic studies may be particularly difficult to conduct and in vitro and in vivo studies may prove more fruitful.

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