CANTOX

# INTERPRETIVE EVALUATION
# OF THE
# POTENTIAL HUMAN HEALTH AND ENVIRONMENTAL EFFECTS
# OF VINYL CHLORIDE (VCM) AND POLYVINYL CHLORIDE (PVC)

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## i) PREFACE

Recently, certain environmental agencies (*e.g.*, IJC, 1992) and a number of environmental groups (Verdict of the NorthSea Tribunal, May 1989; GreenPeace, 1991a,b) have expressed the view that the banning of uses of chlorinated chemicals is the only way to ensure future "protection" of the environment. Such extreme reactions are not based on sound scientific information and arguments, and do not consider the impact of lost benefits to society from the removal of a large number of chlorinated chemicals, many of which do not have known or proven replacements.

Sound scientific information has been the driving force behind the identification of and solution to historical concerns regarding the health effects of chemicals in the workplace and environment. Similarly, future actions governing the production and use of chemicals by society should also be based on the best possible scientific evaluation of their consequences with respect to maintaining environmental quality and serving the benefits of society. Such an evaluation requires an understanding of i) the potential for chlorinated organic chemicals to produce adverse effects on the ecosystem, including humans, ii) the contributions of both anthropogenic (*i.e.*, related to human activities) and natural (independent of human activities) sources of chlorinated chemicals to total environmental loading rates, iii) the environmental fate characteristics of the chemicals that determine the distribution and losses from the environment, and iv) the determination of environmental loading rates from anthropogenic activities that could be sustained without the occurrence of adverse effects on the ecosystem.

In an effort to assist continued progress in the application of sound scientific principles to the environmental assessment of chlorinated chemicals, the Chlorine Institute commissioned a detailed review and interpretive evaluation of the scientific information available on the historical, current and future status of chlorinated chemicals in the environment. The objective of this interpretive review was to provide an overview perspective on the potential environmental impacts of chlorine and chlorinated organic chemicals for seven categories of products that involve specific chlorinated organic chemicals. The product categories identified included:

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chlorine, polychlorinated biphenyls, vinyl chloride/polyvinyl chloride, chlorinated organic solvents, chlorine disinfection of drinking water/waste water, incineration of chlorinated materials, and pulp and paper bleaching and the use of chlorine in the development of pesticides. For the first seven product categories an interpretive review of the human health and environmental impact of representative chlorinated chemicals of potential concern has been prepared and is available from the Chlorine Institute. For the eighth product category, pesticides, a slightly different approach was adopted which addressed the issue of risk/benefit analysis as applied to the use of chlorine in the development of pesticides.

The protocol followed in preparation of the seven product category documents has been outlined below.

- A preliminary list of chlorinated chemicals of the greatest concern and of the most relevance to each of the product categories was developed based on published quantitative analytical and hazard data. A total of 93 chlorinated chemicals were identified and were grouped by chemical class (*i.e.*, chlorinated inorganics, chlorinated alkanes, chlorinated alkenes) (see Table 1-1).

- It was beyond the scope and intention of this project to conduct a detailed assessment of the environmental and health effects of all 93 chlorinated chemicals. The pertinent mammalian toxicity data for all 93 were reviewed and the chemicals were further classified according to their mechanisms of action (*i.e.*, genotoxic carcinogen, non-genotoxic carcinogen, mutagen, systemic toxicity) based on the most critical toxicological endpoint for which a positive effect was observed. This hazard information has been summarized in Appendix I. For some chemicals (*i.e.*, bromodichloroethane, pentachloropropene, pentachlorobutadiene, hexachlorohexatriene, *etc.*,),no toxicity data was identified in the literature. For these chemicals it is also unlikely that there is much environmental concentration or emissions data, thus precluding any form of human health or environmental assessment.



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- Based on the hazard classification, two or three representative chemicals, for which there were considerable hazard data in the scientific literature, from each chemical group, were selected for detailed human health assessment with respect to each product category. This approach tended to focus on the most potent compounds (*i.e.*, carcinogens); however, the authors recognize that not all chlorinated chemicals are carcinogenic and therefore to maintain this perspective, a number of those priority compounds acting via mechanisms not involving carcinogenesis have also been included for detailed discussion (*i.e.*, 2,4-dichlorophenol a systemic toxicant *vs* 2,4,6-trichlorophenol, a liver carcinogen). The human health impact of approximately 42 representative priority chlorinated chemicals/ chemical groups from the original 93 chemicals of concern, relevant to each product category, were selected for detailed assessment (see Table 1-2).

- Due to the wide range in species sensitivity to specific chemicals within a chemical group and the influence of abiotic and biotic environmental factors on toxicity, environmental effects (aquatic, terrestrial and other) were dealt with on a chemical group basis. This involved an interpretive review of the relevant toxicity data for all of the chlorinated chemicals per chemical group included in the preliminary list (see Table 1-1).

- A discussion of both natural and anthropogenic sources contributing to historical, present and future environmental concentrations, the physical-chemical properties governing their environmental fate and biological behaviour, and the environmental fate of the representative chlorinated chemicals has also been presented.

- To provide a balanced perspective of the potential for human and wildlife exposure to these compounds associated with each product category, historical and present ambient environmental concentrations or emission levels were identified for the representative chemicals on a product category basis. From a comparison of the identified environmental concentration data and the critical hazard data (*i.e.*, exposure limit), the likelihood of adverse human health or environmental effects associated with each product category was identified. Qualitative estimates of future environmental loading rates based

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on best-available technologies, industry standards, and government emission policies, were used to draw predictions regarding future environmental concentrations of chlorinated chemicals and their potential impact on human health and the environment.

- Furthermore, to maintain a balanced perspective of the impact of chlorinated chemicals on human and environmental health, the health benefits to society associated with the use of chlorine use (*i.e.*, chlorine disinfection) as well as alternatives were examined and considered in the final conclusions regarding the human health and environmental impact of each product category.

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Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | Chemical | PRODUCT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| **Chlorinated Inorganics** | | | | | | | | |
| | HCl | | | | ● | | ● | |
| | Chlorate | ● | | | | | | |
| | Chlorite | ● | | | | | | |
| **Chlorinated Alkanes** | | | | | | | | |
| | Dichloromethane | ● | ● | ● | ● | | | |
| | Chloroform | ● | ● | ● | ● | ● | | |
| | Carbon Tetrachloride | | ● | ● | ● | | | |
| | Chloromethane | | | ● | ● | | | |
| | Bromodichloromethane | ● | ● | ● | | | | |
| | Chlorodibromomethane | ● | ● | ● | | | | |
| | Trichlorodihydroxyethane | ● | ● | | | | | |
| | Chloroethane | ● | ● | ● | | | | |
| | Dichloroethane | ● | ● | | | | | |
| | 1,1-Dichloroethane | | | ● | ● | | | |
| | 1,2-Dichloroethane | | | ● | ● | | | |
| | Trichloroethane | | ● | | | | | |
| | 1,1,1-Trichloroethane | | | ● | | | | |
| | 1,1,2-Trichloroethane | | | ● | ● | | | |
| | 1,1,2,2-Tetrachloroe hane | | | ● | ● | | | |
| | Bromodichloroethane | | | ● | | | | |
| | Hexachloroethane | | | ● | | | | |
| | Pentachloroethane | | | | | | | |
| | Dibromochloropropane | ● | | | | | | |

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Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | Chemical | PRODUCT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| | 1,2-Dichloropropane | | ● | ● | | | | |
| | 1,2-Dibromo-3-chloro-propane | | | ● | | | | |
| **Chlorinated Alkenes** | | | | | | | | |
| | Dichloroethylene | | ● | | | | | |
| | 1,1-Dichloroethylene | | | ● | ● | | | |
| | 1,2-Dichloroethylene (Cis) | | | ● | | | | |
| | 1-2,Dichloroethylene (Trans) | | | ● | | | | |
| | Trichloroethylene | | ● | ● | ● | | | |
| | Tetrachloroethylene | | ● | ● | ● | | | |
| | 1,3-Dichloropropene (Cis) | | | ● | | | | |
| | Pentachloropropene | | | | | ● | | |
| | Pentachlorobutadiene | | | | | ● | | |
| | Hexachlorobutadiene | | | ● | | ● | | |
| | Hexachlorocyclopentadiene | | | ● | | | | |
| | Hexachlorohexatriene | | | | | ● | | |
| | Vinyl Chloride | | | ● | ● | | ● (monomer) | |
| **PVC** | | | | | | | | |
| | Polyvinyl Chloride | | | | | | ● | |
| **Chlorinated Acids** | | | | | | | | |
| | Monochloroacetic Acid | ● | ● | | | | | |
| | Trichloroacetic Acid | ● | ● | | | | | |

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## Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | PRODUCT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|
| | Chemical | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| **Chlorinated Ketones** | | | | | | | | |
| | Trichloroacetone | | | | | ● | | |
| | Tetrachloroacetone | | | | | ● | | |
| | 1,1-Dichloropropanone | ● | ● | | | | | |
| | 1,1,1-Trichloropropanone | ● | ● | | | | | |
| | *Dichlorocyclopentene-1,2-dione* (various isomers) | | | | | ● | | |
| | 3-Chloro-4-[dichloromethyl]-5-hydroxy-2(5H)-furanone | ● | ● | | | ● | | |
| **Chlorinated Benzenes** | | | | | | | | |
| | Chlorobenzene | | ● | ● | | | | |
| | Dichlorobenzene | | ● | | | | | |
| | 1,2-Dichlorobenzene | | | ● | ● | | | |
| | 1,3-Dichlorobenzene | | | ● | | | | |
| | 1,4-Dichlorobenzene | | | ● | ● | | | |
| | Trichlorobenzene | | ● | | | | | |
| | 1,2,4-Trichlorobenzene | | | ● | ● | | | |
| | Pentachlorobenzene | | | ● | | | | |
| | Hexachlorobenzene | | | ● | ● | | | |
| | Dichlorotoluene | | ● | | | | | |
| | 2-Chloroethylbenzene | | ● | | | | | |

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Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | PRODUCT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|
| Chemical | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| **Chlorinated Phenols, Catechols, Guaiacols** | | | | | | | |
| 2-Chlorophenol | ● | ● | ● | | | | |
| 2,4-Dichlorophenol | ● | ● | ● | ● | ● | | |
| 2,6-Dichlorophenol | | | | | ● | | |
| 2,4,5-Trichlorophenol | | | ● | ● | | | |
| 2,4,6-Trichlorophenol | ● | ● | ● | | ● | | |
| 2,3,4,5-Tetrachlorophenol | | | ● | | ● | | |
| 2,3,4,6-Tetrachlorophenol | | ● | ● | | ● | | |
| Pentachlorophenol | | ● | ● | ● | ● | | |
| Tetrachlorophenol | | | | | ● | | |
| Dichlorocatechol | | | | | ● | | |
| Tetrachlorocatechol | | | | | ● | | |
| Trichlorocatechol | | | | | ● | | |
| 3,4,5-Trichlorocatechol | | | | | ● | | |
| 4,5-Dichloroguaiacol | | | | | ● | | |
| Dichloroguaiacol (other isomers) | | | | | ● | | |
| Tetrachloroguaiacol | | | | | ● | | |
| Trichloroguaiacols | | | | | ● | | |
| Trichlorodihydroconiferyl Alcohol | | | | | ● | | |
| Chlorovanillin | | | | | ● | | |
| Trichlorovanillylalcohol | | | | | ● | | |
| Trichloroacetosyringone | | | | | ● | | |
| Dichloro-3,4-dihydroxy-propiophenone | | | | | | | |

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Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | Chemical | PRODUCT CATEGORY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| **Chlorinated Nitrogenous Compounds** | | | | | | | | |
| | Dichloroacetonitrile | ● | ● | | | | | |
| | Nitrochloroform | ● | ● | | | | | |
| **Chlorinated Aldehydes** | | | | | | | | |
| | Trichloroethanal | ● | ● | | | | | |
| | Chloropropenal | | | | | ● | | |
| | Chloromethoxydibenzaldehyde | | | | | ● | | |
| | Chloralhydrate | ● | | | | | | |
| **Chlorinated PCDD, PCDF** | | | | | | | | |
| | 2,3,7,8-$T_4$CDD | | ● | | ● | ● | ● | ● |
| | 1,2,3,7,8-$P_5$CDD | | ● | | ● | ● | ● | ● |
| | 1,2,3,4,7,8-$H_6$CDD | | ● | | ● | ● | ● | ● |
| | 1,2,3,4,8,9-$H_6$CDD | | ● | | ● | ● | ● | ● |
| | 1,2,3,6,7,8-$H_6$CDD | | ● | | ● | ● | ● | ● |
| | 1,2,3,4,6,7,8-$H_7$CDD | | ● | | ● | ● | ● | ● |
| | $O_8$CDD | | ● | | ● | ● | ● | ● |
| | 2,3,7,8-$T_4$CDF | | ● | | ● | ● | ● | ● |
| | 2,3,4,7,8-$P_5$CDF | | ● | | ● | ● | ● | ● |
| | 1,2,3,7,8-$P_5$CDF | | ● | | ● | ● | ● | ● |
| | 1,2,3,4,7,8-$H_6$CDF | | ● | | ● | ● | ● | ● |
| | 1,2,3,7,8,9-$H_6$CDF | | ● | | ● | ● | ● | ● |
| | 1,2,3,6,7,8-$H_6$CDF | | ● | | ● | ● | ● | ● |
| | 2,3,4,6,7,8-$H_6$CDF | | ● | | ● | ● | | ● |
| | 1,2,3,4,6,7,8-$H_7$CDF | | ● | | ● | | ● | ● |

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## Table 1-1 Preliminary List of Chemicals of Concern Per Product Category

| CHEMICAL GROUP | PRODUCT CATEGORY | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Chemical | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCDD/ PCDF/ PCB |
| | 1,2,3,4,7,8,9-$H_7CDF$ | | ● | | ● | ● | ● | |
| | $O_8CDF$ | | ● | | ● | ● | ● | ● |
| **PCBs** | | | | | | | | |
| | PCBs | | | | | | | |
| **Chlorinated Fatty Acids** | Dichlorostearic Acid | | | | | ● | | |
| **Chlorinated Resin Acids** | Chlorodehydroabietic acid | | | | | ● | | |
| | Dichlorodehydroabietic acid | | | | | ● | | |
| **Chlorinated Amines** | 3,3'-Dichlorobenzidine | | | ● | | | | |
| | 4,4'-methylene-bis-(2-chloroaniline) | | | ● | | | | |
| **Chlorinated Ethers** | Bis(2-chloroethyl)ether | | | ● | | | | |
| **Chlorinated Sulfones and Thiophenes** | | | | | | | | |
| | Chloro-2-thiophenic Acid | | | | | ● | | |
| | Chlorothiophenedicarboxylic Acid | | | | | ● | | |
| | 1,1-Dichlorodimethylsulfone | | | | | ● | | |
| **TOTAL NO. CHEMICALS** | 93 | 22 | 49 | 44 | 37 | 54 | 20 | 18 |

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Table 1-2 Representative Priority Chemicals Assessed in Stand-Alone Documents

| CHEMICAL GROUP | Chemical | PRODUCT CATEGORY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Chlorine | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCB |
| **Chlorinated Inorganics** | | | | | | | | | |
| | $Cl_2$ | ■ | | | | | | | |
| | $ClO_2$ | | ■ | | | | | | |
| | HCl | | | | | ■ | | ■ | |
| | Chlorate | | ■ | | | | | | |
| | Chlorite | | ■ | | | | | | |
| **Chlorinated Alkanes[a]** | | | | | | | | | |
| | Chloroform | | ■ | ■ | ■ | ■ | ■ | | |
| | Carbon Tetrachloride | | | ■ | ■ | ■ | | | |
| | Dichloromethane | | | | | | | | |
| | 1,1-Dichloroethane | | ■ | ■ | ■ | ■ | | | |
| | 1,2-Dichloroethane | | ■ | ■ | ■ | ■ | | | |
| | dichloromethane | ■ | ■ | ■ | ■ | | | | |
| | 1,1,1-Trichloroethane | | | | ■ | | | | |
| **Chlorinated Alkenes[a]** | | | | | | | | | |
| | Trichloroethylene | | | ■ | ■ | ■ | | | |
| | 1,1-Dichloroethylene | | | | ■ | ■ | | | |
| | Tetrachloroethylene | | | | ■ | | | | |
| | Vinyl Chloride/PVC | | | | | ■ | | ■ | |
| | Hexachlorobutadiene | | | | | | ■ | | |
| **Chlorinated Acids[a]** | | | | | | | | | |
| | Trichloroacetic acid | | ■ | ■ | | | | | |

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Table 1-2 Representative Priority Chemicals Assessed in Stand-Alone Documents

| CHEMICAL GROUP | Chemical | PRODUCT CATEGORY | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Chlorine* | *Drinking Water* | *Waste Water* | *Solvents* | *Incineration* | *Pulp & Paper* | *PVC/VCM* | *PCB* |
| **Chlorinated Ketones[a]** | | | | | | | | | |
| | Trichloroacetone | | | | | | ■ | | |
| | Tetrachloroacetone | | | | | | ■ | | |
| | 1,1-Dichloropropanone | | ■ | ■ | | | | | |
| | 1,1,1-Trichloropropanone | | ■ | ■ | | | | | |
| | Dichlorocyclopentene-1,2-dione | | | | | | ■ | | |
| | 3-Chloro-4-[dichloromethyl]-5-hydroxy-2(5H)-furanone | | ■ | ■ | | | ■ | | |
| **Chlorinated Benzenes[a]** | | | | | | | | | |
| | Hexachlorobenzene | | | | ■ | ■ | | | |
| | Dichlorobenzene | | | ■ | ■ | ■ | | | |
| | 1,4-Dichlorobenzene | | | | | | | | |
| | 1,4-dichlorobenzene | | | ■ | ■ | | | | |
| | 1,2,4-Trichlorobenzene | | | ■ | ■ | ■ | | | |
| **Chlorinated Phenols, Catechols, Guaiacols[a]** | | | | | | | | | |
| | Pentachlorophenol | | | ■ | ■ | ■ | ■ | | |
| | 2,4,6-Trichlorophenol | | ■ | ■ | ■ | | ■ | | |
| | 2,4-Dichlorophenol | | ■ | ■ | ■ | ■ | ■ | | |
| | Chlorocatechols[b] | | | | | | ■ | | |
| | Chloroguaiacols[b] | | | | | | ■ | | |
| **Chlorinated Nitrogenous Compounds[a]** | | | | | | | | | |
| | Dichloroacetonitrile | | ■ | ■ | | | | | |
| | Nitrochloroform | | ■ | ■ | | | | | |

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Table 1-2 Representative Priority Chemicals Assessed in Stand-Alone Documents

| CHEMICAL GROUP | PRODUCT CATEGORY | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Chemical | Chlorine | Drinking Water | Waste Water | Solvents | Incineration | Pulp & Paper | PVC/VCM | PCB |
| **Chlorinated Aldehydes**[a] | | | | | | | | | |
| | Trichloroethanal | | ■ | ■ | | | | | |
| | Chloralhydrate | | ■ | ■ | | | | | |
| **PCDD/PCDF**[b,c] | | | | ■ | | ■ | ■ | ■ | |
| **PCBs**[a] | | | | | | | | | ■ |
| **Chlorinated Fatty Acids**[a] | | | | | | | | | |
| | Dichlorostearic acid | | | | | | ■ | | |
| **Chlorinated Resin Acids**[a] | | | | | | | | | |
| | Chlorodehydroabietic acid | | | | | | ■ | | |
| | Dichlorodehydroabietic acid | | | | | | ■ | | |
| **Chlorinated Sulfones and Thiophenes** | | | | | | | | | |
| | 1,1-Dichlorodimethylsulfone | | | | | | ■ | | |

[a] Environmental effects to be discussed for the group of chlorinated chemicals in the preliminary list (see Table 1-1).
[b] Human and mammalian toxicity data to be discussed for the chemical group.
[c] 2,3,7,8- substituted dioxin and furan isomers.

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## ii) EXECUTIVE SUMMARY

This document focuses on the interpretation of the potential adverse effects of vinyl chloride (VCM) and polyvinyl chloride (PVC) on human health and the environment. Potential secondary effects related to pyrolysis products from VCM and PVC are addressed in the Chlorine Institute document on The Potential Adverse Effects on Human Health and the Environment from the Incineration of Chlorinated Chemicals.

### Physical/Chemical Properties and Environmental Fate

Polyvinyl chloride is a polymer of VCM, and is highly stable, solid material that is relatively inert chemically, environmentally and biologically. PVC does not depolymerize or degrade under natural environmental conditions. One of the historical concerns of the presence of non-polymerized VCM in PVC products have been largely addressed by modified manufacturing and production techniques. Under good manufacturing procedures, the residual concentration of VCM in modern PVC products is below analytical detection limits.

Vinyl chloride monomer (VCM) (also referred to as chloroethene, chloroethylene, monochloroethylene) is a molecule of two carbon atoms joined by an unsaturated bond and containing three hydrogen atoms and one chlorine atom. VCM has a high vapor pressure and is slightly soluble in water, consequently volatilization into the atmosphere is the major transport process in the environment. VCM is highly reactive, and readily polymerizes in the presence of oxygen, sunlight or heat to form PVC. Vinyl chloride monomer rapidly degrades in the troposphere via photochemical oxidation. As indicated by the low log $K_{ow}$ of 1.38, vinyl chloride does not adsorb to organic carbon of soils/sediments or accumulate in biological tissues. Certain strains (*e.g.*, *Mycobacterium*) can utilizing vinyl chloride as a carbon and energy source under aerobic conditions. Mineralization of VCM to $CO_2$ can occur under both aerobic and anaerobic conditions.

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Hazard Potential of VCM

As with other chemicals, the potential for adverse effects of VCM depends on the concentrations that occur in target tissues within the body where adverse effects develop. These tissue concentrations depend on the bioavailability of the chemical from various environmental media through different routes of exposure.

At room temperature, vinyl chloride is a gas. As such, exposure via inhalation is the most significant route of exposure in the environment and occupational setting. Vinyl chloride is rapidly absorbed by the lung and readily metabolized to the reactive epoxide intermediate chloroethylene oxide, which can rearrange spontaneously to chloroacetaldehyde which is further metabolized. VCM does not accumulate in tissues.

Vinyl chloride is not a potent acute toxic agent, and acute lethality is observed at air concentrations as great as 113,000 to 230,000 ppm (294 to 595 g/m$^3$). At these high exposures VCM acts as a narcotic or anaesthetic agent. In addition, at high acute doses, tissue damage to lung, liver and kidneys has been observed. Following repeated sub-chronic exposures, the principle target organ for VCM is the liver.

VCM is not teratogenic in a number of mammalian laboratory studies. Evidence of carcinogenicity in animals is conclusive based positive data from numerous mammalian laboratory studies. Vinyl chloride administered orally or by inhalation to mice, rats and hamsters produced tumours in the mammary gland, lung, Zymbal gland, and skin and angiosarcomas of the liver. The major conclusions supported by the available toxicity data are: vinyl chloride induced tumours in all species and strains of animals tested; it was found to be a multipotential carcinogen at extreme exposures (*i.e.*, tumours of different types were induced at different sites); angiosarcoma of the liver occurred in all species of animal tested, vinyl chloride was carcinogenic by inhalation and ingestion, and possibly by injection; obvious dose-response relationships were observed for both ingestion and inhalation experiments; treatment duration and schedule markedly affected the neoplastic response, as did the species strain, and sex of the animals tested; neonatal animals were highly responsive; vinyl chloride acted as a

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transplacental carcinogen; and it was carcinogenic at low exposure levels (*i.e.*, 50 ppm and lower).

Both IARC and the U.S. EPA have concluded that there is sufficient evidence for vinyl chloride carcinogenicity in humans based upon the epidemiological data collected from workers exposed to extreme concentrations between the 1940s and late 1960s. Vinyl chloride exposure has been associated with the development of angiosarcoma of the liver, a very rare tumour type in humans. There is some evidence of a general nonspecific carcinogenic effect, in addition to angiosarcomas, in humans.

The results of in vitro mutagenicity studies and observations of chromosomal aberrations in peripheral blood lymphocytes in occupational workers exposed to VCM indicate a DNA-reactive mechanism for mutagenicity/carcinogenicity. Vinyl chloride has also been shown to be activated, via P450, to a reactive epoxide intermediate, with increased hepatotoxicity following administration of P450 inducers such as phenobarbital, Aroclor 1254 (a PCB mixture), and hexachlorobenzene.

Sources and Environmental Concentrations

The majority of VCM is man-made. The major use of vinyl chloride is in the production of vinyl chloride homopolymer and copolymer resins. Vinyl chloride is also used to a lesser extent as a component in the synthesis of methyl chloroform and as a comonomer with vinylidene chloride to produce resins. A former use of vinyl chloride was as a propellant in aerosol cans and as a refrigerant. Polyvinyl chloride resins manufactured from VCM are used in the manufacture of a variety of industrial and commercial products ranging from building materials to household and medical items.

Undefined quantities of VCM can be produced from bio- and abiotic transformation of chlorinated solvents such as 1,1,1-trichloroethane and 1,1-dichloroethane. 1,1,1-trichloroethane and 1,1-dichloroethane both have a large number of anthropogenic and natural sources. The

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natural sources of these VCM precursors suggest that there may be sources of VCM independent of human activities, although such sources have not been equivocally identified to date.

The primary source of VCM in the environment is from emissions and effluents from vinyl chloride and polyvinyl chloride production and manufacturing facilities. Such releases rapidly volatilize into the atmosphere. Since 1979, VCM emissions from such production facilities have been regulated in both Canada and the United States. Prior to 1975, it was estimated that American PVC plants released 22.7 million kg of PVC and 110 million kg/year of VCM. Implementation of regulatory standards have substantially reduced total environmental releases of VCM and PVC, and currently the major sources are from accidental releases and spills.

The air concentrations of VCM are greatest near industrial facilities involved in its production and use in various manufacturing processes. Average air concentration of 44 $\mu g/m^3$ and 10 to 40 $\mu g/m^3$ were reported near production facilities for Houston, Texas, and in England in the late 1970s. Air concentrations near production facilities were generally below analytical detection limits (about 13 $\mu g/m^3$ or 5 ppb) by the mid 1980s. In the work environment, air concentrations of VCM have decreased over the years with the reduction of emissions through improved operating technologies. Workplace concentrations in the Netherlands decreased from approximately 1000 ppm in 1945-1955 to 5 ppm after 1975 (Barnes, 1980), and data from the late 1980s to the present indicate workplace air concentrations generally $<0.1$ ppm with occasional values near 1 ppm in specific production/handling areas. Since production and manufacturing facilities are major sources of VCM, decreases in workplace concentrations would be expected to coincide with decreases in environmental releases. This relationship is supported by the declining environmental concentrations of VCM reported near production and manufacturing facilities observed since the early 1980s.

Potential Significance of Environmental Concentrations of VCM

The available information on the physical/chemical properties, environmental fate characteristics and sources of VCM indicate that the major environmental concerns for VCM are exposures of production and manufacturing workers and possibly populations living near such facilities.

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There would be little opportunity for exposures, and therefore risks of adverse effects, to the general public, or aquatic and terrestrial wildlife from VCM at locations distant from production and manufacturing facilities. As outlined above, the air concentrations near such facilities were historically in the range of 10 - 40 ppb in the mid-1970s. Information from the mid-1980s indicated air concentrations near facilities were generally <5ppb, and based on current air concentrations in the work environment, the concentrations near facilities would be expected to be about 50-fold lower at present.

The characterization of the potential health risks that could potentially result from exposures to such air concentrations requires the comparison of resulting levels of exposure against a cancer potency estimate. The U.S. EPA has, over the years, proposed cancer potency slope values for VCM of 0.0174, 0.0295 and 2.3 based on lung and liver tumors, respectively, following inhalation exposure to up to 30,000 ppm VCM and oral exposure to 0-17 mg/kg body weight/day (5 days/week) in laboratory rats. These cancer potency slopes translate into RsD values of 0.575, 0.339 and 0.00435 $\mu$g/kg body weight/day at a lifetime risk of one per 100,000, a range of 132-fold.

Cancer potency factors estimated from epidemiological studies of workers exposed to VCM in the 1940s, 1950s and 1960s, range from 0.00024 to 0.000024 $(mg/kg\ body\ weight/day)^{-1}$. These estimates assume exposures to 100 to 1000 ppm VCM resulted in a mortality incidence due to liver cancer of 2 per 100. The cancer potency estimates from the epidemiological data would translate into RsD values of approximately 42 to 420 $\mu$g/kg body weight/day at a lifetime risk of one per 100,000. These exposure limits differ from those proposed by EPA by some 9500- to 95000-fold.

Such large differences in cancer potency estimates, using different data and approaches, will result in equivalent differences in the risk estimates, and therefore, the interpretation of the potential significance of the environmental concentrations of VCM near production/manufacturing facilities. Risk estimates based on the EPA values range from approximately 14 to 7800 per 100,000 for the mid-1970s air concentrations, and from 74 to 982 per 100,000 for the mid-1980s air concentrations of VCM. Risk estimates based on the



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epidemiological data range from 0.008 to 0.2 per 100,000 for the mid-1970s air concentrations, and from 0.001 to 0.01 for the mid-1980s air concentrations.

Based on a critical evaluation of the available epidemiological evidence available from workers exposed to VCM between the early 1940s and the 1960s, Doll (1988) concluded that potential risks from VCM to the "general public (if there is any at all) must be negligible". This conclusion is in agreement with the risk assessment summarized above using cancer potency estimates based on epidemiological data.

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# Chapter 1

# Introduction

# 1.0 INTRODUCTION

Polyvinyl chloride (PVC) is a rigid "plastic" polymer of vinyl chloride (VCM) and is widely used in the manufacture of a wide range of industrial and commercial products. PVC products are widely used as building materials, furnishings, plumbing materials, appliances and medical items. PVC is a polymer of vinyl chloride (VCM).

PVC is physically, chemically and biologically inert; however, VCM is a highly reactive chemical. Although short-term exposures to VCM, even at high ppm concentrations, are without apparent toxic effects, evidence of increased liver cancers in exposed workers raised concerns regarding potential human health effects associated with VCM exposures. This document presents an interpretive evaluation of potential effects of PVC and VCM through an assessment of i) potential exposures through an analysis of sources, environmental fate characteristics and concentrations in various environmental media through which exposures can occur, ii) an analysis of the potential hazards from PVC and VCM, and iii) the characterization of potential risks to various biological systems by the comparisons between their potential levels of exposure from environmental media and the hazard potential associated with VCM and PVC. The potential concerns regarding pyrolysis products from PVC and VCM are addressed in a separate document from the Chlorine Institute entitled The Potential Adverse Effects on Human Health and the Environment from the Incineration of Chlorinated Chemicals.

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# Chapter 2

## Properties, Sources and Environmental Fate of Vinyl Chloride and Polyvinylchloride

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## 2.1 SOURCES AND ENVIRONMENTAL FATE

### 2.1.1 Anthropogenic Sources

Uses

The principal products manufactured from VCM in the USA include PVC homopolymer and copolymer resins. Smaller quantities are used as a component in synthesis of methyl chloroform (1,1,1-trichloroethane) and as a co-monomer with vinylidene chloride to produce resins (IARC, 1979). The production of methyl chloroform is being phased out in accordance with the Montreal Protocol because of its potential interactions with stratospheric ozone. VCM also was used as a propellant in aerosol cans and as a refrigerant (Sax, 1986), although these uses have been discontinued and are only of historical interest.

Polyvinyl chloride resins produced from VCM are used in the manufacture of a variety of products such as plastic pipes and conduit, floor covering, windows, siding, upholstery, garden hoses, appliances, gramophone records, wire and cable insulation, bottle-cap liners and gaskets, seat covers, plasticized film and automotive floor mats (IARC, 1979). Vinyl chloride-vinyl acetate copolymers are used in the manufacture of vinyl asbestos flooring tiles, gramophone records, coating resins and for sheet extrusion and injection molding. Vinylidene chloride-vinyl chloride copolymers are approved by the U.S. Food and Drug Administration (FDA) for use in food packaging products (*e.g.*, food wrap, shrink film, bottles), tubing used in the dairy industry and various types of tubing and bags used in medical applications (Vinyl Institute, 1993, personal communication). The copolymers also are used as coatings or liners for other polymer films, for plastics, paper, paperboard, cassette tapes, ship and railroad tanks, fuel storage tanks, tubes, rods and pipes. In addition, they are used in fibers, cements, laminations, colostomy bags, and as binders for paints and non-woven fabric (Wessling and Edwards, 1971; Röth, 1976; IARC, 1979).

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## VCM Emissions

The major anthropoentic sources of VCM include fugitive emissions during the production of VCM and the manufacture of various products from VCM. Most of the fugitive emissions from these processes are vapors released into the air. As indicated by its environmental fate characteristics, fugitive releases into aqueous media would be rapidly volatilized to the atmosphere.

Releases of VCM from various facilities have been documented. The estimated releases of VCM to the atmosphere from PVC plants, prior to 1975, was 110 million kg per year in the U.S. (EPA, 1975). An estimated 22.7 million kg of PVC had been released into the environment from man-made sources before 1975 (EPA, 1974).

In 1981, following the implementation of regulations to control VCM emissions in Canada, a total of 41 emission incidents (*e.g.*, where emission limit of 25 mg/m$^3$ or 10 ppm were exceeded) occurred in Quebec, Ontario and Alberta, resulting in an estimated release of 46 tonnes of VCM. By 1986, the number of incidents of exceedance of the emission limit were reduced to nine and the estimated releases reduced to nine tonnes of VCM (Morcos, 1988).

Microbial or chemical transformation of chlorinated solvents to VCM, leaching of residual VCM monomer from polyvinyl chloride, and the possibility of degradation or depolymerization of polyvinyl chloride are considered as possible sources of VCM in ground water and landfills.

## VCM From Transformation Reactions

Tetrachloroethene, trichloroethene (Parsons *et al.*, 1984; 1985; Kleopfer *et al.*, 1985; Barrio-Lage *et al.*, 1986) and 1,1,1-trichloroethane (Kleopfer *et al.*, 1985; Barrio-Lage *et al.*, 1986; Molten *et al.*, 1987) can be transformed to VCM, cis- and trans-1,2-dichloroethylene by micro-organisms in muck obtained from an aquifer recharge basin.

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In addition, chemical or abiotic transformations of chlorinated solvents, although slower than biotic transformation, may result in VCM production in ground water environments. Abiotic transformations are influenced by the number and type of halogen substitution. As the halogen number increases, oxidation and reduction reactions are more predominant (Vogel *et al.*, 1987). Chemical transformation of 1,1,1-trichloroethane to 1,1-dichloroethene then to VCM, has been documented; however, depending on the environment, microbial flora, and organic content, other routes may be favored (*e.g.*, the transformation of 1,1,1-trichloroethane to 1,1-dichloroethane) (Vogel *et al.*, 1987). Abiotic transformations of trichloroethane to VCM are hindered by thermodynamic factors and activation energy barriers (Wolf *et al.*, 1987); therefore, biological, chemical or thermal catalytic effects are required to overcome the barriers. Thus, the contribution of abiotic transformation of chlorinated solvents is small compared to biotransformation (Vinyl Institute, 1990).

**VCM From Residual Monomer in PVC**

Prior to 1975 polyvinyl chloride contained much higher levels of residual monomer, thus, PVC waste sludges from old material may have contributed to initial VCM levels in landfills. However, the contribution of this source to total VCM releases to the atmosphere, water and soils is probably minor (Molton *et al.*, 1987).

The concentrations of VCM observed in landfills are not the result of degradation or depolymerization of polyvinyl chloride. The majority of the sources of VCM observed in landfills is related to the land disposal of PVC production sludges (a procedure no longer practised), and the crushing or corrosion of cans where VCM was used as a propellant (such uses were banned in 1974) (Vinyl Institute, 1990). High temperatures are required to produce minor amounts of VCM from PVC, therefore, thermal degradation of PVC in landfills is not a significant source of VCM. Following PVC pyrolysis in air at 350 °C, a maximum of 35 ppm of VCM was detected, while a maximum of only 6 ppm was detected following pyrolysis of PVC at 500°C in helium (Molton *et al.*, 1987). Photolytic and high energy degradation of PVC are also improbable sources because of the soil cover and the lack of high energy sources in



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landfills. PVC is also resistant to biological degradation (Vinyl Institute, 1990) and is not known to depolymerize under even severe conditions (Kirk-Othmer, 1983).

**Potential Releases in Remote Locations**

The environmental fate assessment of VCM concluded it was rapidly eliminated from the atmosphere through various photochemical oxidation processes, and that it would not accumulate in biological systems. The rapid destruction of VCM emitted into the environment would preclude the possibility of significant environmental concentrations occurring at locations remote from its release. Air concentration of VCM near (within a kilometer) production facilities in about 1975 were approximately 10 to 40 ppb (EPA, 1975; Baxter *et al.*, 1977), concentrations about 10,000-fold less than those considered an occupational hazard (Doll, 1988). Therefore, any potential adverse effects from VCM would be confined primarily to occupational settings, and would not be observed in remote locations.

### 2.1.2 Natural Sources

At total of at least 1500 halogenated organic chemicals have been identified that are produced by various natural systems, independent of human activities. Many of these are chlorinated organics, and have only been identified in the last decade. The scientific study of such natural products is a growing field. Most of the research to date has focused on chemical identification, and the total quantities produced by natural systems have not been determined for most natural sources of chlorinated organics. In the case of chloromethane, total natural sources (primarily from marine and terrestrial biological systems) has been estimated at 5,000,000 tons per year, compared to total man-made chloromethane emissions of about 26,000 tons per year (Gribble, 1992).

The evidence for natural sources of vinyl chloride are, at present, indirect. Vinyl chloride derivatives have been identified as natural products of two strains of blue-green algae (*Schizothrix calcicola* and *Oscillatoria nigroviridis*) (Gribble, 1992), although these observations to not necessarily mean that these algae produce free VCM. However, tetrachloroethylene,



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trichloroethylene (Parsons *et al.*, 1984; 1985; Kleopfer *et al.*, 1985; Barrio-Lage *et al.*, 1986) and 1,1,1-trichloroethane (Kleopfer *et al.*, 1985; Barrio-Lage *et al.*, 1986; Molten *et al.*, 1987) can be transformed to VCM by both biological and abiotic processes, and these sources of VCM have been identified as concerns in landfills that received VCM wastes (EPA, 1975). The production of VCM through these processes may also provide a natural source of this chemical to the environment.

A large number of halogenated chemicals are produced naturally in the environment independent of human activities (Siuda and DeBernardis, 1973; Gschwend *et al.*, 1985; Neidleman and Geigart, 1986; Gribble, 1992). Enzyme systems (*e.g.*, chloroperoxidase and likely others as yet undefined) in biological systems produce a wide array of chlorinated, iodinated, brominated and fluoridated alkanes, alkenes, ketones, alcohols, carboxylic acids, and simple and complex cyclic/polycyclic organic chemicals (Gschwend *et al.*, 1985; Gribble, 1992).

Naturally formed organohalogens are an integral part of humic soils. Analysis of soil pyrolysates by GC/MS-NCI/SIM indicated the presence of at least twenty different organochlorine compounds, many of which could not be completely identified by this analysis because of low concentrations and overlapping non-chlorinated components. The analyses indicated the presence of dichloropropane or chlorobenzene, several chlorinated alkanes or chlorinated alkenes and chlorophenol (de Lijser *et al.*, 1989).

In addition, a number of physical/chemical processes in the environment also produce a wide array of chlorinated chemicals, including: i) the production of chlorine from chlorides vaporized from the earth's oceans, then the participation of the chlorine in a wide range of atmospheric reactions, ii) volcanic eruptions producing chlorine, hydrochloric acid and a variety of organic chlorine chemicals, including PCBs and chlorinated dioxins/furans, produced as products of incomplete combustion of organic materials and chlorides normally present in plants and animals destroyed by combustion processes associated with the eruptions, and iii) natural combustion processes such as forest and grass fires that burn plants high in chlorides and organic materials (Gschwend *et al.*, 1985; Gribble, 1992).



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Many of the halogenated alkanes identified in the natural environment are also produced by a variety of human activities (*e.g.*, chloroform, carbon tetrachloride, tetrachloroethylene, 1,1,2- and 1,1,1-trichloroethane, chlorinated phenols, PCBs, chlorinated dioxins/furans). These anthropogenic sources have been considered in the identification of natural sources by the identification of the chlorinated chemicals in concentrations much greater than general ambient concentrations in remote locations, the identification of specific enzyme systems and substrates that produce the chlorinated chemicals (*e.g.*, chloroperoxidase enzyme producing chlorophenols) and the identification of specific isomers of chlorinated chemicals that are not prevalent in anthropogenic sources (*e.g.*, specific pentachlorobiphenyl isomers associated with volcanic ash) (Gribble, 1992). However, the natural sources of some halogenated chemicals have not been identified, yet the quantities identified exceed those known to arise from anthropogenic sources. For example, Gribble (1992) concluded that the estimated 650,000 tons of tetrafluoromethane was too large to due to anthropogenic sources alone, and it is unclear what portions of the 1,1,1-trichloroethylene (methylchloroform), difluorodichloromethane and fluorotrichloromethane identified at high elevations over eastern Washington are of biogenic origin.

Clearly, the evidence for the natural production of trichloroethylene, tetrachloroethylene and 1,1,1-trichloroethane combined with that for the transformation of these chlorinated alkanes and alkenes to VCM indicates that VCM is likely produced independent of human activities by these natural processes. However, no information is available on the quantities of the various chlorinated alkanes and alkenes produced by natural processes, therefore estimates of the potential natural production rates of VCM cannot be obtained.

## 2.2 ENVIRONMENTAL FATE

### 2.2.1 Physical-chemical Properties

The physical/chemical properties of VCM are summarized in (Table 2-1) and show that VCM has a high vapor pressure and low $K_{ow}$ value. PVC, on the other hand, is an inert, highly stable solid under a wide range of environmental conditions; however, because PVC is a polymer of variable numbers of vinyl chloride units, no physical/chemical properties can be determined.

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Depending on the polymerization process, some residual free vinyl chloride monomer remaining after the polymerization process; however, the use of best-available-technology involving proper temperature and pressure treatment in the final stages of manufacturing reduced the residual monomer concentrations to below analytical detection limits.

Table 2-1 Physical/Chemical Properties

| Chemical Name | Molecular Weight (g/mol)[a] | Vapor Pressure (Pa) | Solubility ($\mu$g/L) | Log $K_{ow}$ |
|---|---|---|---|---|
| Vinyl Chloride | 62.5 | 354637.5[b] | 1100[b] | 1.38 |

[a] -from Merck, 1989.
[b] -from Verschueren, 1983.

### 2.2.2 Environmental Fate

PVC is a highly stable polymer that remains a solid and does not degrade or migrate under normal environmental conditions. The environmental fate of degradation products formed during pyrolysis of PVC, and products of incomplete combustion are discussed in the Chlorine Institute document on Incineration of Chlorinated Organic Products.

#### Air

Hill *et al.* (1976) reported that the rate of exchange of gaseous VCM between water and air is twice that of oxygen, thus indicating that volatilization is the major process in the environmental disposition of VCM. The vapor density of VCM is higher than the vapor density of air, 2.2 verses 1.0 (Anon., 1972), thus vapors of VCM tend to remain near the ground (Sax, 1986).

In the environment, polymerization of VCM occurs in the presence of air, oxygen, sunlight or heat (Sax, 1986). In the troposphere, VCM undergoes photochemical oxidation with hydroxyl radicals to form hydrogen chloride or formyl chloride. Formyl chloride undergoes further reactions to form carbon monoxide and hydrogen chloride. Since these reactions are extremely

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rapid, the degradation half-life of VCM in the troposphere is less than one day (EPA, 1975; EPA, 1979).

### Water/Sediment

Sorption of significant amounts of VCM by sediments would occur only upon continuous input of extremely high concentrations of VCM to aquatic systems (Hill *et al.*, 1976). The adsorption of VCM to particulate matter is considered insignificant as indicated by the same rates of loss from distilled water, river water and industrial effluents (EPA, 1974). The reported log octanol/water partition coefficient ($K_{ow}$) of VCM ranged from 0.60 (Radding *et al.*, 1977) to 1.78 (Mckay *et al.*, 1992), thus, adsorption to organic carbon and accumulation in lipid tissues of aquatic biota would not occur.

VCM is slightly soluble in water; however, due to its high vapor pressure, VCM entering aquatic systems would be rapidly lost to the atmosphere through volatilization (Sax, 1986; Vinyl Institute, 1990). The volatilization half-life of VCM from surface waters ranges from several minutes to a few hours depending on water turbulence (Dilling *et al.*, 1975; Hill *et al.*, 1976; EPA, 1979).

In groundwater, where volatilization cannot occur, VCM may be slowly hydrolyzed with a half-life of less than ten years (Hill *et al.*, 1976; EPA, 1979; Smith and Dragun, 1984). Reaction products may include chlorinated alcohols and/or carboxylic acids (Smith and Dragun, 1984).

Direct phototransformation of VCM in surface waters would not be expected, since VCM absorbs shorter wavelengths of light than are present in the sunlight radiation spectra at the earth's surface (Hill *et al.*, 1976; EPA, 1979). However, indirect photolysis may be a factor in the transformation of VCM. Hill *et al.* (1976) demonstrated that irradiation with ultraviolet light transforms VCM, via energy transfer, when acetone or hydrogen peroxide are present. In such reactions, acetone acts as a high energy triplet sensitizer and hydrogen peroxide as a free radical source. However, oxidation of VCM in natural waters was not considered to be a significant reaction because of low temperatures and oxygen concentrations (Hill *et al.*, 1976).



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There are limited data concerning the biotransformation of VCM. Lu *et al.* (1977) reported that the high volatility of VCM prevented significant transformation in a model ecosystem. Mineralization of VCM to carbon dioxide may be possible under anaerobic conditions; however, further study is required for confirmation (Vogel and McCarty, 1985).

Early studies concluded that VCM was resistant to microbial transformation (Hill *et al.*, 1976); however, more recent data shows that a strain of *Mycobacterium* can use VCM as a carbon and energy source in aerobic environments (Hartman *et al.*, 1985). *Mycobacterium* were able to metabolize 70% of the carbon present as VCM to carbon dioxide and hydrochloric acid.

In soil-groundwater systems reductive dechlorination under anaerobic conditions is the predominant mechanism for the degradation of many volatile chlorinated hydrocarbons, and the production of ethylene from VCM has been hypothesized to occur through this mechanism (Smith and Dragun, 1984). The degradation of 90% of VCM by microorganisms in a shallow aquifer, with about 50% mineralization to carbon dioxide over at 106 day period has been demonstrated using $^{14}$C-VCM (Davis and Carpenter, Undated).

**Soil**

There is a paucity of information concerning the fate of VCM in soil. However, it is expected that VCM present in superficial soils would rapidly volatilize to the atmosphere. Sorption of VCM to sediment or soil from aqueous environments is not expected to be a very important transport process (EPA, 1979). As described in the previous section, biotransformation of VCM may occur in groundwater; thus, it is probable that under proper conditions biotransformation would also occur in soils.

**Environmental Fate Fugacity Modelling**

Fugacity modelling of chemicals in the environment provides predictions of the partitioning, movement and behaviour of chemicals within different environmental media based on the specific physical properties of chemicals. Level I fugacity modelling predicts the distribution



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of chemicals to air, water, soil, bottom sediment, fish and suspended sediment given a steady-state situation where no removal of the chemical occurs by any chemical or physical processes. Level II fugacity modelling provides predictions of the rates of loss of chemicals from various compartments by reactive or advective means, again, under steady-state conditions. Level III fugacity modelling provides predictions of the rates at which a particular chemical would move between the various environmental compartments.

## Vinyl Chloride

Level I Fugacity modelling was performed for VCM using physical and chemical properties (Table 2-2). The results are displayed graphically (Figure 2-1).

Table 2-2 Physical/Chemical Properties of Vinyl Chloride

| | | | |
|---|---|---|---|
| Temperature °C | 25 | Fish-water partition coefficient | 1.15144 |
| Molecular mass g/mol | 62.5 | Air-water partition coefficient | 8128.813 |
| Vapor pressure Pa | 354637.5 | Soil-water partition coefficient | 0.2950565 |
| Solubility g/m$^3$ | 1.1 | Sedt-water partition coefficient | 0.590113 |
| Solubility mol/m$^3$ | 0.0176 | Susp sedt-water partition coefficient | 0.590113 |
| Henry's Law constant Pam$^3$/mol | 2.0149E7 | | |
| Log octanol-water partition coefficient | 1.38 | Amount of chemical moles | 1000 |
| Octanol-water partition coefficient | 23.98833 | Fugacity Pa | 4.131365E-4 |
| Organic C-water partition coefficient | 9.835216 | Total of VZ products | 2420508 |

The results of the fugacity modelling indicate that virtually all VCM will partition towards the air with very small amounts distributing to the other compartments. This partitioning is consistent with the high vapor pressure of VCM.

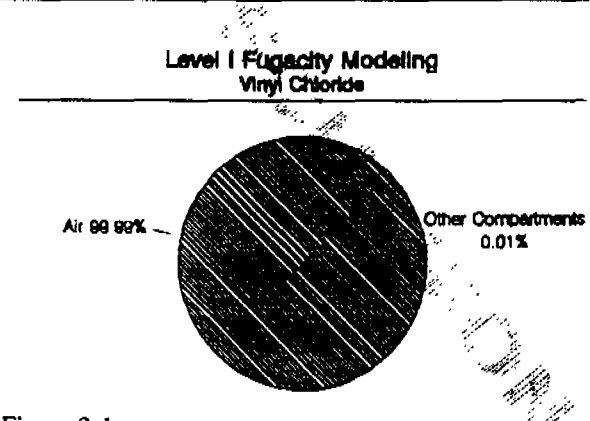


Figure 2-1

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## 2.3 VINYL CHLORIDE REGULATIONS

### 2.3.1 Regulations of VCM in Air

#### 2.3.1.1 Air Concentrations in Emissions

Regulation of emissions of VCM from manufacturing plants in the United States, effective as of July 1, 1979, requires that VCM concentrations in air emissions remain less than 25 mg/m$^3$ (10 ppm) by volume or total releases remain less than 2 kg/day, which ever is greater (Gendron, 1981). According to IARC (1979), the EPA (1977) proposed to be reduced the air emission guideline to 13 mg/m$^3$ (5 ppm). The Federal Republic of Germany has an emission standard of 3 kg VCM/hour/source (150 mg/m$^3$ at the source) (Thomas, 1977).

In Canada there are regulations regarding ambient air concentrations and emissions. The Ontario Ministry of the Environment (1991) guideline value for annual average VCM concentrations in ambient air is 0.2 $\mu$g/m$^3$ based on the estimated exposure limit for the potential development of cancer at a risk level of one per 100,000. Elsewhere in Canada, the Federal Vinyl Chloride National Emission Standards Regulations (SOR/79-299) and the Vinyl Chloride Release Regulations (SOR/90-25) stipulate that air VCM concentrations in any process vent must not exceed 25 mg/m$^3$ (10 ppm) (by volume, measured dry and undiluted), or two kg/day VCM released into the ambient air. For polyvinyl chloride plants, the air concentrations in any process vent must not exceed ten ppm VCM. Regulations of emissions specific to the manufacture of certain resins are also included.

No information concerning the environmental concentrations or emission regulatory guidelines or criteria for polyvinyl chloride was identified.

#### 2.3.1.2 Regulations of VCM in Water

The U.S. drinking water criteria value proposed by the EPA (1991) for VCM in water for human consumption was 2 $\mu$g/L. This value was based on estimated exposure limits for



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potential cancer in humans at a risk level of $10^{-6}$. This criteria level was unchanged from that developed for water consumption by the EPA in 1980 (EPA, 1986). EPA (1986) also reported a Maximum Contaminant Level (MCL) of 925 $\mu$g/L for VCM in water. The quality standard specification used for VCM in ground water in New York State is 5.0 $\mu$g/L (New York State Department of Environmental Conservation, 1986).

#### 2.3.1.3 Soil

No information was identified on soil or sediment quality guidelines or criteria for VCM. Since the environmental fate characteristics of VCM indicate that air is its major environmental medium, soil would not be expected to be an important environmental compartment for VCM.



R&S 143107

# Chapter 3

## Potential Environmental Hazards and Health Significance of Environmental Concentrations of VCM

R&S 143111

## 3.0 INTRODUCTION

The methods for characterizing the risks due to exposure to chemicals such as VCM are outlined in the Chlorine Institute document entitled General Introduction and Methodology for the Evaluation of the Potential Environmental Effects of Chlorine and Chlorinated Chemicals. Basically, these methods involve estimating potential human exposures to VCM from various environmental sources, and comparing these exposures to exposure limits that are considered protective of human health. Therefore, Chapter 3 summarizes i) the information available on the concentrations of VCM in various environmental media, ii) the toxicological/epidemiological information available on the potential health hazards that could result from exposures to VCM, iii) the procedures used to estimate an exposure limit for VCM, and iv) the comparison between the estimated exposures through various environmental media and the exposure limit to characterize potential human health risks to VCM. In addition, the potential effects of ambient sources of VCM on aquatic and terrestrial wildlife are assessed.

## 3.1 ENVIRONMENTAL CONCENTRATIONS

The concentrations of VCM in the environment is determined by the types of environmental releases that occur during production and manufacturing processes. In 1988, an estimated total of approximately 2 million pounds of VCM was either releases or transferred from production facilities in the U.S. Of this total, approximately 67% was released into the air, 0.1% into surface waters and 0.1% to land. The remaining approximately 32% was transferred off-site (EPA-TRI, 1988). This information indicates that the environmental concentrations of vinyl chloride would be highest in air near production and manufacturing facilities. Therefore, the following discussion of environmental concentrations of VCM focuses on air, and is divided into the work place and immediate environment near production/manufacturing facilities, and regions distant (remote) from such facilities.

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### 3.1.1 VCM Concentrations Associated With Production/Manufacturing Facilities

#### Concentrations in the Work Environment

Standards for the concentrations of VCM in the work environment were presented in Section 2.3.1. Generally, VCM concentrations in the workplace prior to the 1960s were greater than 100 ppm, were less than 100 ppm after 1960 and decreased to a limit of 5 ppm (8 hour, time-weighted average (TWA)) by 1975 (Doll, 1988; ACGIH, 1991). The current OSHA workplace standard in the U.S. is 1 ppm (8 hr TWA) with a 5 ppm short term exposure limit (STEL).

Recent data from four PVC resin production facilities in the U.S. indicate that the concentrations of VCM (8 hour TWA based on individual personnel monitoring) in the work environment ranged from approximately $<0.25$ to 10.5 mg/m$^3$ ($<0.1$ to 4.11 ppm) in 1988, and decreased to a range of approximately $<0.25$ to 2 mg/m$^3$ ($<0.1$ to 0.77 ppm) in 1992 (January to September only). In 1990, one facility reported 8 hr. TWA air concentrations for instrument technicians and process operators of 35 to 26.5 mg/m$^3$ (13.5 and 10.34 ppm), respectively. Reactor operators, loading personnel and laboratory technicians showed the greatest potential exposures, with 8 hr. TWA air concentrations ranging from 0.5 to 11 mg/m$^3$ (0.2 to 4.11 ppm) in 1988, decreasing to 0.5 to 2 mg/m$^3$ (0.2 to 0.77 ppm) in 1992 (Vinyl Institute, personal communication, 1992). These data represent the greatest air concentrations reported for the four facilities over the 5 year period, 1988 through 1992.

#### Concentrations Near Production/Manufacturing Facilities

Localized environmental releases of VCM are associated with production and manufacturing facilities, therefore, their environmental concentrations are highest in and around such facilities. Due to the implementation of occupational health standards, the concentrations of VCM in the work environment in the Netherlands decreased from approximately 2600 mg/m$^3$ (1000 ppm) in 1945-1955 to approximately 12 mg/m$^3$ (5 ppm) after 1975 (Barnes, 1980). These decreases in concentrations of VCM in the work environment also would also be indicative of decreases



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in environmental releases. However, no information on this point was identified since the focus on measuring air concentrations of VCM has been on various "hot spots".

Vinyl chloride has been measured in air and in both ground and drinking water in areas near production and manufacturing facilities the United States. Prior to the implementation of VCM emission regulations in 1978, the average air concentrations of VCM at production facilities in the United States was 44 $\mu g/m^3$ (17 ppb) (IARC, 1979). In Houston, Texas where large quantities of VCM are produced, air concentrations ranged from 8 $\mu g/m^3$ (3.1 ppb) to peak values of 3,200 $\mu g/m^3$ (1,200 ppb) (Gordon and Meeks, 1977). In Long Beach, California, ambient air concentrations of VCM near two VCM plants ranged from 260 to 8,800 $\mu g/m^3$ (100 to 3,400 ppb), and these facilities were estimated to have released 12.3 kg of VCM/day in waste water effluent (National Field Investigations Center, 1974). However, within approximately one kilometer of VCM production/manufacturing facilities, reported air concentrations of VCM ranged from approximately 26 to 100 $\mu g/m^3$ (10 to 40 ppb) (EPA, 1975; Baxter *et al.*, 1977).

More recent information based on sampling near production/manufacturing facilities since standards for the work environment were reduced to about 13,000 $\mu g/m^3$ (5 ppm) in 1975, showed that air concentrations of VCM were near the analytical detection limit (about 13 $\mu g/m^3$ or 5 ppb) in three of five British plants. For two other facilities, the VCM air concentrations were approximately 50 $\mu g/m^3$ (20 ppb) 100 m outside the facility boundary, and 225 $\mu g/m^3$ (88 ppb) just inside the boundary fence (Turner *et al.*, 1984).

The highest level of VCM measured in U.S. drinking water was 10 $\mu g/L$ near a production facility (IARC, 1979). Vinyl chloride has also been reported in ground water in the U.S. Measurable levels in California wells averaged 20 $\mu g/L$ and were as high as 23 $\mu g/L$ (Kizer, 1986). In the Los Angeles area, ground water to contain less than 1 $\mu g/L$ of VCM (Baird *et al.*, 1983), while in non-specified areas of Nebraska and California ground water concentrations ranged from 0.75 to 23 $\mu g/L$ (Goodenkauf and Atkinson, 1986; CSDHS, 1990).

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### 3.1.2 VCM Concentrations Remote from Production and Manufacturing Facilities

No information was identified on the concentrations of VCM in air in locations remote from industrial activities. However, it would be expected that the VCM concentrations in such locations that are derived from human activities would be below analytical detection limits, based on: i) the continuing decline in VCM concentrations in the workplace (Table 2-2), ii) the low concentrations measured near production/manufacturing facilities using VCM (EPA, 1975; Baxter *et al.*, 1977; Turner *et al.*, 1984), and iii) the rapid vaporization of VCM and subsequent destruction in the atmosphere.

## 3.2 HAZARD ASSESSMENT

The chemicals addressed in this document are polyvinyl chloride (PVC) and vinyl chloride (VCM).

### 3.2.1 Polyvinyl Chloride

In the scientific literature, PVC has also been referred to as chloroethene homopolymer, chloroethylene polymer, vinyl chloride homopolymer, and vinyl chloride polymer.

There are limited data regarding the toxicology of PVC, with the majority of studies focusing on the pulmonary effects of this polymer. No data on the embryotoxicity, teratogenicity, metabolism, or mutagenicity of this compound were identified by IARC (1979) or subsequent searches of the available literature.

#### 3.2.1.1 Bioavailability, Metabolic Conversion (Pharmacokinetics), and Bioaccumulation

The available data indicate that following a single dose of intratracheally instilled PVC dust (< 0.5 $\mu$m) in rats, the particles are cleared through the lymphatic circulation and progressively accumulate in the tracheobronchial lymph nodes (Agarwal *et al.*, 1978; Takenaka *et al.*, 1987;

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Agarwal *et al.*, 1991). Ingested or rectally administered PVC particles were observed within the lymph vessels associated with the intestinal wall of rats, guinea pigs, rabbits, chickens, dogs, and pigs (Volkheimer, 1975). Particles were observed in the blood, bile, urine, and cerebrospinal fluid of dogs, and in the blood of other species, but details of the experimental methods and results were not provided (Volkheimer, 1975). There is no information on the potential bioavailability or biotransformation of PCV.

### 3.2.1.2 Mammalian Toxicology (Laboratory Animal and Biochemical Studies)

**Lethal Effect**

PVC is relatively inert and no lethality data have been reported.

**Non-Lethal Effects**

The weight-of-available-evidence from data generated by inhalation and intratracheal exposure to PVC particles in experimental animals, indicates that PVC itself possesses little or no biological activity, with its physical presence producing benign pneumoconiosis typical of a nuisance dust at elevated dust concentrations (Pigott and Ishmael, 1979; Groth *et al.*, 1981; Richards *et al.*, 1981; Wagner and Johnson, 1981; Tetley *et al.*, 1981; Agarwal, 1983; Agarwal *et al.*, 1991). Flaws in experimental design, and concomitant exposures to other chemicals makes the significance of earlier studies where animal exposed to PVC dusts by inhalation studies showed pulmonary fibrosis and significant respiratory toxicity (Popow, 1969; Frongia *et al.*, 1974).

**Carcinogenicity**

Since vinyl chloride has been recognized as a carcinogen (IARC, 1979, 1987), the potential carcinogenicity of PVC has received particular scrutiny (Montgomery, 1982). IARC (1979, 1987) concluded that the evidence for PVC carcinogenicity was inadequate based on several

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animal studies, and that the carcinogenicity of PVC was unclassifiable (Oppenheimer *et al.*, 1952, 1955; Kogan and Tugarinova, 1959; Russell *et al.*, 1959; Raikhlin and Kozan, 1961).

### 3.2.1.3 Epidemiology Studies

Based upon the epidemiological evidence available, exposure to extreme concentrations of PVC dusts in the work environment can lead to a low grade pneumoconiosis, similar to that experienced with inhalation of other unreactive, nuisance dusts. Chest X-rays of workers often have shown abnormalities, yet these changes have not always been associated with decreased lung function (Miller *et al.*, 1975; Gamble *et al.*, 1975; Lilis *et al.*, 1976; Mastrangelo *et al.*, 1979; Soutar *et al.*, 1980; Chivers *et al.*, 1980; Mastrangelo *et al.*, 1981; Wagoner, 1983; Baser *et al.*, 1985; Ernst *et al.*, 1988; Siracusa *et al.*, 1988; Nielsen *et al.*, 1989; Lee *et al.*, 1991; Ng *et al.*, 1991). The epidemiological data on the respiratory effects of PVC dusts in humans also indicates that such exposure has not produced neoplastic effects.

Other studies have investigated the effects of PVC degradation products, particularly following heating or combustion. PVC, under these conditions, can release hydrogen chloride gas or large amounts of carbon monoxide, depending on the oxygen supply (Montgomery, 1982).

Two large epidemiological studies have been carried out that have examined the mortality and cancer incidences of workers in the plastics industry, including PVC fabricators (Baxter and Fox, 1976; Chiazze *et al.*, 1977). IARC (1979) concluded that, although there were excess incidences of certain cancers, these studies were limited in that not all the workers studied were engaged in activities directly involving PVC. In addition, monomeric vinyl chloride, a recognized human carcinogen, was likely present in these work environments. In 1974, it was reported that PVC leaving certain manufacturing plants may have contained as much as 200-400 ppm vinyl chloride (IARC, 1979), although current manufacturing technology is capable of producing general PVC which contains less than 1 ppm residual monomer, while modern medical grade PVC is believed to contain less than 10 ppb VCM (Van Dooren, 1991; Thomas and Ramstad, 1992).

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### 3.2.1.4 Exposure Limits

The American Conference of Governmental Industrial Hygienists (ACGIH) considers occupational exposure to PVC dusts under the category Particulates Not Otherwise Classified (PNOC). The threshold limit value (time-weighted average) (TLV-TWA) for this category is 10 mg/m$^3$ (ACGIH, 1992). The United States Occupational Safety and Health Administration (OSHA) has set limits for inert or nuisance dusts of 15 mg/m$^3$ (total) and 5 mg/m$^3$ (respirable), not regulating PVC directly (29 CFR § 1910). Germany, Switzerland, and the United Kingdom have set TLV-TWA limits of PVC (respirable dust) of 5 mg/m$^3$ (ILO, 1991), as have Sweden and Norway (Norsk Hydro, 1992).

## 3.2.2 Vinyl Chloride

In the scientific literature, VCM has also been referred to as chloroethene, chloroethylene, monochloroethylene, and vinyl chloride monomer.

### 3.2.2.1 Bioavailability, Metabolic Conversion (Pharmacokinetics), and Bioaccumulation

**Bioavailability**

Based on measured $^{14}C$ in the urine and expired air, between 70 and 95% of the dose was absorbed following a single oral administration of [$^{14}C$]VCM (0.05-100 mg/kg body weight) to male rats (IARC, 1979).

Absorption of VCM through the skin is considered to be low. Calculations based on the percutaneous absorption of VCM using Rhesus monkeys indicated that a six-foot, 90 kg man exposed to 7000 ppm (dermal) for two hours would absorb the equivalent of approximately 0.2 ppm (EPA, 1980).

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At room temperature, VCM exists as a gas, therefore, inhalation is the most significant route of exposure. Data obtained from the rat indicated that VCM is rapidly absorbed by the lung and readily metabolized (Hefner *et al.*, 1975). Following exposure of male rats to 10 ppm [$^{14}$C]VCM in the air for six hours, 68% of the radioactivity was excreted in the urine within 72 hours, with approximately 2% exhaled unchanged. Similar exposure to 1000 ppm resulted in a lower proportion of radioactivity excreted in the urine and that expired as VCM higher, representing 56 and 12%, respectively (Watanabe *et al.*, 1976; Holmberg, 1984). In a similar system, rats exposed to initial concentrations less than 100 ppm [1,2-$^{14}$C]VCM in the air absorbed approximately 40% of that inhaled. Within 24 hours, 70% of the radioactivity was recovered in the urine.

**Metabolism**

Vinyl chloride is metabolized by the cytochrome P450-dependent polysubstrate monooxygenase system (P450) to the reactive epoxide intermediate chloroethylene oxide, which rearranges spontaneously to chloroacetaldehyde (Bolt *et al.*, 1976; IARC, 1979). As reviewed in IARC (1979), the epoxide has also been shown to be capable of reacting with macromolecules such as DNA, RNA, and protein, forming covalently bound adducts (Kappus *et al.*, 1975; Kappus *et al.*, 1976; Bolt and Filser, 1977). These reactions have been elucidated through results obtained with mouse or rat subcellular fractions or P450 inhibitors and inducers, as there are no data yet available for this pathway *in vivo* (Gothe *et al.*, 1974). Chloroacetaldehyde has been shown to combine directly or enzymatically (glutathione S-transferse-mediated) with glutathione to form S-formylmethylglutathione, which is excreted as N-acetyl-S-(2-hydroxyethyl)cysteine. Chloroacetaldehyde is also oxidized to chloroacetic acid, which is either excreted as such or bound to glutathione in the form of S-carboxymethyl glutathione (Green and Hathway, 1977; Plugge and Safe, 1977).

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**Bioaccumulation**

As indicated in the preceding sections, VCM is rapidly metabolized and excreted, therefore, it does not accumulate in biological systems. Metabolism is so rapid that no VCM *per se* has been identified in the tissues of animals following exposure to high concentrations, even though the alkylation of DNA and other macromolecules occurred (Watanabe *et al.* 1976; Bergman, 1982). Following dosing of rats with [$^{14}$C]VCM via inhalation and oral routes, between 2-15% of the radioactivity was measured in the carcass after 72 hours (IARC, 1979), however, the identity of the compounds containing the radioactivity was unknown.

**Excretion**

In rats, the majority of VCM absorbed by the body is excreted in the form of highly water-soluble metabolites by the kidneys, with up to 70% of the radioactivity associated with a dose of [$^{14}$C]VCM being recovered in the urine within 24 hours (Watanabe *et al.*, 1976; Bolt *et al.*, 1976). Metabolites that were not excreted in the urine were partly excreted via the feces and partly via expiration of $^{14}CO_2$ (Green and Hathway, 1975; Bolt *et al.*, 1976)

### 3.2.2.2 Mammalian Toxicology (Laboratory Animal and Biochemical Studies)

**Lethal Effects**

The acute lethality of VCM is low. The two-hour $LC_{50}$ of VCM for rats, mice, guinea pigs, and rabbits ranges from 113000 to 230000 ppm (294 to 595 g/m$^3$) (IARC, 1979). Vinyl chloride gas produces narcosis or anesthetic effects, with death following extreme exposures being preceded by excitement, contractions and convulsions, accelerated respiration, and respiratory failure. Microscopically, acutely lethal doses are associated with congestion of the internal organs, with intense damage to the lungs, liver, and kidneys (IARC, 1979). Hepatotoxicity is observed laboratory animals after single, high but nonlethal exposures (Prodan *et al.*, 1975). The induction of cytochrome P450 mixed function oxidase enzyme systems, and the depletion of hepatic glutathione stores prior to exposure enhances the hepatotoxic effects of VCM (IARC,



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1979). This effect is of particular interest in interpreting effects from chronic exposures at low doses in both animals and in humans.

**Non-Lethal Effects**

**Teratogenicity**

The available studies reviewed by EPA (1987a) indicate that VCM is not teratogenic in mice, rats, or rabbits exposed via inhalation to air concentrations of 500 ppm, 6000 ppm, and 2500 ppm during the period of major organogenesis In some cases, inconclusive findings of increased fetal deaths or minor skeletal variations have been reported; however, these findings occurred only at levels producing maternal toxicity (EPA, 1984).

**Carcinogenicity**

A large number of experimental studies on VCM carcinogenicity in a number of species, routes of exposure and dosages have been reviewed by IARC (1979) (Viola *et al.*, 1971; Holmberg *et al.*, 1976; Maltoni *et al.*, 1981). Based on these studies it was concluded that there is sufficient evidence for carcinogenicity to animals (IARC, 1979, 1987). Vinyl chloride administered orally or by inhalation to mice, rats and hamsters produced an increased tumor incidence in the mammary gland, lung, Zymbal gland, and skin, in addition to hepatocellular carcinomas and angiosarcomas of the liver. In one study, a combination of orally administered ethanol and inhalation of VCM resulted in more liver tumors (including angiosarcomas) than after treatment with VCM alone (Radike *et al.*, 1981). The most comprehensive and in-depth investigation of VCM carcinogenicity (Maltoni *et al.*, 1981) concluded: i) VCM induced tumors in all species and strains of animals tested; ii) tumors of different types were induced at different sites; iii) angiosarcoma of the liver occurred in all species of animal tested; iv) VCM was carcinogenic by inhalation and ingestion, and possibly by injection; v) obvious dose-response relationships were observed for both ingestion and inhalation experiments; vi) treatment duration and schedule markedly affected the neoplastic response, as did the species strain, and sex of the animals tested; vii) neonatal animals were highly responsive; viii) VCM acted as a transplacental

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carcinogen; and ix) it was carcinogenic at very low exposure levels (*i.e.*, 50 ppm and lower) (Calabrese and Kenyon, 1991).

### Mutagenicity

Vinyl chloride vapor induced reverse mutations in a number of *Salmonella typhimurium* strains in the presence of an activation system (i.e. 9000 x g supernatant of rat liver). The response was much greater in the presence of activation systems, yet in its absence, VCM was still able to induce mutations. In addition, VCM has been reported to induce reverse mutations in *E. coli*, forward mutations in *Schizosaccaromyces pombe*, mitotic gene conversions in *S. cerevisiae*, and forward mutations in Chinese hamster ovary cells. The fact that these responses occurred in the presence of a metabolic activation system, indicated that a metabolite(s) was predominantly responsible for the observed mutagenicity. Vinyl chloride has also been found to give positive responses in the *Drosophila* sex-linked recessive lethal assay, but negative in other *Drosophila* assays, including those designed to detect translocations, sex chromosome loss, and dominant lethal effects (IARC, 1979; Calabrese and Kenyon, 1991). Recently, workers exposed to VCM at levels of 5 to 500 ppm developed chromosomal aberrations in peripheral blood lymphocytes (IARC, 1987).

The mutagenicity of several possible metabolites of vinyl chloride has also been examined. Chloroethylene oxide was found to be the strongest mutagen among those tested in *S. typhimurium*, *E. coli*, *S. pombe*, *S. cerevisiae*, and V79 Chinese hamster cells. Chloroacetaldehyde was mutagenic in *S. typhimurium* and V79 Chinese hamster cells, while chloroethanol was weakly mutagenic in *S. typhimurium*, and chloroacetic acid was not mutagenic in *S. typhimurium* (IARC, 1979).

### 3.2.2.3 Mechanisms of Toxicity

Vinyl chloride has been shown to be activated, via P450 mixed function oxidase enzyme systems, to a reactive epoxide intermediate. Hepatotoxicity increases following administration of P450 inducers such as phenobarbital, aroclor 1254 (a PCB mixture), and hexachlorobenzene

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(IARC, 1979; Anonymous, 1987). In addition, VCM has been shown to alkylate $N^4$-cytidine, $N^6$-adenosine, and $N^7$-guanosine of liver DNA in mice (Osterman-Golkar *et al.*, 1977).

### 3.2.2.4 Epidemiology Studies

Both IARC and the U.S. EPA have concluded, based on evidence from workers following extended periods (*e.g.*, 20 years or more) to extremely high concentrations of VCM (*e.g.*, > 100 and possibly up to 1000 ppm), that there is sufficient evidence for VCM carcinogenicity in humans based upon the epidemiological data (EPA, 1987a; IARC, 1987). The critical review of the available epidemiological data conducted by Sir Richard Doll (1988) forms the basis of the following assessment of VCM. As pointed out by Doll (1988), a number of studies of workers exposed to VCM have demonstrated that excessive exposure are associated with a hazard of angiosarcoma of the liver. However, when a large number of studies are conducted to address pre-defined correlations between events (*e.g.*, VCM exposure and angiosarcoma), findings of significant correlations would be expected in independent studies about once in 20 times. Therefore, it is important to determine whether the correlations observed are causally related to VCM exposures, or due to chance alone. To address this question, Doll (1988) conducted a critical examination of the epidemiological data from comparable studies. The criteria used to ensure the studies were comparable were: i) the exposure levels to not necessarily have to be the same; ii) the observations of the exposed populations occur over a period of time when a clear hazard existed, and iii) the reference or control populations from which the expected incidence rates are derived should be as similar to the study population as possible, except for the absence of exposure to the agent in question (*e.g.*, VCM). Doll (1988) concluded that at the time of his review, four studies were available that met the criteria necessary for comparability: the national survey for the United Kingdom (UK) (Jones, 1988), the national survey in the U.S. (Environmental Health Associates, 1986), and the study of a VCM production/manufacturing facility in Quebec, Canada, (Theriault and Allard, 1981) and a VCM production/manufacturing facility in Italy (originally quoted as Belli *et al.* by Doll, 1988, but finally published as Maltoni and Cotti, 1988). All four studies encompassed 25 years post-first-exposure. All of the facilities in the four studies included the production of VCM and PVC, but not the manufacture of PVC products, thus avoiding confounding of the interpretation

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of the results by marked differences in the levels of exposure to VCM, and the effects of exposures to PVC dusts (see Section 3.2.1.3 on PVC for discussion of such effects).

The U.S. study (Environmental Health Associates, 1986) included 10,173 workers (97% white races) from 37 facilities. Twenty-two of the facilities were in the southern U.S., 14 in the northeastern-northcentral, and one in the west. Exposures began at least one year before December 31, 1972, and the first exposures started in 1942. Except for one facility (955 employees followed till December 31, 1972), follow-ups of the workers were conducted to death or until December 31, 1982. A large portion of the workers were observed for 25 or more years after first exposure since approximately 46% first worked in the facility prior to 1955. Doll (1988) considered there were three minor and two major criticisms of this study. The minor criticisms were: i) the list of employees were compiled by the companies without an independent review, ii) it was assumed all employees were white (3% were black), and white race mortality rates were used for comparisons, and iii) 7.3% of the employees would not be traced. The major criticisms were: i) mortality rates of the workers were compared to those for white males for the whole country, whereas a significant number of the facilities were in the south and these comparisons do not enable consideration of the "healthy worker" effect, and ii) no causes were identified for 97 of the 1,536 deaths in the cohort, and this deficiency was not considered in calculating the disease specific mortality rates. This deficiency could have resulted in underestimation of the standardized mortality ratios by 6.3%.

The UK study (Jones, 1988) evaluated 5,498 workers who experienced at least one year of exposure to VCM for at lease 25% of each work week over a period between 1940 and 1974. Vital status was evaluated in December, 1984. Follow-ups were completed on 98.9% of the men, and 780 deaths were identified. Minor criticisms of the study included: i) national mortality rates for England and Wales for 5-year age groups over quinquennial periods for 66 causes of death were used as reference comparisons to the incidence rates for different causes of death in the workers. Definitions for the 66 causes of death were added over the observational period, and therefore, not all categories could be compared over all time periods of observation; ii) attempts were made to classify exposures as low, medium or high; however, within the groups the exposures were much higher at the beginning than at the end of the

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observation period, presumably due to up-grading of the work environment. In addition, workers often moved from one exposure category to another with changes in job specifications. These factors would tend to overestimate the numbers of deaths in the first two exposure categories (Doll, 1988).

The Canadian study (Theriault and Allard, 1981) reported on 1,611 of a total of 1,659 (97.1%) employees who worked between January 1, 1948 and December 31, 1972 at a facility that manufactured VCM and PVC between 1943 and the late 1960s, at which time VCM production ceased but PVC production continued. Detailed occupational and tobacco smoking histories were obtained through union lists and interviews with next-of-kin, and 156 individuals employed for less than 5 years were excluded from the assessment. The workers were divided into three groups: i) exposed to VCM (451 workers); ii) unexposed (870 workers); and iii) others where exposures were uncertain (134 workers), who were excluded from the assessment. Follow-ups of death certificates was closed on December 31, 1977. A total of 59 exposed (75% with >10 years exposure) and 233 unexposed were included in the final assessment, with histological/cytological information sought on all exposed men who died of cancer. Approximately 44% of the workers were observed >25 years from the first exposure. Mortality and causes of death as specified on death certificates for the exposed and unexposed groups were compared after standardization for 5-year periods and 5-year age groups; and were compared with the mortality expected for similar sex- and age-groups in Quebec in 1971. This procedure may have caused some distortion in the expected numbers of deaths since it did not cover the 1948 to 1977 period; however, Doll (1988) considered such distortion was "unlikely to have been large".

The histopathological examinations were particularly valuable in the interpretation of the effects of VCM exposures; and showed that all 8 liver cancers diagnosed were angiosarcomas, and one additional cancer was diagnosed as angiosarcoma of the peritoneum. Two cases of angiosarcoma had also been certified as hepatic cirrhosis. The relative risk of death from all causes was 0.95, showing the "healthy worker" effect.

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The Italian study (Maltoni and Cotti, 1988) began in 1983 and focused on workers from nine VCM and PVC production facilities in Italy. The study was incomplete in 1988, therefore, the Doll (1988) review followed workers up to 1983 from two production facilities which began operations in 1953 (457 and 181 men in each plant). The expected mortality rates were estimated by multiplying the person-years at risk by the corresponding national mortality rates for each 5-year age group and 5-year period of the study. The expected deaths amounted to 12.4 and 12.8%, respectively, of the workers in the two plants. The final diagnosis indicated a total of four deaths from liver cancer. Doll (1988) excluded from his analysis, the information from a third Italian facility because none of the follow-ups covered more than 24 years, and the expected mortality was only 3.9% of the workers.

A follow-up to the Italian study was published by Pirastu *et al.* (1990), indicating that extreme VCM exposures of workers were associated with significant increases in both liver angiosarcomas and hepatocellular carcinomas. Considerable animal data and human studies on the drug Thorotrast are quoted by the authors as supporting evidence for a relationship between VCM exposure and heptaocellular carcinoma, in addition to angiosarcomas. However, no reference is made to the marked hyperproliferative effects observed in laboratory animals following extreme exposures to VCM (Feron *et al.*, 1981) and the documented evidence between hepatocellular hyperproliferation and hepatocellular carcinomas in rodents (Popper and Thomas, 1977). In addition, the numerous vagaries associated with death certificate diagnosis of particular types of cancers, as pointed out by Doll (1988), raise concerns regarding the data presented by Pirastu *et al.* (1990). It would appear that the weight-of-available-evidence remains in agreement with the conclusions reached by Doll (1988) that the primary carcinogenic effects of VCM are related to liver angiosarcoma. Although hepatocellular carcinomas may be associated with extreme exposures to VCM, it would appear that their occurrence is more likely secondary to concurrent hepatocellular hyperproliferation.

A number of other studies were also available on Norwegian, Swedish, German, French and Japanese workers (Doll, 1988) that contributed supporting evidence, but exhibited a variety of factors that confounded the interpretation of the data produced (*e.g.*, inadequate identification of cohort members lost from follow-up, exposures to a variety of other chemicals in addition to

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VCM and PVC, lack of comparative mortality statistics for the reference populations during the critical period of worker exposures and mortality).

From the analyses of the four main studies, using the remaining studies as supporting information, Doll (1988) reached two major conclusions: i) Apart from liver cancer, the overall mortality of the VCM/PVC workers exposed between the 1940s/1950s and mid-1970s was what would be expected from industries that do not have unusual hazards of accident or disease. The standard mortality ratios (SMR) of approximately 84 were considered typical for diseases other than cancer, considering the "healthy worker" effect. The SMR of 102 for total cancer mortality, other than cancers of the liver, were considered compatible with the absence of hazard; ii) workers exposed to VCM concentrations of "several hundred parts per million or more" clearly showed an increased hazard (risk) of contracting angiosarcoma of the liver, normally an extremely rare disease (annual incidence of 1 to 2 x $10^{-7}$ in the general population; Byren and Holmberg, 1975). Since death certificates are considered highly unreliable in identifying specific types of cancers, Doll (1988) assumed that the 7-fold excess in liver cancers were all due to angiosarcomas. In the four major studies examined, approximately 2% of the deaths observed were attributable to angiosarcoma of the liver.

Doll (1988) also concluded it was "difficult to decide whether vinyl chloride produces small risks of cancers, compared to those due to nonoccupational causes, at sites other than the liver". In sufficient evidence was available to confirm, or refute, the possible causal relationships between occupational exposures to VCM and melanoma or cancer of the thyroid, brain, and the lymphatic or haematopoietic systems. In addition, the evidence of increased risks of lung cancer following occupational exposures to VCM were considered weak and unproven.

Doll (1988) also concluded that, since VCM is a proven mutagen and carcinogen in laboratory studies, and a carcinogen to humans, the minute exposures that would result from emissions escaping from VCM facilities must cause comparably minute risks to the general public. The concentrations of VCM measured near VCM/PVC production/manufacturing facilities are in the order of 10 to 40 ppb (EPA, 1975; Baxter *et al.*, 1977), or some 10,000-fold less than the several hundred or more ppm exposures that resulted in measurable occupational hazards.

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Therefore, cancer risks to the general public could not possibly be detected, with the possible exception of angiosarcoma of the liver, because of its extremely low incidence rate in the general population. The interpretation of causal relationships between VCM and angiosarcoma incidence in the general population is confounded because thorium dioxide and arsenic in pesticides and medicines have also been associated with the occurrence of angiosarcomas (Doll, 1988).

No cases of angiosarcoma were detected in populations living near VCM or PVC production facilities in Yugoslavia and Sweden (Saric *et al.*, 1976; Elinder *et al.*, 1981). In the UK, one cases out of 14 over a 12 year period was found in a man who lived half a kilometre from a PVC manufacturing facility. In New York state, 5 of 19 cases of angiosarcoma were in people living within 1 mile of facilities using or manufacturing VCM (Baxter *et al.*, 1977). However, more detailed examination of the 6 "neighbourhood" cases showed that 2 could not be attributed to VCM because the men only lived near the facilities for 6 and 8 years, respectively, a time period too short for the latency period needed for angiosarcoma. Therefore, Doll (1988) concluded that the discovery of four cases of angiosarcoma in people who lived near facilities that used VCM indicated there may have been a minute hazard to the general public from the VCM concentrations historically observed around manufacturing facilities. However, the concentrations of VCM around production facilities has decreased substantially since the 1970s. VCM air concentrations within a few hundred meters of VCM areas were below analytical detection limits (approximately 5 ppb) for three of five facilities in the UK, and the concentrations for the other two facilities were about 20 ppb (100 m outside the boundary fence), and 88 ppb (just inside the boundary fence). However, accidents and production start-ups were associated with higher concentrations (Turner *et al.*, 1984). Based on this evidence, Doll (1988) concluded that "according to any reasonable criterion the hazard to the general public (if there is any at all) must be negligible".

### 3.2.2.5 Exposure Limits

The U.S. EPA has published several estimates of the potential carcinogenic potency ($Q_1^*$) of VCM, based on the application of the linearized multistage model for dose-response extrapolation of data from various laboratory animal studies. In 1980, a $Q_1^*$ value of 0.0174



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(mg/kg body weight/day)$^{-1}$ was calculated based on preliminary data from laboratory rats exposed to 10,000 ppm VCM. In 1985, this $Q_1^*$ value was modified to 0.0295 (mg/kg body weight/day)$^{-1}$ using the lung and liver cancer incidence from rats exposed to 30,000 ppm VCM for one year. In 1987, the EPA Carcinogen Assessment Group calculated a potency slope of 2.3 (mg/kg body weight/day)$^{-1}$ based on the liver cancer incidence of a 143-week study on rats exposed orally to doses of 0-17 mg/kg body weight/day (5 days/week) (ATSDR, 1989). These three cancer potency slope estimates translate into RsD values of 0.575, 0.339 and 0.00435 μg/kg body weight/day at a lifetime risk of one per 100,000, a range of 132-fold.

With respect to occupational limits, the American Conference of Governmental Industrial Hygienists (ACGIH) has recommended a Threshold Limit Value (TLV) of 5 ppm (12.8 mg/m$^3$) Time-Weighted Average (TWA) (ACGIH, 1991), while a workplace standard of 1 ppm TWA was set by the Occupational Safety and Health Administration (OSHA) (ATSDR, 1989; Calabrese and Kenyon, 1991).

## 3.3 AQUATIC WILDLIFE HAZARD ASSESSMENT

### 3.3.1 Lab Studies

Goldfish exposed to vinyl (polyvinyl chloride) automotive upholstery fabric immersed in water exhibited a variety of toxic effects demonstrated hyperactivity, sluggishness, disoriented swimming, aimless drifting and complete mortality in 24 hours (Ahrens *et al.*, 1978) . Histopathological examination demonstrated congestion, degeneration and haemorrhage in the smaller blood vessels, particularly in the gills, as well as swollen edematous lamellae. Gas chromatography/mass spectrometric analysis identified the major component of the extract of the fabric as triphenyl phosphate. These results suggested that triphenyl phosphate was the compound released from PVC fabric that caused toxic effects in the goldfish.

No further information on the toxic effects of PVC was identified.

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## 3.4 TERRESTRIAL WILDLIFE HAZARD ASSESSMENT

No information was identified specifically on the potential effects of VCM or polyvinyl chloride on terrestrial wildlife. However, the responses of other terrestrial species would be expected to be similar to those demonstrated in the large number of studies on various laboratory animals.

## 3.5 OTHER ENVIRONMENTAL EFFECTS

Since the environmental fate characteristics of VCM indicate it is rapidly transformed in the environment, there would be little opportunity for effects on the physical environment by VCM *per se*.

## 3.6 SIGNIFICANCE OF ENVIRONMENTAL CONCENTRATIONS

The evidence reviewed demonstrates that the potential carcinogenicity related to occupational exposure is the primary environmental and human health concern related to VCM and PVC. Therefore, the evaluation of the significance of the concentrations of VCM in the environment will focus on the potential risks of cancer based on the premise that exposures that would not result in unacceptable cancer risks would not produce other adverse effects in the environment.

The assessment of potential environmental effects of chemicals are based on a large number of assumptions. Since these assumptions are inherently conservative to avoid underestimating risks due to rare circumstances, the compounding of a number of conservative or worst-case assumptions means that the absolute point estimates of the risk are usually over-estimated, although by an unknown degree. Comparative or incremental risks between the two or more different scenarios, on the other hand, can be estimated with much greater confidence since the same methodologies are used in addressing each situation and major uncertainties arise from the accuracies in estimating exposures. The assumptions used in the estimation of exposure limits and various exposure modifying factors are common across the scenarios being compared.

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Therefore, the assessment of the potential carcinogenic risks from VCM and PVC in the environment, as outlined below, is based on a comparison of the predicted risks, as characterized by different assessment procedures, associated with exposures to historical, present-day and predicted future concentrations of VCM in the environment.

## PVC

Except for pyrolytic breakdown products (addressed in a separate Chlorine Institute document on the Interpretive Review of the Potential Human Health and Environmental Effects Associated with the Incineration of Chlorinated Chemicals), the potential human health effects of PVC relate to exposures to PVC dusts in work environments. Exposures to such dusts would not be expected to occur outside the work environment. Historically, there were concerns about the measurable concentrations of non-polymerized VCM that could diffuse from materials constructed of PVC, or be released during pyrolysis. Changes in production processes have now resulted in a PVC product where VCM residues are below the detection limits of analytical procedures; thus alleviating potential concerns related to exposures to VCM diffusing from PVC.

## VCM

### Environmental Concentrations

Based on the physical/chemical properties and the resulting information on the environmental fate of VCM (*e.g.*, the majority partitioning into air where it is degraded quickly though reactions catalyzed by ultraviolet light), environmental concentrations, and therefore levels of potential exposures to VCM, would be virtually zero at locations remote (*e.g.*, several kilometres) from facilities involving the production, manufacturing and disposal of VCM and PVC. Therefore, the potential environmental and human health concerns related to VCM would be at locations near (within a few kilometres) of its production and use.

Since concentrations of VCM in air are greater inside production and manufacturing facilities, the potential levels of exposure of workers would be greater than for the general population.

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Primarily because of greater understanding of the potential risks of angiosarcoma of the liver from VCM exposures, the concentrations of VCM in air in the workplace showed marked decreases from values commonly in the range of 260 to 2600 mg/m$^3$ (approximately 100 to 1000 ppm) prior to 1955 to concentrations of approximately 13 mg/m$^3$ (5 ppm) by about 1975.

Further decreases in work environment concentrations have occurred since the mid 1970s. Workplace monitoring data demonstrate that air concentrations in non-production areas of facilities that manufacture and use VCM ranged from $<0.25$ to 10.5 mg/m$^3$ ($<0.1$ to 4.11 ppm) in 1988, and $<0.25$ to 2 mg/m$^3$ ($<0.1$ to 0.77 ppm) in 1992. In areas of plants involved in production and handling, VCM air concentrations ranged from 35 to 26.5 mg/m$^3$ (13.5 and 10.34 ppm) in one facility, and 0.5 to 11 mg/m$^3$ (0.2 to 4.11 ppm) in 1988, decreasing to 0.5 to 2 mg/m$^3$ (0.2 to 0.77 ppm) in 1992 in another facility (Vinyl Institute, personal communication, 1992). These data represent the greatest air concentrations reported for the four facilities over the 5 year period, 1988 through 1992.

Near (within a few hundred metres) VCM and PVC production and manufacturing facilities, IARC (1979) reported average air concentrations of 44 $\mu$g/m$^3$ (17 ppb) prior to 1979. Other researchers reported a range of 26 to 102 $\mu$g/m$^3$ (10 to 40 ppb) during this same time period (EPA, 1975; Baxter *et al.*, 1977). Air monitoring data collected after 1975, subsequent to the implementation of more stringent standards for workplace air concentrations, showed air concentrations within a few hundred meters of VCM production/handling areas were below analytical detection limits (approximately 13 $\mu$g/m$^3$ or 5 ppb) for three of five facilities in the UK, and the concentrations for the other two facilities were about 20 ppb (100 m outside the boundary fence), and 88 ppb (just inside the boundary fence) (Turner *et al.*, 1984).

Potential Consequences Associated with Environmental Concentrations of VCM

Based on the weight-of-available-evidence demonstrating the rapid dispersion and degradation of VCM in the atmosphere, and that the air concentrations measured near (within a kilometre) of VCM/PVC production/manufacturing facilities are below analytical detection limits (*e.g.*, $<5$ ppb), exposures of the general public to VCM would be virtually zero. A similar conclusion



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was reached by Doll (1988) regarding potential cancer risks to the general public from potential exposures to VCM emissions from production/manufacturing facilities. Very low exposures may be associated with VCM produced from the degradation of other chlorinated organic chemicals from natural and man-made sources (*e.g.*, 1,1,1-trichloroethane and 1,1-dichloroethane); however, no measurable health risks would be expected from such sources.

The question of potential risks to the general public living very near VCM production/manufacturing facilities remains to be addressed. The various risk estimates from exposures to the VCM concentrations observed near production/manufacturing facilities, based on the application of the various EPA cancer potency estimates for VCM, and the cancer incidence rates reported in workers exposed to VCM are summarized in Table 3-1. The first point arising from the various risk estimates in Table 3-1 is the large variation in risks estimated by the different methods. The most recent EPA exposure limit (0.00435 $\mu$g/kg body weight/day) (Calabrese and Kenyon, 1991) results in risk estimates at least 98000-fold greater than estimated by simple linear extrapolation of the cancer incidence observed in workers exposed to VCM concentrations of 100 to 1000 ppm to those observed near production/manufacturing facilities (*e.g.*, 10-40 ppb in the mid 1970s and $<5$ ppb in the mid 1980s). The 1980 EPA cancer potency estimate for VCM results in cancer mortality incidence at least 7400-fold greater than those predicted from observations in workers.

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Table 3-1 Cancer Risk Estimates for Near-Plant Air Concentrations of VCM

| Cancer Potency Estimate[1] $(mg/kg/day)^{-1}$ | Predicted Risks Near-Plant[2] (per 100,000) | |
|---|---|---|
| | Air Concentrations 10 - 40 ppb[3] | Air Concentrations <5 ppb[4] |
| 0.0174 (EPA, 1980) | 14 - 59 | 74 |
| 0.295 (EPA, 1985) | 25 - 100 | 26 |
| 2.3 (EPA, 1987b) | 1954 - 7816 | 982 |
| Epidemiology | | |
| 0.00024 @ 100 ppm | 0.08 - 0.008 | 0.01 |
| 0.000024 @ 1000 ppm | 0.2 - 0.02 | 0.001 |

(1) EPA (1980) cancer potency estimate = 0.0174; EPA (1985) cancer potency estimate = 0.0295; EPA (1987b) cancer potency estimate = 2.3, all expressed as $(mg/kg\ body\ weight/day)^{-1}$. Epidemiology cancer potency estimates are based on a liver cancer mortality of 2 per 100 (2%) (Doll, 1988) at estimated air concentrations between 100 and 1000 ppm (IARC, 1979), giving a cancer potency estimate range of 0.00024 to 0.000024 $(mg/kg\ body\ weight/day)^{-1}$, respectively, for a 70 kg individual breathing 23 $m^3$ of air per day and assuming a linear dose-response extrapolation.

(2) Near-plant air concentrations (within a few meters) were 26 to 102 $\mu g/m^3$ (10 to 40 ppb) in the mid-1970s (Baxter *et al.*, 1977), and $<13\ \mu g/m^3$ (<5 ppb) in the mid-1980s (Turner *et al.*, 1984).

(3) Exposure estimates calculated for a 70 kg individual breathing 23 $m^3$ of air per day. Predicted risk = (estimated exposure) x cancer potency factor.

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Assuming that environmental concentrations near production facilities were roughly proportional to the air concentrations in the work environment, a reduction in work environment air concentrations to $< 257\ \mu g/m^3$ ($< 100$ ppb) would be expected to result in an approximately 50-fold reduction in air concentrations near production facilities (*e.g.*, concentrations in the range of $0.26\ \mu g/m^3$, assuming values of $13\ \mu g/m^3$ associated with workplace concentrations at the time Turner *et al.* (1984) conducted their measurements. Therefore, risks from predicted present-day air concentrations near VCM production/manufacturing facilities would be expected to be some 50-fold less than those estimated in Table 3-1.

The estimates of risks associated with VCM exposures near production facilities as predicted by the EPA cancer potency factors are in stark disagreement with the conclusions of Doll (1988) that the potential risks associated with VCM exposures to the "general public (if there is any at all) must be negligible". One major reason for this apparent disagreement in potential risks may be related to the large degree of conservatism inherent in the EPA (1987) exposure limit for VCM as estimated using the linearized multistage model. An indication of this conservatism can be obtained through a comparison of the VCM cancer potency estimate derived by extrapolation of liver cancer mortality observed in workers with the various potency estimates of the EPA. This comparison indicates a difference in cancer potency of between approximately 9500 and 95000-fold. The greatest uncertainty in the epidemiological data lies in the estimated air concentrations to which the workers were exposed. However, even if the VCM exposure levels experienced by the workers were in the range of 10 ppm, the EPA (1987) approach would over-estimate the risk by approximately 950-fold. According to the information available, it is highly unlikely that the VCM air concentrations in work environments were $< 10$ ppm during the 1950s and 1960s when the workers were exposed (IARC, 1979).

If it is assumed that the cancer potency estimates based on the epidemiological data are reasonable, then the potential risks associated with the air concentrations of VCM predicted near production facilities would be in the range of 1 per 10 million and 1 per 100 million (Table 3-1). Such levels of risk would be clearly unmeasurable in any practical sense, and in agreement with the conclusions of Doll (1988) regarding potential risks of liver cancers from VCM exposures to the general public. In the future, improved production and manufacturing control

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technologies will continue to reduce emissions of VCM from production and manufacturing facilities. These expected reductions will reduce environmental loadings of VCM from anthropogenic point sources, thereby continuing to reduce the already negligible risks currently predicted from environmental concentrations of VCM near production and manufacturing facilities. The above assessment focuses primarily on potential exposures of the general public living near (*e.g.*, within a few kilometres) of VCM production and manufacturing facilities. Since VCM emissions remain almost exclusively in air, and it has a half-life in the environment of only a few days, its concentrations in air would decrease rapidly with distance from point sources. Therefore, potential health risks to the general public in regions remote from VCM production and manufacturing facilities would be negligible, and certainly unmeasurable.

Based on the above evaluation, the primary direct concerns regarding the potential impacts of anthropogenic sources of VCM on human health and the environment relate to point source emissions from facilities that production VCM or use it to manufacture various products. Therefore, the reduction or elimination of environmental impacts from VCM must be based on controlling air concentrations due to environmental releases from production and manufacturing facilities. Historically (*e.g.*, 1940s/50s) the concentrations of VCM reported in the workplace environment would have resulted in unacceptably high risks of cancer in workers. In addition, releases of VCM from production/manufacturing facilities were unacceptably high. The implementation of emission controls in such facilities resulted in substantial (*e.g.*, 200-fold or greater) reductions in VCM concentrations in the workplace. Releases to the surrounding environment would also be substantially reduced through these actions. Therefore, the available information does not indicate excessive cancer risks to workers or populations in the vicinity of industrial facilities that use VCM.

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