

Vista Chemical Company

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VRD 0002029891

VISTA

September 23, 1992

Mr. Art Dungan
The Chlorine Institute
2001 L Street, N.W.
Washington, D.C. 20036

Dear Art:

I have reviewed the first drafts of the PVC/VCM document and have the following general and specific comments.

PVC/VCM support document

A general concern is that the PVC/VCM support document is not as complete and detailed as it should be. The draft ATSDR(Oct. 1991) and EPA(1985) reviews of vinyl chloride are much more comprehensive. Since this document is to provide the needed scientific support, it should be as complete as possible. CanTox should compare this document with the ATSDR and EPA reviews for completeness.

The discussion of PCDDs and PCDFs should be handled as a separate issue. There are other sources of these materials besides PVC incineration. Including the discussion of PCDDs and PCDFs with PVC/VCM gives the false impression, to those who may read these documents superficially, that PCDDs/PCDFs are unique to this product category.

One of the most unique aspects of this document could be the risk assessment section. However, no alternative cancer potency estimate methodologies for VCM other than those currently in use by EPA are discussed. This should at least be mentioned, particularly the applicability of physiologically based pharmacokinetic methods. Dow Chemical and others have published work in this area.

Specific Comments:

Page A-3, Line 2: "Polyvinyl chloride is a polymer with undefinable physical chemical properties." On the contrary, PVC does have definable physical and chemical properties.

Page B-3, line 74: This sentence is incomplete.

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- Page C-2, line 22; "PVC is relatively inert and no lethality data have been reported." PVC producers may have some data that can be provided.
- Page C-2, lines 24-30: A more complete review of studies investigating the pulmonary effects of PVC dust needs to be given.
- Page C-2, lines 32-38: No mention is made of a recent report by Maltoni of an oral gavage carcinogenicity study of PVC dust(was supposed to be published in Acta Oncologia.
- Page C-3, line 56: "...a limit of 1 mg/m³" should be changed to: "a limit of 10 mg/m³".
- Page C-6, lines 119-131: Should include references the different pathways of metabolism and their saturation at different exposure concentrations.
- Page C-7, Line 155: What does this sentence mean?
- Page C-8, line 159: Peripheral circulatory and nervous system effects have long been associated with VCM overexposure and should be discussed under non-lethal effects.
- Page D-5, line 13: What is the reference for the EPA recommended VCM exposure limit?
- Page D-5, line 13: How was this exposure limit calculated? How was the 125-fold margin for VCM exposure calculated? The basis for these numbers should be clarified.
- Page D-6 Consideration of PVC pulmonary effects needs to be woven into the human health discussion in addition to consideration of the carcinogenicity of VCM.
- Page D-6, line 31 "...controlling VCM levels in PCV products would alleviate such concerns.". This sentence is too vague. There needs to be more discussion of the health concerns associated with PVC besides those associated with the presence of VCM(such as pulmonary effects).

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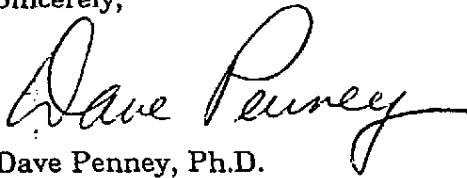
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HCL support document

The document should contain references to the work done by the Vinyl Institute and others showing the difference in both short-term and long-term responses to acute HCL exposure between rodents and baboons.

I would be happy to discuss these comments further, if needed.

Sincerely,

A handwritten signature in cursive script that reads "Dave Penney". The signature is fluid and extends to the right.

Dave Penney, Ph.D.
Manager, Product Safety
Vista Research and Development

cc: Bob Burnett, Vinyl Institute

bcc: J. Kirkpatrick, R. Quay

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VISTA

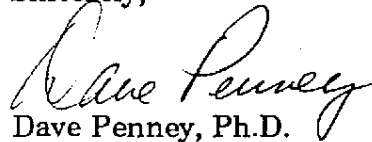
March 30, 1993

Dr. Robert Willes
Vice President, Environmental Services
CAN TOX Inc.
2233 Argentia Road
Suite 308
Mississauga, Ontario, Canada L5N 2X7

Dear Dr. Willes:

Enclosed is a mark up of the VCM/PVC document. I have only included the pages where a comment has been made. I hope this is helpful.

Sincerely,



Dave Penney, Ph.D.
Research Manager, Product Safety
Corporate R&D

cc: Art Dungan, The Chlorine Institute (with attachments)

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.

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/m³). 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 ^{on} positive data from numerous mammalian laboratory studies. Vinyl chloride administered orally or by ~~inhalation~~ ^{or} to mice, rats and hamsters produced tumors 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

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

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.

(units ?)

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 2.34 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 $\mu\text{g/kg}$ body weight/day at a lifetime risk of one per 100,000, a range of 132-fold.

Need to
define RsD
values

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 $\mu\text{g/kg}$ 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

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.

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).~~ *redundant*

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.

VCM Emissions

- The major anthropogenic 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).

VCM?

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/m³ 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).

What about recent EPA tri data? (see 3-1)

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.

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).

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

(MacKay et al., 1992)

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.

Level I Fugacity Modelling
Vinyl Chloride

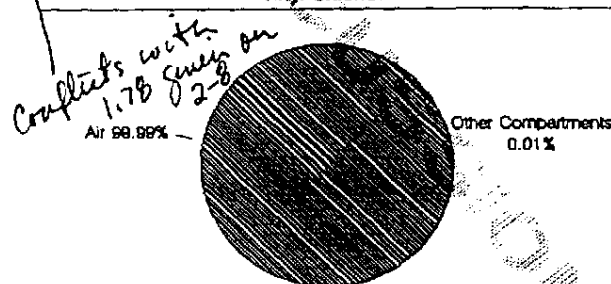


Figure 2-1

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/m³ (10 ppm) by volume or total releases remain less than 2 kg/day, whichever is greater (Gendron, 1981). According to IARC (1979), the EPA (1977) proposed to be reduced the air emission guideline to 13 mg/m³ (5 ppm). The Federal Republic of Germany has an emission standard of 3 kg VCM/hour/source (150 mg/m³ 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 µg/m³ 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/m³ (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.

The current OSHA workplace standard in the U.S. is 1 ppm (8 hr TWA) with a 5 ppm short term exposure limit (STEL). 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 µg/L. This value was based on estimated exposure limits for

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 released 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.

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

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 $44 \mu\text{g}/\text{m}^3$ (17 ppb) (IARC, 1979). In Houston, Texas where large quantities of VCM are produced, air concentrations ranged from $8 \mu\text{g}/\text{m}^3$ (3.1 ppb) to peak values of $3,200 \mu\text{g}/\text{m}^3$ (1,200 ppb) (Gordon and Meeks, 1977). In Long Beach, California, ambient air concentrations of VCM near two VCM plants ranged from 260 to $8,800 \mu\text{g}/\text{m}^3$ (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 $100 \mu\text{g}/\text{m}^3$ (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 $13,000 \mu\text{g}/\text{m}^3$ (5 ppm) in 1975, showed that air concentrations of VCM were near the analytical detection limit (about $13 \mu\text{g}/\text{m}^3$ or 5 ppb) in three of five British plants. For two other facilities, the VCM air concentrations were approximately $50 \mu\text{g}/\text{m}^3$ (20 ppb) 100 m outside the facility boundary, and $225 \mu\text{g}/\text{m}^3$ (88 ppb) just inside the boundary fence (Turner *et al.*, 1984).

The highest level of VCM measured in U.S. drinking water was $10 \mu\text{g}/\text{L}$ 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 $20 \mu\text{g}/\text{L}$ and were as high as $23 \mu\text{g}/\text{L}$ (Kizer, 1986). In the Los Angeles area, ground water ~~to contain~~^{ed} less than $1 \mu\text{g}/\text{L}$ of VCM (Baird *et al.*, 1983), while in non-specified areas of Nebraska and California ground water concentrations ranged from 0.75 to $23 \mu\text{g}/\text{L}$ (Goodenkauf and Atkinson, 1986; CSDHS, 1990).

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 ($< 0.5 \mu\text{m}$) 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;

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 PVC.

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

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/m³ (ACGIH, 1992). The United States Occupational Safety and Health Administration (OSHA) has set limits for inert or nuisance dusts of 15 mg/m³ (total) and 5 mg/m³ (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/m³ (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 ¹⁴C in the urine and expired air, between 70 and 95% of the dose was absorbed following a single oral administration of [¹⁴C]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).

↑
This is not a dose.
Are units correct?

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 [¹⁴C]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 [1,2-¹⁴C]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-transferase-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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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%.

Should explain this effect briefly for those not acquainted with it.

The UK study (Jones, 1988) evaluated 5,498 workers who experienced at least one year of exposure to VCM for at least 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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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". Insufficient 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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(mg/kg body weight/day)⁻¹ was calculated based on preliminary data from laboratory rats exposed to 10,000 ppm VCM. In 1985, this Q₁* 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 μ g/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/m³) 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.

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 $<257 \mu\text{g}/\text{m}^3$ ($<100 \text{ ppb}$) would be expected to result in an approximately 50-fold reduction in air concentrations near production facilities (e.g., concentrations in the range of $0.26 \mu\text{g}/\text{m}^3$, assuming values of $13 \mu\text{g}/\text{m}^3$ 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 overestimate the risk by approximately 950-fold. According to the information available, it is highly unlikely that the VCM air concentrations in work environments were $<10 \text{ ppm}$ 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