

Appendix B

Evaluation of the Bioaccumulation Potential for Vinyl Chloride

1.0 Introduction

The terminology of bioaccumulation is used to describe the uptake of chemicals from both water and diet whereas bioconcentration is used to represent uptake from water alone. The mechanism behind this bioaccumulation process is the propensity for some chemicals to have much higher solubility in an organisms lipid (fat) than in the ambient water. The bioaccumulation process is driven by the lipophilic contaminants that have much lower fugacity (escaping tendency) from fatty tissues than from water.

The following sections present a brief summary of the terminology, key processes and important considerations that have been developed over the last 30-plus years of research regarding bioaccumulation in aquatic organisms. Four types of variables affect bioaccumulation:

- 1) Physical-chemical properties of the contaminant molecules
- 2) Environmental conditions
- 3) Characteristics of the exposed organism
- 4) The organism's food chain

Each of these differing factors may work to increase or decrease bioaccumulation. As a result, a wide range of bioaccumulation potentials for various compounds and conditions have been predicted and observed.

2.0 Chemical Related Factors

The physical/chemical properties of a contaminant molecule play a central role in the bioaccumulation process. Key chemical/physical properties include the following:

- 1) Lipophilicity, which is directly related to the magnitude of a chemical's solubility in octanol, and typically characterized by the magnitude of the octanol-water partition coefficient K_{ow} .
- 2) Low water solubility (hydrophobicity) due to the lack of polar functional groups
- 3) Structural stability resulting in environmental persistence (typically years instead of days).
- 4) Chemicals of moderate molecular weight and size (i.e., molecular weight of about 350 and molecular breadth of less than 10 Angstroms), and lacking ionizable functional groups have a greater tendency to bioaccumulate.

2.1 Applicability to Vinyl Chloride

Related to these specific physical/chemical properties, the bioaccumulation potential for vinyl chloride is considered low based on the following:

The K_{ow} of 21 is very low relative to other compounds which have been shown to bioaccumulate. The solubility of 2,700 mg/L is sparingly soluble but still much higher than other compounds which have been shown to bioaccumulate.

The persistence in the environment is low (typically hours to days).

Vinyl chloride is of a molecular weight and size that could potentially bioaccumulate.

3.0 Environmental Related Factors

The environmental presence of chemicals that meet most of the chemical/physical properties noted above does not always lead to high degrees of bioaccumulation. This attenuation of bioaccumulation is often due to limited bioavailability. For bioaccumulation to occur, a contaminant must contact a tissue membrane and move through the membrane to lipid-rich fat cell tissues within the organism. The amount of chemical making contact with an organism's

absorbing membranes is dependent not only on its environmental concentration in the bulk water phase (also including any sorbed phases on small particulates), but also on the fractional amount that is available for uptake (i.e., the bioavailable fraction). This bioavailable fraction usually corresponds with the fraction of chemical that is truly dissolved in water.

Lipophilic or bioaccumulative chemicals also have high affinities for organic carbon particulates suspended in the water and also present in sediments. The organic carbon common in sediments has some of the same chemical characteristics as lipid. In many aquatic systems most of the mass of a highly lipophilic contaminants are usually sorbed on particulate organic carbon, not dissolved in water.

Another critical factor that affects the potential of a compound to bioaccumulate is the environmental stability or persistence of the compound in the specific media. The effects of environmental degradation processes (e.g., hydrolysis, photolysis and microbial degradation) on contaminant molecules typically result in more hydrophilic (water-loving) or polar products, which have lower bioaccumulation potentials than the parent compounds. In addition, transfer from the dissolved phase through volatilization, may significantly limit the persistence (and hence the time-frame feasible for bioaccumulation to occur). The overall effect of these degradation/removal processes is to reduce parent compound concentrations and organism exposure time. These factors can, in some circumstances, reduce the amount of contaminant available to be bioaccumulated.

3.1 Applicability to Vinyl Chloride

Related to these environmental factors, the bioaccumulation potential for vinyl chloride is considered extremely low based on the following:

The persistence in the environment is low (typically hours to a day or two).

The known environmental degradation products are ethene and CO₂.

4.0 Organism Related Factors

Lipophilic contaminants are accumulated by aquatic organisms from water via respiration, and from ingestion of food or sediments. Bioconcentration (uptake from water) is generally viewed as the predominant route of uptake for most chemicals by aquatic organisms. Fish can ventilate multiple liters of water across the gill membranes, and the gill is generally the principal point of contaminant entry into an aquatic organism. The assimilation efficiencies of a variety of lipophilic compounds by this route range from about 20 to 90% of the contaminant residues present in ventilated water.

Diet is more likely to be the major route of uptake when chemicals are persistent and have high K_{ow} (i.e., greater than 10^5). This is particularly true for the top predators of a food chain (such as seals or other marine mammals in aquatic ecosystems and raptors or polar bears in terrestrial ecosystems). The assimilation efficiency of lipophilic chemicals across the gut is dependent on the quality of the ingested materials. Gut assimilation efficiencies for a series of lipophilic chemicals, from high quality fish food (e.g., animal or plant tissues), have been shown to range from about 50 to 85%. The lipid content of the consumer organism has little or no effect on dietary and respiratory uptake rates of chemicals but it does affect the ultimate capacity of an organism to accumulate a chemical.

Bioaccumulation occurs only if the rate of a chemical's uptake exceeds the rate of its elimination. In aquatic organisms, depuration of many lipophilic chemicals occurs passively across the gills. This route of elimination is of primary importance for nonpolar compounds that are not

metabolized and the elimination rates for these compounds are generally inversely related to their K_{ow} (Spacie and Hamelink 1985).

In many organisms (especially mammals, birds, and aquatic vertebrates), both the enzyme system known as the cytochrome mixed-function monooxygenase (MFO) system, and the aryl hydrocarbon hydroxylase system are responsible for the biotransformation of a variety of compounds, such as vinyl chloride. Biotransformation products are typically more hydrophilic and have more rapid elimination rates than their parent compounds. In fish, birds, and mammals, most MFO activity is localized in the liver and the route of elimination of the more hydrophilic metabolites is by the bile. Although the MFO system effectively detoxifies and reduces the bioaccumulation of many contaminants, certain compounds can also be transformed to intermediates that are more toxic than the parent compounds.

The ability to eliminate accumulated contaminants by all processes is thought to vary among species according to the following general trend:

mammals > fishes > crustaceans > bivalve molluscs.

4.1 Depuration/Elimination by Aquatic Organisms

Bioaccumulation can only occur if the rate of a chemical's uptake exceeds the rate of its elimination. Both the toxicity and bioaccumulation potential of a contaminant are greatly affected by the rate of elimination from an organism. If an unaltered chemical can be eliminated rapidly, it will not bioaccumulate. In aquatic organisms, depuration of many lipophilic chemicals occurs passively across the gills, and in some cases the skin.

Gill elimination appears to be most important for nonpolar compounds that are not rapidly biotransformed. The rates of elimination for these compounds are generally inversely related to K_{ow} , (Spacie and Hamelink 1985), unless metabolism is the major route of elimination.

In the case of contaminants that are readily metabolized, such as vinyl chloride, the major route of elimination in fish and other vertebrates is by the bile or urine. Metabolites are usually formed in the liver and transported to the gallbladder, where they are discharged with the bile into the gut and eliminated in the feces. These metabolites have much greater elimination rates than the parent compound.

4.2 Metabolism of Vinyl Chloride

The metabolism of vinyl chloride is relatively rapid and has been studied extensively since the metabolites play a key role in its' toxicity. Metabolism of vinyl chloride is believed to proceed via three different pathways; the extent of which is dependent on vinyl chloride concentrations. At low concentrations, vinyl chloride is oxidized sequentially to 2-chloroethanol, 2-chloroacetaldehyde and 2-chloroacetic acid by alcohol dehydrogenase (ATSDR, 1988). At higher concentrations, vinyl chloride is metabolized by liver cytochrome P-450 IIE1 to the reactive oxirane, 2-chloroethylene oxide, and its rearrangement product 2-chloroacetaldehyde (Guengerich et al, 1991; Gwinner et al., 1983). Both 2-chloroethylene oxide and 2-chloroacetaldehyde have been shown to produce DNA adducts, which are thought to play a role in vinyl chloride toxicity (Fedtke et al., 1990; Barbin et al. 1985, Swenberg et al., 1992). The elimination of vinyl chloride follows first-order kinetics (ACGIH, 1991). The excretion pathway is governed by the extent of exposure, rather than the route of exposure. At low exposure levels, the majority is excreted in urine (Watanabe et al., 1978).

As noted in the laboratory tests implemented to measure a BCF for vinyl chloride, the metabolic processes complicate any reliable measurements (Freitag et. al. 1985, Lu et. al. 1977). The measurements of ^{14}C in fish and test water is actually a measurement of the radioactive components remaining in the system. For fish, this will include the parent compound (if any) and all metabolites/degradates that contain the labeled ^{14}C . The applicability of BCFs measured in this fashion (when metabolism is important) have been seriously questioned over the last 25 years (e.g., see Spacie and Hamelink 1982, Sijm et. al. 1995). This type of BCF test measures the ^{14}C labeled atoms, not the molecules which are subject to metabolism and the molecules (not the atoms) are the toxic compounds of concern.

4.3 Applicability to Vinyl Chloride

Related to these organism-specific factors (metabolism and depuration), the bioaccumulation potential for vinyl chloride is considered extremely low for the following reasons: Vinyl chloride is known to be rapidly metabolized.

5.0 Food Chain Related Factors

Biomagnification is the increase in the bioaccumulation factors (BAFs) of certain chemicals in organisms occupying sequentially higher trophic positions in a food chain. This phenomenon is generally thought to occur through the following sequence of events. As lipids of contaminated prey are digested in the gut of predator, the capacity of the digestate (due to its increased polarity) to retain nonmetabolized lipophilic contaminants is reduced, resulting in the net transfer of these chemicals to the predator's lipid-rich tissues. As the predator continues to consume numerous prey, the rates of uptake by the diet can exceed the rate of elimination, resulting in contaminant concentrations higher than those that would be found in the predator's fatty tissues at equilibrium (with ambient water). If this animal is, in turn, consumed by a predator of higher trophic level, a further magnification in residue concentrations can occur. In cases where the predators are fish-eating birds and mammals having high consumption rates of contaminated fatty prey and limited elimination pathways, biomagnification can result in residue concentrations that are 100-fold higher than the equilibrium values.

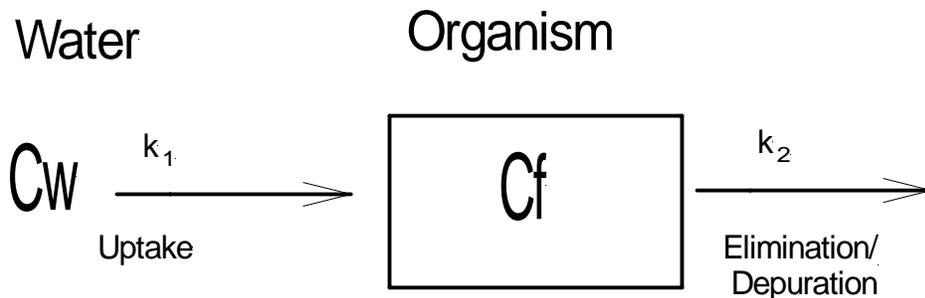
5.1 Applicability to Vinyl Chloride

Related to these food chain bioaccumulation considerations, the bioaccumulation potential for vinyl chloride is considered extremely low for the following reasons: Vinyl chloride is known to be rapidly metabolized and therefore cannot be biomagnified to higher trophic levels.

6.0 Kinetic Models of Bioaccumulation

Bioaccumulation is a dynamic biological process but the bioconcentration portion (uptake from water) of the process is generally modeled by a simple, one-compartment kinetics model. A compartment model is a simple mass balance describing the quantity of a chemical (assumed to be in a uniform matrix) which is determined by competing rates of chemical uptake and elimination. Compartment models are a standard tool used in pharmacokinetic studies and are useful to help understand the relations between competing processes which affect bioaccumulation.

The simplest example is a single cell diatom, in which bioconcentration is governed by passive diffusion through the cell membrane and the chemical partitioning between the cell's lipid and the surrounding water. In this case the rate of change of contaminant concentration in the cell lipid over time is given by (Spacie and Hamelink 1982):



$$dC_f/dt = \text{uptake} - \text{loss} = k_1 C_w - k_2 C_f$$

where k_1 is the uptake rate constant, C_w , is the concentration of the chemical in water, k_2 , is the first-order elimination or depuration rate constant, and C_f is the concentration of the chemical in tissue. After a sufficient exposure duration (days to months), concentrations in tissues approach steady state with the surrounding water.

$$dC_f/dt = k_1 C_w - k_2 C_f = 0$$

Integration of the differential equation yields;

$$C_f = k_1/k_2 C_w [1 - \exp(-k_2 t)] \quad \text{or} \quad C_f = \text{BCF} C_w [1 - \exp(-k_2 t)]$$

where,

$$\text{BCF} = C_f/C_w = k_1/k_2$$

The assumptions used in deriving this type of one-compartment model are that uptake is solely from water, the water concentration remains constant, and that the compartment is homogeneous with respect to chemical concentration. The time required to reach steady state is dependent on the magnitude of k_2 (the loss-rate constant) and this information may be used to predict suitable half-lives for process reactions/experimental designs. Additionally, the compartment model specifically defines the BCF as the ratio of uptake (k_1) and loss (k_2) functions. The uptake and loss functions (k_1 and k_2 relationships) may be derived empirically from lab studies (Spacie and Hamelink 1985). Alternatively, they may be described in further process related equations representing an organism's respiration rate, chemical transfer efficiencies, excretion rates and growth rates which are normalized (typically) to the K_{ow} of a compound (e.g., see Thoman et al., 1992, and Connelly 1991).

6.1 Applicability to Vinyl Chloride

Related to the kinetic modeling of uptake considerations, the bioaccumulation potential for vinyl chloride is considered undefined for the following reasons:

We are not aware of any data to calibrate a kinetic uptake model, all relevant research has focused on chemicals expected to be problems. The form of the compartment model, where ($\text{BCF} = k_1/k_2$), does provide a useful illustration of the relation between losses (metabolism/elimination) and a BCF.

7.0 Summary of Available BCF Measurements/Estimates

The potential for bioaccumulation of vinyl chloride has been studied in both laboratory and field-scale settings. A brief summary of pre-existing research (specifically related to vinyl chloride and used in the prior risk evaluation of discharges from the EMF VOC plume) is presented in the following sections.

7.1 Field Measurements

Several field studies are summarized in the literature that have included direct measurements of the BCF potential for vinyl chloride. The following sections provide a brief summary of relevant information.

7.1.1 Gossett et. al., 1983

An early research project (field measurements) regarding bioaccumulation of organic compounds in marine organisms (Gossett, et al., 1983) describes extensive water, sediment and biological tissue sampling completed at and around the discharge zone of the Los Angeles County wastewater treatment plant (WWTP). The research was funded by a grant from NOAA to the Southern California Coastal Research Project. The Los Angeles County WWTP has a design capacity of 400 MGD and a reasonable average discharge over the period would be 75% of design capacity (300 MGD or 208,000 gpm). Sampling included quarterly monitoring of the final WWTP effluent from November 1980 to August 1981. Sediments were also sampled (0-2 inch depth) in the discharge zone corresponding with the WWTP sampling dates. Biological tissue samples were collected in June 1981 using standard otter trawls to collect halibut, sandabs, sole, scorpion fish, white croaker, prawns and crabs (*Paralichthys californicus*, *Citharichthys xanhostigma*, *Microstomus pacificus*, *Scorpaena guttata*, *Genyonemus lineatus*, *Sicyonia ingentis*, and *Mursia quadichaudii*).

The laboratory testing used EPA approved protocols for priority pollutant analysis. The fish liver samples were from a composite of 1-10 individuals. The analyses of crab digestive glands and shrimp muscle tissue were a composite of ten individuals. The whole invertebrate samples were based on a composite of at least 100 individuals (Gossett, et al 1983). Vinyl chloride was detected in the WWTP final effluent at an average concentration of 6.2 ug/L (5 samples) but was below the method's reporting limits in all of the sediment or biological tissue samples. The vinyl chloride loading to the discharge zone is estimated at 15.4 lbs/day (based on 300 MGD discharge and 6.2 ug/L average vinyl chloride concentration). The reported results for selected analytes are shown in Table B-1.

The primary conclusions of this seminal paper regarding organic compounds in marine organisms included:

- 1) Bioaccumulation of organic compounds with a high K_{ow} , can present an important ecological and human health risk.
- 2) Bioaccumulative compounds (high K_{ow} s) may represent a risk even when discharges are at sub-ppb (ug/L) levels whereas compounds with low K_{ow} s may not represent significant bioaccumulation risk even 100 ppb levels.

Table B-1 BCF Potential Data Reported by Gossett et. al., 1983

Compound	Log K _{ow}	Effluent Concr.	(n)	Sediment Concr.	(n)	Sanddab liver	(n)	Scorpion Fish liver	(n)	Sole Liver	(n)	Croaker liver	(n)	Shrimp muscle	(n)	Invertebrates whole	(n)
Aroclor 1254	6.11	0.052	(2)	678	(1)	4,920	(5)	1,140	(3)	615	(5)	1,100	(5)	18	(5)	19	(3)
Aroclor 1242	5.58	0.94	(2)	256	(1)	772	(5)	143	(3)	166	(5)	224	(5)	22	(5)	13	(3)
PCE	2.6	29	(5)	<0.5	(2)	23	(1)	29	(1)	19	(1)	11	(1)	<0.3	(1)	8	(1)
TCE	2.29	17	(5)	<0.5	(2)	2	(1)	6	(1)	4	(1)	2	(1)	0.3	(1)	7	(1)
Vinyl chloride	1.52	6.2	(5)	<0.5	(2)	<0.3	(1)	<0.3	(1)	<0.3	(1)	<0.3	(1)	<0.3	(1)	<0.3	(1)

Effluent concentrations in ug/L

Sediment concentrations in ug/kg dry weight

Tissue concentrations in ug/kg wet weight

7.1.2 Wang et. al.,1985

Another relevant project was implemented in a drainage canal connecting to the Indian River near Vero Beach Florida in 1981 and 1983 (Wang et. al., 1984 Wang et. al., 1985). The Indian River is a lagoonal estuary along the central east coast of Florida, the drainage channel is a small canal (width of approximately 20 feet, with flow rates from 7 to 550 cfs). The project was initiated when solvent contamination (TCE, DCE and vinyl chloride) in groundwater was found in a well at the airport. A city supply well was impacted and closed immediately. The remedial action selected was to pump the groundwater (average extraction rate of 0.2 MGD; 138 gallons per minute) and discharge it to an adjacent drainage canal which flows to the Indian River. The plan was to spray the extracted water into a hydraulic jump in the drainage canal to promote volatilization (and also to mix the discharge with the canal flow).

Performance monitoring indicated that a portion of the VOCs were volatilized in the discharge process (~ 70-80%). The canal and river were monitored weekly to assess the potential impacts on the canal and estuarine environment. Measurements in the discharge zone were basically reduced by the dilution of the discharge concentration (after treatment) with the baseline canal flow. The project essentially used the drainage canal as a physical/biological treatment zone for the secondary treatment of extracted groundwater. In order to verify the effectiveness and safety of the treatment process, a weekly sampling program was implemented throughout the project which included surface water, sediments and biological tissues (on different frequencies). The monitoring work was completed by the Harbor Branch Foundation (now known as the Harbor Branch Oceanographic Institute). The ranges of VOC concentrations reported in the treated water include:

TCE	3,165 to 30.3 ug/L
cis-1,2 DCE	1,883 to 413 ug/L
vinyl chloride	136 to 34 ug/L

Dilution flow rates from the baseline flow in the drainage canal varied (with rain events) from roughly 24:1 to as high as 1790:1 (from 7.4 to 556 cubic feet per second, cfs). The vinyl chloride loading to the canal is estimated to have ranged from 0.2 to 0.04 lbs/day, with TCE loading ranging from 4.6 to .05 lbs/day (based on 0.2 MGD discharge and the measured discharge concentrations, after treatment). The discharge to the canal was continuous for a 31-month period. VOCs were detected in water samples throughout the length of the canal (decreasing in distance from the discharge area). Tissue samples from oysters (*Crassostrea virginica*) collected at the saltwater transition in the canal detected TCE at concentrations from <0.1 to 10.8 ng/g. Within the canal, sediments and biota, vinyl chloride was not detected in any of the water samples (<1 ug/L), sediment samples (<2 ng/g) or oyster tissue samples (< 4 ng/g). All samples included duplicates.

7.1.3 USGS 2003

The USGS has completed extensive soil, groundwater, storm water, lake water and fish tissue sampling at the Naval Weapons Industrial Reserve Plant (NWIRP, USGS 2003) near Dallas Texas. Some of the primary compounds of concern at NWIRP are chlorinated solvents in groundwater discharging to surface water. A plume of chlorinated solvents is present in groundwater beneath most of NWIRP derived from degreaser operations and tanks. Several areas have been identified on where fuel and chlorinated compounds have been found in soil and groundwater. The groundwater plume at the site is known discharge to Cottonwood Cove (a narrow embayment with limited flushing) connected to Mountain Creek Lake.

Chlorinated compounds are detected in groundwater wells throughout the site and have been detected in storm discharges at the west lagoon and east lagoon outfalls. Overall, vinyl chloride was detected in 13% of the storm water samples with concentrations ranging from non-detect up to 9 ug/L. Samples of lake water and fish tissue samples (catfish fillets) are reported as non-detect for vinyl chloride for all sampling events.

7.1.4 Other NPL sites with Vinyl Chloride Discharges to Surface Water

Several other NPL sites have included fish tissue sampling (for VOCs) in cases where vinyl chloride is present in groundwater which discharges to an adjacent surface water body. Examples include; Air Force Plant 4 near Fort Worth Texas (ATSDR 1998); the Brio Refinery near Houston Texas (ATSDR 2002); and Kelly Air Force Base near San Antonio, Texas. The fish tissue sampling results for these sites are reported in EPA's STORET database. All samples are reported as non-detect for vinyl chloride in all fish tissue samples.

7.2 Laboratory Measurements

Very few laboratory measurements of BCF potential for vinyl chloride have been reported or identified. The two that have been identified are summarized in the following sections.

7.2.1 Lu et. al., 1977

This report tests the BCF potential for three compounds using ^{14}C labeled formulations; benzo(a) pyrene, benzidine, and vinyl chloride. The authors report their results as vinyl chloride equivalents based on the ^{14}C distributions (between water and fish tissue). The authors note:

“ the extractable ^{14}C from the various organisms showed clear cut spots at the origin (hexane solvent) suggesting that the ^{14}C was present as polar radioactivity from conjugates, etc., rather than as vinyl chloride.”

This statement indicates they believe that metabolism of vinyl chloride was apparent. They also emphasize the difficulty in working with the highly volatile vinyl chloride and suggest that vinyl chloride is not biomagnified to any substantial degree.

7.2.2 Freitag et. al., 1985

This report tests the BCF potential for 100 organic compounds using ^{14}C labeled formulations. The authors report their results as vinyl chloride equivalents based on the ^{14}C distributions (between water and fish tissue) as a BCF <10 indicating that bioaccumulation was not detected at their minimum level of measurement precision. The authors note that their results may suggest a detoxification process in higher developed organisms such as fish.

7.2.3 Laboratory Approaches to Measure BCF

The laboratory procedures, typically counting the phase partitioning of ^{14}C labeled compounds, is not effective for compounds such as vinyl chloride which are known to be metabolized. The laboratory tests also note the difficulty in working with highly volatile compounds (under ideal controlled laboratory conditions). That information should clearly be applied to dose-modification factors where the common/typical methods of fish preparation are known (EPA 2000b).

7.3 BCFs Derived from Regression Equations with K_{ow}

Several useful regression equations have been developed expressing the relationship between BCFs (for fish) and K_{ow} s of nonpolar, stable (“inert”) chemicals. Many well known examples are published the relevant literature (e.g., see Neely et al 1974, Veith 1979, Boethling and Mackay 1992, and others). The high correlations that have been observed between BCF and K_{ow}

however, limited to the specific classes and types of chemicals in the dataset. Many of these correlation studies are derived from data for relatively stable compounds such as polychlorinated biphenyls, chlorinated benzenes, and chlorinated naphthalenes. Correlations on the basis of more polar and "less inert" chemicals often have a much lower statistical quality which is due to various metabolic processes (de Wolf, et. al. 1992). The compartment model of bioaccumulation processes explicitly defines the loss rate (as a first order degradation rate constant) due to metabolic processes in the denominator of the BCF equation.

7.4 Applicability to Vinyl Chloride

Related to the applicable data (field measured, lab measured and other estimates), the bioaccumulation potential for vinyl chloride is considered extremely low for the following reasons:

- 1) Field measurements where long-term significant vinyl chloride loading has occurred to aquatic systems have not detected any bioaccumulation.
- 2) Attempts at laboratory measurement of a BCF for vinyl chloride are necessarily qualified with statements that metabolism appears to be important and that the ^{14}C counts do not measure vinyl chloride molecules in a tissue (only labeled carbon atoms).
- 3) The existing BCF/ K_{ow} regression equations have been developed with data sets that do not reflect the well documented metabolic processes affecting vinyl chloride elimination/depuration. Current guidance prepared by EPA 2000a (specifically related to AWQCs and the potential for organic chemicals to bioaccumulate in fish) indicates that use of BCF/ K_{ow} regression equations are not appropriate for chemical which are known to be metabolized.

8.0 References

ATSDR 1998 Public Health Assessment , U.S. Air Force Plant No. 4 (General Dynamics), Fort Worth, Tarrant County, Texas. Prepared by Texas Department of Health and the Agency for Toxic Substances and Disease Registry.

ATSDR 2002 Health Consultation, Clear Creek, Harris, Brazoria, Galveston Counties, Texas. Prepared by Texas Department of Health and the Agency for Toxic Substances and Disease Registry.

Barbin A, Besson F, Perrard MH, et al. 1985. Induction of specific base-pair substitution in E. coli trpA mutants by chloroethylene oxide, a carcinogenic vinyl chloride metabolite. *Mutat Res* 152:147-156.

Boethling R.S. and D. Mackay. 1992 Handbook of Property Estimation Methods for Environmental Chemicals: Environmental and Health Sciences, Lewis Publishers

EPA 1979 , Callahan, M.A., M.W. Slimak, N.W. Gabel, et al. Water-Related Environmental Fate of 129 Priority Pollutants. Volume II. EPA-440/4-79-029b. U.S. Environmental Protection Agency, December 1979, Washington, D.C.

EPA 1980a. Ambient Water Quality Criteria for Trichloroethene, EPA 440/5-80-077. U.S. Environmental Protection Agency Office of Water, Criteria and Standards Division.

EPA 1980b. Ambient Water Quality Criteria for Dichloroethene, EPA 440/5-80-041. U.S. Environmental Protection Agency Office of Water, Criteria and Standards Division.

EPA 1980c. Ambient Water Quality Criteria for Vinyl Chloride, EPA 440/5-80-078. U.S. Environmental Protection Agency, Office of Water, Criteria and Standards Division.

EPA 1999 Toxicity Reference Values; Screening Level Ecological Risk Assessment Protocol U.S. Environmental Protection Agency, Washington, D.C.

EPA 2000a. Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (2000) Technical Support Document Volume 2: Development of National Bioaccumulation Factors.

EPA 2000b Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories Volume 2 Risk Assessment and Fish Consumption Limits. Third Edition. United States Environmental Protection Agency Office of Water, EPA 823-B-00-008.

EPA 2002. ACQUIRE Database Search, ECOTOX:Ecotoxicology Database USEPA/Office of Research and Development, Mid-Continent Ecology Division.

Federal Register: December 31, 2003 (Volume 68, Number 250), Page 75507-75515

Fedtke N, Boucheron JA, Walker VE, et al. 1990. Vinyl chloride-induced DNA adducts. II: Formation and persistence of 7-(2-oxoethyl)guanine and N2,3-ethenoguanine in rat tissue DNA. *Carcinogenesis* 11(8):1287-1292.

Gossett RW, Brown DA, and Young DR. 1983. Predicting the bioaccumulation of organic compounds in marine organisms using octanol/water partition coefficients. *Mar Pollut Bull*, 14: 387-392.

Guengerich FP, Kim D-H, Iwasaki M. 1991. Role of human cytochrome P-450 IIE1 in the oxidation of many low molecular weight cancer suspects. *Chem Res Toxicol* 4(2):168-179.

Gwinner LM, Laib RJ, Filser JG, et al. 1983. Evidence of chloroethylene oxide being the reactive metabolite of vinyl chloride towards DNA: Comparative studies with 2,2'-dichlorodiethyl ether. *Carcinogenesis* 4:1483-1486.

Lu P-Y, Metcalf RL, Plummer N, and Mandel D. 1977. The environmental fate of three carcinogens: Benzo-(alpha)-pyrene, benzidine, and vinyl chloride evaluated in laboratory model ecosystems. *Arch Environ Contam Toxicol*, 6: 129-142

Neely, W B, D R Branson, and G E Blau 1974. Partition Coefficients to Measure Bioconcentration Potential of Organic Chemicals in Fish. *Environ. Sci. Technol.* 1974, 8, 1113-1115.

Sijm, Dick T.H.M., and J. Tolls. Bioconcentration and Biotransformation of the Nonionic Surfactant Octaethylene Glycol Monotridecyl Ether ¹⁴C-C₁₃EO₈. *Environmental Toxicology and Chemistry*. 18, pp 2689-2695

Spacie, A. and J.L. Hamelink. 1982. Alternative Models for Describing the Bioconcentration of Organics in Fish. *Environmental Toxicology and Chemistry*. 1: pp.309-320.

Spacie, A. and J.L. Hamelink. 1985. Bioaccumulation. In G.M. Rand, and S.R. Petrocelli, eds. *Fundamentals of Aquatic Toxicology*. Hemisphere Publishing Corporation, Washington, D.C. pp. 495-525.

Swenberg JA, Fedtke N, Ciroussel F, et al. 1992. Etheno adducts formed in DNA of vinyl chloride exposed rats are highly persistent in liver. *Carcinogenesis* 13(4):727-729.

Thomann, R.V., J.P. Connolly, T.F. and Parkerton. 1992. Modeling Accumulation of Organic Chemicals in Aquatic Food Webs. In F.A. Gobas, P.C. and McCorquodale, J.A. Eds. *Chemical Dynamics in Freshwater Ecosystems*. Lewis Publishers, Boca Raton, Fl. pp. 153-185.

USGS 2003. Chemical Quality of Water, Sediment, and Fish in Mountain Creek Lake, Dallas, Texas, 1994–97. U.S. Geological Survey, Water-Resources Investigations Report 03–4082

Veith G D, D F L DeFoe, B V Bergstedt. 1979. Measuring and estimating the bioconcentration factor in fish. *Jou Fish Res Board Can* 36:1040-1045.

Wang T, R Lenahan, and J. TenEyck. 1984. Case Study - Trichloroethylene groundwater contamination at Vero Beach, Florida. Technical Report No. 054. Harbor Branch Foundation and City of Vero Beach Florida. December 1984.

Wang T, R Lenahan, and M Kanik. 1985. Impact of trichloroethylene contaminated groundwater discharged to the main canal and Indian River Lagoon, Vero Beach, Florida. *Bull Environ Contam Toxicol*, 34: 578-586.

Watanabe PG, Zempel JA, Gehring PJ. 1978. Comparison of the fate of vinyl chloride following single and repeated exposure in rats. *Toxicol Appl Pharmacol* 44:391-399.

de Wolf, W, J. H. M. de Bruijn, W. Selnen, and J. L. M. Hermens 1992. Influence of Biotransformation on the Relationship between Bioconcentration Factors and Octanol-Water Partition Coefficients. *Environ. Sci. Technol.* 1992, 26, 1197-1201