DETERMINATION AND EVALUATION OF ENVIRONMENTAL LEVELS OF TRICHLOROETHYLENE

to

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF TOXIC SUBSTANCES

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NOTICE

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EXECUTIVE SUMMARY

This report is a determination and evaluation of environmental levels of trichloroethylene (TCE), based on a review of the literature and other information sources and on monitoring data obtained to fill gaps in the published data.

Trichloroethylene is of environmental concern because of its toxicity and its widespread use. The major users by far are metal degreasing and dry cleaning, and, though TCE is incurring disfavor in these applications, it may soon find wide application in nonaqueous textile processing and finishing. The major production of TCE in the U.S. is on the Gulf Coast of Louisiana and Texas, and the annual production is about 435 million pounds (1974 figures). It is estimated that approximately 60 percent of this is released into the environment each year.

The concentrations of TCE in the atmosphere of the U.S. ranges from about 1 ppt in remote areas to over 100 ppb in areas near where the substance is manufactured or used. The concentration drops off rapidly as one moves away from a source facility.

Surface water concentrations of TCE range from less than 1 ppb (the limit of detection) to several hundred ppb in the vicinity of TCE manufacturers. One measurement as high as 5 ppm was made in a canal of stagnant water near a producer site.

TCE concentrations in sediments range from less than 0.04 ppb to over 100 ppb. Again the high values were found near manufacturers, but

some of the lowest values were as well.

Soil concentrations of TCE appear to be no higher near manufacturers than in rural areas, though the data are very limited. The concentrations are only a few ppb or less.

The behavior of TCE in the environment is controlled by its structure. TCE is an unsaturated chlorinated hydrocarbon which is not susceptible to hydrolysis and thus is relatively stable in water and in the soil. However, the double bond in the compound is susceptible to attack by free radials and electrophilic reagents and thus is easily degraded in a photochemical environment such as ambient air. The ultimate degradation products are simple species commonly found in the environment, but there are some intermediates for which little toxicity data exist.

There are very little data on the presence of TCE in food raised and sold in the U.S. However, data from the United Kingdom suggest that TCE is found on the order of parts per billion in almost all common foodstuffs. Measured concentrations of TCE in U.S. drinking water are less than 1 ppb except in unusual circumstances such as in Des Moines, Iowa. An unknown source of TCE contamination has caused levels of TCE as high as 80 ppb to be found in Des Moines water.

There is little evidence to judge if TCE is accumulating in living systems. Limited data on TCE levels in human tissue and in marine organisms show levels on the order of a few parts per billion.

The data are also insufficient to enable trends in the TCE levels in the environment to be determined.

1. INTRODUCTION

Trichloroethylene (TCE) is an important chemical whose health and ecological effects, environmental behavior, and technologic and economic aspects are important to the U.S. Environmental Protection Agency. In a recent report prepared for the EPA by the Office of Toxic Substances, the reasons for concern regarding TCE are discussed (U.S. Environmental Protection Agency, 1976). These include its wide use in the production of fabricated metals and cleaning fluids which results in extensive worker exposure; the detection of this compound in ambient air and water, in food, and in human tissues; and finally its identification by the National Cancer Institute (NCI) as a carcinogen in laboratory animals.

The purpose of this program has been to determine and evaluate environmental levels of trichloroethylene. The approach taken involved four distinct phases:

1. Review and evaluation of literature and other sources of previously collected monitoring data
2. Development of an environmental monitoring program for filling selected data gaps
3. Environmental sample collection and analysis
4. Presentation of the above material as an integrated information data package.

Previously collected monitoring data from the literature and levels of trichloroethylene in the environment as determined under this program will be summarized and evaluated.

Levels of a substance in the environment can be reported in various ways. The level of trichloroethylene in air will be reported in two ways -- as ppb (volume/volume) and in $\mu g/m^3$. Either both values will be given or a conversion factor will be indicated. For all other media -- water, soil, and sediment -- the data will be given as ppb (weight/weight). Various conversion factors can be found in Table 2.3.

There are several important reviews on the subject of trichloroethylene: Specifically, a preliminary study of selected potential environmental contaminants including trichloroethylene (U.S. Environmental Protection Agency, 1975), a preliminary economic impact assessment of possible regulatory action to control atmospheric emissions of selected halocarbons (Shamel et al., 1975), an impact overview and an abstracted literature collection on trichloroethylene (Waters et al., 1976), an air pollution assessment of trichloroethylene (Fuller, 1976), a criteria for a recommended standard for occupational exposure to trichloroethylene (National Institute for Occupational Safety and Health, 1973), a proposed occupational exposure standard for trichloroethylene (Department of Labor, 1975), a toxicology study called "Methylchloroform and Trichloroethylene in the Environment" (Aviado et al., 1976). These references have been consulted (in addition to many original journal articles and various reports) in preparing this document.

2. OCCURRENCE OF TRICHLOROETHYLENE IN THE ENVIRONMENT

SOURCES OF TRICHLOROETHYLENE IN THE ENVIRONMENT

In Figure 2.1, the presence of trichloroethylene in the environment and the flow from production to use to human exposure is diagrammed. Some of the information to be presented is summarized in this figure. Trichloroethylene is a synthetic material created by man in huge amounts. The ultimate sources are the production facilities, and the amount produced largely determines how much trichloroethylene might eventually find its way into the environment.

Trichloroethylene Production

The evidence is that all trichloroethylene that appears in the environment is produced by man. The estimated world production capacity for trichloroethylene is $1,010 \times 10^3$ tons/year (1973) (McConnell et al., 1975). U.S. production of trichloroethylene was $435,000 \times 10^3$ pounds in 1974 (Chemical and Engineering News, May 19, 1975). Of the total world production, it is estimated that approximately 600×10^3 tons of trichloroethylene are released to the atmosphere and 10,000 tons to the ocean each year.

The production sites, annual capacity, and raw material for the manufacture of trichloroethylene are given in Table 2.1. As is obvious from the table, the bulk of trichloroethylene is produced on the Gulf coast of Louisiana and Texas.

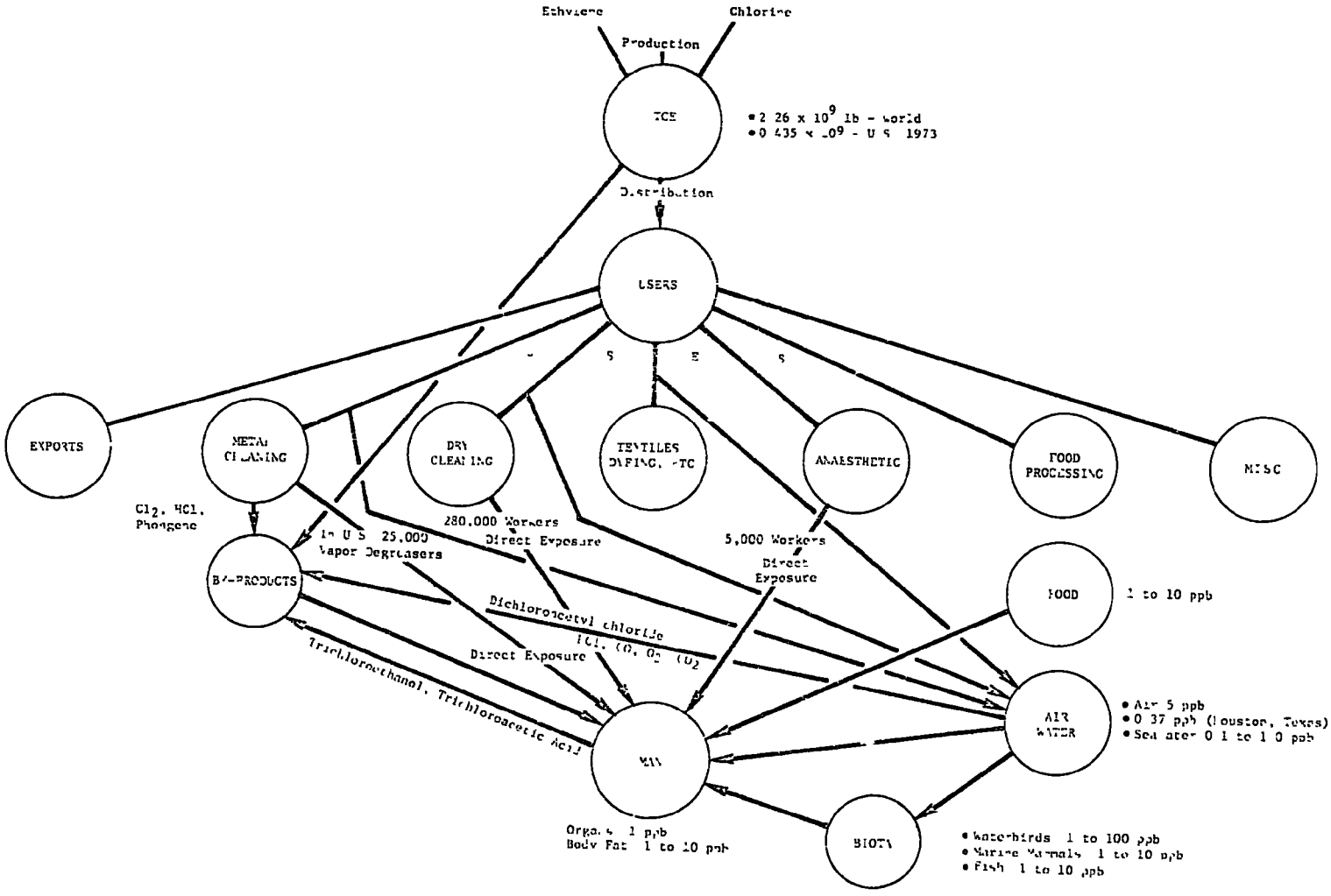

Ethylene
Chlorine
Production
TCE
• 2 26 x 10^9 lb - world
• 0 435 x 10^9 - U S 1973
Distribution
USERS
EXPORTS
METAL CLEANING
DRY CLEANING
TEXTILES DYEING, ETC
ANAESTHETIC
FOOD PROCESSING
MISC
Cl2, HCl, Phosgene
In U S 25,000 Vapor Degreasers
280,000 Workers
Direct Exposure
5,000 Workers
Direct Exposure
BY-PRODUCTS
Dichloroacetyl chloride
HCl, CO, O2, Cl2
Direct Exposure
Trichloroethanol, Trichloroacetic Acid
FOOD
1 to 10 ppb
AIR WATER
• Air 5 ppb
• 0 37 ppb (Houston, Texas)
• Sea ater 0 1 to 1 0 ppb
MAN
Orga. s 1 ppb
Body Fat 1 to 10 ppb
BIOTA
• Waterbirds 1 to 100 ppb
• Marine Mammals 1 to 10 ppb
• Fish 1 to 10 ppb

TABLE 2.1 MANUFACTURE OF TRICHLOROETHYLENE

Company and Location	Annual Capacity as of September 1972, millions of pounds	Raw Material
Dow Chemical U.S.A.[a] Freeport, Texas	150	Ethylene
Diamond Shamrock Chemical Co.[b] Electric Chemicals Div. Deer Park, Texas	60	Ethylene
Ethyl Corporation Industrial Chemicals Div. Baton Rouge, Louisiana	50	Ethylene
Hooker Chemical Corporation[c] Industrial Chemicals Div.		
Tacoma, Washington	30	Acetylene
Taft, Louisiana	40	Acetylene
PPG Industries, Inc.[d] Industrial Chemicals Div. Lake Charles, Louisiana	200	Ethylene
Total	530	

Source: U.S. Environmental Protection Agency, 1975.

[a]An additional 50 million pounds per year unit was closed in late 1971. An 18-month modernization beginning in 1977 is planned. New project will result in improved technology to reduce by-products and increase efficiency in use of raw material chlorine. Expected capacity of refurbished unit will be 120 million pounds per year.

[b]Believed to be producing only small quantities (production was not reported to the U.S. Tariff Commission in 1971 or in the first 6 months of 1972). Capacity of the plant will be expanded by April, 1973.

[c]A 60-million-pounds-per-year acetylene-based TCE plant at Niagara Falls, New York, was closed in early 1972.

[d]Expanding to 280 million pounds per year by the end of 1973.

Based on the reactions involved in the production of trichloroethylene (Figure 2.2), several other chlorinated hydrocarbons might also be expected to reach the environment. Thus, at the trichloroethylene plants, in addition to trichloroethylene, tetrachloroethane, hexachlorobutadiene, and dichloroethane might be detected. At all sites, chlorine and hydrogen chloride are important inorganics that are generated and consumed in these processes.

Uses of Trichloroethylene

Table 2.2 gives some indication of the major uses to which trichloroethylene was put in 1971. By far, the major use of this solvent was in metal degreasing and dry cleaning. Trichloroethylene has, in the past, been the solvent of choice in vapor degreasing; but because of its lower toxicity and less severe pollution problem, methylchloroform is replacing trichloroethylene in many places. While trichloroethylene has incurred disfavor in these applications, it may soon find wide application in nonaqueous textile processing and finishing.

Trichloroethylene has also been used as an anesthetic and many hospital personnel are routinely exposed to trichloroethylene (Lloyd et al, 1975).

Some of the other industries that are using trichloroethylene on a large scale are the following: food products, textile mill products, paper products, printing trades, chemical manufacturing, rubber and plastics manufacturing, stone and clay products, primary steel manufacturing, metal fabrication, machinery manufacturing, electrical equipment, transportation equipment, communication, wholesale trade, business services, auto repair, and mechanical services. Each of these industries is estimated to have over 1,000 people exposed to trichloroethylene (Lloyd et al., 1975).

From Ethylene Through Ethylene Dichloride (90% of Total Production)

$$CH_2 = CH_2 + Cl_2 \rightarrow ClCH_2CH_2Cl$$

$$8ClCH_2CH_2Cl + 6Cl_2 + 7O_2 \rightarrow 4ClCH = CCl_2 + 4\,Cl_2C + CCl_2 + 14H_2O$$

From Acetylene (10% of Total Production)

$$HC \equiv CH + 2Cl_2 \rightarrow Cl_2CHCHCl_2$$

$$Cl_2CHCHCl_2 \xrightarrow[\text{or Catalyst}]{\text{Base}} ClCH = CCl_2 + HCl$$

Figure 2.2 Trichloroethylene Production Processes

TABLE 2.2 TRICHLOROETHYLENE CONSUMPTION, 1971

	Millions of Pounds	Percent
Metal cleaning	455	84
Exports	52	10
Miscellaneous	32	6
Total	539	100

Source: U.S. Environmental Protection Agency, 1975

Pathways for Entry of Trichloroethylene into the Environment

The pathways for entry of trichloroethylene into the environment are determined primarily by the physical properties and to a lesser degree by the chemical properties of the compound.

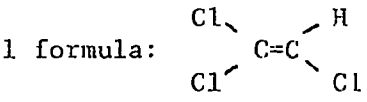
Trichloroethylene (TCE) is a colorless, nonflammable, volatile liquid, which boils at 87 C at atmospheric pressure. It has appreciable vapor pressure--58 mm Hg at 20 C--and limited, though not insignificant, solubility in water--0.11 g trichloroethylene in 100 g H_2O at 25 C. This compound is thermally stable, is sensitive to oxidation, but is resistant to hydrolysis. These and other properties are summarized in Table 2.3.

Trichloroethylene is manufactured on a large scale--about 435 million pounds in 1974 in the U.S. Trichloroethylene is used primarily as a cleaning solvent either in vapor degreasing or in cold cleaning. It is estimated that approximately 60 percent of the trichloroethylene produced is released into the environment each year.

These facts lead to the conclusion that trichloroethylene is released into the air in relatively large amounts. There is some evidence that trichloroethylene is rapidly degraded and has a relatively short half-life in the atmosphere. However, the fate of trichloroethylene in air is not clearly understood, and its fate in water is even less well understood.

All of these related facts are combined into a picture depicting the pathways for entry of trichloroethylene into the environment in Figure 2.3. The heavier the line, the more important is the pathway. Thus, for trichloroethylene, the most important pathway for entry into the environment is release of this substance by users into the air, followed by release into

TABLE 2.3 PHYSICAL PROPERTIES OF TRICHLOROETHYLENE



Molecular formula: C_2HCl_3
Analysis: C, 18.128 percent; H, 0.77 percent; Cl, 80.95 percent
Molecular weight: 131.29
Appearance: Colorless liquid
Boiling point: 86.7 C
Melting point: -87.1 C
Decomposition temperature: 700 C
Flash point: None
Autoignition temperature: 410 C
Specific gravity (20 C/4 C): 1.465
Vapor density at 25 C: 4.53 g/ℓ
Surface tension at 20 C: 29 dyne/cm
Odor threshold: Aproximately 20 ppm
Viscosity at 20 C: 0.58 centipoise
Refractive index at 20 C: 1.4773
Dielectric constant (liquid) at 16 C: 3.42

Vapor pressure:

°C	mm Hg
0	20.1
20	57.8
40	146.8

Solubility in water:

°C	g/100g water
25	0.11
60	0.125

Solubility of water in TCE:

°C	g/100g TCE
25	0.033
60	0.080

Distribution coefficient of solubility:

	20 C	37 C
Water/air	3	1.6
Blood/air	18-22	8-10
Plasma/air	16-20	--
Fat/water	34.4	

Conversion factors:
Air (25 C): 1 ppb (vol/vol) = 5.27 $\mu g/m^3$
1 µg/l = 186.2 ppb (vol/vol)
Water (20 C): 1 ppb (vol/vol) = 1.465 ppb (vol/vol)
1 ppb (wt/wt) ≈ 1 µg/l
Other media: 1 ppb (wt/wt) = 1 µg/kg

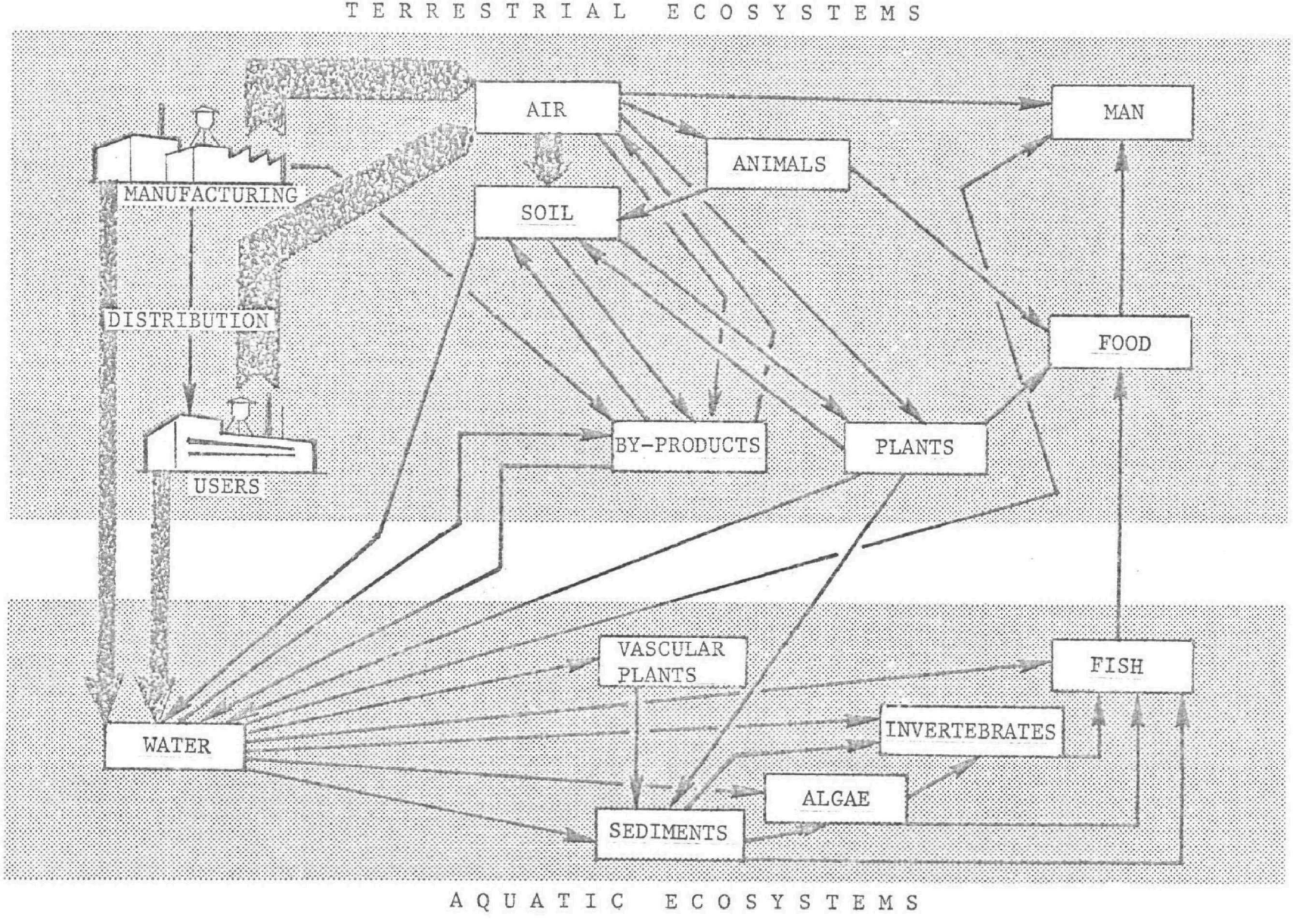


Figure 2.3 Pathways for entry of trichloroethylene into the environment.

the air by manufacturers, followed by release into water by manufacturers and users, followed by absorption in soil, collection in sediment, and then all of the other interactions shown in the figure. The environmental media would thus be ranked as follows in order of decreasing trichloroethylene concentration: air, water, soil, sediment, and biota.

TRICHLOROETHYLENE LEVELS IN THE ENVIRONMENT

Data From the Literature

No extensive monitoring programs designed specifically for trichloroethylene have been identified. The concentration of trichloroethylene in various parts of the environment has been estimated, Table 2.4. In addition, trichloroethylene has been quantified in air and surface water at various sites and these data are presented in the following sections.

However, there are serious gaps in these data. There are no data available in the literature on production sites or on sites or cities where there is known to be extensive use of trichloroethylene. New information on such sites is reported in the section on "Data From the Battelle Monitoring Program". In addition, time studies could be very informative. For example, how does the trichloroethylene concentration vary from hour to hour, from day to day, and from season to season? Is washout important? Is the amount of sunshine critical to the degradation of trichloroethylene or is degradation relatively constant? These and similar questions might be answered if a single site were sampled over an extended period of time. No such study has yet been undertaken.

TABLE 2.4 OCCURRENCE OF TRICHLOROETHYLENE IN THE ENVIRONMENT

	Typical Concentrations	
	Minimum	Maximum
Air	10^{-9}	10^{-8}
Rain water	10^{-11}	10^{-9}
Surface water	10^{-11}	10^{-9}
Potable water	10^{-11}	10^{-9}
Sea water	10^{-10}	10^{-9}
Marine sediments	10^{-10}	10^{-9}
Marine invertebrates	10^{-9}	10^{-8}
Fish	10^{-9}	10^{-8}
Waterbirds	10^{-9}	$>10^{-7}$
Marine mammals	10^{-9}	$>10^{-8}$
Fatty foods	10^{-9}	10^{-8}
Non-fatty foods	10^{-9}	10^{-9}
Human organs	10^{-9}	10^{-9}
Human body fat	10^{-9}	10^{-8}

Source: McConnell et al., 1975.

Trichloroethylene in the Atmosphere

Trichloroethylene has been determined along with other halocarbons at various locations throughout the U.S. and around the world. The most extensive data are reproduced in Tables 2.5 and 2.6. These data are taken from a study done at Cook College, Rutgers University (Lillian et al., 1975). Other data are summarized in Table 2.7.

Trichloroethylene in Surface Waters

In 1975, a program entitled "Monitoring to Detect Previously Unrecognized Pollutants" began at the University of Illinois at Urbana-Champaign. This program is administered within the Institute for Environmental Studies under a contract with the U.S. Environmental Protection Agency. The coprincipal investigators are Professor E.S.K. Chian, Department of Civil Engineering, and Professor B. S. Ewing, Director of the Institute for Environmental Studies.

The objective of the program is to direct previously unrecognized pollutants in surface waters. Approximately 200 water samples are being collected from 14 heavily industrialized river basins. These areas and the approximate number of samples to be taken at each location are indicated in Figure 2.4 (Chian and Ewing, 1976. Progress Report No. 4). The results are summarized in Table 2.8. For some of the samples, values for trichloroethylene were not reported. When the presence of a substance was not reported, it is not clear whether the substance was not present, was not quantified, or was not detected for some reason such as interference by another compound. However, trichloroethylene was detected in 142 of

TABLE 2.5 MAXIMUM AND MINIMUM LEVELS OF TRICHLOROETHYLENE IN THE ATMOSPHERE AT VARIOUS LOCATIONS IN THE UNITED STATES

Monitoring Period and Location	Levels	Concentration, ppb
June 18-19, 1974	Max.	2.8
Seagirt, N.J.	Min.	<0.05
(National Guard Base)	Mean	0.26
June 27-28, 1974	Max.	1.1
New York, N.Y.	Min.	0.11
(45th & Lexington)	Mean	0.71
July 2-5, 1974	Max.	0.80
Sandy Hook, N.J.	Min.	<0.05
(Fort Hancock)	Mean	0.34
July 8-10, 1974	Max.	0.56
Delaware City, Delaware	Min.	<0.05
(Road 448 & Route 72 intersection)	Mean	0.35
July 11-12, 1974	Max.	<0.05
Baltimore, MD.	Min.	<0.05
(1701 Poncabird Pass, Ford Holabird area)	Mean	----
July 16-26, 1974	Max.	0.63
Wilmington, OH	Min.	<0.05
(Clinton County Air Force Base)	Mean	0.19
September 16-19, 1974	Max.	0.35
White Face Mountains	Min.	<0.05
(New York State)	Mean	0.10
March-December, 1973	Max.	8.8
Bayonne, N.J.	Min.	<0.05
	Mean	0.92

Source: Lillian et al., 1975.

TABLE 2.6 TYPICAL LEVELS OF TRICHLOROETHYLENE IN THE ATMOSPHERE

Date and Time	Location	Concentration, ppb
June 27, 1974 2300	New York, N.Y.	0.11
September 17, 1974 1200	White Face Mountains N.Y. State (nonurban)	<0.02
July 2, 1974 1400	Over Ocean Sandy Hook, N.J. 4.8 km (3 mi.) offshore	0.18
July 19, 1974 1300	Seagirt, N.J. (National Guard Base)	<0.02
July 17, 1974 1228	Above the inversion elevation 1500 m (5000 ft.) Wilmington, Ohio	<0.02
July 17, 1974 1203	Inversion Layer elevation 450 m (1500 ft.) Wilmington, Ohio	0.075

Source: Lillian et al., 1975.

TABLE 2.7. MISCELLANEOUS MONITORING DATA FOR TRICHLOROETHYLENE IN THE ATMOSPHERE

Location	Date of Data Collection	Concentration	Method[a]	Reference
New Brunswick NJ	1973	Detected	Coulometric GC	Lillian and Singh, 1974
" "	Unreported	0.75 ppb	" "	" "
Kansas City-NASN Station	1974	Detected	GC/MS	Bunn et al., 1975
Houston TX and vicinity	Nov. 1974	"	GC/MS computer	Pellizzari et al., 1976
Los Angeles Basin	April 1975	"	" "	" "
Worldwide	1974	5 ppb	Estimate	Goldberg, 1975
Pullman WA	Dec. 1974 to Feb. 1975	<5 ppt	GC/MS	Grimsrud and Rasmussen, 1975
Western Ireland	June/July 1974	15 ppt	Coulometric GC	Lovelock, 1974
North Atlantic	Oct. 1973	<5 ppt	" "	" "
Northern Hemisphere	1974	15 ppt	EC/GC	Cox et al., 1976
Southern Hemisphere	1974	1.5 ppt	"	" "
Liverpool, England	March 1972	850 ng/m^3 (~160 ppt)	"	Murray and Riley, 1973
Rural areas of Britain	1972	11 ng/m^3 (average)	"	" "
Over the northeast Atlantic	Aug. 1972	6 ng/m^3	"	" "
Britain, perimeter of a manufacturing plant	1972-1974	40-64 ppb (mass)	"	Pearson and McConnell, 1975
Heath, near the above plant	"	12-42 ppb (mass)	"	" "
Suburban area, removed from plant	"	1-20 ppb (mass)	"	" "
Tokyo	May 1974-April 1975	1.2 ppb (annual average_	"	" "

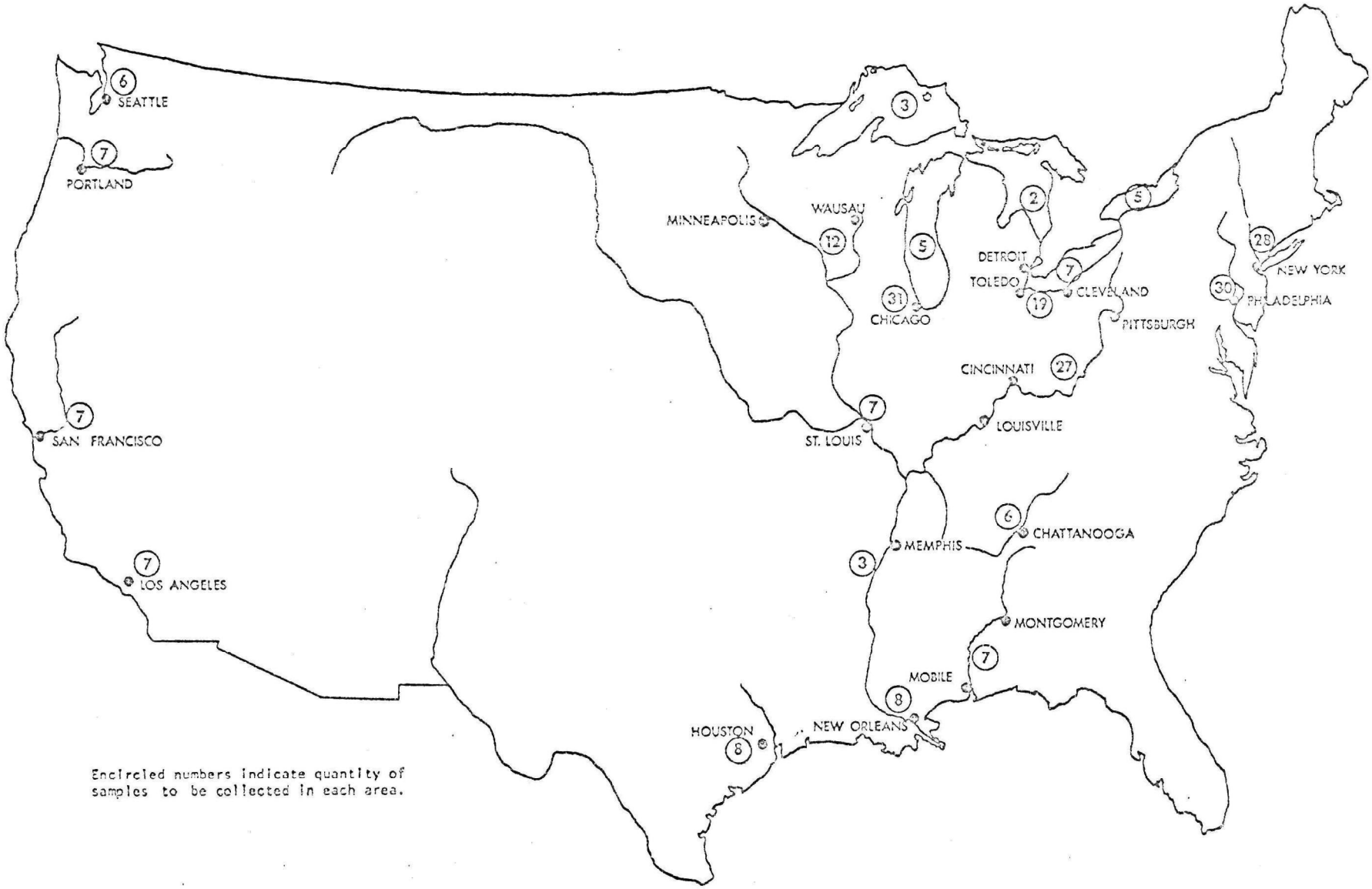


Figure 2.4. Industrialized area where surface water was sampled (Source: Chian and Ewing, 1976).

TABLE 2.8. TRICHLOROETHYLENE CONCENTRATION IN SURFACE WATER SAMPLES TAKEN BY THE INSTITUTE FOR ENVIRONMENTAL STUDIES

Area	Type of Water Analyzed	Number of Samples	Concentration Range (Average), ppb
Chicago, Illinois	Lake Michigan, sewage treatment plant effluent, filtration plant, channels	9	0.5 to 10(5)
Illinois	Illinois River	11	<1 to 7 (<2)
Pennsylvania	Delaware, Schuylkill, and Lehigh Rivers	25	<1 to 18 (<2)
New York City area	Hudson River and bays	16	<1 to 7 (<3)
Hudson River area	Hudson River	12	<1 to 4 (<1)
Upper and Middle Mississippi River	Mississippi River	19	<1 to 29[a] (<4)
Lower Mississippi River	Mississippi River	9	<1 to 20 (<5)
Houston area	Galveston Bay and channels	8	<1 to 29[b] (<5)
Alabama	Black Warrier, Tombigee, Alabama, and Mobile Rivers	7	<1 to 1 (<1)
Ohio River Basin	Ohio River and tributaries	10	<1 to 5 (<1)
Great Lakes	Lake Superior, Michigan, Huron, Ontario, Erie, and vicinity	13	<1 to 188[c]
Tennessee River Basin	Tennessee River and tributaries	1	<1 to 3 (<2)

[a]This concentration determined on the shore at St. Louis.
[b]This concentration determined in the Houston Ship Channel.
[c]This concentration determined in Fields Brook at Lake Erie. All other samples in this area reportedly contained <1 ppb.

the over 200 samples analyzed and the concentrations range from <1 ppb to 188 ppb in the surface waters sampled. This information has all been taken from the first five progress reports from the Institute for Environmental Studies on EPA Contract 68-01-3232 (Chian and Ewing, 1976).

Many other organics have been identified and quantified and elemental inorganic analyses were done during this program. From this information and details of the methodology used, the reader is referred to the original reports.

Pearson and McConnell (1975) report concentrations of 0.15 ppb trichloroethylene in rainwater collected in Runcorn, England. The highest concentrations that these researchers measured in upland river waters was 6 ppb. These same authors also reported that they have never detected organochlorines in well waters. With a normal detection limit of 0.01 ppb, Pearson and McConnell (1975), between April, 1973 and August, 1973, determined that the average concentration of trichloroethylene in Liverpool Bay sea water was 0.3 ppb with the maximum concentration of 3.6 ppb found. In Liverpool Bay sediments a maximum trichloroethylene concentration of 9.9 ppb was found.

There have been several studies on the presence of trichloroethylene and other halocarbons in drinking water and raw water samples. This information is presented in the section on "Drinking Water".

Data From the Battelle Monitoring Program

A program to determine environmental levels of trichloroethylene was initiated in 1976 at the Battelle Columbus Laboratories. Based on a review of the literature, it was decided that determinations of trichloroethylene

levels in the vicinity of producer and user plants were lacking. A sampling rationale and protocol were established. During late 1976 and early 1977, samples were collected from various production sites, a user site, and a background site. The samples were analyzed and the results are summarized in Table 2.9 and 2.10. Details of the results and methodology can be found in a companion report (Battelle Columbus Laboratories, 1977).

Discussion of the Data

The concentration of trichloroethylene in the atmosphere ranges from about 1 ppt in remote areas to over 100 ppb in areas where the substance is manufactured or used. Pearson and McConnell (1975) point out that as one moves away from a manufacturing facility, the concentration of trichloroethylene in air drops off rapidly. These results are summarized in Table 2.7. Ohta and coworkers (1976) make a similar observation. They state that the distribution peak for trichloroethylene coincides with locations of machine or metal product plants which use the solvent.

The Battelle Columbus Laboratories (1977) study in the United States confirms these observations. In Table 2.9, the highest concentrations of trichloroethylene are observed downwind from a producer or user site and the concentration seems to be dependent on the distance from the discharge point. Most of the higher concentrations are observed at distances of less than 1 km. Considerable variation, however, was observed in the maximum downwind levels of trichloroethylene at various production sites. The variations in the observed maximum concentrations between plants may be due to differences in (1) production processes, (2) emission control equipment, (3) meteorological conditions, and (4) distance from the plant.

TABLE 2.9. CONCENTRATION RANGES FOR TRICHLOROETHYLENE IN THE ATMOSPHERE AROUND PRODUCER AND USER SITES

Location	Date of Collection	Site	Concentration, ppb[a]	Distance from Plant	Upwind (U), Downwind (D), or Variable (V)
Dow Chemical Co. Freeport TX	Nov. 1976	1	<1	1.9	-
		2	<1	1.4	U
		3	<1	1.8	-
		4	<1	2.4	D
		5	<1 to 11.5	2.4	D
		6	<1	3.4	D
		7	<1	3.1	D
		8	<1 to 4.4	4.4	D
		9	<1	3.5	D
Hooker Chemical Hahnville LA	Nov. 1976	1	21 to 140	0.2	D
		2	<1	0.6	U
		3	<1 to 5.4	0.8	U
		4	<1 to 270	0.5	V
		5	<1	2.7	-
		6	<1	2.2	-
		7	<1	1.1	D
		8	<1 to 6.0	1.8	D
		9	<1 to 45	1.8	D
Ethyl Corporation Baton Rouge LA	Nov. 1976	1	1.9 to 5.6	0.4	D
		2	<1 to 7.2	0.2	D
		3	<1	2.4	D
		4	<1	2.6	D
		5	<1	2.2	-
		6	<1	0.7	U
		7	<1	2.2	-
		8	<1	3.2	D
PPG Industries Lake Charles LA	Dec. 1976	1	2.2 to 2.7	1.3	U
		2	<1	4.2	U
		3	<1	3.5	V
		4	<1	2.7	U
		5	<1	1.4	D
		6	<1 to 12	4.0	D
		7	<1	0.6	U
		8	<1	1.3	-
Boeing Company Seattle WA (user)	Jan. 1977	1	<1	0.6	D
		2	<1	1.1	-
		3	17 to 38	0.4	D
		4	15 to 44	0.5	D
St. Francis National Forest AK (background)	Nov. 1976	-	<1	-	-

[a]Limits of detection: 1 ppb.

TABLE 2.10. CONCENTRATION OF TRICHLOROETHYLENE IN WATER, SOIL, AND SEDIMENT IN THE VICINITY OF PRODUCER SITES

Location	Date of Collection	Description of Media	Concentration, ppb
Dow Chemical Co., Plant B, Freeport TX	Nov. 1976	Surface water, mouth of plant effluent canal	172
		Water, as above except 4 m deep	197
		Surface water, 400 m downstream from plant outfall	5
		Water, as above except 5-6 m deep	13
		Surface water, 800 m upstream of plant outfall	0.9
		Soil, approximately 2 km from plant	<0.06 to 0.45
		Sediment, mouth of plant effluent canal	0.15
		Sediment, 400 m downstream of plant outfall	None detected
		Sediment, 800 m upstream of plant outfall	0.04
Hooker Chemical Co. Hahnville LA	Nov. 1976	Surface water, Mississippi River, 150 m upstream of plant outfall	1
		Surface water, at plant outfall	535
		Surface water, 1 km downstream of plant outfall	22
		Surface water, open stagnant canal about 2.7 km from plant	5,227
		Soil, close to the plant out to about 2.7 km	0.23 to 5.6
		Sediment, 150 m upstream of plant outfall	0.18
		Sediment, 100 m downstream of plant outfall	0.63
		Sediment, 200 m downstream of plant outfall	0.03

TABLE 2.10 (Continued)

Location	Date of Collection	Description of Media	Concentration, ppb
Ethyl Corporation Baton Rouge LA	Nov. 1976	Surface water immediately above settling pond	128
		Surface water, 200 m upstream of plant outfall	0.4
		Surface water, 300 m downstream of plant outfall	37
		Soil, various locations in vicinity of plant	None detected
		Sediment, 200 m upstream of plant outfall	None detected
		Sediment, 300 m downstream of plant outfall	116
PPG Industries Lake Charles LA	Dec. 1976	Surface water, 50 m upstream of plant outfall	353
		Surface water, at plant outfall No. 1	447
		Surface water, at plant outfall No. 2	179
		Surface water, 50 m downstream of outfall No. 2	403
		Surface water, lake--downstream of plant outfalls	29
		Soil, quadrants surrounding plant	None detected to 0.11
		Sediment, 50 m upstream of plant outfall	146
		Sediment, at plant outfall No. 2	15
St. Francis National Forest AK (background)	Nov. 1976	Surface water, from lake	<0.05
		Soil	0.63
		Sediment	2.2

Higher production capacity apparently does not necessarily imply higher emissions since the maximum concentrations observed at the larger plants were no higher than those observed at the smaller operations and sometimes lower. Large temporal variations are observed when measuring these chlorinated hydrocarbons downwind from a production facility. Changes in meteorological conditions, particularly wind speed and direction, and/or variations in the emissions may account for this phenomenon.

The range of concentrations in surface waters is more difficult to judge. The analytical techniques presently used do not allow routine determinations at the ppt level. So the actual background has to be taken as somewhat less than 1 ppb. However, surface waters in urban areas can have concentrations on the order of 100 ppb.

The study by the Institute for Environmental Studies (Chian and Ewing, 1976) indicates the concentration of trichloroethylene in surface waters may be as high as 188 ppb (in the vicinity of Lake Erie), but for the most part surface waters contain less than 1 ppb (Table 2.8.).

In the Battelle study carried out in the vicinity of manufacturing plants, the concentration of trichloroethylene was higher (Table 2.10). One sample went as high as 5 ppm. Again, the distance from the source was important as the concentration dropped off with distance. Also, samples upstream from plant discharge channels usually had lower concentrations than samples taken downstream.

The literature provides no information on the presence of trichloroethylene in soil. In the Battelle study, it was found that the concentration of trichloroethylene in soil in the vicinity of manufacturing plants

was on the order of a few ppb or less (Table 2.10); but unexpectedly, the same concentration was found at a background site in Arkansas. Sediment samples analyzed in this same study showed more variable results. Concentrations ranged from less than 0.04 ppb to as high as 146 ppb (Table 2.10); but again the rural background site showed a level of 2.2 ppb which was higher than anticipated.

It is clear that the source of trichloroethylene is anthropogenic. It is at highest concentration where it is made and used. The background level in the atmosphere is fairly low, on the order of 5 ppt, indicating that trichloroethylene is degraded in the atmosphere. However, in close proximity to manufacturing or user plants the concentration may be considerably higher and at times may approach 1 ppm.

3. BEHAVIOR OF TRICHLOROETHYLENE IN THE ENVIRONMENT

PHYSICAL/CHEMICAL CHARACTERISTICS OF TRICHLOROETHYLENE IN THE ENVIRONMENT

This section might also be considered the degradability section since the data contained herein deals with how long trichloroethylene holds up in the environment and in the human body. Table 3.1 brings together some of this information.

The structure of the compound dictates its behavior in the environment. Trichloroethylene is an unsaturated chlorinated hydrocarbon. The double bond is susceptible to attack by free radicals and electrophilic reagents. Thus, it is not suprising that it is easily degraded in a photochemical environment such as ambient air. On the other hand, since the vinyl bond between carbon and chlorine is very strong, this molecule is not susceptible to hydrolysis and is relatively stable in water and in the soil.

Some researchers have concluded that "... not only are the simple chloroaliphatic compounds not particularly persistent, but their degradation products are simple species commonly found in the environment" (McConnell et al., 1975). This statement needs to be accepted with some reservations for there is still the question of how quickly the "simple species commonly found in the environment" form and of what the intermediates in these processes might be. The next section attempts to answer these questions.

TABLE 3.1. PHYSICAL/CHEMICAL CHARACTERISTICS OF TRICHLOROETHYLENE IN THE ENVIRONMENT

Media	Half-Life/Change	Reference
Human blood; after human exposure at 100 ppm, 6 h/10 days	13.3 hr/trichloroethanol disappearance	Müeller et al., 1974
Ditto	99 hr/trichloroacetic acid disappearance	" "
Human, anaesthesia	∿40 min/chloral hydrate from blood	Cole et al., 1975
Human	∿41 hr/urinary metabolites excreted	Ikeda and Imamura, 1973
Simulated atmospheric conditions	Estimate 5-12 hr under bright sunlight	Dilling et al., 1976
One ppm in water containing natural and added contaminants	19 min/evaporation	" "
Troposphere, 3.1 parts/thousand	6 weeks (±50%)	Pearson and McConnell, 1975

TRANSFORMATIONS OF TRICHLOROETHYLENE IN THE ENVIRONMENT

This section indicates what new substances are produced when trichloroethylene enters the environment. This information is summarized in Table 3.2. Figure 3.1 shows the transformations of trichloroethylene schematically. Figure 3.2 shows the degradation of trichloroethylene in a photochemical chamber in the presence of nitrogen/dioxide in air (Gay et al., 1976). The chamber was irradiated with ultraviolet light as the reactants and products were continuously monitored using longpath infrared spectroscopy. This study was undertaken in order to obtain more information on the atmospheric degradation of halogenated compounds particularly with regard to the rates of photooxidation and the identity of photooxidation intermediates and final products.

What is seriously needed in this area is the same kind of study on a more comprehensive environmental scale. What is the rate, fate, and transport mechanism for the dispersion and degradation of trichloroethylene in the environment? Perhaps this can best be determined in studies of model ecosystems using labeled compounds as tracers and sophisticated analytical procedures for the analysis of the substances and their degradation products. Radiolabeled trichloroethylene (trichloroethylene [1,2-^{14}C]) is available from various suppliers on special order.

In looking at the various transformations of trichloroethylene, the question of the toxicity of the intermediates arises. Some of the compounds that are produced are simple molecules that have been previously studied. These are carbon dioxide, carbon monoxide, hydrogen chloride, chlorine, acetic acid, and ozone; but others such as dichloroacetic chloride, phosgene,

TABLE 3.2. TRANSFORMATIONS OF TRICHLOROETHYLENE IN THE ENVIRONMENT

Media	What is Produced	Reference
Photochemical Chamber, TCE (3.45 ppm) with NO_2 (2.66 ppm)	Dichloroacetyl chloride, HCl, CO, phosgene (TCE half-life: ~2 hr)	Gay et al., 1976
Atmosphere near welding	HCl, Cl_2, and phosgene (severe decomposition, dangerous levels)	Rinzema and Silverstein, 1972
Smog chamber	Ozone	Farber, 1973
Human (100 ppm, 6 h/10 days)	Trichloroethanol and trichloroacetic acid in blood	McNutt et al., 1975
Atmosphere, xenon arc exposure	Dichloroacetic acid, CO_2, HCl	McConnell et al., 1975

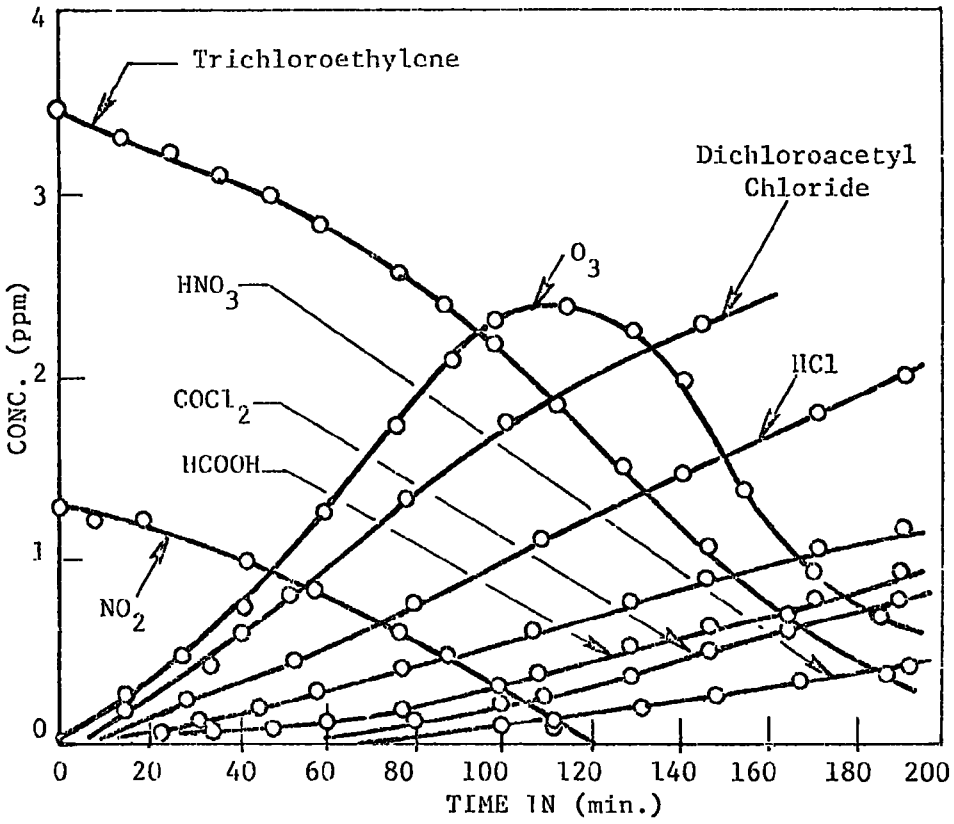
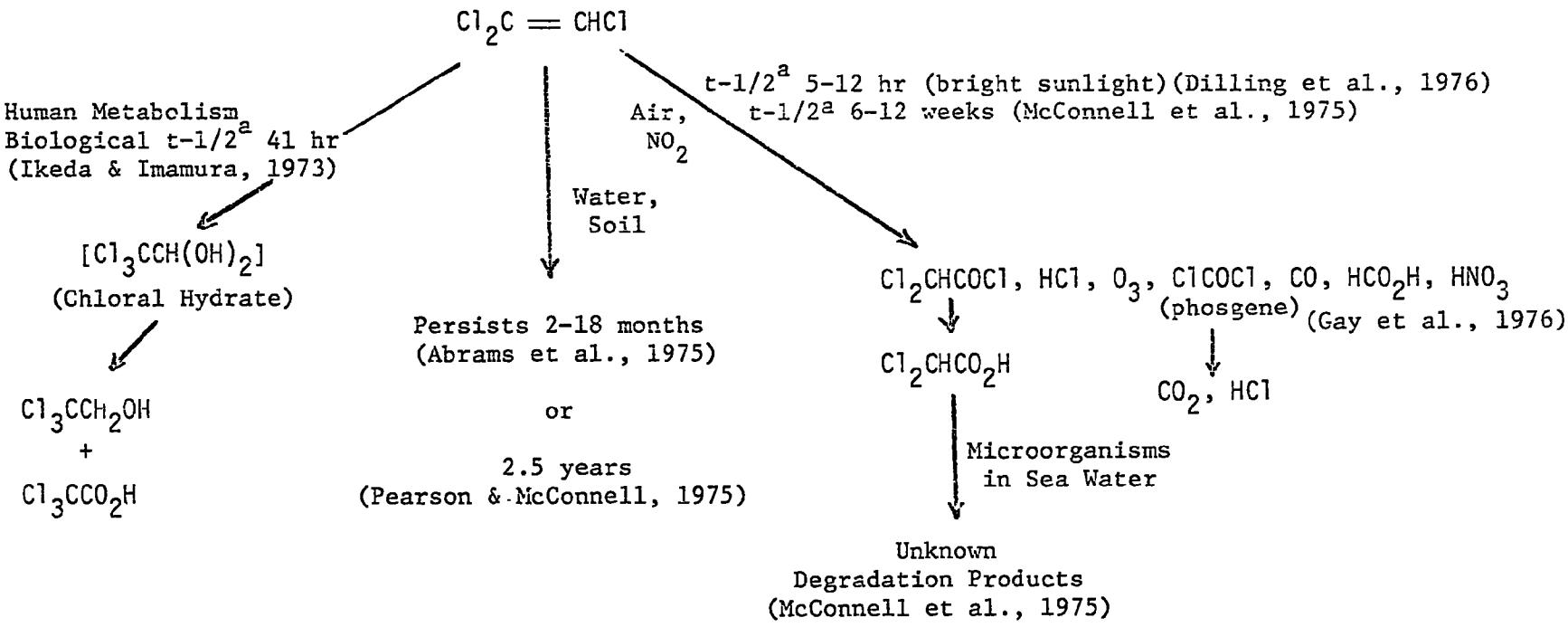


Figure 3.1. Reactants and products of trichloroethylene and NO_2 irradiation (Source: Gay et al., 1976).[2]



[a]t-1/2 = Time required for one-half of the chlorinated hydrocarbon to disappear by the indicated process.

Figure 3.2. Transformations of trichloroethylene.

and dichloroacetic acid are not commonly found in the environment and may be of some concern. The toxicity of these materials is addressed in the next section. The evidence is that phosgene, although extremely toxic, is not produced in very large amounts except under special circumstances such as when high concentrations of trichloroethylene are present in the atmosphere where welding is taking place. According to Pearson and McConnell (1975) any phosgene produced in the atmosphere would be quickly hydrolyzed to carbon dioxide and hydrogen chloride.

There are other special circumstances that could produce toxic substances. Trichloroethylene in the presence of a strong base or at high temperatures is converted to dichloroacetylene which is extremely toxic but is quickly converted by moisture to phosgene. These toxic products of trichloroethylene would not be expected to exist in significant concentrations for any length of time under normal circumstances in the environment.

The only degradation products that may exist in the environment in appreciable quantities for any period of time are dichloroacetyl chloride produced by the photodegradation of trichloroethylene in the atmosphere and dichloroacetic acid produced by the hydrolysis of dichloroacetyl chloride. Limited animal experimentation suggests low toxicity for dichloroacetyl chloride although it may be irritating to eyes and mucous membranes. There is also little information available on dichloroacetic acid (see next section). There is some evidence that the ultimate fate of the dichloroacetyl chloride and dichloroacetic acid is degradation by microorganisms (McConnell et al., 1975). Although the degradation products have not been determined, they are probably carbon dioxide and chloride ions which are already present in the

environment. The effect of dichloroacetyl chloride on the environment and its ultimate fate should, however, be determined since such large quantities of trichloroethylene are being released into the atmosphere and degraded each year.

TOXICOLOGY OF TRICHLOROETHYLENE AND ITS POSSIBLE DEGRADATION PRODUCTS

In the introduction to this section on trichloroethylene, some of the reasons for the concern over this substance were enumerated; but boiled down, this concern amounts to the fact that a large amount of this material is produced and used by people who are exposed to it and who may be directly or indirectly harmed by such exposure. This section attempts to answer the question: In what way does or might trichloroethylene harm people?

There are several reviews on the toxicity and toxicology of trichloroethylene. A recent and comprehensive review by Avalado et al., 1976, is available and the toxicity of this substance is discussed at length in the review by the U.S. Environmental Protection Agency (1975). Biological studies and toxicology of trichloroethylene are discussed in other reviews as well (National Institute for Occupational Safety and Health, 1973; Waters, et al., 1976; World Health Organization, 1976). Of somewhat older vintage is the text by Browning (1965) dealing with industrial solvents in general and specifically with trichloroethylene. Some of this information will be summarized here.

Regardless of the exposure of a substance, there is no harm possible unless there is some interaction with the organism. Figure 3.3 shows the uptake of trichloroethylene and other solvents in relation to the

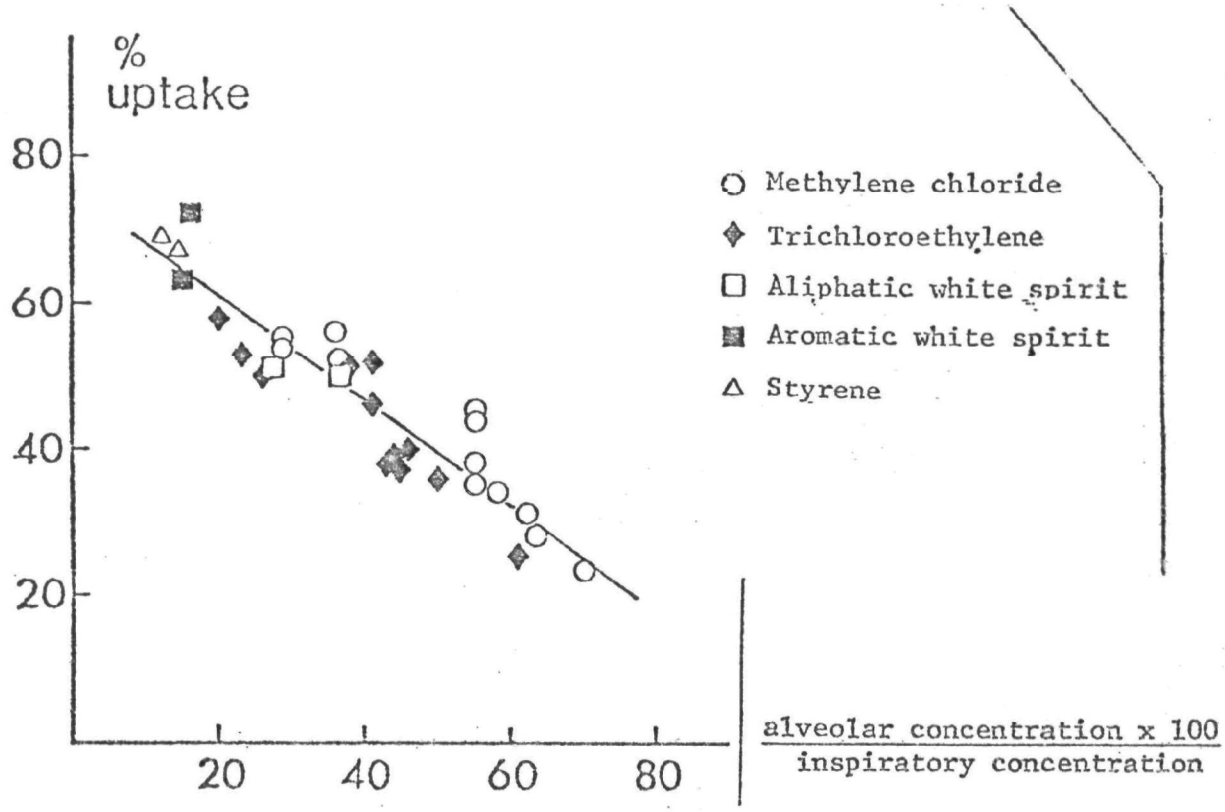


Figure 3.3 Uptake (percentage of amount supplied) in relation to alveolar concentration (percentage of concentration in inspiratory air) after 30 minutes of exposure at rest and during exercise. (Each symbol gives the mean value of two subjects for styrene and the aliphatic and aromatic components of white spirit, the mean value of four or five subjects for methylene chloride, and the mean value of five subjects for trichloroethylene. (Regression line: $y = -0.72x = 74.91$) (Source: Astrand, 1975).

concentration in inspiratory air. This figure was taken from a review by Astrand (1975) on the uptake of solvents in the blood and tissues of man. Once inside the body the inhalation (as above) or through skin absorption (Fukabori et al., 1976) or by ingestion (U.S. Environmental Protection Agency, 1975), this substance is rapidly metabolized and the major products are excreted. The metabolites are trichloroethanol, trichloroethanol glucuronide, and trichloroacetic acid. Monochloroacetic acid is also a detectable trichloroethylene metabolite. Chloral hydrate is a demonstrated intermediate in the metabolism of trichloroethylene to trichloroethanol and trichloroacetic acid (Cole et al., 1975).

It is obvious then that trichloroethylene is taken into the body and interacts (is metabolized) with it. The question now becomes, what effect does this interaction have on the tissues of the organism? Table 3.3 summarizes the toxicity of trichloroethylene and compares it with related compounds (Waters et al., 1976). The U.S. Environmental Protection Agency (1976) summarized trichloroethylene health effects. Trichloroethylene has been responsible for the death of humans. One study reports on trichloroethylene poisoning in 284 cases, including 26 fatalities, in European plants where trichloroethylene vapors were inhaled. Toxic action involves the central nervous system. Short-term studies indicate that exposure to a concentration of 100 ppm in air may interfere with psychophysiological efficiency. Six students exposed to 110 ppm from two 4-hour periods separated by 1-1/2 hours showed significantly lower levels of performance in perception, memory, and manual dexterity tests.

Recently as a part of a continuing NCI bioassay program to screen chemicals for cancer-causing activity, trichloroethylene was tested and

TABLE 3.3. COMPARATIVE TOXICITY OF TRICHLOROETHYLENE AND RELATED COMPOUNDS

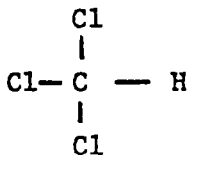
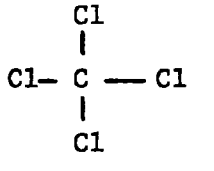
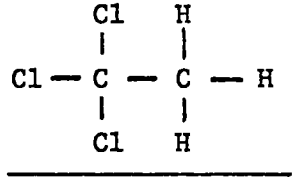
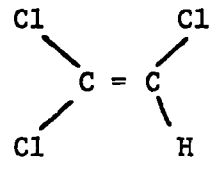
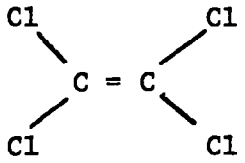
Compound and parent alkane	Oral LD50 mg/kg	Inhalation, LC50, ppm	Lowest published toxic concentration, ppm	Structural forms
Chloroform (Methane derivative)	Rat: 800 Rat: 2,180	Mouse: 5,687/7 hr Mouse: 28 Rabbit: 59 Dog: 100	Human: 10/yr Systemic effects	
Carbon tetrachloride (Methane derivative)	Mouse: 12,800 Rat: 1,770 Rat: 7,460 Rabbit: 6,380	Mouse: 9,526/8 hr Mouse: 9,528/7 hr Rat: 23,900/30 min	Human: 20 CNS: toxic effects	
1,1,1-Trichloroethane (Ethane derivative)	Guinea Pig: 9,470 Rabbit: 5,660	Rat: 14,000/7 hr Rat: 18,000/3 hr	Human: 350 Psychotrophic effects Human: 920/70 min CNS: toxic effects	
1,1,2-Trichloroethylene	Rat: 5,200 Rat: 4,920 Dog: 5,900		Human: 160/83 min CNS: toxic effects Human: 11C/8 hr	

TABLE 3.3. (Continued)

Compound and parent alkane	Oral LD50 mg/kg	Inhalation, LC50, ppm	Lowest published toxic concentration, ppm	Structural forms
(Ethylene derivative)				
1,1,2,2-Tetrachloroethylene	Mouse: 8,850 Mouse: 10,900		Human: 230 Systemic effects Human: 280/2 hr Eye: toxic effects Human: 600/10 min CNS: toxic effects	
(Ethylene derivative)				

Source: Waters et al., 1976.

found to be active in mice (Anonymous, 1976). Much of the data is described in that HEW News release. The report goes on to day that investigations of compounds that can be substituted for trichloroethylene (such as methyl-chloroform) are underway, but NCI states concern regarding substitution for trichloroethylene before the alternative compounds can be adequately evaluated.

The carcinogenicity of trichloroethylene has also been reviewed recently by the International Agency for Research on Cancer (World Health Organization, 1976).

Table 3.4 presents a summary of carcinogenic data for trichloroethylene (Waters et al., 1976). The question remains whether any relationship exists between trichloroethylene and liver cancer in man. Until that is resolved, trichloroethylene must be regarded as a useful but potentially hazardous substance.

In the section on "Transformations of Trichloroethylene in the Environment", some of the known transformations of trichloroethylene in the environment were indicated. In considering the possible harm of a substance to people or to animals, it is not sufficient to know the toxicity of the parent compound; the toxicity of the degradation or transformation products must also be considered and evaluated in terms of the quantities of these by-products produced. Table 3.5 provides a summary of the toxicity of trichloroethylene and its various transformation products. Unfortunately, little is known about the quantities of these substances that are produced when trichloroethylene is degraded.

TABLE 3.4 SUMMARY OF DATA ON THE CARCINOGENICITY OF TRICHLOROETHYLENE

Species	Number	Exposure	Results
		Inhalation	
Dogs	16	150-750 ppm in air 20-48 hr/wk for 7-16 wk	No tumors, no deaths
		Inhalation	
Rats	12	3,000 ppm, 27 exposures	3 rats died, no tumors
Guinea pigs	11	100 ppm, 132 exposures	
Monkeys	2	200 ppm, 148 exposures	
Rabbits	4	200 ppm, 178 exposures	
		Inhalation	
Cats	8	200 ppm 75 min/day for 6 mo	No tumors, no deaths
		Intragastric	
Mice	28	0.1 ml in 40% oil solution 2/wk	No tumors, no deaths
		2,339 mg/kg (M) 5 wk for 78 wk	Hepatocellular carcinoma; Metastases, mainly lung
		1,739 mg/kg (F) 5 wk for 78 wk	
		1,169 mg/kg (M) 5 wk for 78 wk	
		869 mg/kg (F) 5 wk for 78 wk	
		Intragastric	
Rats		1,097 mg/kg (M&F) 5/wk for 78 wk	No hepatocellular carcinoma, many deaths from toxic doses during experiment
		549 mg/kg (M&F) 5 wk for 78 wk	

Source: Waters et al., 1976.

TABLE 3.5. TOXICITY OF TRICHLOROETHYLENE AND ITS TRANSFORMATION PRODUCTS

Compound	Toxicity	Threshold Limit Value
Trichloroethylene	orl-hmn LDLo:857 mg/kg ihl-hmn TCLo:160 ppm/83M TFX:CNS ihl-man TCLo:110 ppm/8H orl-rat LCLo:8000 ppm/4H orl-mus TDLo:351 gm/kg/78WI TFX:CAR ihl-mus LCLo:3000 ppm/2H ivn-mus LD50:34 mg/kg orl-dog LDLo:5860 mg/kg ipr-dog LD50:1900 mg/kg ivn-dog LDLo:150 mg/kg ihl-rbt LCLo:11000 ppm scu-rbt LDLo:1800 mg/kg	100 ppm ∿535 mg/m^3 U.S. OCCUPATIONAL STANDARD USOS air TWA:100 ppm; C:200 ppm; PK:300 ppm/5M/2H CRIT DOC: RECOM. STANDARD air TWA:100 ppm:C 150 ppm
Chloral hydrate	orl-rat LD50:285 mg/kg ipr-rat LDLo:500 mg/kg scu-rat LD50:620 mg/kg orl-mus LD50:1100 mg/kg skn-mus TDLo:960 mg/kg/W TFX:NEO ipr-mus LDLo:650 mg/kg scu-mus LDLo:800 mg/kg orl-dog LDLo:1000 mg/kg orl-cat LDLo:400 mg/kg orl-rbt LDLo:1200 mg/kg scu-rbt LDLo:1000 mg/kg ivn-rbt LDLo:400 mg/kg rec-rbt LDLo:1000 mg/kg orl-frg LDLo:938 mg/kg par-mus LDLo:900 mg/kg	

TABLE 3.5 (Continued)

Compound	Toxicity	Threshold Limit Value
Trichloroethanol	orl-rat LD50:600 mg/kg ipr-rat LDLo:300 mg/kg ivn-mus LD50:201 mg/kg ivn-rbt LDLo:50 mg/kg	
Trichloroacetic acid	orl-rat LD50:3320 mg/kg irp-mus LDLo:500 mg/kg	
Dichloroacetic acid	orl-rat LD50: 2820 mg/kg skn-rtb LD50:510 mg/kg	
Formic acid	orl-rat LD50:1210 mg/kg orl-mus LD50:1100 mg/kg ipr-mus LD50:940 mg/kg irn-mus LD50:145 mg/kg orl-dog LD50:4000 mg/kg ivn-rbt LDLo:239 mg/kg	5 ppm ∿9 mg/m^3
Hydrochloric acid	ihl-hmn LCLo:1300 ppm/30M ihl-rat LC50:3124 ppm/1H ihl-mus LC50:2142 ppm/30M ipr-mus LD50:40 mg/kg orl-rbt LD50:900 mg/kg	
Hydrogen chloride	ihl-rat LC50:4701 ppm/30M ihl-mus LC50:2644 ppm/30M ihl-rbt LCLo:4416 ppm/30M ihl-gpg LCLo:4416 ppm/30M ihl-mam LCLo:1000 mg/m3/2H	5 ppm ∿7 mg/m^3

TABLE 3.5 (Continued)

Compound	Toxicity	Threshold Limit Value
Ozone	ihl-man TCLo:1860 ppb/75M TFX:CNS ihl-hmn TCLo:100 ppb TFX:IRR ihl-hmn TCLo:1 ppm TFX:PUL ihl-rat LC50:4.8 ppm/4H ihl-mus LC50:3.8 ppm/4H ihl-mus LCLo:4.5 ppm/50HI TFX:NEO ihl-ham LC50:10.5 ppm/4H	01 ppm ∿02 mg/m^3
Phosgene	ihl-hmn TDLo:25 ppm/30M TFX:IRR ihl-rat LC50:75 ppm/30M ihl-mus LC50:110 ppm/30M ihl-dog LCLo:79 ppm/30M ihl-mky LC50:1087 ppm/1M ihl-cat LC50:1482 ppm/1M ihl-rbt LC50:3211 ppm/1M ihl-gpg LC50:141 ppm/30M ihl-gpg LDLo:31 mg/m3/20M	
Chloroacetyl chloride	ihl-rat LCLo:1000 ppm/4H	
Dichloroacetyl chloride	orl-rat LD50: 2460 mg/kg ihl-rat LCLo:2000 ppm/4H skn-rbt LD50:650 mg/kg	
Carbon monoxide	ihl-man LCLo:4000 ppm/30M ihl-man TCLo:650 ppm/45M TFX:CNS ihl-rat LC50:1807 ppm/4H ihl-mus LC50:5718 ppm/4H ihl-dog LCLo:3841 ppm/46M ihl-cat LCLo:8730 ppm/35H ihl-gpg LC50:2444 ppm/4H	50 ppm ∿55 mg/m^3
Nitric acid		2 ppm ∿5 mg/m^3

TABLE 3.5 (Continued)

Key to Abbreviations

AZTX - aquatic toxicity

CNS - central nervous system
gpg - guinea pig
H - hour
hmn - human
ihl - inhalation
ipr - intraperitoneal
ivn - intravenous

LC50 - lethal concentration 50% kill
LCLo - lowest published lethal concentration
LD50 - lethal dose 50% kill
LDLo - lowest published lethal dose

M - minute
mam - mammal
mus - mouse

pph - parts per hundred (V/V)(percent)
Pfy - psychotropic
Pk - peak concentration

rbt - rabbit
rec - rectal
scu - subcutaneous
skn - skin

TCLo - lowest published toxic concentration
TDLo - lowest published toxic dose
TFX - toxic effects
TLV - threshold limit value
TWA - time weighted average
TXDS - qualifying toxic dose

USOS - U.S. Occupational Health Standard

Source: Christensen and Luginbyhl, 1975.

4. OCCURRENCE OF TRICHLOROETHYLENE IN FOOD AND OTHER PRODUCTS THAT COME IN CONTACT WITH MAN

FOOD

There are, unfortunately, very little data on the presence of TCE in food raised and sold in the United States. There is some information on the presence of TCE in foodstuffs found in the United Kingdom. This information is summarized in Table 4.1. TCE is found on the order of parts per billion in almost all common foodstuffs.

Trichloroethylene has also been used to extract spice oleoresins and to decaffeinate coffee. The FDA regulations of the concentration of TCE in these materials are listed in the section on "Exposure and Biological Accumulation of Trichloroethylene in Man". In 1974, approximately 90 percent of the decaffeinated coffee was produced using trichloroethylene (Valle-Riestra, 1974); but since July, 1975, TCE has not been used by U.S. makers of decaffeinated coffee. It has largely been replaced by methylene chloride, according to FDA, even though the safety of methylene chloride has not been established. In a recent publication, TCE was not detected in any of the oleoresins analyzed for that substance (Page and Kennedy, 1975).

DRINKING WATER

Shortly after the identification of trichloroethylene and other halogenated hydrocarbons in New Orleans drinking water, the results were published (Dowty et al., 1975a and 1975b) and several other significant events occurred. The Safe Drinking Water Act was signed into law in December, 1974, and a National Organics Reconnaissance Survey (NORS) was undertaken.

Table 4.1 TRICHLOROETHYLENE IN FOODSTUFFS

Foodstuff	Concentration, µg/kg
Dairy produce	
Fresh milk	0.3
Cheshire cheese	3
English butter	10
Hens eggs	0.6
Meat	
English beef (steak)	16
English beef (fat)	12
Pig's liver	22
Oils and fats	
Margarine	6
Olive oil (Spanish)	9
Cod liver oil	19
Vegetable cooking oil	7
Castor oil	ND[b]
Beverages	
Canned fruit drink	5
Light ale	0.7
Canned orange juice	ND
Instant coffee	4
Tea (packet)	60
Wine (Yugoslav)	0.02
Fruit and vegetables	
Potatoes (S. Wales)	ND
Potatoes (N.W. England)	3
Apples	5
Pears	4
Tomatoes[a]	1.7
Black grapes (imported)	2.9
Fresh bread	7

a Tomato plants were grown on a reclaimed lagoon at Runcorn Works of ICI.
b ND = not detected.
Source: McConnell et al., 1975.

As part of the NORS, drinking water supplies at five selected sites were analyzed. These supplies were chosen to represent the major types of raw water sources in the United States at that time. The results for TCE are summarized in Table 4.2. The NORS was extended to cover a total of 10 cities in the United States. In the extended survey, trichloroethylene was also detected but not quantified in the drinking water of Lawrence, Massachusetts (U.S. Environmental Protection Agency, 1975b). A follow-up study on finished and raw water samples from Miami, Florida, was carried out. The results of this study are summarized in Table 4.3.

Several U.S. Environmental Protection Agency regional offices have analyzed various waters for TCE. The Surveillance and Analysis Division of Region IV under the direction of James H. Finger has detected TCE at the following locations at the estimated concentrations shown:

Dalton, Georgia, Wastewater Treatment Plant - < 5 ppb

Rome, Georgia, Treatment Plant - < 0.5 ppb

Rome, Georgia, Wastewater Treatment Plant - < 5 ppb.

Region IV personnel also analyzed discharge from the Stauffer Chemical Co. plant at Louisville and determined the TCE concentration to be 500 ppb. It is believed that Stauffer produces TCE at this plant. Region IV personnel may have conducted an organics study of the Ohio River, but this information is not yet available.

As a result of a National Organic Monitoring Survey conducted between March 1 and April 3, 1976, which indicated that trichloroethylene was present in the finished drinking water at Des Moines, Iowa, to the

Table 4.2 PROPERTIES AND TCE CONCENTRATION OF FINISHED WATER IN FIVE CITIES

City	Type of supply	Type of raw water	Nonvolatile total organic carbon, mg/l	Conductivity, MMHOS/CM	Chlorine, mg/l	pH	TCE concentration, ppb
Cincinnati, Ohio	Surface	Industrial waste	1.3	295	2.7	8.6	0.1
Miami, Florida	Ground	Natural waste	6.5	350	2.3	8.7	0.3
Ottumwa, Iowa	Surface	Agricultural waste	2.3	500	1.4	9.2	<0.1
Philadelphia, Pennsylvania	Surface	Municipal waste	1.9	260	2.0	8.3	0.5
Seattle, Washington	Surface	Natural waste	1.0	50	0	6.6	ND

ND = not detected.

Source: Keith, 1976.

Table 4.3 SOME OF THE ORGANIC COMPOUNDS IDENTIFIED IN MIAMI, FLORIDA-FINISHED AND RAW WATER SAMPLES

Organic compound identified	Finished water, 1/29/75, ppb	Finished water, 7/7/75, ppb	Raw water, 7/7/75, ppb	Test wall, 7/7/75, ppb
Trichloroethylene	P[a]	P	P	ND[b]
Methylchloroform	P	P	P	ND
Carbon Tetrachloride	P	P	ND	ND
Chloroform	311	220	0.7	ND

Source: Keith, 1976.

a P = Present but not quantified.
b ND = Not detected.

extent of 32 ppb, the Surveillance and Analysis Division of Region VII under the direction of Donald A. Townley became involved in a rather extensive sampling and analysis effort. This effort was lead by Dr. Robert D. Kleopfer, Organic Chemistry Working Unit Leader, Laboratory Branch, Region VII. Following is a summary of the results obtained in this study.

Samples taken at Des Moines, Iowa, on August 4, 1976, were analyzed using a Tekman liquid sample concentrator with computerized gas chromatography/mass spectrometry. Raw water was determined to have no detectable TCE while the finished water contained TCE at a concentration of 53 ppb. Then on August 12, 1976, a more extensive series of samples were taken. The results are reproduced in Table 4.4. It was concluded that the TCE originates in the gallery infiltration system and is not being produced in the water treatment process.

The next step was to attempt to determine the ultimate source of TCE by sampling the infiltration gallery at various points along the system. The gallery system is approximately 3 miles in length and access by manholes is available at 2,000-foot intervals. Assuming a flow of 25 million gallons per day through the gallery and a TCE concentration of 61 ppb, the source would have to provide 5,772 g (12.7 lbs.) or 3.95 liters (1.04 gallons) of TCE per day to the infiltration gallery water. On September 2, 1976, samples were taken at various points along the gallery. The samples were analyzed and the results are summarized in Table 4.5. It was concluded that contamination of the gallery infiltration system was responsible for the presence of TCE in Des Moines drinking water and that the contamination occurs

Table 4.4 TCE CONCENTRATION IN WATER SOURCES FOR DES MOINES, IOWA, DRINKING WATER AND IN CONTROLS

Sample description	Concentration, ppb
Raccoon River at Rock Dam recharge pumping station	ND[a]
Raccoon River water treated with hypochlorite	ND
Gallery infiltration water	61
Gallery infiltration water treated with hypochlorite	33
Raccoon River water from sedimentation basin	ND
Mixed water prior to softening	39
Mixed water after softening	41
Finished water at Des Moines Airport	24
Finished water at water treatment plant laboratory	31
Kansas City, Kansas, water transferred at water treatment plant lab	ND
Meredith Canal	11
Meredith Canal just prior to recharge basin	3

a ND = none detected; the detection limit was 1 ppb.

Table 4.5 TCE CONCENTRATION IN INFILTRATION GALLERY AND IN ASSOCIATED WATERS

Sample description	Concentration, ppb
Meredith composite at west end of creek	1
Meridith composite of process water at north end of building	8
Meredith composite of process water at east end of creek	12
Meredith grab of process water at east end of creek	14
Meredith canal grab just prior to recharge basin	2
Grab at Cabin Creek bridge	ND[a]
South bank at middle of west part of recharge basin #14	1
Gallery at manhold #12	ND
Gallery at valve chamber #11	ND
Gallery at valve chamber #10	ND
Gallery at valve chamber #8	ND
Gallery at valve chamber #5	ND
Gallery at water plant	45
Raccoon River at intake	ND
Finished water at lab	22

a ND = not detected; the detection limit was 1 ppb.

somewhere downstream from Valve Chamber Number 5. On September 22 and 23, 1976, samples were taken downstream from Valve Chamber Number 5 and at other sites. The analytical results are presented in Table 4.6. These results show that the north end of the gallery is heavily contaminated by TCE. The exact source of this substance has not been reported at this writing. Table 4.7 summarizes the data for Des Moines finished water.

It is interesting to note that the levels of TCE reported in Des Moines, Iowa, drinking water may result from the dumping of 1 gallon per day of this substance into the water system.

In an earlier, unrelated study (1974), raw wastewater processed in the Oro, Iowa, Sanitary District of the San Francisco Bay was estimated to contain 1.2 mg per liter in the 49,205 cubic meters per day average discharge (Camisa, 1975).

In an investigation of the chlorination of water for purification and the potential for the formation of potentially harmful chlorinated compounds by this process, T.A. Bellar, et al (1974) at the National Environmental Research Center of EPA at Cincinnati, Ohio, reported the following concentrations of trichloroethylene in water from a sewage-treatment plant: Influent before treatment, 40.4 $\mu g/\ell$; effluent before chlorination, 8.6 $\mu g/\ell$; and effluent after chlorination, 9.8 $\mu g/\ell$. These workers concluded that the number of organohalides formed during the chlorination process does not constitute any immediate threat to the public health.

The prevalence of TCE and other halogenated hydrocarbons in the environment cannot be denied. However, the source of these substances

Table 4.6 TCE CONCENTRATIONS IN NORTH END OF INFILTRATION GALLERY AND IN ASSOCIATED WATERS

Sample description	Concentration, ppb
Laboratory tap (9/23/76)	16[a]
Gallery pump discharge	37[a]
River intake	ND[b]
Valve chamber #1	391[a]
Manhole #1	457[a]
Manhole #2	229[a]
Birds Run sewer overflow	ND
Raccoon River below dam	ND
Raccoon River near steel sheeting	ND
Drainage culvert	ND
Sewer manhole west	151[c]

a These samples all contained lesser amounts of dichloroethylene.
b ND = not detected; the detection limit was 1 ppb.
c This sample contained significant amounts of TCE, methylchloroform and dimethyldisulfide with smaller amounts of dichloroethane and dichloroethylene.

Table 4.7 SUMMARY OF TCE DATA FOR DES MOINES FINISHED WATER

Date of sample	Location	Concentration, ppb
December 10 or 11, 1974	At Plant	P[a]
March 20, 1975	Ditto	80[a]
March-April, 1976	"	32[b]
Spring, 1976	"	53[b]
August 4, 1976	"	53
August 12, 1976	"	31
August 12, 1976	At Airport	24
September 2, 1976	At Plant	22

a Two analyses were done by the Iowa State Hygienic Laboratory; the earlier sample indicated a "third peak" which was tentatively identified as trichloroethylene.

b These samples were taken as part of a national survey.

in such media as drinking water has not been determined. Much more information about the presence of these substances in the environment is needed as well as information on the mechanism of transport from one medium to another.

OTHER SUBSTANCES

Trichloroethylene occurs in many commercial products, but information on these products is not readily obtained from the manufacturers. There are several reasons for this which include the proprietary nature of many manufacturer's formulations, the constantly changing types and composition of products manufactured, the alertness of manufacturers to new information on the hazards of chemicals contained in their formulations, and regulations imposed by various agencies.

Table 4.8 lists representative commercial products containing trichloroethylene. This list appeared in 1975 and is probably out of date in many respects. It is meant to show types of products that might come in contact with man and is not meant to reflect negatively on any manufacturer.

Table 4.8 REPRESENTATIVE COMMERCIAL PRODUCTS CONTAINING TRICHLOROETHYLENE

Product	Composition		Manufacturer
	Substance	Percent	
Brush Top Spot Remover[a], regular	Expersol 2530 (xylene)	87	Product Sales Company
	Trichloroethylene	10	
	Perchloroethylene	1.5	
	Methylene Chloride	1.5	
Brush Top Spot Remover[a], super	Chlorinated solvents	100	Ditto
	Triethane (1,1,1-trichloroethane)	50	
	Trichloroethylene	25	
	Perchloroethylene	10	
	Methylene Chloride	5	
Carbona Cleaning Fluid	Trichloroethylene	44	Carbona Products Co.
	Petroleum hydrocarbons	56	
Carbona #10 Special Spot Remover	1,1,1-Trichloroethane	10	Ditto
	Trichloroethylene	40	
	Petroleum hydrocarbons	50	
Carbona Spray Spot Remover	Trichloroethylene		"
	1,1,1-Trichloroethane		
	Cab-O-Sil		
	Freon 12		
Crater 2X and 5X Fluid	Petroleum lubricating oil		Texaco, Inc.
	Trichloroethylene		
	Pine tar		
DuPont Dry Clean	Trichloroethylene		duPont
Dux Water Repellant	Piccotex 120 Solution (synthetic resin)	25	Detrex Corp.
	Wax (paraffin)		
	Trichloroethylene		

Table 4.8 (Continued)

Product	Composition		Manufacturer
	Substance	Percent	
Glamorene Dry Cleaner for Rugs (Formerly Galmorene Wool Rug Cleaner)	Chlorinated hydrocarbon (trichloroethylene) Petroleum distillate Wool flour		Glamorene Products Corp.
Glamorene Rug Cleaner	Trichloroethylene Ethylene dichloride Heavy naphtha		Ditto
Helmac Spot Pic-Up Aerosol spot remover	Perchloroethylene Methylene chloride Trichloroethylene		Helmac Products Corp.
HH Tree Wound Healer Protective seal for pruned and damaged trees and shrubs	Asphaltum Petroleum oils Phenylmercury oleate Allantoin Inert ingredients: Dichlorodifluoromethane Trichloroethylene Methylene chloride		Hubbard-Hall Chem. Co.
Instant Chimney Sweep Aerosol spray application	Trichloroethylene Active chemicals Propellant (Freon)	34 41 25	Miracle Adhesives
Joy Solvent[a]	Trichloroethylene		Joy Chemical Inc.
Kwik Kleen Drug Shampoo[a] Dry shampoo	Trichloroethylene		Royal Bond, Inc.
Lash Bath Cleanser for false eyelashes	Naphtha Trichloroethylene		Revlon

Table 4.8 (Continued)

Product	Composition		Manufacturer
	Substance	Percent	
O'Cedar Sea Spray[a]	Methylene chloride Trichloroethylene Cellosolve acetate Wax Freon propellant		O'Cedar
Perm-A-Clor NA	Trichloroethylene		Detrex Corp.
Sears Air Freshener			
Sears Odor Neutralizer	Essential oils Perfume Trichloroethylene	55.2 10.4 34.5	Sears, Roebuck & Co.
Spot Chief[a]	Trichloroethylene Perchloroethylene Solvent 310 (petroleums) Solvent 310 (petroleum solvent) Paradichlorobenzene Lanolin 1,1,1-Trichloroethane Freon 12		White Frost, Inc.
Surfisan Spray[b] Surface disinfection, preservation and deodorizing	Chloroform Kerosene Camphor Trichloroethylene		Royal Bond, Inc.
Triad Metal Cleaner	Trichloroethylene		
Triad Metal Polish	Trichloroethylene		
Trichlor - Solvent	Trichloroethylene	100	PPG Industries, Chemical Division

Table 4.8 (Continued)

Product	Composition		Manufacturer
	Substance	Percent	
Tri-Clene Dry Clean	Trichloroethylene		PPG Industries, Chemical Division

Source: Lloyd et al., 1975. The above product descriptions are not to be construed as current or accurate since changes in product composition are being made continually by manufacturers.

a No longer marketed, but some may still be in use.
b No longer contains TCE but listed since some products may still be in use.

5. EXPOSURE AND BIOLOGICAL ACCUMULATION OF TRICHLOROETHYLENE IN MAN

EXPOSURE

Following is a table with an estimation of the number of workers exposed to trichloroethylene by industry. Table 5.1 not only gives an indication of the number of workers exposed but also indicated the diverse industries using this solvent. It is also estimated that approximately 5,000 medical, dental, and hospital personnel are routinely exposed to trichloroethylene as an anesthetic (Lloyd et al., 1975).

A 2-year series of studies involving cleaning operations throughout the United States was carried out by Dow Chemical (Skory, 1974). The purpose was to determine the extent of worker exposure during solvent vapor degreasing and to compare the three most commonly used chlorinated solvents: trichloroethylene, methylchloroform, and perchloroethylene. Dow estimates that there are over 25,000 chlorinated solvent vapor degreasers throughout the United States. The studies were conducted in the worker breathing zones which were adjacent to some 275 industrial vapor degreasing operations. The results of this study show that trichloroethylene and perchloroethylene vapor concentrations measured around vapor degreasers frequently exceeded the allowable standards for health and safety. Peak concentrations were high enough to present a definite health and safety hazard from anesthetic affects such as dizziness, lack of coordination, and impaired judgment. Although the national primary and secondary photochemical oxidant standards for chlorinated

TABLE 5.1. OCCUPATIONAL EXPOSURE

Industry	Estimated Number Exposed
Agricultural Services	124
Oil and Gas Extraction	267
Ordnance	57
Food Products	2,502
Textile Mill Products	1,014
Apparel/Textile Products	858
Lumber Products	72
Furniture Mfg.	162
Paper Products Mfg.	2,240
Printing Trades	2,876
Chemical Mfg.	9,552
Petroleum Products	713
Rubber/Plastics Mfg.	4,985
Leather Products	725
Stone/Clay Products	2,685
Primary Steel Mfg.	11,672
Metal Fabrication	11,709
Machinery Mfg.	7,481
Electrical Equipment	66,727
Transportation Equipment	54,174
Instrument Mfg.	4,815
Miscellaneous Mfg.	1,516
Trucking/Warehousing	642
Air Transportation	23
Communication	5,560
Wholesale Trade	3,327
Automotive Dealer	223
Furniture Stores	597
Banking	2,391
Personal Services	583
Misc. Business Services	27,759
Auto Repair	5,246
Misc. Repair	17,198
Amusement Services	7,987
Mechanical Services	20,053
Misc. Unclassified	4,138
ESTIMATED TOTAL	282,653

Source: Lloyd et al., 1975.

solvents are < 3 lb/hr or 15 lb/day maximum for each piece of equipment, it is not uncommon for an idling open top (measuring 24 x 58 inches) vapor degreaser to lose 47 lb/day of trichloroethylene or 33 lb/day of methylchloroform (Archer, 1973). Judging from production figures, this material is being lost to the atmosphere and is then replaced.

It is estimated that 2×10^5 tons of chlorinated hydrocarbons are lost to the environment each year (Murray and Riley, 1973) and that 1×10^4 tons of trichloroethylene are discharged annually (Abrams et al., 1975).

It is estimated that 500 tons/day of industrial effluents are released into the air over Los Angeles County. Of this amount, 25 tons are dry cleaning fluids and 95 tons are degreasing solvents, that is, chlorinated hydrocarbons (Simmonds et al., 1974). Because trichloroethylene has been implicated as an oxidant-producing contaminant, its use in Los Angeles County has been restricted since 1967 (Farmber, 1973). This restriction, the famous Rule 66, may provide a control in monitoring trichloroethylene. Since the amount of trichloroethylene over Los Angeles County should be reduced in relationship to other chlorinated hydrocarbons that have replaced it, the determination of the relative amounts there and over other cities where there no restrictions should be very informative.

Trichloroethylene is subject to certain county, state, and federal regulations. The regulation of trichloroethylene in Los Angeles County has already been mentioned. Also, NIOSH has recommended that the current 8-hour time-weighted average (TWA) exposure limit for trichloroethylene of 100 ppm be kept; but the ceiling limit of 200 ppm be reduced to 150 ppm measured over a 15-minute period, and the current 300 ppm peak concentration be eliminated (Anonymous, 1976).

In addition, the Food and Drug Administration (FDA) has set the following limits: 10 ppm trichloroethylene in instant decaffeinated coffee, 25 ppm trichloroethylene in decaffeinated ground coffee and 30 ppm trichloroethylene in spice oleoresins (Valle-Riestra, 1974).

The basis for these regulations is various toxicological data. The stricter regulations for trichloroethylene are based on more recent information including studies on the carcinogenicity of trichloroethylene. The toxicology of trichloroethylene was considered in an earlier section.

Concentrations of chlorinated hydrocarbons around a vapor degreaser should be controlled but their presence comes as no surprise. What of solvents in the home or living area? In a study of the air near a solvent recovery plant in Maryland, levels of carbon tetrachloride were measured and compared with levels of indoor air. At times, concentrations of 10 to 45 ppm of carbon tetrachloride were measured inside a house near the plant when levels outside were 1 ppm. The highest indoor concentration record was 90 ppm (Bridbord et al., 1975).

What about trichloroethylene in the vicinity of manufacturing plants or industrial areas using large quantities of these solvents? There are no good answers at this time. There are no published reports of environmental levels experienced in the manufacture of trichloroethylene (National Institute for Occupational Safety and Health, 1973). The data that are available are summarized in the section on "Occurrence of Trichloroethylene in the Environment".

BIOLOGICAL ACCUMULATION

There is little evidence to judge if trichloroethylene is accumulating in living systems, and the opinions of scientists conflict with each other.

There is some limited data on the occurrence of trichloroethylene in human tissue (Table 5.2). Also, dogs were exposed to relatively high concentrations (7,000 to 20,000 ppm) of trichloroethylene and then, after sacrificing the animals, tissure was analyzed for trichloroethylene (Table 5.3). The limited human data and the lack of exposure and medical histories makes this data of little value in judging if trichloroethylene is accumulating in man. In the care of dogs, such massive doses were given by inhalation that judgements about accumulation in living tissue are impossible.

Doruty et al., (1975a) in a paper on hologenated hydrocarbons in drinking water concludes that "in view of the lipophilic nature of hologenated hydrocarbons and their occurrence in drinking water, it is not surprising that they might be found accumulating in blood or other body tissues". There authors present no data or references to support their contentions. They not only lack quantitative information about levels of hologenated hydrocarbons in blood and body tissues, but fail to produce quantification of these substances in drinking water. Even in their full paper (Doruty et al., 1975b) they are still talking about relative concentrations.

A Study Panel on Assessing Potential Ocean Pollutants (1975) reports that the bioaccumulation of low-molecular weight chlorinated hydrocarbons is quite low compared to accumulation of chlorinated pesticides in vertebrates. This same group reports on another study in which it was determined that bioaccumulation factor is determined by the partition

TABLE 5.2. OCCURRENCE OF TRICHLOROETHYLENE IN HUMAN TISSUE

Age of Subject	Sex	Tissue	Concentration, µg/kg (wet tissue) Trichloroethylene
76	F	Body fat	32
		Kidney	<1
		Liver	5
		Brain	1
76	F	Body fat	2
		Kidney	3
		Liver	2
		Brain	<1
82	F	Body fat	1.4
		Liver	3.2
48	M	Body fat	6.4
		Liver	3.5
65	M	Body fat	3.4
		Liver	5.2
75	M	Body fat	14.1
			5.8
66	M	Body fat	4.6
74	F	Body fat	4.9

Source: McConnell et al., 1975.

TABLE 5.3. TRICHLOROETHYLENE RECOVERED FROM TISSUE

Animal Number	Mode of Exposure	Concentrations, mg %, wet weight						
		Adrenal	Blood	Brain	Fat	Heart	Kidney	Liver
12	Acute	22.4	72.5	17.0	17.9	8.6	1.6	27.0
15	Acute	6.24	46.0	15.1	14.7	5.0	8.2	9.6
16	Acute	——	52.7	19.7	——	5.4	5.8	38.8
17	Acute	——	22.3	——	4.8	4.2	3.6	10.8
20	Acute	22.5	28.4	8.2	70.4	18.9	3.2	9.2
25	Acute X3	13.8	50.0	20.9	70.5	13.9	17.5	49.4
14	Chronic-Acute	60.6	46.1	——	——	7.5	21.1	20.6
21	Chronic-Acute	23.1	50.6	23.6	22.1	12.9	5.3	9.7
19	Chronic	——	9.6	2.7	30.7	1.2	1.0	3.2
22	Chronic	0.94	0.13	0.22	14.4	0.11	0.13	0.12
24	Chronic	1.06	0.25	0.22	6.5	0.11	0.25	0.25

		Lung	Muscle	Pancreas	Spinal Cord	Cerebro Spinal Fluid	Spleen	Thyroid
12	Acute	2.8	2.7	——	8.8	——	0.71	——
15	Acute	2.2	——	3.2	——	3.8	3.9	2.0
16	Acute	0.92	0.15	9.8	——	1.5	1.2	6.6
17	Acute	0.92	3.3	6.4	——	0.61	5.4	——
20	Acute	0.40	5.1	14.1	——	1.7	1.3	3.9
25	Acute X3	10.4	9.3	43.8	28.3	——	5.1	14.1
14	Chronic-Acute	2.0	——	8.1	——	0.15	——	5.8
21	Chronic-Acute	1.3	3.8	16.0	——	1.8	8.5	7.4
19	Chronic	0.53	4.1	2.5	——	0.15	0.71	1.1
22	Chronic	0.26	0.45	<0.05	0.13	0.15	<0.05	<0.05
24	Chronic	0.13	0.30	0.28	0.13	0.15	0.12	0.63

Source: U.S. Environmental Protection Agency, 1975.

TABLE 5.4. CHLORINATED HYDROCARBONS IN MARINE ORGANISMS[a]

Species	Source	(Concentrations expressed as parts per 10^9 by mass on wet tissue) CCl_2CHCl	CCl_2CCl_2	CH_2CCl_2+CCl_4	
		Invertebrates			
plankton	Liverpool Bay	0.05-0.4	0.05-0.5	0.03-10.7	0.04-0.9
plankton	Torbay	0.0	2.3	2.2	
Nereis diversicolor (ragworm)	Mersey Estuary	ND	2.9	0.6	
Mytilus edulis (mussel)	Liverpool Bay	4-11.9	1.3-6.4	2.4-5.4	
	Firth of Forth	9	9	10	2
	Thames Estuary	8	1	5	0.7
Cerastoderma edule (cockle)	Liverpool Bay	6-11	2-3	0-2	0.4-1
Ostrea edulis (oyster)	Thames Estuary	2	0.5	0.9	0.1
Buccinum undatum (whelk)	Thames Estuary	ND	1	6	0.9
Crepidula fornicata (slipper limpot)	Thames Estuary	9	2	4	0.3
Cancer pagurus (crab)	Tees Bay	2.6	2.3	8.4	
	Liverpool Bay	10-12	8-9	5-34	3-5
	Firth of Forth	15	7	1	2
Carcinus maenas (shore crab)	Firth of Forth	12	6	14	3
Eupagurus bernhardus (hermit crab)	Firth of Forth	15	15	0.7	1
	Thames Estuary	5	2	2	0.2

TABLE 5.4. (Continued)

Species		Source	(Concentrations expressed as parts per 10^9 by mass on wet tissue) CCl_2CHCl	CCl_2CCl_2	$CH_2CCl_2+CCl_4$
Crangon crangon (shrimp)		Firth of Forth	16	3	2	6
Asterias rubens (starfish)		Thames Estuary	5	1	5	0.8
Solaster sp. (sunstar)		Thames Estuary	2	2	3	0.2
Echinus esculentus (sea urchin)		Thames Estuary	1	1	3	0.1
			Marine algae			
Enteromorpha compressa		Mersey Estuary	19-20	14-14.5	24-27	
Ulva lactuca		Mersey Estuary	23	22	12	
Fucus vesiculosus		Mersey Estuary	17-18	13-20	9.4-10.5	
Fucus serratus		Mersey Estuary	22	15	35	
Fucus spiralis		Mersey Estuary	16	13	17	
			Fish			
Raja clavata (ray)	flesh	Liverpool Bay	0.8-5	0.3-8	2-13	
	liver	Liverpool Bay	5-56	14-41	1.5-18	
Pleuronectes platessa (plaice)	flesh	Liverpool Bay	0.8-8	4-8	0.7-7	
	liver	Liverpool Bay	16-20	11-28	2-47	

TABLE 5.4. (Continued)

Species		Source	(Concentrations expressed as parts per 10^9 by mass on wet tissue) CCL_2CHCl	CCl_2CCl_2		CH_2CCl_2+CCl_4
Platycthys flesus (flounder)	flesh	Liverpool Bay	3	2	4	2
	liver	Liverpool Bay	2	1	3	0.3
Limanda limanda (dab)	flesh	Liverpool Bay	3-5	1.5-11	1.3-8	
	liver	Liverpool Bay	12-21	15-30	2-14	
Scomber scombrus (mackerel)	flesh	Liverpool Bay	5	1	5	2
	liver	Liverpool Bay	8	ND	3	ND
Limanda	flesh	Redear, Yorks	4.6	5.1	9.9	
limanda	flesh	Thames Estuary	2	3	4	0.3
Pleuronectes platessa	flesh	Thames Estuary	3	3	3	0.9
Solea solea (sole)	flesh	Thames Estuary	2	4	2	6
	guts	Thames Estuary	11	1	26	1
Aspitrigla cuculus (red gurnard)	flesh	Thames Estuary	11	1	4	0.6
	guts	Thames Estuary	6	2	10	0.3
Trachurus trachurus (scad)	flesh	Thames Estuary	2	4	1	2
Trisopterus luscus (pout)	flesh	Thames Estuary	2	2	2	0.3
Squalus acanthias (spurdog)	flesh	Thames Estuary	3	1	ND	1

TABLE 5.4. (Continued)

Species		Source	(Concentrations expressed as parts per 10^9 by mass on wet tissue) CCl_2CHCl	CCl_2CCl_2	$CH_2CCl_2+CCl_4$
Scomber scombrus (mackerel)	flesh	Torbay, Devon	2.1	ND	2.4
Clupea sprattus	flesh	Torbay, Devon	3.4	1.0	5.6
Gadus morrhus (cod)	flesh	Torbay, Devon	0.8	<0.1	3.3
	air bladder	Torbay, Devon	<0.1	3.6	NA
		Sea and freshwater birds			
Sula bassana (gannot)	liver	Irish Sea	4.5-6	1.5-3.2	1.2-1.9
	eggs	Irish Sea	9-17	4.5-26	17-20
Phalacrocerax aristotelis (shag)	eggs	Irish Sea	2.4	1.4	39.4-41
Alca torda (razorbill)	eggs	Irish Sea	23-26	19-29	35-43
Rissa tridactyla (kittiwake)	eggs	North Sea	33	25	40
Cygnus olor (swan)	liver	Frodsham Marsh (Merseyside)	2.1	1.9	4.7
	kidney		14	6.4	2.4
Gallinula chloropus (moorhen)	liver	(Merseyside)	6	3.1	1.6
	muscle	(Merseyside)	2.5	0.7	1.1
	eggs	(Merseyside)	6.2-7.8	1.3-2.5	14.5-21.8
Anas platyrhyncos (mallard)	eggs	(Merseyside)	9.8-16	1.9-4.5	4.2-24

Table 5.1 (Continued)

Species		Source	(Concentrations expressed as parts per 10^9 by mass on wet tissue) CCl_2CHCl	CCl_2CCl_2	CH_2CCl_2+CCl_4
			Mammals		
Halichoerus grypus (grey seal)	blubber	Farne Is.	2.5-7.2	0.6-19	16-30
	liver	Farne Is.	3-6.2	0-3.2	0.3-4.6
Sorex araneus (common shrew)		Frodsham Marsh	2.6-7.8	1	2.3-7

Notes: NA, no analysis; ND, not detectable.

a Source: Barson and McConnell, 1975.

of the compound between the water and the tissues of the organism, and further that the log of bioaccumulation is linearly related to the log of the partition coefficient between octanol and water for some compounds. This relationship offers a method of estimating bioaccumulation. A compound such as trichloroethylene would act similarly to carbon tetrachloride in organisms, exhibiting rapid uptake to steady state concentration and rapid clearance.

By far the most definitive study on bioaccumulation was carried out by Pearson and McConnell (1975). Based on the results of an extensive analysis of a large number of species, reproduced in Table 5.4, these authors made some estimates of bioaccumulation in nature. They estimated that the maximum overall increase in concentration, between sea water and the tissues of animals at the top of food chains such as fish liver, bird eggs, and seal blubber is less than 100-fold for a solvent like trichloroethylene; while a higher molecular weight chlorinated compound such as hexachlorobutadiene would have a maximum factor of 1000. They further concluded that the pattern of extensive bioaccumulation of marine food chains, which is postulated for chlorinated insecticides, does not appear. In laboratory tests where organisms are maintained for up to 3 months in apparatus similar to that used for toxicity determinations, Pearson and McConnell (1975) have shown that bioaccumulation can occur. These results indicate the following: (1) the concentration of chlorinated hydrocarbons accumulated in a tissue tends to an asymptotic level, (2) concentrations in fatty tissues such as liver

are higher than in muscle (concentration is proportional to fat content), and (3) when the test organism is returned to clean sea water, the concentration of the chlorinated hydrocarbon in the tissue falls. These researchers conclude that there is no evidence for the bioaccumulation of C1/C2 compounds in food chains and the maximum concentrations found in the higher trophic levels are still only parts per 10^8 by mass.

Despite this strong statement, it is based on a limited set of data, and caution should be exercised. More information is needed before final judgment is made about the accumulation of volatile chlorinated hydrocarbons in the tissues of animals and man.

6. ENVIRONMENTAL TRENDS

To describe environmental trends, it would be necessary to have accurate data on TCE determined over a period of time for various media. Such data are not available for trichloroethylene. Any environmental trends would have to be inferred from actions taken with regard to the manufacture, use, or regulation of trichloroethylene.

There is evidence that trichloroethylene is widespread in the environment, that it interacts with living systems, and that it appears in air, water, food, and animal tissue. Whether it is accumulating in the environment, in living systems, or in food cannot be judged from the evidence available at this time.

The highest environmental concentrations of Trichloroethylene are in close proximity to manufacturers and users. Near these sources, levels on the order of hundreds of parts per billion are found in the air and surface waters. In remote areas the levels are less than 1 ppb.

Because of the efforts of manufacturers and users to reduce the quantity of TCE being released to the atmosphere, because of its recognized toxicity, and because of regulations, it is likely that the amount in that media will decline in the future. However, an offsetting factor is the increased use of the solvent in other ways such as a textile solvent. This will perhaps lead to the appearance of more TCE in water and probably in the air. The net effect cannot be determined without more extensive monitoring data.

Perhaps such efforts as the National Organics Reconnaissance Survey will ultimately provide sufficient information to establish a trend for environmental levels of trichloroethylene.

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