7. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting, measuring, and/or monitoring 1,1,1-trichloroethane, its metabolites, and other biomarkers of exposure and effect to 1,1,1-trichloroethane. The intent is not to provide an exhaustive list of analytical methods. Rather, the intention is to identify well-established methods that are used as the standard methods of analysis. Many of the analytical methods used for environmental samples are the methods approved by federal agencies and organizations such as EPA and the National Institute for Occupational Safety and Health (NIOSH). Other methods presented in this chapter are those that are approved by groups such as the Association of Official Analytical Chemists (AOAC) and the American Public Health Association (APHA). Additionally, analytical methods are included that modify previously used methods to obtain lower detection limits and/or to improve accuracy and precision.

7.1 BIOLOGICAL MATERIALS

In the analysis of 1,1,1-trichloroethane in biological materials, a key factor in the determination is the sample matrix under consideration. In the broadest sense, this can be broken down into liquid samples (e.g., blood or urine), solid samples (which would include adipose tissue, liver samples), and expired air samples. After 1,1,1-trichloroethane has been recovered from the sample matrix, a number of similar techniques can then be used to complete the analysis. A synopsis of these methods can be found in Table 7-1. In general, the methods for determining the metabolites of 1,1,1-trichloroethane are the same as those used for the parent compound, with slight modifications (Nolan et al. 1984).

The quantification of 1,1,1-trichloroethane in blood and urine samples can be achieved by the initial use of purge and trap methodology (Antoine et al. 1986; Barkley et al. 1980). This technique involves the liberation of the volatile chlorinated hydrocarbon by bubbling an inert gas through the sample matrices at elevated temperatures (≈50–95 °C). Higher temperature increases the vapor pressure of the compound, and the bubbling action serves, essentially, to increase the gas-liquid partition, and thus volatilize the compound of interest. The gaseous sample is collected on an adsorption tube, which frequently uses a polymeric sorbent such as Tenax GC.

At this point, the sample is analyzed by gas chromatography (GC), the analytical method of choice for volatile halogenated hydrocarbons. Information on the analysis of these samples by GC is presented in

Table 7-1. Analytical Methods for Determining 1,1,1-Trichloroethane in Biological Samples

Sample matrix	Preparation method	Analytical method	Limit	Percent recovery	Reference
Exhaled air	Collection in Tedlar bag; adsorption on Tenax GC; thermal desorption	HRGC/MS	0.1 µg/m^3	87–94	Barkley et al. 1980; Wallace et al. 1984a, 1985, 1987a
Exhaled air	Collection in charcoal cloth wafers; desorption in carbon disulfide	GC/FID	2 mg/m^3 (for 50 L sample)	89–120	Glaser and Arnold 1989
Exhaled air	Collection into canister by portable spirometer; aliquot injection into a cryogenic trap	HRGC/MS	3.3 µg/m^3 (for 300 L sample)	94–98	Raymer et al. 1990
Urine	Purging at 50 °C; trapping on Tenax GC; thermal desorption into GC	HRGC/MS	No data	No data	Barkley et al. 1980
Adipose tissue	Purging at 95 °C; trapping on Tenax GC; thermally desorption at 250 °C	HRGC/MS	0.01 mg/kg	No data	Stanley 1986a,1986b
Blood	Purging at 50 °C; trapping on Tenax GC; thermal desorption	HRGC/MS	No data	No data	Antoine et al. 1986; Barkley et al. 1980
Blood	Purging at 30 °C; trapping on Tenax GC; thermal desorption into GC	HRGC/MS	0.049 µg/L	147	Ashley et al. 1992
Blood	Static headspace	HRGC/FID	<0.1 mg/L	214 (at 0.5 mg/L)	Dills et al. 1991
Liver, kidney, brain, heart, lung, perirenal fat and skeletal muscle	Homogenization with ice-cold saline and iso-octane; vortexing and centrifugation; iso-octane layer withdrawn for head space analysis	GC/ECD	1 ng	85.5–91.3	Chen et al. 1993
Milk	Purging at 70°C; trapping in Tenax GC; thermal desorption	HRGC/MS	No data	No data	Pellizzari et al. 1982

ECD = electron capture detector; FID = flame ionization detector; GC = gas chromatography; HRGC = high resolution gas chromatography; MS = mass spectrometry

Section 7.2, with a discussion of the advantages and disadvantages of each method. The technique of Antoine et al. (1986) showed a 5% variance on a series of 2 ppb spiked samples, and the analysis had a linear response ranging from 0.5 to 50 ppb. Although infra-red spectrometry has less sensitivity than electron capture detectors (ECD), Hall electroconductivity detectors (HECD), and mass spectrometric detectors (MS), it has been used to quantify the levels of 1,1,1-trichloroethane in biological samples (IARC 1979).

The concentration of 1,1,1-trichloroethane in solid samples can be determined by headspace techniques, which involve analysis of the air above a heated sample in either a dynamic or a static system. In a static system, an aliquot of the atmosphere above the sample is obtained and analyzed by direct GC. In a dynamic system, an inert gas is passed over the top of a heated, rapidly stirred suspension of sample in water (Stanley 1986a, 1986b). The gas stream is then passed through an adsorption tube, trapping the volatile compounds. For adipose tissue, the detection limits were 0.01 mg/kg and the average recovery for spiked samples (concentration range 0.15–0.44 μg/20 g tissue) was 105%, with a precision of 11.8% (Stanley 1986a, 1986b).

In biological samples, losses during the sample preparation stage (weighing, transferring, etc.) can arise due to the volatility of 1,1,1-trichloroethane or from an incomplete recovery from the biological matrix. Samples should be analyzed shortly after they are obtained. Otherwise, they should be carefully stored at low temperature, preferably in a dessicator. Handling and manipulation also should be kept to a minimum, preventing both premature loss by volatilization and contamination of the sample through the adsorption of vapors from ambient air. The need for blank water with very low levels of volatile organic compounds (VOCs) has increased because of the constant improvement in the sensitivity of detection of these VOCs. A method that uses distillation in conjunction with helium stripping has been described to obtain high purity blank water (Cardinali et al. 1994).

7.2 ENVIRONMENTAL SAMPLES

A short description of the methods used for analysis of 1,1,1-trichloroethane in environmental samples is presented in Table 7-2. An extensive list of methods for analysis of 1,1,1-trichloroethane in environmental samples can be compiled from the literature. Two methods are commonly used for collection of 1,1,1-trichloroethane and other volatile organics in ambient and occupational air. One method uses adsorbents to trap and concentrate organics in air, and the other method uses passive

Table 7-2. Analytical Methods for Determining 1,1,1-Trichloroethane in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample Detection Limit	Percent recovery	Reference
Air	Charcoal tube collection and carbon disulfide desorption	GC/FID (NIOSH 1003)	18 ppm	No data	NIOSH 1987
Ambient air	Trapping on adsorbent; thermal desorption	HRGC/ECD	0.006 µg/m^3 (based on 127 L sample)	100	Frank and Frank 1988
Waste water	Purge and trap onto adsorbent; desorption into GC column by rapid heating	GC/HECD (EPA 601)	0.03 µg/L	75±12	EPA 1982c
Waste water	Purge and trap onto adsorbent; thermal desorption	GC/MS (EPA 624)	3.8 µg/L	102±16	EPA 1982a
Solid waste matrices, groundwater, liquid wastes, sediment	Purge and trap into adsorbent; thermal desorption	GC/MS (EPA-8240 SW 846)	5 µg/L (groundwater) 5 µg/kg (soil and sediment)	113 (at 10 µg/kg)	EPA 1986e
Soil	Purge and trap onto adsorbent; rapid heating desorption	GC/MS (EPA Contract Lab)	5 µg/kg	No data	EPA 1987a
Drinking water	Purge and trap onto adsorbent; backflush to cryogenically cooled trap	GC/HECD (EPA 502.1) HRGC/ HECD (EPA 502.2)	0.003 µg/L 0.01 µg/L	93±8 96±2.6	EPA 1986a
Drinking water, raw source water	Purge and trap onto adsorbent; backflush to packed or cryogenically cooled capillary trap	GC/MS (EPA 524.1) HRGC/MS (EPA 524.2)	0.3 µg/L 0.04 µg/L	105±8.9 100±4	EPA 1988c, 1988d
Food	Heating sample in closed container at 95 C for 55 minutes; analysis of headspace gas	GC/ECD	0.6–2.4 µg/kg (for various foods)	No data	Norman 1991

ECD = electron capture detector; EPA = Environmental Protection Agency; FID = flame ionization detector; GC = gas chromatography; HECD = Hall Electroconductivity detector; HRGC = high resolution gas chromatography; MS = mass spectrometry; NIOSH = National Institute for Occupational Safety and Health

stainless steel canisters (SUMMA canisters). The advantage of SUMMA canisters is that sample breakthrough does not occur with this method as it may occur with adsorbent tubes (Hsu et al. 1991). The disadvantages of the canister method are its inability to concentrate pollutants during sample collection and the potential analytical problems associated with the presence of moisture in the sample (Bianchi and Varney 1993). In all methods, however, there is a consensus that after the sample collection and preparation stage, mixture separation and quantitative analysis is best done with GC, coupled with an assortment of detectors. Standardized methods, with slight alterations, also can be used for determining the metabolites of 1,1,1-trichloroethane (Hallen et al. 1986; Parsons et al. 1985; Vogel and McCarty 1987).

The analysis of 1,1,1-trichloroethane in occupational air samples can be accomplished by NIOSH method 1003 (NIOSH 1987). The sample is obtained in the field with a pumping system to pass a measurable quantity of air (≈3 L) through a tube loaded with a solid sorbent, such as charcoal. Extraction of the tube with the solvent CS_2 liberates the 1,1,1-trichloroethane collected, an internal standard is added, and quantitation is then achieved by GC. For packed column analysis, an OV-101 column using a flame ionization detector (FID) is given as the preferred choice (alternates, including capillary columns, are acceptable). For the estimation of low levels of 1,1,1-trichloroethane in ambient air, thermal desorption following collection of the sample in an absorbent trap is the method of choice (Frank and Frank 1988).

Capillary columns are used to separate 1,1,1-trichloroethane from the other components in a mixture. Capillary columns provide wider versatility offering superior resolution of components. A comparison of capillary and packed column for analysis of volatile organics by GC is available (Clark and Zalikowski 1990). Narrow-bore capillary columns have high resolving power, but may not be suitable for headspace analysis because of easy column saturation (Ohno and Aoyama 1991). Wide-bore capillary columns are suitable in such cases (Ohno and Aoyama 1991). Different detectors can be used; ECD, HECD, and MS have been described. The MS is the most selective detector, but the HECD is the most sensitive. Both closed path and open path Fourier transform infrared spectrometry (FTIR) have recently been used for the determination of 1,1,1-trichloroethane in air (Carter et al. 1992; Trocha and Samimi 1993; Xiao and Levine 1993). Although the FTIR methods have higher detection limits than the some of the other conventional methods, they afford the opportunity of remote monitoring of real-time samples (Xiao and Levine 1993).

In the analysis of 1,1,1-trichloroethane in air, the weakest link in analysis is irreversible adsorption of the desired compound to the sorbent material during sample collection. For highly volatile, nonpolar

compounds such as 1,1,1-trichloroethane, complete removal of the substrate may not occur if the adsorbent irreversibly adsorbs the substrate.

The collection methods commonly used for water and aqueous effluents are grab or proportional sampling. However, a solid phase microextraction method, which involves exposing a fused silica fiber coated with a stationary phase to the aqueous sample until equilibrium is achieved, has been proposed as a collection method (Arthur et al. 1992). Analysis for 1,1,1-trichloroethane in municipal and industrial waste water is described in EPA method 601—purgeable halocarbons (EPA 1982a). A 5 mL grab sample is connected to an apparatus called a purging chamber. This chamber allows for an inert gas to be sparged through the water sample, carrying the 1,1,1-trichloroethane onto an adsorbent tube. The organics are subsequently desorbed from the adsorbent tube by rapid heating and back flushing into the GC column. Analysis is then made by GC elution using an HECD. Detection limits for this method are given as 0.03 μg/L, with a 75% average recovery for spiked samples. EPA test method 624, purgeables, also can be used for the analysis of 1,1,1-trichloroethane in waste water (EPA 1982a). This method is similar to method 601, except that MS is used for quantitation.

EPA method 502.1 can be used in the analysis of 1,1,1-trichloroethane in finished or raw source water (EPA 1986a). This method is analogous to method 601. The detection limit for this method is 0.003 μg/L, with an average recovery of 93%.

The EPA guidelines for contract laboratories (EPA 1986c) include methodology for the analysis of groundwater and soil samples. The method for water analysis is similar to method 524.1. Detection limits for this method are given at 5 μg/kg.

7.3 ADEQUACY OF THE DATABASE

Section 104(i)(5) of CERCLA, as amended, directs the Administrator of ATSDR (in consultation with the Administrator of EPA and agencies and programs of the Public Health Service) to assess whether adequate information on the health effects of 1,1,1-trichloroethane is available. Where adequate information is not available, ATSDR, in conjunction with NTP, is required to assure the initiation of a program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of 1,1,1-trichloroethane.

The following categories of possible data needs have been identified by a joint team of scientists from ATSDR, NTP, and EPA. They are defined as substance-specific informational needs that if met would reduce the uncertainties of human health assessment. This definition should not be interpreted to mean that all data needs discussed in this section must be filled. In the future, the identified data needs will be evaluated and prioritized, and a substance-specific research agenda will be proposed.

7.3.1 Identification of Data Needs

Methods for Determining Biomarkers of Exposure and Effect.

Exposure. The urinary concentration of 1,1,1-trichloroethane can be used as an appropriate biological indicator of exposure (Imbriani et al. 1988; Salkinoja-Salonen and Jokela 1991). Both in the experimentally exposed subjects and in the occupationally exposed workers, the urinary concentration of 1,1,1-trichloroethane showed a linear relationship to the corresponding environmental time-weighted average concentration with a correlation coefficient of 0.90–0.95 (Imbriani et al. 1988). Levels of 1,1,1-trichloroethane (as parent compound) in blood and expired air may also serve as biomarkers of exposure. Laparé et al. (1995) found closer correlations between 1,1,1-trichloroethane exposure levels and levels of parent compound in both blood and expired air than between 1,1,1-trichloroethane exposure levels and urinary levels of parent compound or 1,1,1-trichloroethane metabolites. Present analytical methods for determination of levels of biomarkers of exposure to 1,1,1-trichloroethane are adequate; additional studies do not appear necessary.

Effect. There is no known effect of 1,1,1-trichloroethane that can be quantitatively related to its exposure.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Analytical methodology for determining the levels of 1,1,1-trichloroethane and its biotic/abiotic degradation products such as 1,1-dichloroethene, 1,1-dichloroethane, and chloroethane in environmental samples are well established (Hallen et al. 1986; Mehran et al. 1988a; Parsons et al. 1985; Vogel and McCarty 1987). Existing methods that provide acceptable detection limits for background levels in the environment and for levels at which health effects occur can be found for all types of environmental samples. The precision, accuracy, reliability, and specificity of each method are well documented, and potential pitfalls have been described. Development of a new methodology to

determine 1,1,1-trichloroethane in environmental samples that would provide both increased speed and decreased levels of difficulty may be desirable in situations where environmental monitoring of 1,1,1-trichloroethane is required on a rapid or routine basis.

7.3.2 Ongoing Studies

No ongoing studies involving analytical techniques of 1,1,1-trichloroethane were found in a search of the Federal Research in Progress database (FEDRIP 2005).