7. ANALYTICAL METHODS

The purpose of this chapter is to describe the analytical methods that are available for detecting, measuring, and/or monitoring toluene, its metabolites, and other biomarkers of exposure and effect to toluene. 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

Toluene can be determined in biological fluids and tissues and exhaled breath using a variety of analytical methods. Representative methods are summarized in Table 7-1. Most analytical methods for biological fluids use headspace gas chromatographic (GC) techniques. Breath samples are usually collected on adsorbent traps or in sampling bags or canisters, and then analyzed by GC.

Because of its volatility, toluene is lost from biological samples, such as plant and animal tissue and body fluids, relatively easily. Therefore, samples must be collected and stored with care (e.g., at low temperatures in sealed containers) to prevent analyte loss. While blood sample collection is more invasive than breath or urine samples, maintaining the integrity of blood in the collection, transportation, and storage of the samples is easier. Blood is relatively nonpolar, which results in less diffusion loss (Chambers et al. 2006).

Headspace techniques are usually used to separate toluene from biological fluids such as blood and urine. The headspace method involves equilibrium of volatile analytes such as toluene between a liquid and solid sample phase and the gaseous phase. The gaseous phase is then analyzed by GC. There are two main types of headspace methodology: static (equilibrium) headspace and dynamic headspace which is usually called the "purge and trap" method (Seto 1994). The static headspace technique is relatively simple, but may be less sensitive than the purge-and-trap method. The purge-and-trap method, while providing increased sensitivity, requires more complex instrumentation and may result in artifact formation (Seto 1994). Packed columns and capillary columns are used for chromatographic separation,

Table 7-1. Analytical Methods for Determining Toluene in Biological Materials

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Blood	Lyse; extraction with carbon disulfide	GC/FID	No data	No data	Benignus et al. 1981
Blood	Purge and trap	No data	7.5 µg/L	No data	Cocheo et al. 1982
Whole blood	Purge and trap	GC/MS	0.088 µg/L	91–147	Ashley et al. 1992
Blood	Purge and trap	capillary GC/FID	50 ng/L	50	Fustinoni 1996
Blood	Headspace extraction	capillary GC/ITD	0.04 µmol/L	No data	Schuberth 1994
Blood	Headspace SPME	GC/MS	24 pg/mL	No data	Chambers et al. 2006
Mother's milk	Purge and trap	capillary GC/FID	No data	63 (chloro-benzene)	Michael et al. 1991 Pellizzari et al. 1982
Urine	Purge and trap	capillary GC/FID	50 ng/L	59	Fustinoni 1996
Urine	Heated headspace extraction	capillary GC/FID	1 ng/mL	42.3	Lee et al. 1998b
Urine	Headspace (Purge and Trap)	GC/PID	15 ng/L	No data	Skender et al. 2004
Biofluids	Headspace extraction	GC/FID	No data	No data	Suitheimer et al. 1982
Adipose tissue	Evaporation at 150°C into nitrogen, direct gas injection	GC/FID	No data	88–112	Carlsson and Ljungquist 1982
Brain tissue	Extraction with carbon disulfide; homogenization; centrifugation	GC/FID	No data	No data	Benignus et al. 1981
Breath	Collection in modified Haldane-Priestly tube; transfer to adsorption tube; thermal desorption	capillary GC/MS	1 nmole	No data	Dyne et al. 1997
Breath	Collection via spirometer into passivated canisters	capillary GC/MS	low µg/m^3	80–136	Thomas et al. 1991
Breath	Collection via spirometer into 1.8°L passivated canisters	capillary GC/MS	~2 µg/m^3	91–104	Thomas et al. 1992
Breath	Collection via spirometer onto charcoal traps; microwave desorption	capillary GC/MS-SIM	3 µg/m^3	No data	Riedel et al. 1996

FID = flame ionization detector; GC = gas chromatography; ITD = ion trap detection; MS = mass spectrometry; SIM = selected ion monitoring

followed by identification and quantitation using various detectors; flame ionization detection (FID), photoionization detection (PID), and mass spectrometry (MS) are used most often. Other sample preparation methods have been used, but less frequently. Solvent extraction permits concentration, thereby increasing sensitivity, but the extraction solvent can interfere with analysis. Direct aqueous injection is a very rapid method, but sensitivity is low and matrix effects can be a serious problem.

In addition, the dynamic headspace purge-and-trap GC method with PID was utilized for the determination of toluene in urine samples obtained from participants of Zagreb, Croatia. The detection limit was 15 ng/L (Skender et al. 2004).

Headspace solid phase microextraction (SPME) is a relatively new alternative method to detect nonpolar species in the blood. Chambers et al. (2006) utilized this method, along with GC/MS to detect BTEX in the blood. The authors also improved the technique by minimizing contamination from the vacutainers, disposable syringes and vial septa. The limit of detection for toluene was 25 pg/mL (Chambers et al. 2006).

A sensitive and reliable method for identification and quantitation of toluene in samples of whole blood taken from humans following exposure to volatile organic compounds has been developed by researchers at the Centers for Disease Control and Prevention (Ashley et al. 1992, 1996). The method involves purge-and-trap of a 10 mL blood sample with analysis by capillary GC/MS. Anti-foam procedures were used, as well as special efforts to remove background levels of volatile organic compounds from reagents and equipment (Ashley et al. 1992). The method is sensitive enough (ppt levels) to determine background levels of volatile organic compounds in the population and provides adequate accuracy (91–147% recovery) and precision (12% relative standard deviation [RSD]) for monitoring toluene in the population. Most modern purge and trap methods provide detection limits in the ppt range for toluene in both blood and urine (Ashley et al. 1992; Fustinoni et al. 1996).

Few methods are available for the determination of toluene in other body fluids and tissues. Toluene may be extracted from biological materials using solvents such as carbon disulfide (Benignus et al. 1981); homogenization of tissue with the extractant and lysing of cells improves extraction efficiency. Care must be taken to avoid loss of low-boiling compounds. Highly purified solvents may be used to minimize problems with solvent impurities. A modified dynamic headspace method for urine, mother’s milk, and adipose tissue has been reported (Michael et al. 1980). Volatiles swept from the sample are analyzed by capillary GC/FID. Acceptable recovery was reported for model compounds, but detection limits were not

reported (Michael et al. 1980). Supercritical fluid extraction using pure carbon dioxide or carbon dioxide with additives has good potential for the extraction of organic analytes such as toluene from biological samples.

Sensitive, reliable methods are available for measuring toluene in breath. Exhaled breath is collected in modified Haldane-Priestly tubes (Dyne et al. 1997), into passivated canisters (Thomas et al. 1992), or directly onto adsorbent traps (Riedel et al. 1996). The detection limits are in the low $\mu g/m^3$ range (Riedel et al. 1996; Thomas et al. 1991, 1992); accuracy, where reported, is good (≥80%) (Riedel et al. 1996; Thomas et al. 1991, 1992).

Representative methods for determination of biomarkers of exposure to toluene are shown in Table 7-2. Measurement of toluene in blood (Kawai et al. 1993), urine (Kawai et al. 1996) and exhaled air (Lapare et al. 1993) provide reliable markers of exposure to toluene. Measurement of toluene metabolites is also utilized for monitoring toluene exposure in humans. Hippuric acid is formed in the body by the metabolism of toluene, and it is the glycine conjugate of benzoic acid.

High performance liquid chromatography (HPLC) with ultraviolet (UV) detection is usually used for determination of metabolites in urine. Currently, ACGIH (2010, 2013) recommends measuring *ortho*-cresol levels in the urine at the end of the workshift to assess toluene levels in exposed workers (along with toluene levels in urine at the end of a workshift and toluene levels in blood immediately prior to the last shift of a workweek). Previously, the level of hippuric acid in urine at the end of a workshift was recommended as a biomarker of exposure, but this recommendation was withdrawn because background urinary hippuric acid from consumption of benzoate in foods and beverages is expected to mask contributions from workplace exposure to toluene, especially at concentrations below 50 ppm (ACGIH 2001, 2010). Other metabolites such as benzylmercapturic acid (BMA) (Inoue et al. 2002, 2004; Maestri et al. 1997) or S-*p*-toluylmercapturic acid (Angerer et al. 1998a, 1998b) may also be measured; however, their usefulness may be limited by variability among individuals. See Section 3.8 (Biomarkers of Exposure and Effect) for more information.

Detection of hippuric acid was done by ^1H NMR Spectroscopy after the samples were prepared by adding deuterium oxide (D_2O) and sodium trimethylsilyl [2,2,3,3-$2H_4$] propionate (TSP) to urine samples of glue abusers (glue sniffers). Toluene is reported as the main component in glue. Hippuric acid levels were the highest after glue sniffing (Kwon et al. 2011).

Table 7-2. Analytical Methods for Determining Biomarkers of Toluene in Biological Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Blood (toluene)	Headspace	GC	No data	No data	Kawai et al. 1993
Urine (toluene)	Headspace	GC/FID	2 µg/L	No data	Kawai et al. 1996
Urine (HA)	Extraction with ethyl acetate; evaporation; redissolve in water	HPLC/UV	30 mg/L	No data	NIOSH 1984b
Urine	Extraction with MTBE, elution with phosphate buffer/methanol/ formaldehyde	HPLC	0.1 mmol	101	Tardif et al. 1989
Urine (*o*-cresol)	Hydrolysis; solvent extraction	HPLC/UV	0.5 mg/L	95[a]	Kawai et al. 1996
Urine	Addition of deuterium oxide and TSP to samples	^{1}H NMR	No data	No data	Kwon et al. 2011
Urine (BMA)	Adsorbent column cleanup; derivatization	HPLC/Fl	0.5 µg/L	No data	Maestri et al. 1997
Breath	Collection in Tedlar bags	GC/FID	No data	No data	Lapare et al. 1993

[a]Extraction efficiency.

BMA = benzylmercapturic acid; FID = flame ionization detector; Fl = fluorescence detector; GC = gas chromatography; HA = hippuric acid; HPLC = high performance liquid chromatography; MTBE = methyl tertiary butyl ether; UV = ultraviolet detection

7.2 ENVIRONMENTAL SAMPLES

Methods are available for determining toluene in a variety of environmental matrices. A summary of representative methods is shown in Table 7-3. Validated methods, approved by agencies and organizations such as EPA, ASTM, APHA, and NIOSH, are available for air, water, and solid waste matrices. GC is the most widely used analytical technique for quantifying concentrations of toluene in environmental matrices. Various detection devices used for GC include FID, MS, and PID. Because of the complexity of the sample matrix and the usually low concentrations of volatile organic compounds in environmental media, sample preconcentration is generally required prior to GC analysis. Air samples may be collected and concentrated on adsorbent or in canisters for subsequent analysis. Methods suitable for determining trace amounts of toluene in aqueous and other environmental media include three basic approaches to the pretreatment of the sample: gas purge-and-trap technique, headspace gas analysis, and extraction with organic solvent. Purge-and-trap is the most widely used method for the isolation and concentration of volatile organic compounds in environmental samples (Lesage et al. 1993). The purge and trap technique offers advantages over other techniques in that it allows facile isolation and concentration of target compounds, thereby improving overall limits of detection and recovery of sample.

Sampling techniques for air include collection in sample loops, on adsorbent, in canisters, and by cryogenic trapping. The analysis is normally performed by GC/FID, GC/PID, or GC/MS. Detection limits depend on the amount of air sampled, but values in the ppt range have been reported (Dewulf and Van Langenhover 1997).

BTEX was monitored in the urban air of nine sites by use of GC/MS. Toluene concentrations were the highest among the compounds. The limit of detection was also highest for toluene at 1 $\mu g/m^3$ (Nicoara et al. 2009).

Toluene may be determined in occupational air using collection on adsorbent tubes, solvent desorption and GC/FID analysis (NIOSH 1994). Detection limits depend upon the amount of air sampled; accuracy is very good (11.4% bias) (NIOSH 1994).

Campos-Candel et al. (2009) compared HPLC-fluorescence (HPLC-FL) to GC/MS measurements of toluene in air samples. The limit of detection for the samples in HPLC-FL method was 0.5 mg/L or 5 µg/sample and the limit of detection for GC/MS was 0.6 pg/s or 0.08 µg/sample. The GC/MS was deemed to be more sensitive.

Table 7-3. Analytical Methods for Determining Toluene in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Workplace air	Sorption on activated carbon; extraction with carbon disulfide	GC/FID	0.01 mg	±11.4[a]	NIOSH 1994 Method 1501
Workplace air	Sorption on activated charcoal or Radiello diffusive samplers	HPLC	0.5 mg/L or 5 µg/sample	No data	Campos-Candel et al. 2009
Workplace air	Sorption on activated charcoal or Radiello diffusive samplers	GC/MS	0.6 pg/s or 0.08 µg/sample	No data	Campos-Candel et al. 2009
Indoor air	Solid phase microextraction (SPME)	GC/MS	0.004 mg/m^3	No data	Gorlo et al. 1999
Air	Sorption onto Tenax®; solvent extraction; thermal desorption	GC/MS	<0.88 ppbv	111–163	Crist and Mitchell 1986
Air	Sorption onto Tenax®; thermal desorption	GC/MS	No data	93–94	EPA 1988a Method TO-1 Krost et al. 1982
Air	Collection in passivated canisters	GC/MS	low ppb	No data	EPA 1988b Method TO-14
Air	Collection on multisorbent tubes; thermal desorption	GC/MS	No data	No data	EPA 1997a Method TO-17
Air	Collection in sorbent sampler tubes	GC/FID	0.01 mg/ sample	94	USEPA, EMMI 1997 NIOSH 1500
Air	Sorption on activated charcoal; extraction with carbon disulfide	GC/FID	0.01 mg/sample	No data	USEPA, EMMI 1997 NIOSH 4000
Air	Solid phase membrane samplers (SPMS)	GC/MS	0.0001 µg/sampler	No data	Esteve-Turrillas et al.2009
Air	Preconcentration in SKS glass tube with charcoal, desorption	GC/MS	1 µg/m^3	No data	Nicoara et al. 2009
Stack gas effluents	Sorption onto Tenax®; thermal desorption	GC/MS	No data	50–150	USEPA, EMMI 1997 OSW 5041A
Vehicle exhaust	Direct	GC/FID	0.5 ppb	No data	Dearth et al. 1992
Drinking water	Purge and trap	capillary GC/PID	0.01–0.02 ppb	98–99	DeMarini et al. 1991 EPA 1991a Method 502.2
Drinking water	Purge and trap	GC/PID	0.02 ppb	94	EPA 1991b Method 503.1
Drinking water	Purge and trap	capillary GC/MS	0.08–0.11 ppb	100–126	EPA 1992a Method 524.2
Water/ waste water	Purge and trap	GC/PID	0.2 ppb	77	EPA 1982a Method 602

Table 7-3. Analytical Methods for Determining Toluene in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Water/ waste water	Purge and trap	GC/MS	6.0 ppb	98–101	EPA 1982b Method 624
Water/ waste water	Addition of isotopically labeled analog; purge and trap	GC/MS	10 ppb	No data	EPA 1984 Method 1624
Industrial effluents	Purged with inert gas onto Tenax®; thermally desorbed	GC/IDMS	20 ppb	No data	Colby et al. 1980
Drinking water, waste water	Purged with inert gas onto Tenax®; thermally desorbed, cryofocused	GC/MS	1 ppb	74–107	Michael et al. 1988
Groundwater	Solid-phase microextraction	GC/FID	2 ppb	No data	Arthur et al. 1992
Water	Purge and trap	GC/MS	0.047 ppb	106	USEPA, EMMI 1997 APHA 6210-B
Water	Direct aqueous injection	GC	1.0 ppm	No data	USEPA, EMMI 1997 ASTM D3695
Water	Purge and trap	GC	0.5 ppb	80–120	USEPA, EMMI 1997 APHA 6220-B
Water	Dilution in appropriate solvent	FS	2.1 ppm	No data	USEPA, EMMI 1997 ASTM D4763
Water	Static mode sampling	IMS	No data	No data	Wan et al. 1998
Groundwater, aqueous sludges, waste solvents, acid and caustic liquors, soils, sediments	Purge and trap	GC/MS	5 ppb	47–150	USEPA, EMMI 1997 OSW8240B-W
Groundwater, aqueous sludges, waste solvents, acid and caustic liquors, soils, sediments	Purge and trap or direct injection	GC/EC or GC/PID	0.01 ppb	99	USEPA, EMMI 1997 OSW 8021B-PID
Solid waste	Purge-and-trap	capillary GC/PID	0.01 ppb	99	EPA 1996a Method 8021B
Solid waste	Purge-and-trap	GC/PID	0.08–0.11 ppb	100–102	EPA 1996b Method 8260B
Solid waste	Static Headspace sampling (HS)	GC/MS	0.72 ng/L	101	Bernado et al. 2009

Table 7-3. Analytical Methods for Determining Toluene in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Soil	Methanol extraction; SPE	capillary GC	sub-ppm	>90	Meney et al. 1998
Soil (screening)	Filter	immunoassay	7 ppm	No data	EPA 1996c Method 4030
Soils and sediments	Headspace extraction	GC/PID	0.2 ppb	46–148	USEPA, EMMI 1997 OSW 8020A
Soils and other solid matrices	Headspace extraction	GC/FID GC/PID/ ELCD	No data	No data	USEPA, EMMI 1997 OSW 5021
Solid waste matrices	Purge and trap or direct aqueous injection or concentration by azeotropic distillation or automated static headspace	GC/MS	0.11 ppb	102	USEPA, EMMI 1997 OSW 8260B
Plant cuticle	Headspace extraction	GC/FID	No data	No data	Keymeulen et al. 1997
Food	Headspace extraction, 1 hour at 90°C	GC	No data	No data	Walters 1986
Foods	Purge and trap	capillary GC/MS	8 ppb	54–76[b]	Heikes et al. 1995
Bottled water	Headspace extraction	GC/MS	0.5–1 ppb	No data	Page et al. 1993
Olive oil	Homogenization; headspace	capillary GC/MS	No data	No data	Biedermann et al. 1995

[a]Reported accuracy.
[b]Intralaboratory accuracy. Single lab accuracy is reported as 100–106% recovery.

ELCD = electrolytic conductivity detector; FID = flame ionization detector; FS = fluorescence spectroscopy; GC = gas chromatography; IDMS = isotope dilution mass spectrometry; MS = mass spectrometry; PID = photoionization detector; SPE = solid-phase extraction

Esteve-Turrillas et al. (2009) developed a versatile, easy, and rapid atmosphere monitor (V-E-R-A-M) for the detection of BTEX in the air. Solid-phase membrane samplers (SPMS) and HS-GC-MS were utilized for the study. The limit of detection was determined to be 0.001 μg/sampler.

Older studies have suggested that passive samplers were utilized in the detection of toluene, but performance data on those samplers were unavailable (Ballesta et al. 1992; Periago et al. 1997). Newer studies demonstrate the efficacy of these samplers. SPME, a passive sampling method, was utilized to detect toluene in the indoor air in freshly renovated flats. The detection limit was 0.004 mg/m^3 (Gorlo et al. 1999).

Gas purge and trap is the most widely used method for the isolation and concentration of volatile organic compounds in environmental samples (Lesage et al. 1993). The purge and trap technique offers advantages over other techniques in that it allows facile isolation and concentration of target compounds, thereby improving overall limits of detection and recovery of sample. Detection limits of less than 1 μg of toluene per liter of sample have been achieved. Very low detection limits for drinking water are reported for the purge and trap method with GC/PID (0.01–0.02 ppb) (DeMarini et al. 1991, EPA 1991a). Accuracy is very good (94–99% recovery) (DeMarini et al. 1991, EPA 1991a). While the analytical method is selective, confirmation using a second column or GC/MS is recommended (EPA 1992a). Good sensitivity (0.08–0.11 ppb) and accuracy (100–126% recovery) can also be obtained using capillary GC/MS detection (EPA 1992a). Purge-and-trap methodology may be applied to waste water as well (EPA 1982a, 1982b, 1984). Sensitivity is in the low ppb range and recovery is good (77–101%) (EPA 1982a, 1982b, 1984).

Ion mobility spectrometry (IMS) was used in the detection of BTEX compounds in water. Static mode sampling determined the toluene concentration of 0.101 mg/L in purified water, which resulted in a headspace concentration of 2.75 $\mu g/m^3$ (Wan et al. 1998).

Soil, sediment, and solid waste are more difficult to analyze. Volatilization during sample handling and homogenization can result in analyte loss. Purge-and-trap methods with capillary GC/PID or GC/MS analysis provide detection limits of approximately 0.5 ppm for wastes and 5 μg/g for soil and sediment (EPA 1982a, 1982b, 1984). Static headspace sampling (HS), along with GC-MS, was utilized in a study conducted by Bernardo et al. (2009) to effectively detect toluene in solid residues (waste) produced from the co-pyrolysis of plastics and pine biomass. The detection limit was 0.72 ng/L.

No methods were found for the determination of toluene in fish and biota. Few methods are available for the determination of toluene in food. A purge and trap extraction method is available for determining toluene in a variety of foods. The quantitation limit is 8 ppb; single lab recovery is very good (100–106%) and precision is good (9.8–25% RSD). Both intra- and inter-laboratory studies were conducted, and precision was found to be ≤25% RSD (Heikes et al. 1995).

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 toluene 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 toluene.

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. Although toluene and its metabolites can be measured in body fluids using a number of techniques (Kawai et al. 1993, 1996; NIOSH 1984a), some of the metabolites have limited value as biomarkers. A number of common food materials produce the same metabolites; thus, measurement of toluene metabolites can be used to confirm a known exposure but cannot be used to determine whether or not exposure occurred in a poorly defined situation. It is also very difficult to quantify the magnitude of exposure from levels of either toluene or its metabolites in biological samples. Currently, ACGIH (2010, 2013) recommends using a combination of three biological exposure indices (BEIs®) to assess exposure of workers to toluene in the workplace: (1) *ortho*-cresol levels in the urine at the end of the workshift; (2) toluene levels in urine at the end of a workshift; and (3) toluene levels in blood immediately prior to the last shift of a workweek). The specific values for these BEIs® correspond to concentrations likely to be observed in individuals exposed by inhalation to 20 ppm, the current ACGIH 8-hour TWA Threshold Limit Value (TWA-TLV®) for

occupational exposure to toluene (ACGIH 2010). A technique that could more accurately quantify exposure to toluene in biological fluids may be useful.

Exposure. Additional research to develop more sensitive methods for analysis of toluene and metabolites may be useful to increase sensitivity of exposure assessment.

Effect. It is difficult to monitor the effects of toluene exposure. MRI and BAER evaluations of the brain have some value in determining the neurological damage resulting from long-term exposures to high levels of toluene, but have no known value for determining the effects of low-level and/or short-term exposures.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. There are methods available for the determination of toluene and its metabolites in environmental samples. Sensitive techniques for air, drinking water, and waste water allow detection of toluene at low levels (Bernado et al. 2009; Campos-Candel et al. 2009; Wan et al. 1998). These techniques are adequate to measure both background toluene levels and the levels of toluene in environmental media that could cause health effects. However, when toluene is present in combination with other volatile materials, interference from the companion volatiles often raises the detection limit and decreases the accuracy and precision of the technique. Improved methods for separation of toluene from other volatiles would be useful.

Research on measuring the levels of metabolites in soil and water would be valuable especially in studying the end products of microbial degradation. Few methods are available for monitoring toluene in foods; reliable methods are needed for evaluating the potential for human exposure that might result from toluene ingestion.

7.3.2 Ongoing Studies

The Environmental Health Laboratory Sciences Division of the National Center for Environmental Health, Centers for Disease Control and Prevention, is developing methods for the analysis of toluene and other phenolic compounds in urine. These methods use high-resolution gas chromatography and magnetic sector mass spectrometry, which give detection limits in the low parts per trillion (ppt) range.