7. ANALYTICAL METHODS

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

Exposure to pentachlorophenol is most commonly evaluated by analysis of urine, blood, feces, or adipose or other tissues, using gas chromatography (GC) combined with electron capture detection (ECD) or high-performance liquid chromatography (HPLC) combined with ultraviolet (UV) detection. Recovery is generally high and sensitivity using GC/ECD and HPLC/UV is in the parts per billion (ppb) range. Some efforts are currently in development to detect pentachlorophenol metabolites in urine as a biological marker.

Many purification schemes take advantage of the fact that pentachlorophenol is a weak organic acid. These methods involve extracting the compound into the organic phase under acidic conditions, and/or extracting into alkaline solution as phenolate salts (Chou and Bailey 1986; EPA 1986b). Thus, the standard methods involve multiple extractions, with potential for sample loss; some of these methods derivatize pentachlorophenol prior to analysis (EPA 1980b; NIOSH 1984b). Derivatization often involves diazomethane or diazoethane, which are toxic substances (Bevenue et al. 1968; Holler et al. 1989; Morgade et al. 1980; Shafik 1973; Wagner et al. 1991). Recent methods have tried to simplify the purification scheme and avoid using toxic chemicals for derivatization (Maris et al. 1988).

In an effort to use less toxic materials, blood and urine samples were derivatized with acetic anhydride (Needham et al. 1981). The detection limit was 1–2 ppb using GC/ECD. Penta- and tetrachlorophenols were analyzed simultaneously in urine using HPLC (Pekari and Aito 1982). This method was used for

3 years in Finland in the biological monitoring of workers exposed to chlorophenols. It is more rapid than GC and does not involve the use of chemicals such as benzene, diazomethane, or pyridine, which pose health risks to the analyst. A rapid extraction method followed by GC/ECD had a detection limit of 0.5 ppb (Kalman 1984).

Because pentachlorophenol exists in urine as both free pentachlorophenol and conjugated pentachlorophenol (glucuronide and sulfate), hydrolysis of urine is necessary to determine total pentachlorophenol (Edgerton and Moseman 1979; Pekari et al. 1991). Acid hydrolysis is preferable to enzymatic hydrolysis because the pentachlorophenol metabolite TCHQ is an inhibitor of β-glucuronidase (Drummond et al. 1982). Although pentachlorophenol and other chlorinated phenols are stable in frozen urine samples, they are degraded by repeated thawing and refreezing (Edgerton 1981). Acid hydrolysis followed by reverse phase HPLC/UV and GC/ECD have been used to measure total pentachlorophenol in urine of people occupationally exposed to pentachlorophenol (Drummond et al. 1982; Pekari et al. 1991). The detection limits for HPLC/UV and GC/ECD were 0.20 and 0.01 ppm, respectively, which are sufficiently sensitive to detect occupational exposure. Using a simplified method without derivatization, total pentachlorophenol and free pentachlorophenol were measured in plasma and urine, with a detection limit of 1.5 pg (Rick et al. 1982). This modification shortens analysis time and allows the use of GC/ECD, which increases sensitivity.

The pentachlorophenol metabolites, TCHQ and tetrachloropyrocatechol, were identified in human urine samples using GC/MS (Edgerton et al. 1979). The detection limit was 1 ppb and recovery was about 95%. Pentachlorophenol and TCHQ were also detected using a cheaper GC/ECD method following a simple extraction (Reigner et al. 1990), but the detection limit was at least 50 ppb.

Negative chemical ionization (NCI) mass spectrometry (MS) was used to detect pentachlorophenol in human serum (Kuehl and Dougherty 1980). The NCI mass spectrometer was reported to be uniquely suited for screening partially purified samples. High sensitivity was obtained by dansylating purified compound and using HPLC/UV detection (de Ruiter et al. 1990).

Hexane extraction, cleanup on thin layer chromatography (TLC) plates, and HPLC/UV detection were used to isolate and characterize pentachlorophenol in human fat, demonstrating that pentachlorophenol is present in human adipose tissue as an ester of palmitic acid (Ansari et al. 1985). Fatty acid conjugates of pentachlorophenol and other chlorinated phenols could be separated by reverse-phase HPLC (Kaphalia 1991). TLC followed by GC/ECD was used to analyze pentachlorophenol in adipose tissue (Ohe 1979).

GC/ECD has been used to quantify pentachlorophenol residues in tissues (Wagner et al. 1991). The sensitivity of this method is in the sub-ppm range; >100% recoveries were obtained. GC/MS (NCI) was then used to confirm the identity of the pentachlorophenol residues in the samples. Precision data were not reported.

Analytical methods for determining pentachlorophenol in biological fluids and tissues are shown in Table 7-1.

7.2 ENVIRONMENTAL SAMPLES

Concerns about contamination of environmental media, plants, and animals with pentachlorophenol have led to the need for more rapid, sensitive, and selective methods of analysis. As with biological samples, the most common methods of analysis are GC/ECD, high resolution gas chromatography (HRGC)/ECD, and HPLC/UV detection. Under EPA's Contract Laboratory Program for semivolatiles such as pentachlorophenol, the Contract Required Quantitation Levels (CRQL) for water and low soil sediments are 50 mg/L (50 ppm) and 160 mg/kg (160 ppm), respectively (EPA 1986a). Methods are available that detect pentachlorophenol in water or sediment at the 1–10-ppb range.

Pentachlorophenol could be detected in marine water at concentrations ranging from 0.2 to 200 ppb in volumes as small as 5 mL using a simplified monitoring procedure with HPLC/UV detection (Giam et al. 1980). This method reduces costs and analysis time, and can also be used in other aquatic toxicity studies. Differential pulse polarography was used for direct determination of trace amounts of pentachlorophenol (Wade et al. 1979). It was demonstrated that pentachlorophenol is electrochemically reduced and direct determinations are possible at levels as low as 0.27 ppm. HPLC/UV was used to distinguish among 10 different phenolic compounds at mg/L levels in water (Realini 1981). HPLC/UV was also used to measure chlorinated phenols in surface-treated lumber and to distinguish between tetra- and pentachlorophenol (Daniels and Swan 1979). Automated HPLC is 10 times faster than wet chemical techniques. Once the method for analysis has been established and tested thoroughly, the HPLC method requires neither extensive pretreatment nor highly trained laboratory personnel (Ervin and McGinnis 1980).

For relatively clean water samples, HPLC offers a rapid and sensitive method, but its advantages are lost when a complex matrix such as municipal waste water has to be analyzed (Buisson et al. 1984). The resolution possible with capillary gas chromatography and the selectivity of the ECD towards halogenated

Table 7-1. Analytical Methods for Determining Pentachlorophenol and Metabolites in Biological Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Blood	Add sulfuric acid. Extract with hexane, derivatize with diazomethane, elute pentachloroanisole from alumina with benzene/hexane	GC/ECD	1 µg/L	90%	NIOSH 1984b (Method 8001)
Blood	Extract with benzene and convert PCP to its methyl ether derivative	GC/ECD	10 µg/L	92%	EPA 1980b
Blood	Add H_2SO_4 and benzene to the sample and stir while heating; centrifuge; collect benzene layer, evaporate and add diazomethane to make methyl ether derivative	GC/ECD	20 µg/L	87–100%	Bevenue et al. 1968
Blood	Add benzene and conc H_2SO_4 to the sample and rotate. Transfer benzene layer and add methylating agent and vortex. Dilute with isooctane or hexane.	GC/ECD	No data	No data	EMMI 1997
Serum	Acidify with phosphoric acid; elute from reverse phase column with dichloromethane; dansylate; concentrate	LC/UV	0.4 ppb	85%	de Ruiter et al. 1990
Serum	Acidify sample to pH 1 with hydrochloric acid; extract with dichloromethane; concentrate; derivatize with diazoethane; cleanup using silica gel	GC/ECD	30.0 µg/L	99%	Morgade et al. 1980

Table 7-1. Analytical Methods for Determining Pentachlorophenol and Metabolites in Biological Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Serum, urine	Acidify to pH 2 with HCl, digest at 100EC, extract with toluene	GC/ECD	0.5 µg/L	105% (urine); 80% (serum)	Kalman 1984
Plasma, urine	Sample collected into tubes containing EDTA and ascorbic acid; plasma mixed with citrate buffer, pH 3, extracted with diethyl ether, and concentrated. Urine was buffered with phosphate buffer pH 7.4 and processed as above	GC/ECD	100 µg/L (urine); 50 µg/L (plasma)	89-93%	Reigner et al. 1990
Urine	ADD HCl and $NaHSO_4$, extract with benzene, derivatize with diazomethane, add hexane; elute pentachloroanisole from alumina with benzene/hexane	GC/ECD	1 µg/L	94.7%	NIOSH 1984b (method 8303)
Urine	Acidify urine; hydrolyze; extract with benzene; methylate phenolic group	GC/ECD	5 µg/L	90%	EPA 1980b
Urine	Add HCl to sample; boil; extract with hexane/isopropanol; centrifuge; dry; collect residue in methanol/water	HPLC/UV	26 ppb	84%	Pekari and Aitio 1982
Urine	Add HCl to sample; boil; extract with hexane/isopropanol; centrifuge; back extract to basic borate buffer; derivatize with acetic acid anhydride and pyridine	GC/ECD	10 µg/L	No data	Pekari et al. 1991
Urine	Acidify with HCl; boil; add Na bisulfite; centrifuge; extract with benzene	GC/ECD	<1 µg/L	91–97%	Edgerton et al. 1979

Table 7-1. Analytical Methods for Determining Pentachlorophenol and Metabolites in Biological Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Urine	Add H_2SO_4; collect distillate and add NaCl and NaOH; acidify aqueous layer; extract with methylene chloride	RPHPLC/UV	200 ppb	>85%	Drummond et al. 1982
Urine	Add HCl to sample; extract twice with benzene; add hexane	GC/ECD	<10 pg	88%	Siqueina and Fernicola 1981
Urine	Add internal standard to sample; mix	HPLC/UV	250 µg/L	89–96%	Chou and Bailey 1986
Urine	Acidify with H_2SO_4; extract with hexane	GC/ECD	1.5 pg	102%	Rick et al. 1982
Urine	Acid hydrolysis; extract with benzene; derivatize with diazoethane; column cleanup	MS (NCI)	1 µg/L	- 100%	Holler et al. 1989
Urine	Add $NaHSO_4$, acidify with HCl, boil, add more $NaHSO_4$, extract with benzene, concentrate, column clean-up	GC/ECD	No data	No data	EMMI 1997
Body fluids	Acidify sample and extract with hexane; add acetic anhydride; wash with boric acid / NaOH	GC/ECD	1–2 µg/L	No data	Needham et al. 1981
Human semen and adipose tissue	Macerate sample/tissue with sulfuric acid, complete steam distillation into 2,2,4-trimethylpentane; concentrate organic layer	MS (NCI)	low ng	>90%	Kuehl and Dougherty 1980

Table 7-1. Analytical Methods for Determining Pentachlorophenol and Metabolites in Biological Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Adipose tissue	Grind tissue; add hexane; add NaOH; extract with hexane; add concentrated HCl; extract with diethyl ether; mix; add diazoethane; concentrate; add hexane and anhydrous sodium sulfate; analyze hexane layer	GC/ECD	5 ppb	75%	Shafik 1973
Adipose tissue	Homogenize sample; rehomogenize in hexane; combine supernatants; separate extracted fat on TLC; scrape appropriate area and suspend in hexane; evaporate	GC/ECD	5 ppb	85–98%	Ohe 1979
Adipose t issue	Add hexane; homogenize; add aqueous sodium hydroxide; extract with hexane; add diethyl ether; extract; derivatize with diazoethane	GC/ECD	140 ppb	91%	Morgade et al. 1980
Feces	Collect sample into tubes containing EDTA and ascorbic acid; acidify in warm sulfuric acid, extract with diethyl ether; concentrate	GC/ECD	100 ppb	No data	Reigner et al. 1990
Liver	Homogenize, incubate with sulfuric acid at 100EC; extract with hexane/toluene	LC/ECD	1.5 ppb	60–70%	Maris et al. 1988

Table 7-1. Analytical Methods for Determining Pentachlorophenol and Metabolites in Biological Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Fat, liver muscle, serum	Fat: homogenize with HCl; extract with ethyl acetate-hexane; elute from florisil chlorophenol with methanol-chloroform Other tissues: homogenize; reflux with Na_2SO_4 and NaOH; add TBAH and ether extract; concentrate extract; elute from silica column with methanol chloroform	RPHPLC/UV	<100 ppb	73–108% maximum	Mundy and Machin 1981
Tissues (testes, kidney, prostate, liver and omentum fat)	Homogenize tissue sample, extract with hexane/propanol and centrifuge; remove hexane layer; repeat extraction twice; partition into potassium hydroxide; acidify aqueous layer; extract with hexane; derivatize with diazomethane; cleanup on Florisil column; elute with hexane; additional clean up on activated silica gel column; elute with benzene in hexane	GC/ECD; GCMS (NCI)	4 ppb	115%	Wagner et al. 1991

ECD = electron capture detection; EDTA = ethylendiaminetetraacetic acid; GC = gas chromatography; HCl = hydrochloric acid; HPLC = high-performance liquid chromatography; H2SO4 = sulfuric acid; LC = liquid Chromatography; MS = mass spectrometry; Na = sodium; NaCl = sodium chloride; $NaHSO_4$ = sodium bisulfite; NaOH = sodium hydroxide; Na_2SO_4 = sodium sulphate; NCl = negative chemical ionization; PCP = pentachlorophenol; RPHPLC = reverse phase high performance liquid chromatography; TBAH = tetrabutylammonium hydroxide; TLC = thin layer chromatography

compounds make HRGC/ECD the method of choice for the detection and quantification of chlorinated phenols at trace levels in complex matrices. Derivatization with a halogen-containing reagent enhances the ECD response. For measuring pentachlorophenol in waste water using HRGC/ECD, sensitivity is in the ppt range. Recoveries are adequate and precision is good.

Similar results were obtained in a comparison of HPLC and GC techniques for determination of pentachlorophenol in animal materials (Mundy and Machin 1981). Pentachlorophenol could be separated from acidic pesticides and other organic acids possibly present in a mill effluent by extraction with an acetylating agent (Rudling 1970). A similar single step extraction and acetylation procedure was used to determine several chlorinated phenolic compounds in paper mill effluent without interference (Lee et al. 1989). GC/MS has been used to measure pentachlorophenol in honey (Muiño and Lozano 1991). This method is simple, accurate, and rapid. Sensitivity is in the low-ppb range. Good recoveries (84–102%) and precision (2.8–6.3% relative standard deviation ([RSD]) were obtained.

A study comparing several methods for rapidly extracting pentachlorophenol from water or soil reported high recovery from all methods using HPLC/UV (Wall and Stratton 1991). A method combining extraction with derivatization by acetic anhydride had a detection limit of about 0.1 ppb for GC/ECD (Xie 1983).

Immunochemical personal exposure monitors (PEMs) are currently being developed for assaying pentachlorophenol sampled from ambient air (Hall et al. 1992). This method is highly selective and involves direct, antibody-based sampling of analytes from air with subsequent quantitation of the analyte by enzyme immunoassay. The lower limit of detection for measuring pentachlorophenol in the assay is approximately 0.5 ng/mL. Recovery and precision data were not reported.

Methods for analyzing pentachlorophenol in environmental samples are shown in Table 7-2.

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 pentachlorophenol is available. Where adequate information is not available, ATSDR, in conjunction with the NTP, is required to assure the initiation of a

Table 7-2. Analytical Methods for Determining Pentachlorophenol and Metabolites in Environmental Samples

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Stack samples	Extract sample with hexane; derivatize with acetic anhydride, collect organic layer; concentrate	GC/MS	No data	80–104%	Cuiu et al. 1986
Air	Air samples collected in PEMs; analyte diffuses across semipermeable membrane into antibody reservoir; analyte is bound by antibody in PEM; antibody is removed from PEM device and quantified by enzyme immunoassay	ELISA	0.5 ng/mL	No data	Hall et al. 1992
Air	Air samples collected in ethylene glycol contained in bubbler using sampler pump, add methanol	GC/UV	8 µg/sample	No data	NIOSH 1994
Waste water	Acidify waste water sample with H_2SO_4; extract with chloroform	HPLC/UV	11 µg/L	No data	Ervin and McGinnis 1980
Water	Acidify sample with HCl extract with methylene chloride	HPLC/UV	1 µg/L	90%	Realini 1981
Water, mill effluent	Acidify sample with H_2SO_4; extract with hexane; extract organic phase with borax; add hexane, acetylate, and analyze the organic phase	GC/ECD	0.1 µg/L	84–93%	Rudling 1970
Pulp mill effluent	Extract onto solid phase sorbents; elute with acetonitrile	LC-ED	No data	>100%	Butler and Dal Pont 1992

Table 7-2. Analytical Methods for Determining Pentachlorophenol and Metabolites in Environmental Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Marine water	Take 5 mL water and acidify with H_2SO_4; extract with petroleum ether/diethyl ether; evaporate solvent; dissolve residue in CH_3CN; measure at 254 nm	HPLC/UV	0.2 µg/L	84%	Giam et al. 1980
Drinking water	Acidify water sample; extract with dichloromethane and hexane; derivatize with diazoethane; cleanup on silica gel	GC/ECD	300 ng/L	64%	Morgade et al. 1980
Waste water	Acidify to pH <2; extract with methylene chloride; exchange into 2-propanol. For ECD, derivatize with pentafluorobenzyl bromide	GC/FID GC/ECD	7.4 µg/L 0.59 µg/L	36–134% 36–134%	EPA 1986b (Method 8040)
Water and waste water	Homogenize with dichloromethane; cleanup by sample concentration; back extract with alkali; derivatize by extractive alkylation with pentafluorobenzoyl chloride	HRGC/ECD	5 ng/L	64–80%	Buisson et al. 1984
Effluent	Mix sample with potassium carbonate, acetic anhydride, and petroleum ether; dry organic layer and concentrate	GC/ECD	#0.6 µg/L	92–104%	Lee et al. 1989
Sludge/soil	Add Na_2SO_4; soxhlet extract using toluene/methanol or acetone/hexane; acid-base partition cleanup. For ECD derivatize with pentafluorobenzylbromide	GC/FID GC/ECD	7.4 µg/L 0.59 µg/L	36–134% 36–134%	EPA 1986b (Method 8040)

Table 7-2. Analytical Methods for Determining Pentachlorophenol and Metabolites in Environmental Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Sediment	Mix with sodium carbonate with or without hexane ("pretreatment"); discard organic phase if present; derivatize by adding acetic anhydride in hexane; centrifuge	GC/ECD	-0.1 ng/g	96–99% (without pretreatment); 89% (with pretreatment)	Xie 1983
Soil	(1) Soxhlet extract in ethanol/toluene; (2) extract with hexane/acetone acidified to pH 2 with HCl centrifuge; (3) add water to sample and acidify with HCl ultrasonically extract with hexane/acetone; centrifuge; (4) vortex extract with acetonitrile; centrifuge; dry extracts and dissolve in acetonitrile	HPLC/UV	No data	(1) 94.3–98% (2) 94.8–97.8% (3) 94.4–98.5% (4) 96.1–100%	Wall and Stratton 1991
Soil/sediment	Add Na_2SO_4 and methanol, centrifuge. To 2 mL of extract, add pentafluorobenzyl bromide, hexacyclooctadecane, Na_2SO_4	GC/ECD	No data	No data	EMMI 1997 (AOB Method 0-001-1)
Soil	Add acidified water, MTBE, and centrifuge. Derivatize with N-nitrosomethyl urea, concentrate	GC/ECD	No data	No data	EMMI 1997 (AOB (0-008-1))
Surface-treated lumber	Grind dried lumber sample; extract with acetonitrile containing *p*-bromophenacyl derivative of ßß-dimethylahyic acid	HPLC/UV	0.1 mg/cm^3	No data	Daniels and Swan 1979

Table 7-2. Analytical Methods for Determining Pentachlorophenol and Metabolites in Environmental Samples *(continued)*

Sample matrix	Preparation method	Analytical method	Sample detection limit	Percent recovery	Reference
Egg	Homogenize sample; extract with ethyl acetate-hexane; elute chlorophenol with methanol chloroform	RPHPLC/ UV	<100 µg/kg	73–108% maximum	Mundy and Machin 1981
Fish tissue	Homogenize in water; acidify to pH 2 with HCl extract with methylene chloride; extract with 0.1 N NaOH; acidify; extract with toluene, dry	GC/ECD	0.5 ppb	86%	Kalman 1984
Honey	Dissolve sample in acidified water; extract onto Sep-Pak C_{18} cartridge; elute with hexane/diethyl ether	GC/MS	7.6 µg/kg	84–102%	Muiño and Lozano 1991
Gelatin	Add 12 N H_2SO_4, extract with hexane-isopropanol, partition into 1 N KOH, acidify with 12 NH_2SO_4, extract with hexane	GC/ECD	10 ppb	No data	Helrich 1990 (AOAC Method 985.24)
General	Add internal standard, sonnicate and separate	HPLC/UV	No data	No data	EMMI 1997 (EPA Method B)
General	Add internal standard and acetone	GC/FID-IS	No data	No data	EMMI 1997 (EPA Method B)

CH_3CN = acetonitrile; ECD = electron capture detection; FID = flame ionization; GC = gas chromatography; HCl = hydrochloric acid; HPLC = high-performance liquid chromatography; H_2SO_4 = sulfuric acid; MS = mass spectrometry; MTBE = methyl-tertiary-butyl ether; NaOH = sodium hydroxide; Na_2SO_4 = sodium sulphate; RPHPLC = reverse phase high performance liquid chromatography; UV = ultra-violet detection

program of research designed to determine the health effects (and techniques for developing methods to determine such health effects) of pentachlorophenol.

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. Methods are available to detect and quantify pentachlorophenol in blood (Bevenue et al. 1968; EMMI 1997; EPA 1980b; NIOSH 1984b), serum (Kalman 1984; Morgade et al. 1980), urine (Chou and Bailey 1986; Edgerton et al. 1979; EMMI 1997; EPA 1980b; Holler et al. 1989; Kalman 1984; NIOSH 1984b; Rick et al. 1982; Siqueina and Fernicola 1981), adipose tissue (Kuehl and Dougherty 1980; Morgade et al. 1980; Ohe 1979; Shafik 1973), feces (Reigner et al. 1990), liver (Maris et al. 1988) and tissue including the liver, muscle, testes, prostrate, and omentum fat (Wagner et al. 1991). Chromatographic techniques, such as GC and HPLC were used to isolate the pentachlorophenol, its derivatives, and its degradation products. ECD and MS were coupled with the separation techniques to detect these compounds. Sensitivity was high (blood: 1–20 ppb; serum: 0.4–30 ppb; urine: 0.5–250 ppb; adipose tissue: low ng–140 ppb; feces: 100 ppb; and other tissues: 1.5–<100 ppb) and recovery was good (blood: 87–100%; serum: 80–99%; urine: 84–105%; adipose tissue: 75–98%; and other tissues: 60–115%). These methods can accurately detect pentachlorophenol at background concentrations in blood, urine, and adipose tissue. Only limited data exist on methods for metabolite characterization. TCHQ, tetrachloropyrocatechol, and palmitoyl-pentachlorophenol are the known metabolites of pentachlorophenol. These compounds can be monitored using GC/ECD (Reigner et al. 1990) or MS (Edgerton et al. 1979). GC/ECD is more economical than MS, but using GC/ECD for metabolite detection has been reported in only one study (Reigner et al. 1990). However, since the majority of pentachlorophenol is excreted unchanged, monitoring of metabolites might not provide useful additional information on exposure concentrations. In general, no attempts have been made to correlate levels of pentachlorophenol in the body with levels absorbed through skin or via inhalation. However, data from a study in log homes demonstrate a positive correlation between serum and urine concentrations of pentachlorophenol and indoor air concentrations of this compound (Hosenfeld et al. 1986; Hill et al. 1989).

No identified biomarkers of effect (e.g., increased SGOT or SGPT enzyme levels in serum, increased blood urea nitrogen, or neurological symptoms) are specific for pentachlorophenol. The identification of specific biomarkers of effect may be useful.

Methods for Determining Parent Compounds and Degradation Products in Environmental Media. Methods are available to measure pentachlorophenol in stack samples (Cuiu et al. 1986), air (Cuiu et al. 1986; Hall et al. 1992; NIOSH 1994), water (Giam et al. 1980; Morgade et al. 1980; Realini 1981), waste water and effluent (Buisson et al. 1984; Butler and Dal Pont 1992; EPA 1986b; Ervin and McGinnis 1980; Lee et al. 1989; Rudling 1970), soil, sludge and sediment (EMMI 1997; EPA 1986b; Wall and Stratton 1991; Xie 1983), surface-treated lumber (Daniels and Swan 1979), fish tissue (Kalman 1984), honey (Muiño and Lozano 1991), and gelatin (Helrich 1990). Sensitivity of detection is as follows: air: 5 ppb; water: 0.1–30 ppb; waste water: 0.1 ppb–7.4 ppm; soil/sludge: 0.1 ppb–7.4 ppm; and foods: 0.5–100 ppb. The recovery of pentachlorophenol varies depending on the method of isolation and detection, and the source of the sample (water: 64–102%; waste water: 36–134%; and soil/sludge: 36–134%). The available methods are, in general, sensitive enough to measure both the background levels and the higher levels of acute exposure. However, even though inhalation is considered to be a major route of human exposure, only limited data concerning methods for determining pentachlorophenol in air were located (Cuiu et al. 1986; Hall et al. 1992), and recovery data were not reported for these methods. Although both occupational exposure and exposure from sources such as log cabins are known to occur, methods for measuring ambient concentrations of pentachlorophenol in air are lacking. An additional source of pentachlorophenol exposure is food; methods are available for analyzing pentachlorophenol in animal tissue and honey (Kalman 1984; Muiño and Lozano 1991), though the recovery is not very good. More methods are required to accurately measure the levels of pentachlorophenol (low ppb levels or lower) in foods.

7.3.2 Ongoing Studies

L.L. Ingram, Jr., of the Forest Products Utilization Laboratory at Mississippi State University, is conducting research on the development of mass spectrometric methods for analysis of creosote and pentachlorophenol (CRISP 1992).

The Environmental Health Laboratory Sciences Division of the National Center for Environmental Health and Injury Control, Centers for Disease Control, is developing methods for the analysis of pentachlorophenol and other phenolic compounds in urine. These methods use high resolution gas chromatography

and magnetic sector mass spectrometry, which gives detection limits in the low parts per trillion (ppt) range.