A STUDY OF THE ORIGIN OF ATMOSPHERIC ORGANIC AEROSOLS

Thesis by
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ABSTRACT

The sources of ambient organic particulate matter in urban areas are investigated through a program of emission source measurements, atmospheric measurements, and mathematical modeling of source/receptor relationships. A dilution sampler intended to collect fine organic aerosol from combustion sources is designed to simulate atmospheric cooling and dilution processes, so that organic vapors which condense under ambient conditions will be collected as particulate matter. This system is used to measure the emissions from a boiler burning distillate oil, a home fireplace, catalyst and noncatalyst automobiles, heavy-duty diesel trucks, natural gas home appliances, and meat cooking operations. Alternate techniques are used to sample the particulate matter emitted from cigarette smoking, a roofing tar pot, paved road dust, brake lining wear, tire wear, and vegetative detritus. The bulk chemical characteristics of the fine aerosol fraction are presented for each source. Over half of the fine aerosol mass emitted from automobiles, wood burning, meat cooking, home appliances, cigarettes, and tar pots is shown to consist of organic compounds.

The organic material collected from these sources is analyzed using high-resolution gas chromatography. Using a simple analytical protocol, a quantitative, 50-parameter characterization of the elutable fine organic aerosol emitted from each source type is obtained, which proves to be a unique fingerprint that can be used to distinguish most sources from each other.

A mathematical model is used to predict the characteristics of fine ambient organic aerosol in the Los Angeles area that would prevail if the primary organic emissions are transported without chemical reaction. The model is found to track the seasonal variations observed in the ambient aerosol at the three sites studied. Emissions from vehicles and fireplaces are identified as significant sources of solvent-extractable organic aerosol.

Differences between the model predictions and ambient concentrations that could be due to atmospheric chemical reaction are discussed. An upper limit on the amount of secondary organic aerosol present is estimated based on the difference between the acidic organic aerosol present in ambient samples versus that due to primary emissions as computed by the model. Finally, several hypotheses concerning the origin of the acidic organic aerosol are proposed.

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Chapter 1

Introduction

1.1 MOTIVATION

Fine particulate matter is easily respirable (Task Group, 1966) and has therefore long been suspected to be responsible for many of the adverse health effects attributed to air pollutants (U.S. Dept. Health, Education and Welfare, 1969). Elevated levels of organic aerosols measured in Los Angeles (Gordon and Bryan, 1973; Gordon, 1976; Grosjean, 1983) and in other areas (Singh *et al.*, 1981; Moller *et al.*, 1982) are of considerable concern because many of the organic compounds present are known carcinogens (IARC, 1980) and mutagens (Pitts, 1983; Schuetzle, 1983). Fine particles also are largely responsible for the severe visibility deterioration observed in urban areas like Los Angeles (Hidy *et al.*, 1974; White and Roberts, 1977; Larson *et al.*, 1988; Larson and Cass, 1989; Larson, Cass and Gray, 1989), and organic aerosol constitutes 25–30% of the total fine aerosol mass in the Los Angeles area (Gray *et al.*, 1984).

Regional differences in ambient organic characteristics have been observed (Grimmer, Naujack and Schneider, 1980; Ellis and Novakov, 1982), indicating a potential for distinguishing between source contributions on the basis of organic chemical attributes. However, the few experimental programs which have investigated organic emissions from sources typically have identified only a few specific compounds like the polynuclear aromatic hydrocarbons (PAHs). The use of PAHs as tracer compounds for modeling source contributions is problematic due to their uncertain chemical reactivity (Korfmacher *et al.*, 1979, 1980; Natusch and Taylor, 1980; Van Vaeck and Van Cauwenberghe, 1984; Albrechcinski, Michalovic and Gibson, 1985; Kamens *et al.*, 1985). Additionally, there are enormous differences in the way that various researchers have collected and analyzed their samples, making comparisons between emissions from different sources difficult (Daisey, Cheney and Lioy, 1986). These problems, along with the complete lack of information on organic aerosol emissions from certain types of sources, have frustrated most attempts at modeling the relationship between source emissions and the chemical composition of the ambient organic aerosol. Hence, at the outset of this study, little was known about primary source contributions to the organic compounds present in atmospheric aerosols.

1.2 APPROACH OF STUDY

To determine the origin of atmospheric organic aerosols, detailed information on the chemical characteristics of organic aerosol emissions was needed for the major sources of organic aerosol. However, no such comprehensive data base existed at the start of this research effort. Information that was available on organic aerosol emissions from sources varied greatly in terms of the methodology used to collect, store, extract and analyze the samples (Daisey, Cheney and Lioy, 1986), ruling out the possibility of compiling already-published information to determine the characteristics of organic aerosol source emissions from different source types. Thus, to fulfill the goal of this research effort, it was necessary to first establish a consistant source sampling methodology and subsequently to conduct a major source sampling program. Only then could an effort be made to characterize the major types of organic aerosol source emissions in an urban area and to determine their relative contributions to the ambient aerosol. Figure 1.1 shows a flow diagram of the steps taken to address the objectives of this research project.

The collection of organic aerosol from sources poses special challenges. Traditional aerosol source sampling methods have used equipment that contains plastics, rubber, and/or greases. While the organic contamination resulting from

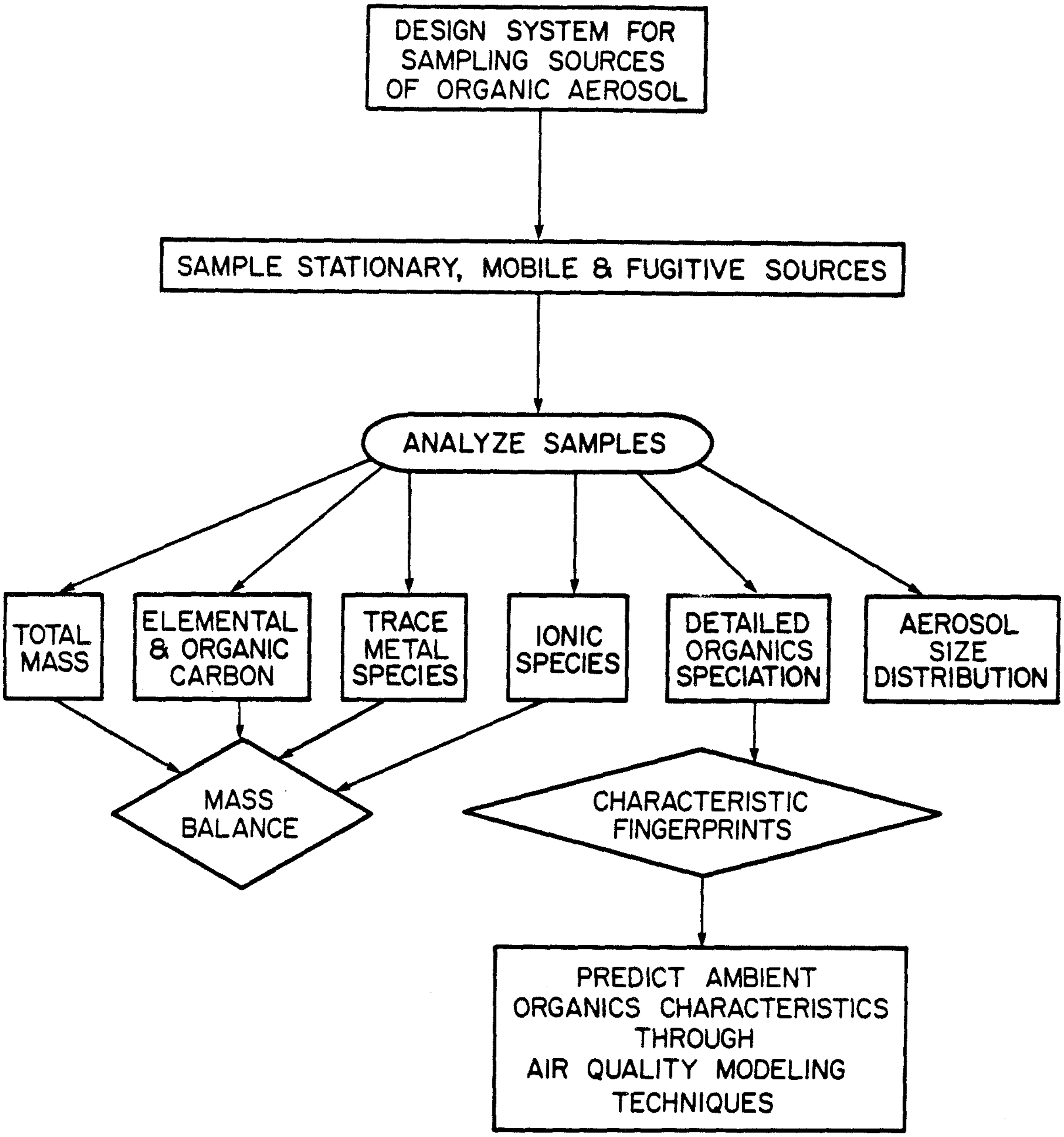

Figure 1.1. Flowchart of research plan.

some types of equipment may be acceptably low if a measurement of total organic aerosol is all that is desired, even small quantities of contaminants can pose overwhelming problems when a more detailed characterization of the organic aerosol is sought via high resolution gas chromatography and gas chromatography/mass spectroscopy analyses. In addition, in order to accurately sample stack emissions of organic aerosol, it is necessary to capture as primary aerosol those gaseous organic compounds that would normally condense into the aerosol phase as they are cooled and diluted in a plume downwind of a source. This requires the use of a dilution sampling system that can simulate the cooling and dilution processes normally undergone by a stack plume.

Hence, the first step undertaken in order to study the sources of organic aerosol was to design, construct and test a dilution sampling system especially intended to sample organics from hot stack exhaust (Chapter 2). This sampling system, constructed of stainless steel and Teflon, allowed the concentrated source emissions to be diluted by a factor of 20- to 100-fold, and provided residence times on the order of a minute to permit supersaturated vapors to diffuse to and condense onto existing aerosol.

A sampling program then was undertaken to collect samples from the major sources of fine organic aerosol. An organic carbon aerosol emissions inventory previously conducted for the Los Angeles Basin (Cass, Boone and Macias, 1982; Gray, 1986) was used to identify the most important sources of fine organic aerosol in that particular urban area. Twelve of those source types, representing nearly 80% of the total inventoried fine organic aerosol emissions into the Basin, were sampled, along with a sample of Los Angeles area urban vegetative detritus (Chapter 3). Besides obtaining samples of organic aerosol from each source type, this field testing program also determined total fine aerosol mass emission rates for most of the sources. Analysis of the mass of fine aerosol, trace metal species, ionic species, and elemental and organic carbon collected from each source type provided information on the bulk chemical characteristics of the fine aerosol emissions. In particular, emissions from meat-cooking operations were found to contain significant amounts of potassium, which has traditionally been used as a nearly-unique tracer for woodsmoke (Appendix A).

During the sampling program, the specially-designed dilution sampling system also was used to measure submicron aerosol size distributions of the emissions from many of the sources using an electrical aerosol analyzer (EAA) (Appendix B). The mass emission rates estimated using these size distributions showed substantial agreement with the fine (aerodynamic particle diameter $< 2\mu m$) aerosol mass emission rates determined gravimetrically.

To obtain a detailed characterization of the organic fraction of the fine aerosol collected from each source, source samples were extracted and analyzed via high-resolution gas chromatography, using procedures developed by Mazurek and coworkers (1987) specifically for small samples of environmental organic aerosol. Both the neutral and acidic fractions of the organic extract were analyzed to provide a more comprehensive picture of the nature of the organic material.

The data obtained via gas chromatography typically consist of hundreds of peaks. The traditional approach has been to identify some of these individual peaks using gas chromatography/mass spectroscopy (GC/MS) techniques, which typically involves months of work for each sample. In a quest for a less time-consuming method for uniquely characterizing each sample, a new approach was undertaken (Chapter 4). Each chromatographic data set was subdivided into 25 groups of peaks based on their elution time relative to the C_{10} to C_{36} n-alkane series. The total area counts of the peaks that elute between each pair of adjacent n-alkanes was summed, and converted to units of organics mass concentration. Examination of the mass distribution obtained for each source using this approach revealed unique characteristics for most of the sources tested. Monthly composites of ambient samples of fine organic aerosol were also analyzed in the same manner for three different sites in the Los Angeles Basin.

The mass distribution data obtained for each source were combined with an existing atmospheric transport model that treats the primary aerosol emissions as if they were nonreactive (Cass, Boone and Macias, 1982; Gray, 1986). Model predictions of the organic characteristics that would be present at each month at each of these ambient sites if the organic source emissions were transported without further atmospheric chemical reaction were compared with analytical results from the ambient samples (Chapter 5). Differences observed between the model predictions and the ambient measurements allowed an examination of the nature, extent, and possible origins of secondary organic aerosol in the Los Angeles Basin.

Finally, the findings of this research project were summarized, and promising avenues for further research were identified (Chapter 6). Many of these avenues involve the use of GC/MS techniques. Identification of unusual chemical compounds in the source samples may reveal promising unique tracers for certain source types. In addition, comparison of the organic compounds present in the ambient samples with those found in the source emissions may shed further light on the nature, extent and origins of secondary organic aerosols.

1.3 REFERENCES

Albrechcinski, T.M., Michalovic, J.G., and Gibson, T.L. (1985). A Smog Chamber Study of Polycyclic Aromatic Hydrocarbons in Diesel Particulates. In *Polynuclear Aromatic Hydrocarbons: Mechanisms, Methods and Metabolism* (M. Cooke and A.J. Dennis, eds.). Batelle Press, Columbus, OH, pp. 69–86.

Cass, G.R., Boone, P.M., and Macias E.S. (1982). Emissions and Air Quality Relationships for Atmospheric Carbon Particles in Los Angeles. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 207–240.

Daisey, J.M., Cheney, J.L., and Lioy, P.J. (1986). Particulate Emissions from Air Pollution Sources: Status and Needs for Receptor Source Apportionment Modeling. *J. Air Pollut. Control Assoc.* 36:17–33.

Ellis, E.C., and Novakov, T. (1982). Application of Thermal Analysis to the Characterization of Organic Aerosol Particles. *Sci. Total Environ.* 23:227–238.

Gordon, R.J. (1976). Distribution of Airborne Polycyclic Aromatic Hydrocarbons Throughout Los Angeles. *Environ. Sci Technol.* 10:370-373.

Gordon, R.J., and Bryan, R.J. (1973). Patterns in Airborne Polynuclear Aromatic Hydrocarbon Concentrations at Four Los Angeles Sites. *Environ. Sci Technol.* 7:1050–1053.

Gray, H.A. (1986). Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, CA.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1984). Elemental and Organic Carbon Particle Concentrations: A Long-Term Perspective. *Sci. Total Env.* 36:17–25.

Grimmer, G., Naujack, K.-W., and Schneider, D. (1980). Changes in PAH Profiles in Different Areas of a City During the Year. In *Polynuclear Aromatic Hydrocarbons: Chemistry and Biological Effects* (A. Bjorseth and A.J. Dennis, eds.). Batelle Press, Columbus, Ohio, pp. 107–125.

Grosjean, D. (1983). Polycyclic Aromatic Hydrocarbons in Los Angeles Air from Samples Collected on Teflon, Glass and Quartz Filters. *Atmos. Environ.* 17:2565–2573.

Hidy, G.M., Appel, B., Charlson, R.J., Clark, W.E., Friedlander, S.K., Giauque, R., Heisler, S., Mueller, P.K., Ragaini, R., Richards, L.W., Smith, T.B., Waggoner, A., Wesolowski, J.J., Whitby, K.T., and White, W. (1974). *Characterization of Aerosols in California (ACHEX).* Science Center, Rockwell International, prepared under California Air Resources Board Contract No. 358.

IARC Working Group (1980). An Evaluation of Chemicals and Industrial Processes Associated with Cancer in Humans Based on Human and Animal Data. *Cancer Research* 40:1–12.

Kamens, R., Bell, D., Dietrich, A., Perry, J., Goodman, R., Claxton, L., and Tejada, S. (1985). Mutagenic transformations of dilute wood smoke systems in the presence of ozone and nitrogen dioxide. Analysis of selected high pressure liquid chromatography fractions from wood smoke particle extracts. *Environ. Sci. Technol.* 19:63–69.

Korfmacher, W.A., Natusch, D.F.S., Taylor, D.R., Wehry, E.L., and Mamantov, G. (1979). Thermal and Photochemical Decomposition of Particulate PAH. In *Polynuclear Aromatic Hydrocarbons: Carcinogenesis and Mutagenesis* (P.W. Jones and P. Leber, eds.). Batelle Press, Columbus, Ohio, pp. 165–170.

Korfmacher, W.A., Wehry, E.D., Mamantov, G., and Natusch, D.F.S. (1980). Resistance to Photochemical Decomposition of Polycyclic Aromatic Hydrocarbons Vapor-Adsorbed on Coal Fly Ash. *Environ. Sci. Technol.* 14:1094–1099.

Larson, S.M., Cass, G.R., Hussey, K.J., and Luce, F. (1988). Verification of Image Processing Based Visibility Models. *Environ. Sci. Technol.* 22:629–637.

Larson, S.M., and Cass, G.R. (1989). Characteristics of Summer Midday Low-Visibility Events in the Los Angeles Area. *Environ. Sci. Technol.* 23:281–289.

Larson, S.M., Cass, G.R., and Gray, H.A. (1989). Atmospheric Carbon Particles and the Los Angeles Visibility Problem. *Aerosol Sci. Technol.* 10:118–130.

Mazurek, M.A., Simoneit, B.R.T., Cass, G.R., and Gray, H.A. (1987). Quantitative High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Analyses of Carbonaceous Fine Aerosol Particles. *Intern. J. Anal. Chem.* 29:119-139.

Moller, M., Alfheim, I., Larssen, S., and Mikalsen, A. (1982). Mutagenicity of Airborne Particles in Relation to Traffic and Air Pollution Parameters. *Environ. Sci. Technol.* 16:221-225.

Natusch, D.F.S., and Taylor, D.R. (1980). Environmental Effects of Western Coal Combustion: Part IV — Chemical and Physical Characteristics of Coal Fly Ash. EPA-600/3-80-094, U.S. Environmental Protection Agency, Duluth, Minnesota.

Pitts, J.N., Jr. (1983). Formation and Fate of Gaseous and Particulate Mutagens and Carcinogens in Real and Simulated Atmospheres. *Environ. Health Perspec.* 47:115-140.

Schuetzle, D. (1983). Sampling of Vehicle Emissions for Chemical Analysis and Biological Testing. *Environ. Health Perspec.* 47:65–80.

Singh, H.B., Salas, L.J., Smith, A.J., and Shigeishi, H. (1981). Measurements of Some Potentially Hazardous Organic Chemicals in Urban Environments. *Atmos. Environ.* 15:601–612.

Task Group on Lung Dynamics (1966). Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract. *Health Physics* 12:173–207.

U.S. Department of Health, Education, and Welfare (1969). *Air Quality Criteria for Particulate Matter.* National Air Pollution Control Administration Publication No. AP-49.

Van Vaeck, L., and Van Cauwenberghe, K. (1984). Conversion of Polycyclic Aromatic Hydrocarbons on Diesel Particulate Matter upon Exposure to PPM Levels of Ozone. *Atmos. Environ.* 18:323–328.

White, W.H., and Roberts, P.T. (1977). On the Nature and Origins of Visibility-Reducing Aerosols in the Los Angeles Air Basin. *Atmos. Environ.* 11:803–812.

Chapter 2

A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests *

2.1 INTRODUCTION

Organic aerosols account for approximately 30% of the fine particulate matter in the atmosphere of urban areas (Gray *et al.*, 1986). Some of these organic compounds are known to be carcinogenic (IARC, 1980; Natusch, 1978) or mutagenic (Pitts, 1983; Schuetzle, 1983), but little is known about the contribution of specific emission sources to the ambient organic aerosol concentrations (Daisey, Cheney and Lioy, 1986).

Source emissions of aromatic compounds are difficult to measure accurately because these compounds are present in both the gas and aerosol phases. The partition of an aromatic compound between the two phases is dependent on the temperature of the system and the partial pressure of the compound in the gas phase; thus, the partition ratio changes as the source emissions are cooled and diluted in the atmosphere. Attempts to evaluate the degree of gas phase/aerosol phase partitioning of various polynuclear aromatic hydrocarbons have produced widely varying results (Cautreels and Van Cauwenberghe, 1978; Thrane and Mikalsen, 1981; Dash and Guldberg, 1983; Schuetzle, 1983), due at least partly to substantial differences in the temperature and vapor pressure history of the source samples taken during different studies. The temperature dependence of the ratio between vapor phase and particulate organics is pronounced even for moderate changes in temperature (Yamasaki, Kuwata and Miyamoto, 1982).

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* L.M. Hildemann, G.R. Cass and G.R. Markowski (1989). *Aerosol Science and Technology* 10:193–204

At the temperatures found in the stacks of most combustion sources, many organics that would be present in the aerosol phase under ambient conditions are still in the gas phase, and hence are not captured by methods that directly filter particles from the hot exhaust gases. Conversely, use of cold liquid impingers or cryogenic traps results in the collection of many organics that would not normally condense under ambient conditions. Hence, filtering of undiluted, hot exhaust may greatly underestimate the amount of organic particulate matter present, while filtering plus cold-trapping may overestimate the organic mass that would be present in the aerosol phase in the ambient atmosphere. Johnson and Merrill (1983) have found that collection of organics is 2 to 23 times as high in the filter plus condensate catch of a SASS train as in the filter catch from a dilution tunnel.

During source sampling, the time and temperature history of the organics collected can be an important factor. Following a change in temperature and/or partial pressure, supersaturated organic gases will either undergo homogeneous nucleation, or diffuse to the surfaces of existing particles and condense heterogeneously. The time required for heterogeneous condensation depends on the number of particles present and their surface area, among other factors (Kittelson and Barris, 1984). For emissions from relatively clean sources, theoretical calculations indicate that the time needed for condensation may exceed the two- to three-second residence times typical (Shure and Natusch, 1982) of many dilution tunnels. Phase-segregated organic samples collected prematurely may show an erroneous overabundance of gas phase compounds, and may indicate incorrect ratios between various particulate phase components due to differences in the diffusivities of the various gaseous species.

2.2 LITERATURE REVIEW

2.2.1 Collection of Source Samples

Present methods of collecting organic particulate matter samples from stationary sources vary greatly. Approaches that have been employed in field studies include collection of particles downwind of the source stack (Natusch, 1978; Broddin, Van Vaeck and Van Cauwenberghe, 1977), hot filtration of stack gases (Ramdahl, 1983), cold-trapping of condensate from the gas phase (Nichols, Gangwal and Sparacino, 1981), simultaneous capture of particulate matter by hot filtration and gases by cold-trapping using either a modified SASS train (Bergstrom, Eklund and Trzciniski, 1982) or variations of EPA Method 5 (Jones *et al.*, 1976; Laube and Drummond, 1979; Knight, Graham and Neal, 1983), and dilution sampling trains (Houck, Cooper and Larson, 1982; Smith *et al.*, 1982). Differences in the time history, dilution, and temperature of samples taken using these various methods contribute to large differences in the results obtained.

Dilution samplers have been used in the past by a number of research groups to collect particulate matter from combustion sources. The main features of the designs that have been documented to date in publicly-available form are listed in Table 2.1. Dilution samplers were first used to sample vehicle exhaust, but these early automotive dilution tunnels could not be used in the field to test stationary sources because they were not portable. More recently, portable sampling devices have been developed. However, the systems available at the outset of the present research project were not suitable for collecting organic aerosol samples for detailed organics analysis by high-resolution gas chromatography (GC) and gas chromatography/mass spectrometry (GC/MS) techniques.

The original dilution stack sampler design reported by Houck, Cooper and Larson (1982) is made of plastic materials that may leach organics into the system, and that would prevent thorough cleaning and heat treatment of the system between tests to lower the organics blank of the system. While this design is useful for collecting samples for inorganic analyses and bulk organics mass concentration determination, the chance of cross-contamination of individual organic compounds from one test to the next could be considerable. In addition, while this sampler has size-fractionation capabilities (through the use of a dichotomous sampler), its low sample flowrate of 17 lpm severely limits the quantity of organic material that can be collected. This restricts detailed work on organics speciation, because accurate GC and GC/MS work requires relatively large amounts (approx. 1 mg or more) of extractable organic material. A newer, but as-yet unpublished sampler designed by this group is constructed of stainless steel and Teflon, but still has a limited sample flowrate (Cooper, 1987).

TABLE 2.1
FEATURES OF PUBLISHED DILUTION SAMPLER DESIGNS

	TYPICAL AUTO EXHAUST SAMPLER	CARPENTER DESIGN	NEA DESIGN	SOUTHERN DESIGN	CALTECH DESIGN
TUNNEL DIAMETER (cm.)	21 – 58	30	10	21	15
DIAMETERS OF EFFECTIVE MIXING LENGTH	7 – 28D	12 – 15D	29D	6D	10D
RESIDENCE TIME (sec.)	0.8 – 6.7	1.3	1 – 3	6.2	2 – 180
DILUTION RATIO	6 – 25X	TYPICALLY 8 – 25X (UP TO 100x)	≥ 20X	25X	TYPICALLY 40X (25x TO 100x)
REYNOLDS NUMBER	29,000 TO 130,000	47,000	11,000 TO 23,000	2,800	10,000
TUNNEL MATERIAL	STAINLESS STEEL, PVC, POLYACRYLATE	STAINLESS STEEL	PVC	PLEXIGLASS AND TEFLON	STAINLESS STEEL AND TEFLON
PORTABLE SYSTEM ?	NO	NO	YES	YES	YES
REFERENCES	CARPENTER (1978), FOSTER ET AL, (1972)	CARPENTER (1978)	HOUCK, COOPER & LARSON (1982)	SMITH ET AL. (1982)	PRESENT PAPER

The dilution stack sampling system designed by Southern Research Institute (Smith *et al.*, 1982) has a low tunnel Reynolds number and a short mixing length, which causes the degree of mixing between the stack gases and dilution air to depend strongly on the temperature of the stack gases. Even at stack gas temperatures of 120 degrees C, almost a two-fold difference in concentration was measured at different points across the tunnel diameter (Smith *et al.*, 1982). This sampler can collect large amounts (up to 440 lpm) of aerosol, but it is only capable of sampling in a single size range determined by an in-stack cyclone.

2.2.2 Analytical Techniques

Approaches to analyzing the organic aerosols collected in source samples also vary widely. Samples have been analyzed by GC, GC/MS, high performance liquid chromatography (HPLC), or ultraviolet (UV) spectroscopy, usually for a handful of specific polynuclear aromatic hydrocarbons and little else. The sensitivity of these analytical methods for various compounds varies considerably; in fact, it has been shown that running identical aliquots through GC/MS and HPLC can give markedly different results (Zelenski, Hunt and Pangaro, 1980).

2.3 DESIGN CONSIDERATIONS

The aforementioned differences in collection and analysis of organic samples preclude using data already in the literature to identify the major sources of the organic aerosol observed in ambient aerosol samples (Daisey, Cheney and Lioy, 1986). To overcome the source sampling problems, the following goals were established for the development of a new source sampling device:

1) The sampler should simulate atmospheric dilution as closely as practicable. The source sample collected on the filter should include the organics that would have condensed into the aerosol phase under ambient conditions. To achieve this, the emissions should be highly diluted and cooled to ambient temperatures. The tunnel must be long enough to allow adequate mixing to occur between the source emissions and the dilution air.

2) The sampler should be designed to minimize contamination of the sample. No rubber, plastics, greases or oils should be used, because these materials outgas organics into the airstream within the sampler. The sampler materials must also withstand thorough cleaning and heat treatment between uses, so that exhaust material deposited in the system from one source will not contaminate the next set of samples taken.

3) The sampler should provide enough residence time to allow condensation processes to occur. An important factor in designing a dilution stack sampler is determining how much time is needed for the cooled (supersaturated) organic vapors to form new particles or to condense onto particulate matter. Both homogeneous nucleation to form new particles and heterogeneous condensation onto existing particles are possible. If a vapor-phase compound reaches a high enough degree of supersaturation, homogeneous nucleation will occur rapidly. The large surface area provided by the condensation nuclei will allow other, less supersaturated vapors to quickly condense. If dilution and cooling of stack gases do not form a significant nucleation mode aerosol, all supersaturated vapors must condense onto the particles emitted by the source. In this case, the time needed to allow for diffusion-limited transport of the supersaturated vapors onto existing particulate matter will range from several seconds to several minutes, depending on the concentration and size distribution of the particulate matter emitted.

4) The sampler should be configured and operated to minimize particle and vapor losses in the system. The diameter of the tunnel should be as large as possible, in order to minimize the loss of particles and the condensation of supersaturated vapor onto the walls. However, pragmatically, the system must stay small enough to remain portable by two persons, so that it can be transported to and assembled on the cramped platforms found atop some industrial stacks. Flowrates in the system also should be chosen to minimize particle and vapor losses in the system.

2.4 DESCRIPTION OF DEVICE

The dilution stack sampler designed in response to the considerations listed above is shown in Figure 2.1. The system is as large as practicable while remaining portable. The tunnel can be disassembled at the flanges shown, and the heaviest single piece of the sampler weighs about 17 kg. The sampler is constructed

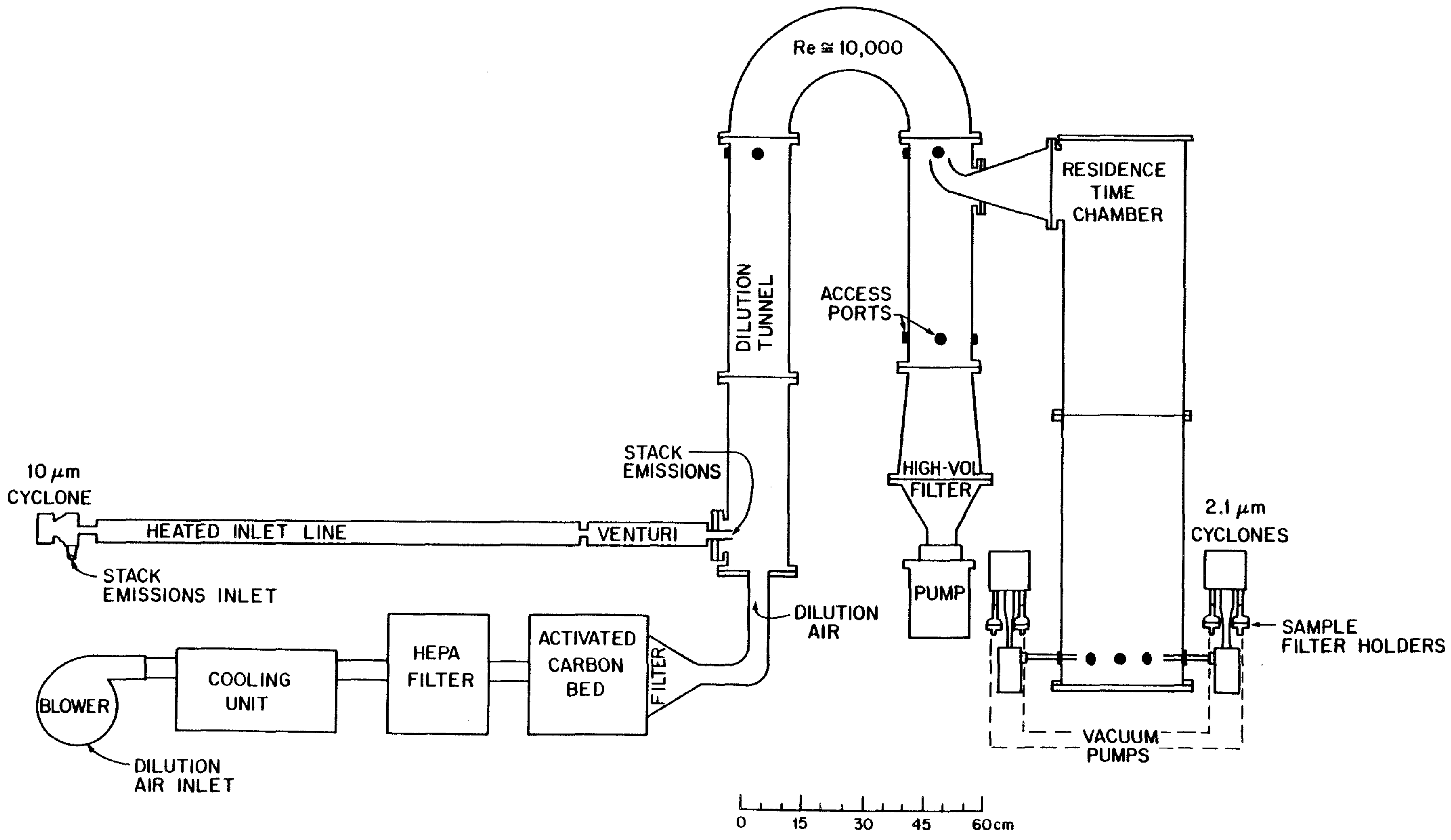

Figure 2.1. Dilution stack sampler schematic.

completely from stainless steel; virgin Teflon is used for all o-rings and gaskets to avoid organic contamination. Multiple sampling ports throughout the sampler enable collection of a large number of samples simultaneously, and allow the use of additional measurement accessories to monitor parameters like temperature, relative humidity, and particle size distribution.

Emissions are typically withdrawn from the stack at a flowrate of 30 lpm through a cyclone separator with a nominal d_{p50} of 10 μm (at 150 degrees C) inserted into the exhaust stream (see Figure 2.1). A nozzle is attached to the cyclone inlet to achieve isokinetic sampling of the exhaust. The cyclone exit is attached to a heated Teflon inlet line, which transports the stack gases to the dilution zone of the sampler. The stack gases must remain hot until diluted, so that the vapors do not condense onto the walls of the inlet line. Removal of large particulate matter by the in-stack cyclone prevents deposition of the large particles in the system, and allows sampling of a PM10-type aerosol fraction. The removal of large particles by the cyclone has a negligible effect on the subsequent condensation processes, because supersaturated vapors preferentially condense on very fine particles which dominate the particulate surface area distribution.

In the dilution tunnel, the exhaust is mixed with dilution air under turbulent flow (Re = 10,000) conditions to cool and dilute the exhaust to near-ambient conditions. The dilution air is ambient air that is completely free of particulate matter and has greatly reduced levels of organic material. A heat exchanger immersed in an ice water bath first is used to lower the ambient dilution air temperature by enough to compensate for the heat added by the dilution air blower and by the source sample. The objective is for the sample plus dilution air mix to be at ambient temperature at the point where filter samples are collected. Next a high efficiency particulate air (HEPA) filter is used to remove particulate matter from the ambient dilution air. An activated carbon bed is used to remove organics, and a quartz fiber filter follows to prevent entrainment of activated carbon particles into the system. It is important that no organic contaminants from the ambient dilution air enter the system, because at a high dilution ratio, small concentrations of ambient organics could interfere with the analysis of organics present due to the stack gases.

After passing through a tunnel length equal to 10 tunnel diameters, a fraction of the total flow is withdrawn from the tunnel into a large chamber, where additional residence time is provided before collecting the aerosol on filters. Twelve sampling ports at the bottom of the residence chamber can be used to capture different size fractions of the source aerosol emissions simultaneously: PM10-type samples can be captured by sampling the diluted exhaust directly, and fine aerosol can be sampled by attaching appropriate cyclone separators to the ports and then sampling downstream of the cyclones. Up to twelve cyclone separators, each operated at 28 lpm, can be used to process fine aerosol samples, enabling large amounts of organic aerosol to be collected for detailed chemical analysis. The use of multiple filters also enables collection of samples for various inorganic analyses, allowing a mass balance to be achieved on the chemical composition of both the fine and PM10 aerosol fractions.

The rest of the tunnel flow passes through a high volume sampler filter before being exhausted. This filter collects a large mass of PM10-type sample, which also can be analyzed in the cases where its short sample residence time (2 seconds) is not considered a problem.

Calibrated orifice plates are used to measure the flow rates at the entrance and exit of the tunnel. The flow rate of the stack gas is measured using a venturi that has been calibrated over a range of temperatures. The dilution ratio can be set anywhere from 25-fold to 100-fold dilution (calculated at standard temperature and pressure), and is kept constant during a sampling event by adjusting the dilution air and stack gas flow rates.

2.5 LABORATORY TESTING

2.5.1 Mixing Within the Sampler

A fraction of the total flow through the tunnel (typically 20%) is withdrawn into the residence chamber before aerosol collection occurs, so mixing must be thorough enough to ensure that the dilution ratio for the fraction being withdrawn is the same as for the system as a whole. To evaluate the degree of mixing in the system, NO gas was injected through the sample inlet line. Air samples were continuously withdrawn at six different points across the crosssection of the tunnel at each of four sampling ports located immediately before and immediately after the 180 degree bend in the top of the dilution tunnel (see Figure 2.2a). A TECO model 12A chemiluminescent NO–NO_x analyzer was used to measure the NO concentration as a function of position in the tunnel. Results show thorough mixing at all four sampling ports for dilutions of 28-fold and 55-fold; Figure 2.2b presents results typical of those obtained for all four ports. NO concentrations were also constant with respect to time (to within the response time of the NOx monitor) at each sampling point.

Originally, the system was designed with a 90 degree bend at the tail end of the heated inlet line, to achieve co-current injection of the exhaust gases into the dilution air. The possibility of high particle losses in this bend led to its elimination. Mixing tests also were performed at lower dilution ratios to determine at what point inhomogeneous mixing would become a problem in the modified system. At 21-fold dilution, transient variations of over two-fold in NO concentrations between sampling points in the tunnel were measured, indicating that thorough mixing was no longer being achieved consistantly.

2.5.2 Particle Losses

Particle losses in the dilution stack sampler were evaluated using ammonium fluorescein particles generated by a TSI Model 3050 Berglund-Liu monodisperse aerosol generator. Samples of the fluorescein aerosol were examined under a scanning electron microscope to determine that the aerosol particles were of the expected size, and, more importantly, that the particles were dry before they entered the sampler. After passage of the monodisperse aerosol through the sampler, the system was disassembled, and each section was washed or wiped out with dilute ammonium hydroxide to redissolve the particles. Samples were analyzed using absorption spectrometry. Figure 2.3 and Table 2.2 show the particle loss characteristics of the system as a function of aerodynamic particle diameter. Results indicate that sampler losses are minimal for the fine particulate matter for which this sampling system was specifically designed. Measurements show that 93% of the

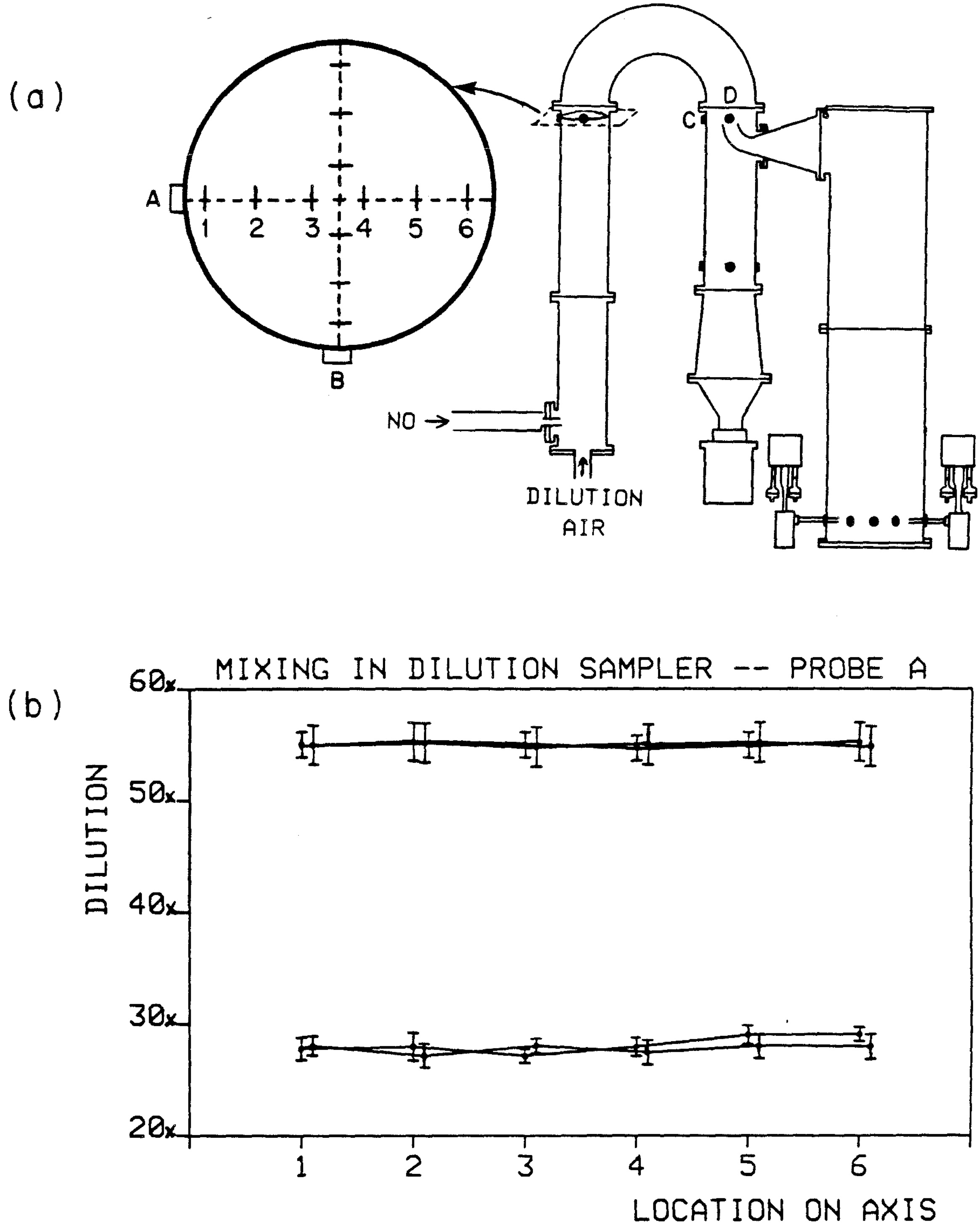

Figure 2.2. Mixing in dilution stack sampler tunnel. (a) Sampling traverses for mixing tests. The ports immediately before and after the 180 degree bend (labelled A, B, C, and D) were used for traverses. (b) Results of traverses performed with probe in port A. These results are typical of those obtained in all four ports.

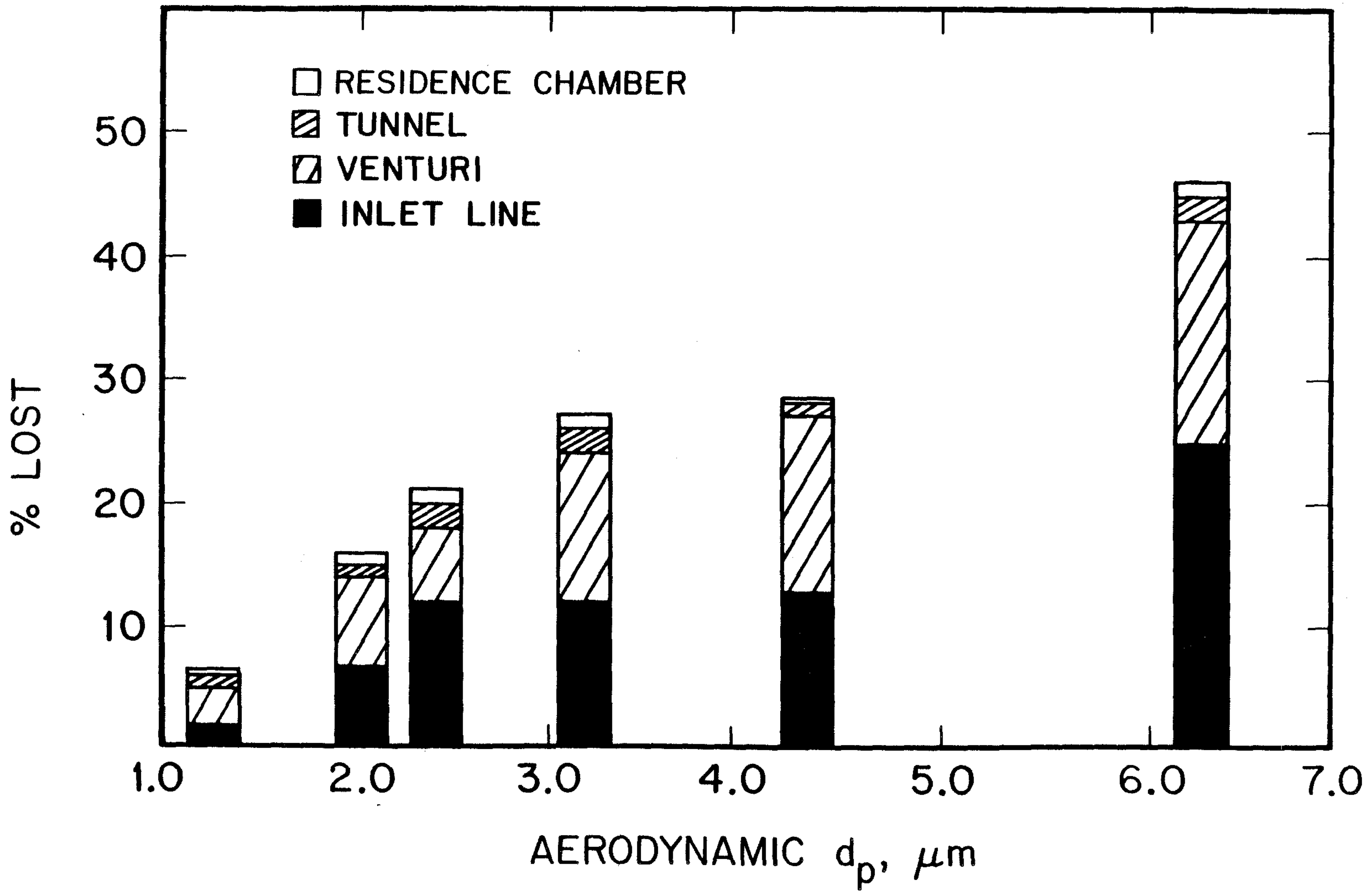

Figure 2.3. Particle losses in stack sampler.

TABLE 2.2

PARTICLE LOSS CHARACTERISTICS IN DILUTION STACK SAMPLER

	AERODYNAMIC PARTICLE DIAMETER (μm)					
AREA OF STACK SAMPLER	1.3	2.0	2.4	3.1	4.3	6.2
INLET LINE	2%	7%	12%	12%	13%	25%
VENTURI	3	7	6	12	14	18
TUNNEL	1	1	2	2	1	2
RESIDENCE CHAMBER	—*	1	1	1	—*	1
FILTERS	93	85	79	73	71	55

* = LESS THAN 0.5%

particles 1 μm in diameter, and 85% of the 2 μm diameter particles were captured on filters at the sampling points in the device, as intended. To use this sampler for PM10 analysis, the inlet line should be shortened and the venturi meter replaced by another type of flow sensor to reduce particle losses in those sections.

Particle losses are heaviest in the inlet line and venturi. In Figure 2.4, the experimental losses measured for the inlet line are shown along with theoretical predictions for gravitational losses in the horizontally-oriented circular tube under more typical laminar flow conditions. The experimental losses measured in the inlet portion of the system represent worst case conditions. This is because the inlet line was not heated during the particle loss experiments, which resulted in a flow with a Reynolds number in the transition regime. Under normal operating conditions, the inlet line will be heated, causing the flow to become laminar due to changes in the viscosity of the air, and actual losses should more closely resemble the theoretical curve.

The temperature of the inlet line will normally be maintained at a value slightly higher than the source exhaust temperature. This will produce temperature gradients that will induce particle motion away from the wall of the inlet line due to thermophoresis, which will further reduce losses. However, because ammonium fluorescein particles are not sticky, reentrainment of deposited particles during these particle loss experiments may be higher than the reentrainment encountered with typical source particles, causing the experimentally measured losses to be lower than the losses occurring under some source sampling conditions.

2.5.3 10 μm Cyclone Calibration

The cyclones used in this system for collection of fine aerosol from the residence time chamber are identical to those commonly used for collection of ambient air samples (Gray, *et al.*, 1986), and have been thoroughly characterized by John and Reischl (1980). In contrast, the 10 μm in-stack cyclone was built specially for this system. Its design, from Smith *et al.* (1982), should achieve about a 10 μm size cut at a 14 lpm flowrate at 25 degrees C, and about a 11 μm size cut at a 28 lpm flowrate at 150 degrees C. However, a somewhat different nozzle

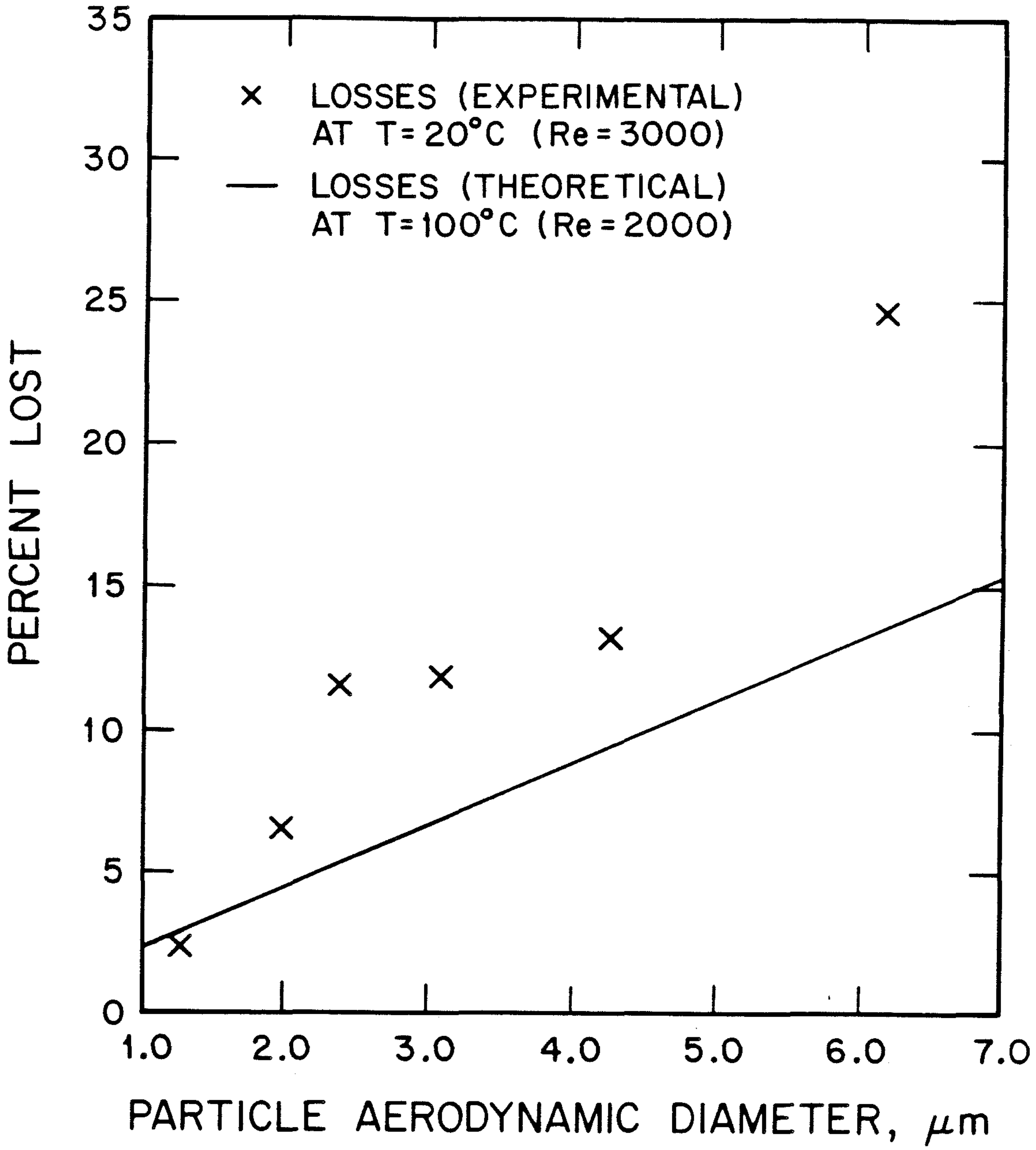

Figure 2.4. Particle losses in inlet line (137 cm long). The experimentally measured losses shown for transition-regime flow represent worst-case conditions. Under normal operating conditions, flow will be laminar and losses should more closely approximate the theoretical curve shown.

design was used with this cyclone.* Experiments were conducted to determine the cyclone's collection efficiency as a function of particle size and flowrate using the newly-designed nozzles under isokinetic conditions. Experiments at 14 lpm using the new nozzles gave the expected sizecut at ambient temperatures; however, tests at 28 lpm showed a sizecut substantially lower than expected for that flowrate, indicating that flow separation was occurring. For the 28 lpm tests, the sizecut showed a dependence on the size of the nozzle, with the lowest sizecuts measured for the smallest sized nozzles.

Lengthening the nozzles to ameliorate the flow separation problem was not feasible, because the cyclone assembly must fit through the limited-size opening found at a standard stack sampling port. Since the fine particulate fraction is the main fraction of interest for our future research on organic aerosols, no further work was done to resolve the PM10 in-stack size cut issue. Hence, PM10-type samples taken with this present sampler may have a sizecut somewhat smaller than 10 μm, depending on the nozzle used and the temperature of the stack. Limited laboratory tests indicate that this sizecut (d_{p50}) can be expected to range from 6 μm to 10 μm.

2.6 FIELD TESTS

Initial tests were conducted to measure the aerosol emissions from an industrial-scale boiler (Babcock & Wilcox Dual Fuel FM-type, with a 22,700 kg/hr steam capacity and an operating pressure of 21 kg/sq cm) at the California Institute of Technology steam plant. The complete details of the results of this test series are presented elsewhere (Hildemann, Markowski and Cass, 1988), but a few of the organic aerosol measurements will be presented here to demonstrate the performance of the sampler design. The boiler was sampled in steady-state mode at about 60% of its rated steam capacity. To measure the emissions typically produced, the operator was given complete freedom to fine tune the boiler operation as he would normally.

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* See Chapter 2 Appendix (Section 2.10) for description of the nozzle design.

Emissions from the combustion of No. 2 fuel oil were sampled. Samples were taken using different dilution ratios, and duplicate samples were taken on different days to evaluate the effects of variability in the weather, the batch of fuel, and the boiler operator on emissions. Measurements of the boiler combustion parameters (*e.g.*, temperature, excess oxygen, concentrations of CO and CO_2) also were taken.

Results indicate that boiler operating parameters had a substantial effect on the measured emission rates from the boiler. On two different days, samples taken at comparable dilutions (46x and 49x at STP) showed large changes in the amounts of elemental carbon, organic carbon, sulfates, aluminum, silicon and phosphorus emitted. The changes in the amounts of the inorganic species are most likely due to changes in the batches of fuel, and day-to-day variations in the concentrations of inorganic substances present in the combustion air. Changes in the masses of organic and elemental carbon emissions are at least partly attributable to changes in boiler operation parameters (*e.g.*, elemental carbon emissions were observed to be higher when excess air to the boiler was lower).

For all experiments, regardless of dilution ratio, the final temperature reached in the sampler was about the same, the volumetric flowrate through the tunnel was the same, and the residence time before sampling was the same. It was expected that when lower dilution ratios were used, the sampler might collect more organic aerosol, because less dilution would cause a higher degree of supersaturation to occur, and there would be a higher concentration of particles on which the vapors could condense. However, this trend was not observed; in fact, the trend shown in Figure 2.5 gives a preliminary indication that more organic carbon may be collected under higher dilution ratios.

2.7 COMPARISON WITH EPA METHOD 5

This same boiler was sampled using standard EPA Method 5 procedures (Environmental Protection Agency, 1971) to collect particulate organic emissions. Two modifications were made for practical purposes:

1) The 10 μm cyclone was used at the probe inlet. As a result, the inlet line sequence located upstream of the sample collection point in the Method 5 test was the same as in the dilution sampler, so that the mass of organic aerosol

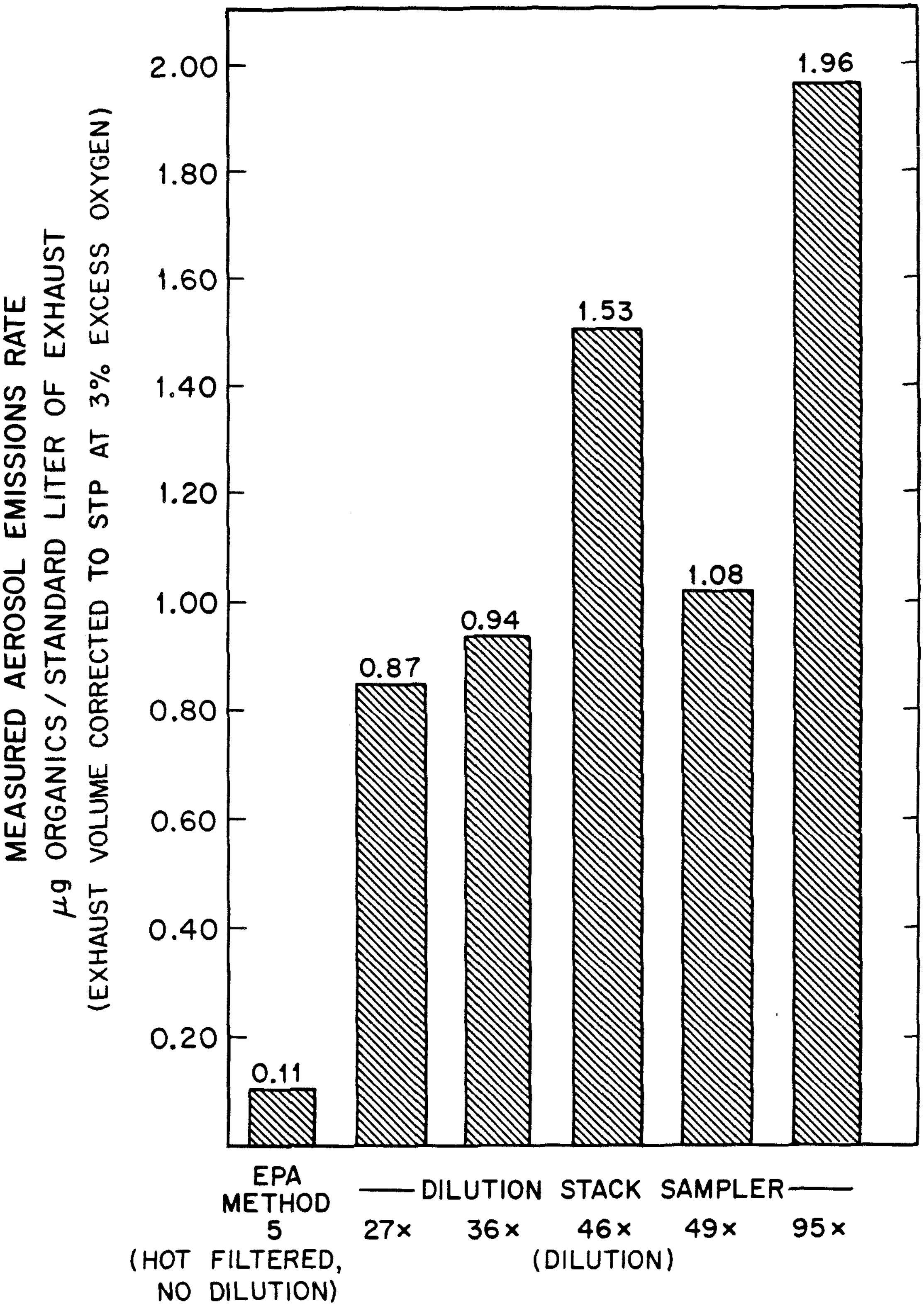


Figure 2.5. Organic carbon collected by filtration vs. dilution sampling procedure for distillate oil-fired industrial boiler.

collected using each type of train could be easily compared with differences due to the dilution system, not the inlet line.

2) The filter holder required for the Method 5 test was heated using heating tape and insulation instead of an oven. The filter holder inlet, outlet, and body temperatures were carefully monitored with thermocouples to conform with Method 5 specifications of 120 (±14) degrees C.

Analysis for organic carbon mass showed that the dilution stack sampler collected from 7 to 16 times as much organic aerosol as the heated filter portion of the Method 5 procedure (see Figure 2.5). Hence, as expected, organic aerosol emissions measurements made using hot filtration alone produce results in this case that are about an order of magnitude lower than the organic aerosol levels that are seen when the source emissions are cooled and diluted before filtration.

2.8 CONCLUSIONS

A dilution stack sampler designed to simulate the cooling and dilution processes that occur in the plume downwind of a combustion source has been specially constructed for collection of fine organic aerosols. The materials used in the sampler minimize organic contamination of the source samples, and allow the system to be thoroughly cleaned between tests. Laboratory tests have verified that minimal losses of fine aerosol material ($d_p \leq 2\ \mu m$) occur in the sampler, and that thorough mixing of the stack gases and dilution air is achieved. A field comparison of this stack sampler with EPA Method 5 has shown that this sampler collects about ten times as much organic material as the hot filter portion of the Method 5 train.

2.9 REFERENCES

Bergstrom, J.G.T., Eklund, G., and Trzciniski, K. (1982). Characterization and Comparison of Organic Emissions from Coal, Oil and Wood Fired Boilers. In *Polynuclear Aromatic Hydrocarbons: Physical and Biological Chemistry* (M. Cooke, A.J. Dennis, and G.L. Fisher, eds.). Battelle Press, Columbus, Ohio, pp. 109–120.

Broddin, G., Van Vaeck, L., and Van Cauwenberghe, D., (1977). On the Size Distribution of Polycyclic Aromatic Hydrocarbon Containing Particles from a Coke Oven Emission Source. *Atmos. Environ.* 11:1061–1064.

Carpenter, K.A. (1978). The Design and Development of a Dilution Tunnel for the Physical and Chemical Characterization of Diesel Particulate Matter. Master's thesis, Michigan Technological University, Houghton, Michigan.

Cautreels, W., and Van Cauwenberghe, K. (1978). Experiments on the Distribution of Organic Pollutants Between Airborne Particulate Matter and the Corresponding Gas Phase. *Atmos. Environ.* 12:1133–1141.

Cooper, J.A. (1987). Personal communication, NEA Incorporated, Beaverton, Oregon.

Dash, A.B., and Guldberg, P.H. (1983). A Generalized Model for Estimating the Concentrations of PAH in Urban Air. In *Polynuclear Aromatic Hydrocarbons: Formation, Metabolism, and Measurement* (M. Cooke and A.J. Dennis, eds.). Battelle Press, Columbus, Ohio, pp. 379–392.

Daisey, J.M., Cheney, J.L., and Lioy, P.J. (1986). Particulate Emissions from Air Pollution Sources: Status and Needs for Receptor Source Apportionment Modeling. *J. Air Pollut. Control Assoc.* 36:17–33.

Environmental Protection Agency (1971). Method 5—Determination of Particulate Emissions from Stationary Sources. *Federal Register* 36(247):24888–24890.

Foster, J.F., Melton, C.W., Mitchell, R.I., and Trayser, D.A. (1972). Chemical and Physical Characterization of Automotive Exhaust Particulate Matter in the Atmosphere. PB-213 593, NTIS, Springfield, Virginia.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1986). Characteristics of Atmospheric Organic and Elemental Carbon Particle Concentrations in Los Angeles. *Environ. Sci. Technol.* 20:580–589.

Hildemann, L.M., Markowski, G.R., and Cass, G.R. (1989). Emissions from Important Sources of Fine Organic Aerosol. *To be submitted.* [See Chapter 3.]

Houck, J.E., Cooper, J.A., and Larson, E.R. (1982). Dilution Sampling for Chemical Receptor Source Fingerprinting. Paper no. 82-61M.2 presented at 75th Annual Meeting of the Air Pollution Control Association, June 20-25, New Orleans, Louisiana.

IARC Working Group (1980). An Evaluation of Chemicals and Industrial Processes Associated with Cancer in Humans Based on Human and Animal Data. *Cancer Research* 40:1–12.

John, W., and Reischl, G. (1980). A Cyclone for Size-Selective Sampling of Air. *J. Air Pollut. Control Assoc.* 30:872–876.

Johnson, L.D., and Merrill, R.G. (1983). Stack Sampling for Organic Emissions. *Tox. and Env. Chem.* 6:109–126.

Jones, P.W., Glammar, R.D., Strup, P.E., and Stanford, T.B. (1976). Efficient Collection of Polycyclic Organic Compounds from Combustion Effluents. *Environ. Sci. Tech.* 10:806–810.

Kittelson, D.B., and Barris, M.A. (1984). The Influence of Adsorption/Desorption Processes on the Nature of Diesel Particles in the Atmosphere. In *Aerosols: Science, Technology, and Industrial Applications of Airborne Particles* (B.Y.J. Liu, D.Y.H. Pui, and H.J. Fissan, eds.). Elsevier Science Publishing Co., Inc., New York, pp. 770–774.

Knight, C.V., Graham, M.S., and Neal, B.S. (1983). Polynuclear Aromatic Hydrocarbons and Associated Organic Emissions for Catalytic and Noncatalytic Wood Heaters. In *Polynuclear Aromatic Hydrocarbons: Formation, Metabolism, and Measurement* (M. Cooke and A.J. Dennis, eds.). Battelle Press, Columbus, Ohio, pp. 689–710.

Laube, A.H., and Drummond, B.A. (1979). Coke Quench Tower Emission Testing Program. EPA-600/2-79-082 (PB80-108400), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Natusch, D.F.S. (1978). Potentially Carcinogenic Species Emitted to the Atmosphere by Fossil-Fueled Power Plants. *Env. Health Perspectives* 22:79-90.

Nichols, D.G., Gangwal, S.K., and Sparacino, C.M. (1981). Analysis and Assessment of PAH from Coal Combustion and Gasification. In *Chemical Analysis and Biological Fate: Polynuclear Aromatic Hydrocarbons* (M. Cooke and A.J. Dennis, eds.). Battelle Press, Columbus, Ohio, pp. 397–406.

Pitts, J.N. (1983). Formation and Fate of Gaseous and Particulate Mutagens and Carcinogens in Real and Simulated Atmospheres. *Env. Health Perspectives* 47:115–140.

Ramdahl, T. (1983). Retene — a Molecular Marker of Wood Combustion in Ambient Air. *Nature* 306:580–582.

Schuetzle, D. (1983). Sampling of Vehicle Emissions for Chemical Analysis and Biological Testing. *Env. Health Perspectives* 47:65–80.

Schure, M.R., and Natusch, D.F.S. (1982). The Effect of Temperature on the Association of POM with Airborne Particles. In *Polynuclear Aromatic Hydrocarbons: Physical and Biological Chemistry* (M. Cooke, A.J. Dennis, and G.L. Fisher, eds.). Battelle Press, Columbus, Ohio, pp. 713–724.

Smith, W.B., Cushing, K.M., Johnson, J.W., Parsons, C.T., Williamson, A.D., and Wilson, Jr., R.R. (1982). Sampling and Data Handling Methods for Inhalable Particulate Sampling. EPA-600/7-80-036 (PB82-249897), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Thrane, K.E., and Mikalsen, A. (1981). High-Volume Sampling of Airborne Polycyclic Aromatic Hydrocarbons Using Glass Fibre Filters and Polyurethane Foam. *Atmos. Environ.* 15:909–918.

Yamasaki, H., Kuwata, K., and Miyamoto, H. (1982). Effects of Ambient Temperature on Aspects of Airborne Polycyclic Aromatic Hydrocarbons. *Environ. Sci. Tech.* 16:189–194.

Zelenski, S.G., Hunt, G.T., and Pangaro, N. (1980). Comparison of SIM GC/MS and HPLC for the Detection of Polynuclear Aromatic Hydrocarbons in Fly Ash Collected from Stationary Combustion Sources. In *Polynuclear Aromatic Hydrocarbons: Chemistry and Biological Effects* (A. Bjorseth and A.J. Dennis, eds.). Battelle Press, Columbus, Ohio, pp. 589–597.

2.10 APPENDIX: NOZZLE DESIGN

A diverging nozzle was used at the inlet of the in-stack 10μm cyclone in order to achieve isokinetic sampling. The design of the set of nozzles intended to be used with this cyclone (Smith *et al.* 1982) contained an expansion angle of 30 degrees in the direction of flow. This nozzle design was considered likely to cause flow separation problems at higher volume flowrates, which would cause particles much smaller than the nominal size cut of 10μm to be removed. (It was suspected that the experimentally-determined calibration curve presented by Smith *et al.* (1982), which also appears in the Sierra Instruments literature for this cyclone, was obtained without using a diverging nozzle on the inlet.)

Due to this concern, a different design was used in constructing the nozzles, so that each nozzle had an expansion angle of 7-3/4 degrees. The six nozzles had inlet diameters ranging from 0.45 to 0.90 cm, allowing near-isokinetic flow to be achieved with stack velocities ranging up to 3000 cm/sec. With these nozzles, the cyclone-and-nozzle assembly could be inserted through an access port of greater than or equal to 13 cm in diameter.

Chapter 3

Emissions from Important Sources of Fine Organic Aerosol

3.1 INTRODUCTION

Chemical compounds that will exist as organic aerosols in the atmosphere are found as a mixture of aerosol phase plus vapor phase organics when sampled directly from the hot stack exhaust. Present methods of measuring particulate matter emissions from sources vary greatly, with large differences in the way that condensable organic vapors are collected. Motor vehicle aerosol source tests typically are conducted by dilution sampling (Carpenter, 1978; Duleep and Dulla, 1980), in which condensable organic vapors are scavenged by condensation onto preexisting aerosol as the exhaust is cooled and diluted with filtered air in a large laboratory facility. In contrast, in the most commonly-used stationary source sampling methods (*e.g.*, EPA Method 5 (USEPA, 1971, 1984) and the Source Assessment Sampling System (SASS) (Blake, 1978)), organic vapors that will form aerosol upon cooling and dilution of the stack exhaust in the atmosphere pass through hot particulate filters without being collected, and then in some systems the condensable vapors are captured in impinger baths or cold traps. However, these vapor traps may also collect other gas-phase organic material that would not form aerosol under ambient conditions. In addition, most of the equipment commonly used at present for collecting aerosol source samples is constructed from components that contain plastics, rubber compounds, and/or greases that can release organics into the system, contaminating the aerosol sample. While slight contamination of the sample with stray organics may not pose a major problem if total carbon data are all that is sought, even slight contamination introduced during sampling can pose overwhelming problems if the ultimate goal is identification and quantification of single organic species in the aerosol by gas chromatography/mass spectrometry (GC/MS). These problems of variations in test methods, variation in contamination control procedures, added to variations in laboratory chemical analysis procedures will frustrate many attempts to synthesize a comparison of the relative character and importance of the different organic aerosol sources based on the present technical literature.

Recently, a new source sampling system has been designed specifically to collect organic particulate matter including the vapor-phase material that would have condensed into the aerosol phase under ambient conditions, while minimizing contamination and particle loss problems (Hildemann, Cass and Markowski, 1989). Briefly, the sampler operates as a portable dilution tunnel, and can be used to test both mobile and stationary sources. The organic vapors present in hot exhaust gases are cooled to ambient temperature and pressure by dilution with cool, filtered air, causing vapor phase organics to condense onto preexisting aerosol in much the same manner as will occur in the plume downwind of the source. Aerosol samples are collected at ambient temperature and pressure on filter substrates identical to those used for the sampling of ambient aerosol, which facilitates later detailed chemical analysis and comparison of source and ambient aerosol samples.

In the present study, that dilution source sampling system is used to explore the relative importance of the various sources of fine ($d_p < 2\mu m$) primary organic aerosol emissions to an urban atmosphere. Emission source tests are conducted for both mobile and stationary sources by a single method so that comparisons between sources reflect differences between the sources rather than differences in sampling and analysis methods. Methods developed are illustrated for the case of organic aerosol emissions in the Los Angeles area. Based on our existing engineering estimates of local organic aerosol emission rates (estimated by literature review; Cass, Boone and Macias, 1982; Gray, 1986), source types are selected for testing that are estimated at the outset of the study to contribute close to 80% of the fine organic aerosol emitted to the Los Angeles area atmosphere (see Table 3.1).

Table 3.1. Preliminary Estimate of the Major Sources of Fine Aerosol Organic Carbon Emissions within an 80 x 80 km Heavily Urbanized Area Surrounding Los Angeles for 1982 (Gray, 1986)

Source Type	Organic Carbon Emitted (kg/day)	% of Organic Carbon Emissions	Source to Be Tested	Notes
1) Paved road dust	5114	18.6	X	(a)
2) Charcoal broilers	4389	15.9	X	(b)
3) Noncatalyst gasoline vehicles	3710	13.5	X	(b)
4) Diesel vehicles	2100	7.6	X	(b)
5) Brake lining	1480	5.4	X	(a)
6) Surface coating	1433	5.2		(c)
7) Cigarettes	1336	4.9	X	(b)
8) Fireplaces	1270	4.6	X	(b)
9) Forest fires	877	3.2		(d)
10) Roofing tar pots	752	2.7	X	(b)
11) Natural gas combustion	692	2.5	X	(b)
12) Organic chemical processes	692	2.5		(c)
13) Tire wear	671	2.4	X	(a)
14) Misc. industrial point sources	393	1.4		(c)
15) Catalyst-equipped gasoline vehicles	335	1.2	X	(b)
16) Nonrefinery petroleum industries	278	1.0		
17) Primary metallurgical processes	228	0.8		
18) Railroad (diesel oil)	211	0.8		
19) Residual oil stationary sources	206	0.7		
20) Refinery gas combustion	195	0.7		
21) Secondary metallurgical processes	167	0.6		
22) Mineral industrial processes	158	0.6		
23) Other organic solvent use	106	0.4		
24) Jet aircraft	92	0.3		
25) Asphalt roofing	81	0.3		
26) Coal burning	76	0.3		
27) Wood processing	74	0.3		
28) Residual oil-fired ships	66	0.2		
29) Structural fires	63	0.2		
30) Distillate oil stationary sources	61	0.2	X	(b)
Other sources	226	0.8		
TOTAL	27532			

(a) Tested by grab sampling and then resuspension of the collected dust.

(b) Tested via dilution sampling.

(c) This category represents a collection of many small dissimilar sources for which a small number of tests cannot be used to represent the emissions from the group as a whole.

(d) Forest fires are an occasional emission source that does not affect ambient samples on a routine basis.

The present paper documents the source tests and presents the bulk chemical characteristics of the sources sampled. In most cases, both the mass emission rate and chemical composition are determined, which is particularly useful in support of quantitative organic aerosol emission inventory studies since many studies of aerosol source chemical composition have focused either on mass emission rate determination or on *relative* chemical abundances (Watson, 1979; Cooper *et al.*, 1988; Friedlander, 1973), but not both.

3.2 EXPERIMENTAL SECTION

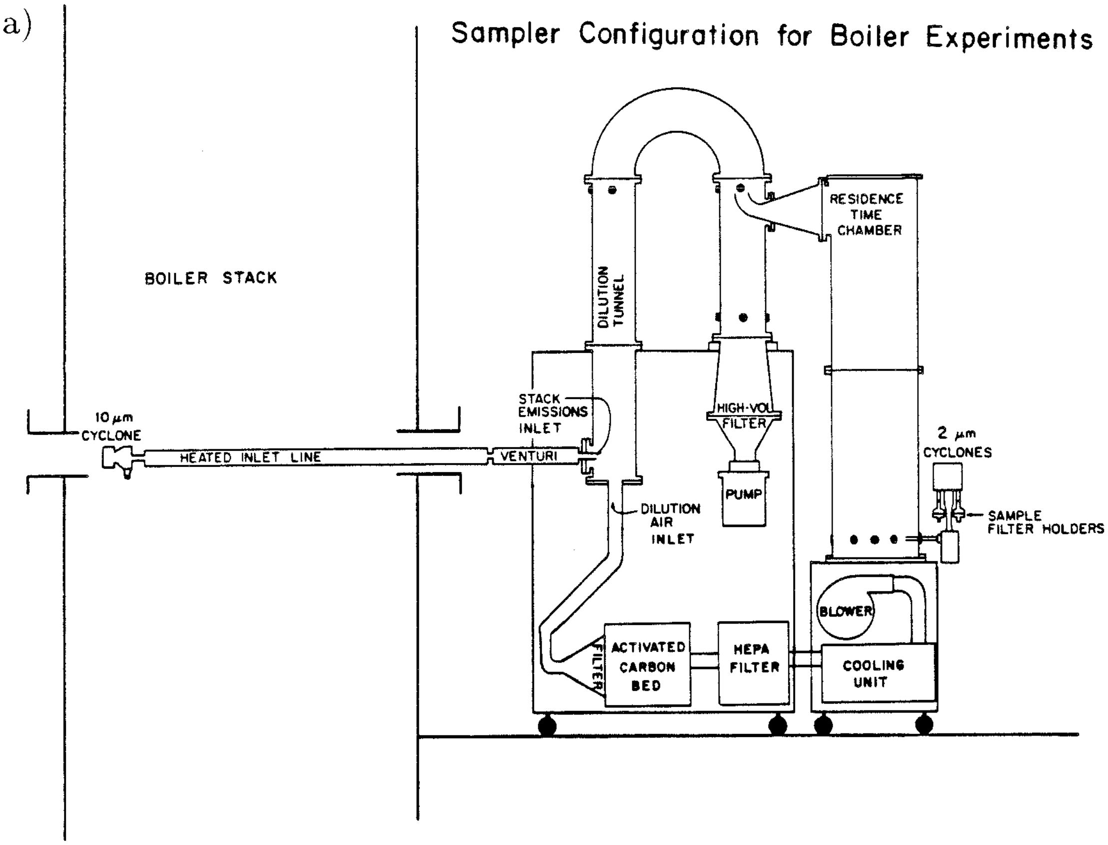
3.2.1 Source Sampler Design.

The source sampler used in this work is shown in Figure 3.1a. In its stationary source test configuration, it employs an in-stack stainless steel cyclone separator to collect particles with aerodynamic diameter greater than about 10 μm. Exhaust gases and particles smaller than 10 μm in diameter are drawn through a heated Teflon sampling line into a stainless steel dilution tunnel. Following rapid and thorough mixing with cooled purified air, approximately 10% of the source sample is drawn into a stainless steel chamber where 40 to 60 seconds of residence time is provided to allow condensation processes to go to completion. The sample next flows from the residence time chamber through several parallel cyclone separators in which particles larger than 2 μm aerodynamic diameter are collected. The fine organic aerosol that remains in the sample stream then is collected by filtration at ambient temperature and pressure using equipment identical to that commonly used for low-volume ambient aerosol sampling. All flows are metered and controlled so that data on quantitative emission rate per unit of source activity are obtained. Details of the sampler's design and performance have been published previously (Hildemann, Cass and Markowski, 1989).

3.2.2 Source Sampler Preparation.

The sampler was cleaned before use at each combustion source sampled. Large parts first were vapor-degreased using tetrachloroethylene, with all open ends wrapped with clean aluminum foil immediately after cleaning to prevent

(a) Sampler Configuration for Boiler Experiments



(b) **Sampler Configuration for Vehicle Experiments (Top View)**

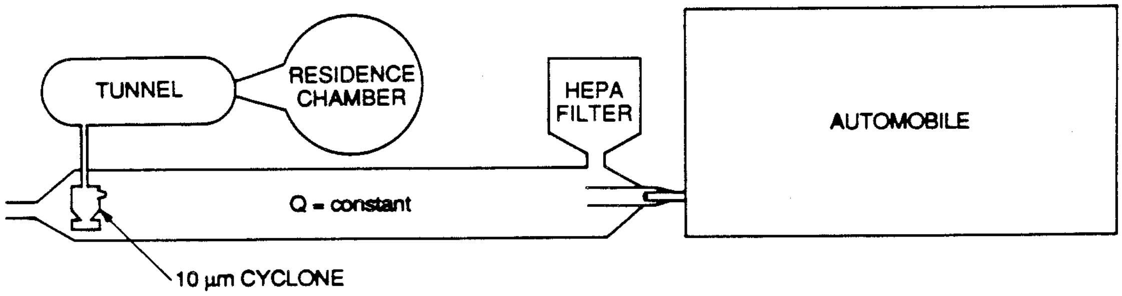
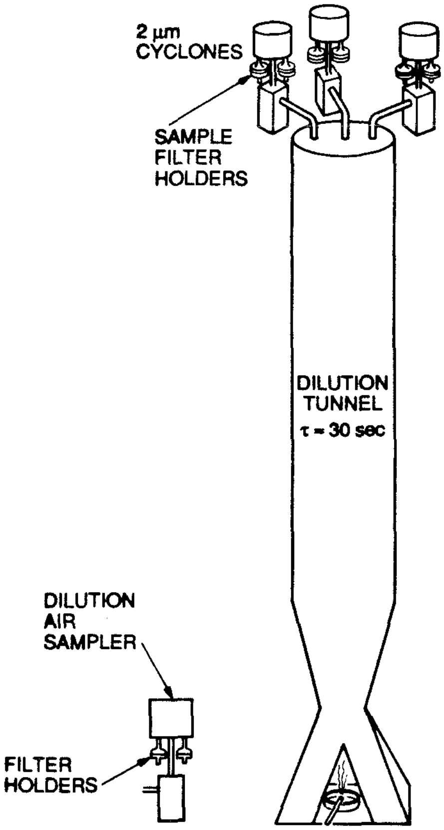


Figure 3.1. Source sampler design. (a) Dilution stack sampler; (b) Vehicle test configuration.

(c) **Dilution Sampler for Cigarette Experiments**



(d) **Dilution Sampler for Tar Pot Experiments**

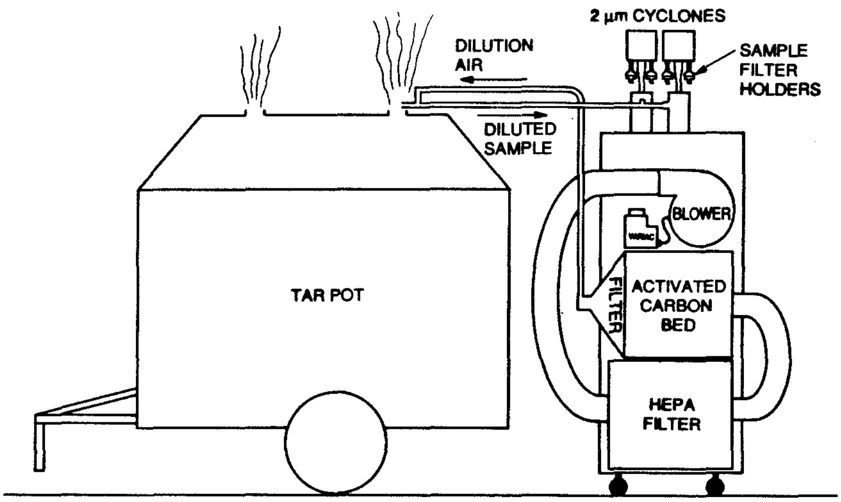


Figure 3.1. Source sampler design (cont.). (c) Cigarette sampling; (d) Tar pot sampling.

recontamination of the interior surfaces. These sampler parts were then assembled in the laboratory, and baked for at least 4 hours at temperatures of greater than 70 C by wrapping electrical heating tape around the stainless steel shell of the dilution sampler while circulating purified air through the system. The smaller sampler parts were washed with detergent, rinsed with deionized water, and then were sonicated first for 5 minutes in glass-distilled methanol, and then for another 5 minutes in glass-distilled hexane. Again, all open ends were wrapped with clean aluminum foil after the cleaning process to prevent contamination during storage and transit.

After assembling the sampler at the site of the combustion source, the system was checked for leaks of unfiltered ambient air into the system. Under a typical operating vacuum of 2500 Pa, this leakage rate was required to be less than 0.1% of the total flow rate through the system. System blank samples then were taken at the site prior to sampling the source in order to detect any potential contaminants, such as ambient organics passing through the dilution air purification system, other artifacts resulting from the handling and storage of the filters, or residues remaining after cleaning the sampler. Collection of the system blank samples was achieved by taking filter samples of the dilution air immediately after passage through the HEPA filter and activated carbon bed, and also at the normal stack aerosol sample extraction points at the downstream end of the entire sampling system attached to the residence time chamber (see Figure 3.1a).

Immediately before each experiment, the stack gas flowrate and temperature were measured at various points, using a pitot probe and a Type J thermocouple. The flowrate measurements were used to select an appropriate nozzle size for the in-stack cyclone in order to achieve isokinetic sampling. The temperature measurements were used to determine the temperature setting for the heated sample inlet line in order to avoid premature condensation of aerosol in the inlet line upstream of the dilution tunnel.

Before and after each sampling experiment, the flowrate through each of the filters was measured using a rotameter calibrated to an accuracy of ±1%. During each experiment, the flowrates of the incoming dilution air, and of the mixture exiting the tunnel, were measured at regular intervals using magnehelic gauges that determined the pressure both upstream and across calibrated orifice plates. The exhaust gas flow through the stack sampler inlet line was measured in the same manner using a venturi meter. All flowrates were corrected to standard temperature and pressure (STP). System temperature and relative humidity also were recorded frequently, and parameters such as excess oxygen, temperature, and concentrations of both CO and CO_2 were measured with a Kane–May Model 9103 Combustion Analyzer using a probe inserted into a sampling port in the stack.

3.2.3 Source Sampling Procedures.

For tests conducted on ducted stationary sources, the dilution stack sampler was erected on a wheeled platform adjacent to the stack, and the entire sampler was moved during sampling to traverse the stack. The hot exhaust gases were withdrawn from the stack through a cyclone separator that removed aerosol with particle diameters greater than 10μm. The source effluent then passed through a straight, 1.2-m long heated Teflon tube at a typical rate of 22–32 lpm (at STP) before being mixed with dilution air in the main part of the dilution sampling system. The dilution air was cooled slightly to achieve an ambient temperature of 25 to 35 degrees C upon mixing with the hot source effluent, and the dilution air was purified before use by passing it through an activated carbon bed and a HEPA filter. The source effluent was typically diluted by a factor of between 35:1 and 50:1. Fine aerosol samples were collected by sampling from the residence time chamber at the downstream end of the sampling system. Aerosol samples were withdrawn through six parallel AIHL cyclone separators (John and Reischel, 1980), each operated at 27.9±0.3 lpm, which removed particles with sizes greater than or equal to 2.0 μm. Downstream of each of these cyclone separators, three 47mm diameter filter holders were used to collect the aerosol at a sample flowrate of 9.0 to 9.6 lpm through each filter holder, yielding 18 separate fine particle samples.

Three of the 18 filter holders contained filter substrates for determination of bulk fine aerosol chemical properties. Two of these three filter holders contained

Teflon filters (Gelman Teflo, 2.0um pore size) for determination of (1) aerosol mass by gravimetric analysis of both filters; (2) trace metals content by x-ray fluorescence; and (3) ionic species by ion chromatography and atomic absorption spectrophotometry. The third filter holder contained a quartz fiber fiber filter (Pallflex 2500 QAO) of the type customarily used for collection of ambient organic aerosol samples. All quartz fiber filters were baked at 750 C for 2 to 4 hours before use to lower their carbon blank. These filter types were chosen in order to match as closely as possible the sampling characteristics of an existing set of Los Angeles ambient aerosol samples (Gray *et al.*, 1986; Mazurek *et al.*, 1987, 1989). From chemical analysis of the two Teflon and one quartz fiber filters, a nearly complete material balance on the bulk chemical content of the source aerosol can be obtained (Gray *et al.*, 1986; Solomon *et al.*, 1989). The remaining 15 filter holders contained prebaked quartz fiber filters destined for later detailed examination of the organic species present. All filter handling was performed with clean, Teflon-coated tweezers. The glass jars used for storing organic aerosol source samples were annealed overnight at 500 degrees C, and had solvent-washed Teflon liners in the lids. Samples for trace elements, ionic species and gravimetric analysis (collected on Teflon filters) were stored in petri dishes sealed with Teflon tape. All samples were stored at minus 25 degrees C within 2 hours of the end of an experiment.

The aerosol mass emission rate from the combustion source was determined gravimetrically by weighing the Teflon filters before and after sampling using a Mettler balance (Model M-55-A) in a temperature- and humidity-controlled room (20–24 C, 50–55% r.h.). Thirty-four trace elements were determined by x-ray fluorescence. Sulfate, nitrate and chloride emission rates were measured by ion chromatography (Model 2020i, Dionex Corp.), and sodium and magnesium were analyzed by flame atomic absorption (Model AA-6, Varian Techtron). The emission rate of aerosol ammonium ion was measured using a modified indophenol colorimetric method (Bolleter, Bushman and Tidell, 1961) with a rapid-flow analyzer (Model RFA-300, Alpkem Corp.). Organic and elemental carbon mass emissions rates were determined from a quartz fiber filter using a thermal evolution and combustion technique (Huntzicker *et al.*, 1982; Johnson *et al.*, 1981). The mass emission rate of organic compounds was estimated as 1.2 times the organic carbon measured (Gray *et al.*, 1984). The mass emission rate of each chemical species found in the exhaust aerosol was determined after subtraction of any trace pollutant concentrations measured in the dilution air supply.

3.2.4 Sources Tested by Dilution Sampling.

The sources selected for sampling are identified in Table 3.1, and were chosen to represent source types responsible for close to 80% of the fine primary organic aerosol emissions to the Los Angeles atmosphere based on existing engineering estimates drawn from a literature review (Cass, Boone and Macias, 1982; Gray, 1986). Those sources where dilution sampling is necessary are indicated by note (a) in Table 3.1.

3.2.4.1 Stationary Industrial Sources. A Babcock & Wilcox Dual Fuel FM-type industrial-scale watertube boiler (steam production capacity of 53 x 10^6 kJ/hr) was tested equipped with a steam atomizer burner for No. 2 fuel oil combustion. For each test, the boiler being sampled was operated in steady state mode at about 60% of capacity, with a second boiler used to absorb the demand fluctuations. Sampling was conducted on the roof of the steam plant facility, using access ports built into the exhaust stacks. These access ports allowed samples to be taken by traversing only along one axis, and prevented samples from being taken closer than 8-cm to the wall. The 1.1-m diameter stack was traversed twice during each experiment, and samples were taken from five equidistant points within the stack. The cross-sectional area of the stack was divided into 5 zones surrounding each sampling point, and the duration of sample extraction at each point was directly proportional to the volumetric flux of exhaust gas through the area of the stack assigned to that point. Hence, samples were taken for long periods near the stack wall, while the center of the stack was sampled for a shorter time. The volumetric flow rate of the stack exhaust gases was adjusted to 3% oxygen, dry, based on fuel consumption and excess oxygen measurements.

3.2.4.2 Mobile Sources. A fleet of automobiles and heavy-duty diesel trucks was tested at the California Air Resources Board's Haagen-Smit Laboratory dynometer facilities. Vehicles tested are described in Table 3.2. For the automobiles, the cold-start Federal Test Procedure Urban Driving Cycle (see Figure 3.2a) was used to simulate city driving conditions. The heavy-duty dynometer used for the trucks could not simulate a complicated driving cycle. Instead, the cycle illustrated in Figure 3.2b was used. Cars were tested in as-received condition, and an effort was made to include both domestic and foreign model vehicles. Each catalyst-equipped automobile was tested while burning the brand of unleaded gasoline normally purchased by its owner. For the noncatalyst Mercury and Buick, leaded premium with a lead content of 0.22 gm/gal was used. For the other four noncatalyst cars, leaded regular gasoline with a lead content of 0.34 gm/gal was used. The trucks, which were provided by the City of Pasadena, were both late-model, low-mileage vehicles, and were tested while burning the diesel fuel normally purchased by that city. To sample an amount of vehicle exhaust proportional to the total amount being emitted at any time, an additional dilution tunnel segment was added upstream of the normal intake to the dilution sampler (see Figure 3.1b). A combination of vehicle exhaust plus filtered dilution air was drawn through this tunnel segment at a constant flowrate, using variation of the dilution air flowrate to maintain a constant flow rate in the face of changing engine speed. Using this approach, the concentration of the diluted emissions in this tunnel was proportional to the flux of exhaust from the tailpipe at any time. A fraction of this prediluted exhaust was withdrawn into the stack sampler at a constant flowrate and then was diluted a second time by the standard dilution air supply to the sampler, effectively sampling an exhaust aerosol concentration proportional to the total emission rate at any time.

3.2.4.3 Dispersed Area Sources. An undampered, traditional brick fireplace in an older single-family home was utilized for the sequence of wood combustion experiments, each involving a different type of wood: seasoned pine, oak, almond, and a synthetic log (Pine Mountain brand, 5 lbs). For the wood, pieces ranging from 1000 to 6000 g were preweighed to the nearest 5 g and labeled, as was the

Table 3.2. Characteristics of Vehicles Tested

	Number of Cylinders	Engine Displacement (cu in)	Odometer Reading (miles)	FTP Fuel Economy (mi/gal)
NONCATALYST AUTOMOBILES				
1965 Mercury Monterey	8	390	139192	10.7
1969 Ford Mustang	8	302	141843	14.7
1970 Buick Skylark	8	350	88726	13.0
1972 Chevrolet Caprice	8	400	147249	12.3
1974 Ford Pinto	4	140	107138	16.7
1976 Volkswagen Beetle	4	97	80876	26.6
CATALYST AUTOMOBILES				
1977 Chevrolet Vega	4	140	88598	22.0
1980 Honda Civic 150	4	91	83862	27.5
1980 Honda 1500	4	91	149424	28.0
1980 Toyota Corolla	4	108	66832	20.6
1981 Datsun 200SX	4	119	81541	24.6
1983 Chevrolet Malibu CL	6	231	38826	17.7
1983 Dodge Omni	4	135	27280	22.7
HEAVY-DUTY DIESEL TRUCKS				
1987 GMC Truck (2-axle)	8	636	2920	7.9(a)
1987 Ford Dump Truck (3-axle)	8	636	5581	7.2(a)

(a) Fuel economy is for the truck driving cycle shown in figure 2b.

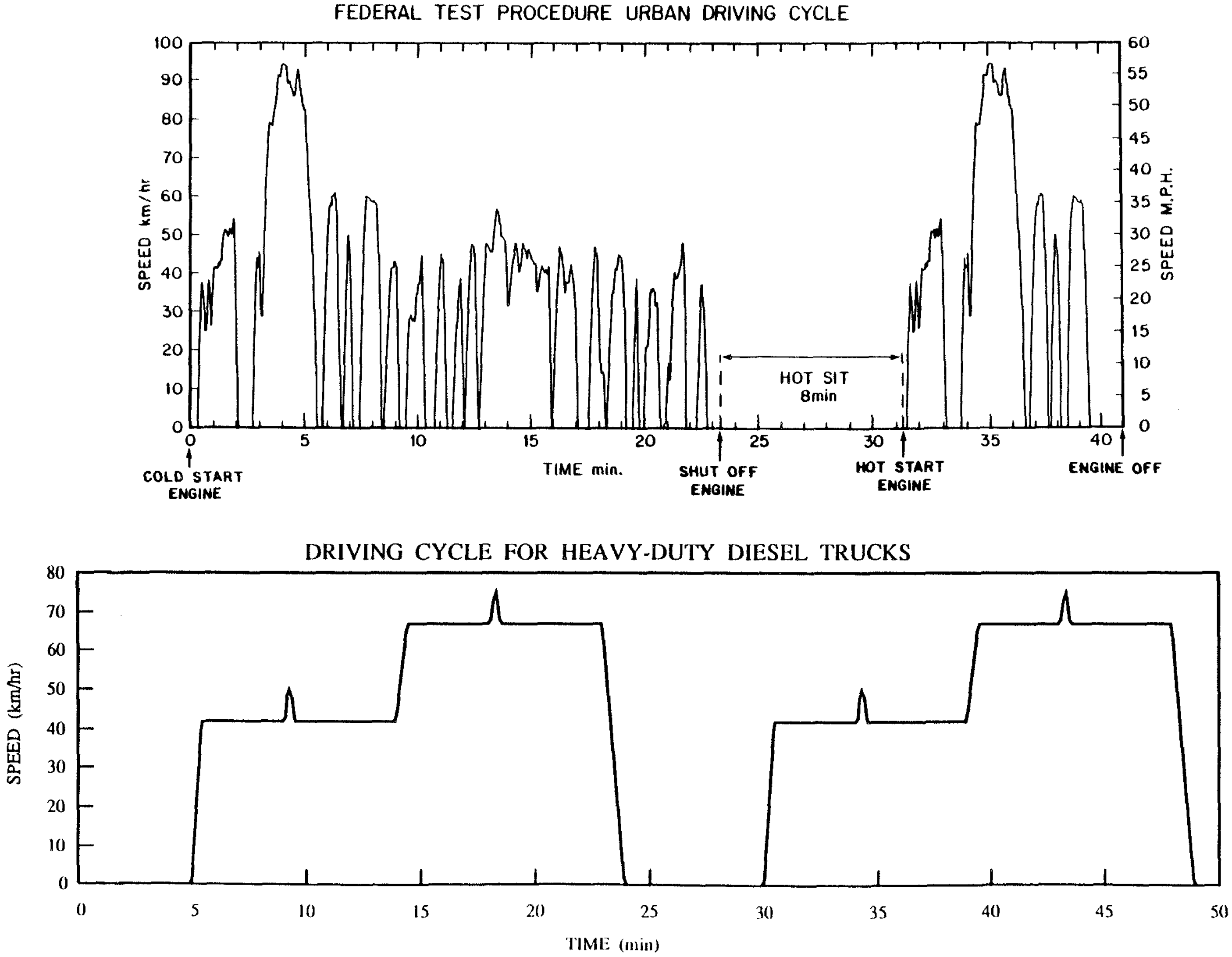


Figure 3.2. Driving cycles. (a) Federal Test Procedure urban driving cycle; (b) Driving cycle for heavy-duty diesel trucks.

kindling. In an effort to mimic the course of a traditional home fire, wood was added at intervals through the course of the fire, and the fire was periodically stirred. A record was kept of the time when various logs were added and when the fire was stirred. For the synthetic log, the fire was left undisturbed, in accordance with the manufacturer's directions. Emissions were withdrawn from the flue through a hole bored into the side of the chimney. Four different sampling points along the long axis of the chimney were used, obtaining effluent samples both near the wall and near the center of the flue. For each test, emissions were sampled from the time that the fire was lit to the late ember stage, a 3–4 hr period. Pieces of newspaper were used to ignite the fire, but otherwise the material being combusted (including the kindling) was strictly limited to the type of wood being used for the particular experiment.

For the meat-cooking experiments, a local commercial-scale kitchen was utilized. Two types of hamburger meat, regular (approx. 21% fat) and extra-lean (approx. 10% fat), were cooked by two methods: by charbroiling over a natural gas flame, and by frying. In each of four experiments, 80 quarter-pound (113 g) hamburger patties were cooked until they were medium to well-done, eight at a time, over a period of 70 to 80 minutes. The aerosol generated during the cooking was withdrawn through a 14,000 cfm (6.6 m^3 sec^{-1}) overhead exhaust hood equipped with a baffle-type grease extractor. The source sampler was located on the roof of the kitchen, and samples were withdrawn at the exit to the exhaust duct. The air flow rate through the exhaust vent was verified through pitot probe measurements.

A natural gas-fired space heater (Western Gravity Heat, Model 8G100) and water heater (American Standard, Model G-531-H) were used to generate emissions from natural gas combustion at a single family home. The two devices were connected to a common exhaust duct, and this duct was traversed using the stack sampler to withdraw emissions from 5 points in the 23 x 23 cm exhaust duct. For each experiment, the heaters were turned off for 1 to 3 minutes approximately twice per hour in an attempt to mimic the cyclic nature of their operation; otherwise, both heaters were left on continuously for the 8 to 12 hour duration of each experiment.

For collection of cigarette smoke, the dilution stack sampler was not used. Instead, a vertically oriented dilution tunnel made of stainless steel, aluminum, and Teflon was erected in the laboratory as shown in Figure 3.1c. This tunnel, which was solvent cleaned prior to use, was constructed to collect *all* the aerosol released to the atmosphere while smoking a cigarette. As the cigarette was smoked, the smoker would exhale into the triangular opening at the bottom of the tunnel. During the periods between puffs, the cigarette was placed in an ash tray at the bottom of the tunnel, and the sidestream smoke from the smoldering cigarette was drawn into the tunnel. As the smoke was drawn up into the tunnel, it underwent dilution, passed through 2μm size cut cyclone separators, and the fine aerosol finally was captured on a set of filters identical to those used with the dilution sampling systems employed for the earlier work in this series of experiments. Consumption of regular, filtertip, light, and menthol cigarettes was estimated based on market-share data from 1981 (House of Reps., 1982) (see Table 3.3). One of the five most popular brands of each type of cigarette was used for testing, as shown in Table 3.3.

The roofing tar pot tested contained petroleum-based built-up roofing asphalt (GAF brand) maintained at 250–300 C. The full dilution stack sampler was not used to collect roofing tar pot emissions. Instead, a smaller-scale dilution sampler was constructed of stainless steel, aluminum and Teflon (see Figure 3.1d), and solvent-cleaned prior to use. A Variac was used to regulate the speed of the blower that determines the dilution air flowrate such that a sample intake rate of 2 lpm was subsequently diluted by 18-fold before collection of fine aerosol on filter sets downstream of two 2μm size cut cyclones. Samples were taken from a vent opening at the top of the tar pot for 10 to 15 minutes.

3.2.5 Sources Tested by Resuspension.

For collection of paved road dust, a grab sampling technique was used. A small vacuum sweeper truck (Tennant 255, 36HP) was driven up and down several blocks of Pasadena-area streets that had accumulated road dust during a 2-week dry period in May 1988. The material collected was resuspended in a clean Teflon bag, using air passing through a HEPA filter and an activated carbon bed to maintain a

Table 3.3. Market Share Data for Cigarettes [a]

Cigarette Type	1981 Market Share (%)	Most Popular Brands	1981 Market Share (%)	Brand Sampled
Regular	41.6	Marlboro 85s	11.2	
		Winston 85s	7.1	
		Pall Mall 100s	3.6	
		Salem 85s	2.7	
		Camel 85s	2.3	X
Filtertips (NonMenthol)	28.5	Kool 85s	4.8	
		Marlboro 100s	2.5	
		Merit 85s	2.0	X
		Vantage 85s	1.8	
		Kool 100s	1.5	
Lights/ Ultralights (NonMenthols)	22.1	Marlboro 85s	3.1	
		Winston 85s	2.3	X
		Salem 85s	2.2	
		Salem 100s	1.6	
		Marlboro 100s	1.3	
Menthols	7.8	Virginia Slims 100s	1.3	
		Benson & Hedges 100s	1.2	X
		Benson & Hedges Lts.	0.9	
		More 100s	0.5	
		Carlton 100s	0.4	

(a) Calculated from data in House of Representatives (1982).

slightly positive pressure in the bag. The contents of the Teflon bag were agitated and samples were withdrawn through 2μm size cut cyclone separators for subsequent collection on filter substrates.

A bulk sample of organo-metallic brake dust from the rear drum brakes of a late model light-duty truck was obtained by brushing the dust from the inside of the drum after removing the wheel. The sample was resuspended in a clean Teflon bag and aerosol in the sub-2μm size range was collected in the same manner as for the road dust.

A radial tire (195/60R15 Toyo) that had already been driven for 7200 miles was run on a rolling resistance test at a tire testing laboratory over a period of several days. Wear particles that accumulated on the horizontal surfaces of the machine were collected as a grab sample. The tire particles were resuspended to form an aerosol from which a sample of fine particles less than 2μm in diameter could be obtained via cyclone separation. However, when resuspension was attempted, the tire particles became electrically charged and adhered to the walls of the sampling equipment. The attempt to obtain a fine aerosol sample was abandoned. Instead, a total particle sample was collected directly onto filters, giving a sample that was mainly composed of coarse particles.

Organic aerosol produced by the abrasion of surface waxes from the leaves of plants are readily identifiable as a component of ambient particulate matter samples (Simoneit and Mazurek, 1982; Mazurek and Simoneit, 1984; Mazurek, Cass and Simoneit, 1989). To collect a representative sample of vegetative abrasion products, the predominant plant species in the Los Angeles area, both cultivated and natural, were identified based on studies by Winer, Fitz and Miller (1983) and Miller and Winer (1984). Based on their data, 51 cultivated species representing six types of urban vegetation (broad leaf trees, conifers, palms, shrubs, grasses, and groundcover), 10 species of natural vegetation, and 1 species of agricultural vegetation were selected for study, as shown in Table 3.4. Separate samples of green and dead leaves were acquired for each of these 62 species over a 3-day period from botanical collections at the Los Angeles County Arboretum in Arcadia,

Table 3.4. Vegetation Sample Composite

		Leaf Mass per Area of Land Covered (g/m²)	Area Covered by Vegetation in Los Angeles (m²/km²)	Scale Factor(a)	Fraction of Mass in Composite Los Angeles Leaf Sample(b) (%)
URBAN VEGETATION					
BROAD-LEAF TREES					
Ribbon Gum	*Eucalyptus viminalis*	490	7300	1.20	2.10
Ash	*Fraxinus sp.*	756	3100	1.20	1.36
Calif Live Oak	*Quercus agrifolia*	1230	1600	1.20	1.20
Elm	*Ulmus sp.*	140(c)	3000	1.20	0.25
Maple	*Acer sp.*	300	1200	1.20	0.20
Calif Sycamore	*Platanus racemosa*	342	1000	1.20	0.22
Peruvian Pepper	*Schinus molle*	362	970	1.20	0.21
Jacaranda	*Jacaranda mimosafolia*	283	900	1.20	0.15
Victorian Box	*Pittosporum undulatum*	2500	630	1.20	0.91
Black Locust	*Robinia psudoacacia*	50	570	1.20	0.017
Crape Myrtle	*Lagerstroemia indica*	2140	520	1.20	0.66
Avocado	*Persea americana*	215	490	1.20	0.061
Camphor	*Cinnamonum camphora*	153	440	1.20	0.039
Magnolia	*Magnolia grandiflora*	1110	400	1.20	0.26
Brazilian pepper	*Schinus terebinthifoliu*	109	280	1.20	0.018
Olive	*Olea europaea*	1190	230	1.20	0.16
Willow	*Salix sp.*	176	500	1.20	0.051
Silver dollar gum	*Eucalyptus polyanthemos*	503	340	1.20	0.10
Citrus (orange)	*Citrus sp.*	490	380	1.20	0.11
Others		—	4900	—	—
SHRUBS					
Calif. Sage Brush	*Artemesia californica*	70	1500	1.28	0.065
Golden Wattle	*Acacia longifolia*	647	1300	1.28	0.51
Juniper	*Juniperus sp.*	3430	1000	1.28	2.17
Glossy Privet	*Ligustrum iucidum*	482	820	1.28	0.26
Bottlebrush	*Callistemon sp.*	773	820	1.28	0.41
Chinese Juniper	*Juniperus chinensis*	2360	660	1.28	0.98
Camellia	*Camellia sp.*	2080	580	1.28	0.75
Oleander	*Nerium oleander*	417	540	1.28	0.14
Hibiscus	*Hibiscus sp.*	789	530	1.28	0.26
Rose	*Rosa sp.*	329	520	1.28	0.11
Shiny Xylosma	*Xylosma congestum*	589	420	1.28	0.16
Coyote Bush	*Baccharis pilularis*	1000(d)	400	1.28	0.25
Japanese Pittosp.	*Pittosporum tobira*	2160	380	1.28	0.52
Toyon	*Heteromeles arbutifolia*	1500(d)	340	1.28	0.32
Cape honeysuckle	*Tecomaria capensis*	478	97	1.28	0.028
Cotoneaster	*Cotoneaster sp.*	717	250	1.28	0.11
Heavenly bamboo	*Nandina domestica*	547	160	1.28	0.053
India hawthorn	*Raphiolepis indica*	496	240	1.28	0.075
Holly	*Ilex sp.*	600(d)	150	1.28	0.056
Podocarpus	*Podocarpus sp.*	255	300	1.28	0.047
Yucca	*Yucca sp.*	1700(d)	290	1.28	0.31
Others		—	3200	—	—

(cont.)

Table 3.4. Vegetation Sample Composite (cont.)

		Leaf Mass per Area of Land Covered (g/m^2)	Area Covered by Vegetation in Los Angeles (m^2/km^2)	Scale Factor$^{(a)}$	Fraction of Mass in Composite Los Angeles Leaf Sample$^{(b)}$ (%)
URBAN VEGETATION (cont.)					
CONIFERS					
Monterey Pine	*Pinus radiata*	941	2500	1.12	1.29
Other Pine	*Pinus sp.*	1000	820	1.12	0.45
Italian Cypress	*Cupressus sempervirens*	8500	450	1.12	2.07
Others		—	450	—	—
PALMS					
Cocos Palm	*Arecastrum romanzoffianum*	722	720	1.02	0.26
Fan Palm	*Washingtonia sp.*	1570	620	1.02	0.48
Canary Is. Palm	*Phoenix canariensis*	2050	320	1.02	0.33
Other		—	38	—	—
GRASS					
mixed grasses	(various unidentified)	380$^{(d)}$	92000	1.02	17.42
dichondra	*Dichondra repens*	—	2200	—	—
GROUND COVER					
Ivy	*Hedera sp.*	580$^{(d)}$	8200	1.10	2.55
African Daisy	*Osteospermum fruticosum*	800$^{(d)}$	2500	1.10	1.05
Ice Plant	*Lampranthus spectabulus*	1400$^{(d)}$	1300	1.10	1.02
Others		—	1900	—	—
NATURAL VEGETATION					
Black sage	*Salvia sp.*	305	34000	1.23	6.25
Buckthorn	*Rhamnus sp.*	225	3200	1.23	0.44
Buckwheat	*Eriogonum sp.*	205	11000	1.23	1.40
Calif. sage brush	*Artemesia californica*	18	33000	1.23	0.36
Ceanothus	*Ceanothus sp.*	770	31000	1.23	14.27
Chamise	*Adenostoma sp.*	92	52000	1.23	2.86
Manzanita	*Arctostaphylos sp.*	5050	3600	1.23	10.84
Scrub oak	*Quercus sp.*	64	13000	1.23	0.53
Sugar bush	*Rhus sp.*	305	11000	1.23	2.08
Grass	*Gramineae*	400$^{(d)}$	58000	1.23	13.85
Others		—	41000	—	—
AGRICULTURAL VEGETATION					
Citrus lemon	*Citrus limon burm*	429	23000	23000	4.81
OTHER LAND					
Nonvegetated			66000	—	
Urban barren			430000	—	
Natural barren			18000	—	

(a) Scale factor to account for species not sampled, which appear as the last item in each vegetation category. Amounts of the species actually sampled were scaled up by this factor within each category.

(b) Calculated as: $\dfrac{100 \times \text{Column 1} \times \text{Column 2} \times \text{Column 3}}{\sum(\text{Column 1} \times \text{Column 2} \times \text{Column 3})}$

(c) Average of values for Chinese and American Elm.

(d) Leaf mass per area estimated for this study. Other values calculated from data in Winer, Fitz and Miller (1983) and Miller and Winer (1984).

California, Rancho Santa Ana in Claremont, California, and Eaton Canyon Park in Pasadena, California. Leaves from the species collected were composited to form a mixed sample in which the mass of leaves from each species was proportional to the fraction of the estimated total leaf area in the Los Angeles region represented by that species (see Table 3.4). Two composite samples were formed — one with dead leaf material, and one with green leaf material. Each composite sample was then agitated in a clean Teflon bag for about 2 hours to release and collect the plant waxes and other vegetative detritus that results when the leaves are rubbed together by the wind. Sample collection was by the same approach as for the road dust.

3.3 RESULTS AND DISCUSSION

3.3.1 Oil-fired Boiler Emissions.

Five tests were conducted on a boiler burning No. 2 fuel oil. For each test, the boiler was restricted to steady-state operation at about 60% of capacity, and the operator was allowed to adjust the fuel/air ratio as he would do in normal practice. Table 3.5 lists the boiler operating parameters measured during each experiment.

The magnitude and chemical composition of the fine aerosol emissions ($< 2.0\ \mu m$) observed during these boiler tests are shown in Figure 3.3. These tests, conducted on different days using different dilution ratios and different batches of No. 2 fuel oil, show fine aerosol mass emission rates of 5 to 13 μg/kJ of fuel burned. Between 58 and 90% of the fine particulate emissions are accounted for by the chemical species measured.

In Figure 3.4, the mass emission rate of various chemical species is shown as a function of the percent excess oxygen in the flue gas. The concentrations of organic compounds and ammonium ion in the exhaust aerosol do not show large systematic variations with the amount of excess oxygen present. In contrast, although other factors cannot be conclusively ruled out, elemental carbon concentrations appear to vary strongly with excess oxygen: below 7% excess oxygen, the leaner the combustion conditions, the higher the elemental carbon emission rate. These

Table 3.5. Industrial boiler experiments burning No. 2 Fuel Oil

Date:	3/31/86	4/3/86	4/4/86	4/9/86	4/21/86
Test Duration (min)	185	375	190	360	360
Dilution Ratio[(a)]	46x	49x	27x	94x	35x
Boiler Operation Level					
—GJ per hour	30.6	30.6	32.2	32.7	28.5
—% of capacity	58%	58%	61%	62%	54%
Avg. Excess Oxygen	6.9%	6.5%	5.6%	6.3%	7.1%
Avg. CO_2 Conc.	—	10.8%	11.7%	10.9%	10.3%
Avg. Boiler Temp. (C)	—	213	219	228	213
Avg. CO Conc. (ppm)	—	—	—	105	109
Operator	Carter	Kane	Kane	Wiig	Kane

(a) $\text{Dilution Ratio} = \frac{\text{Volume of dilution air at STP} + \text{Volume of stack gas at STP}}{\text{Volume of stack gas at STP}}$

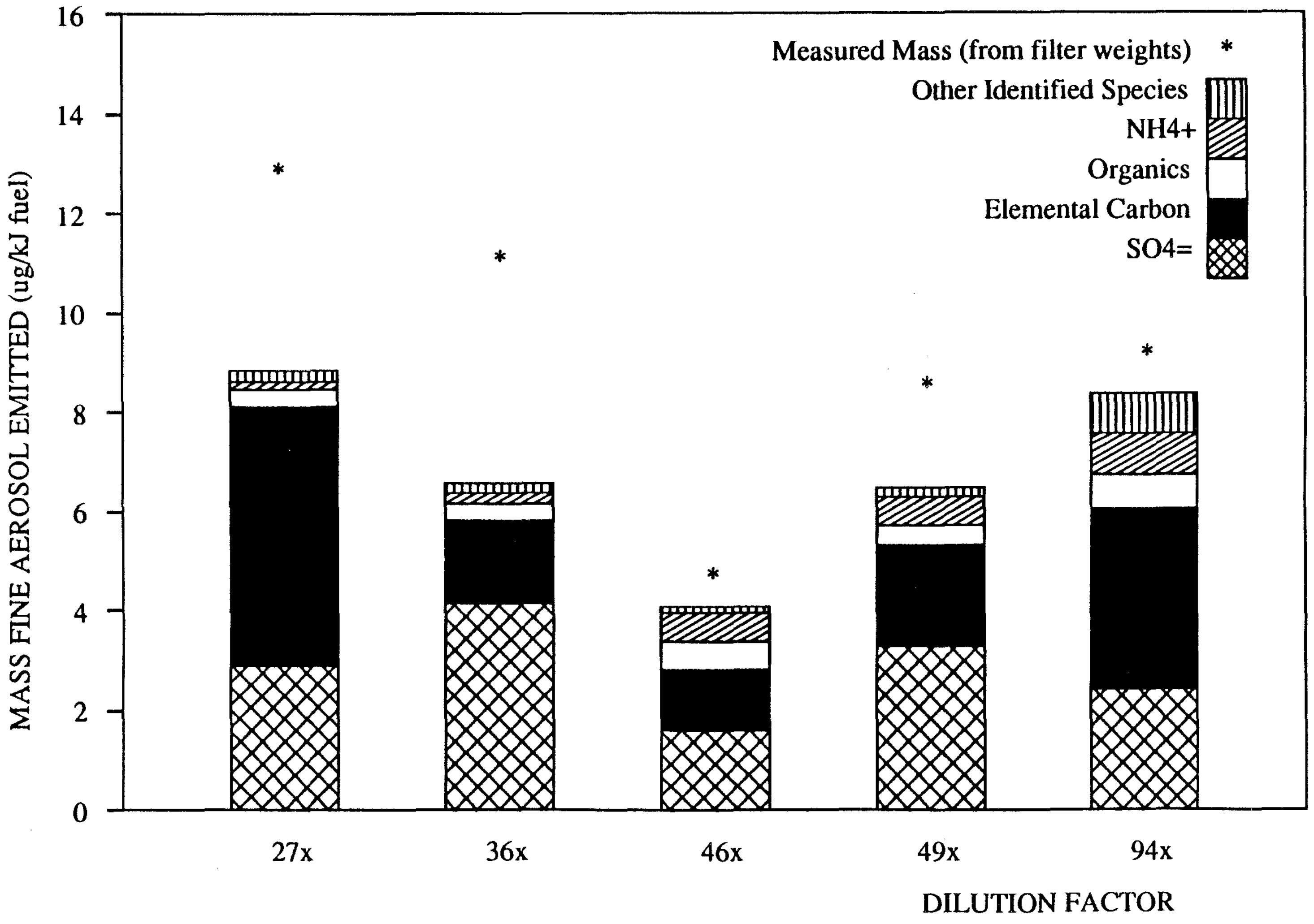


Figure 3.3 Fine aerosol emissions from a midsize industrial boiler burning No. 2 fuel oil.

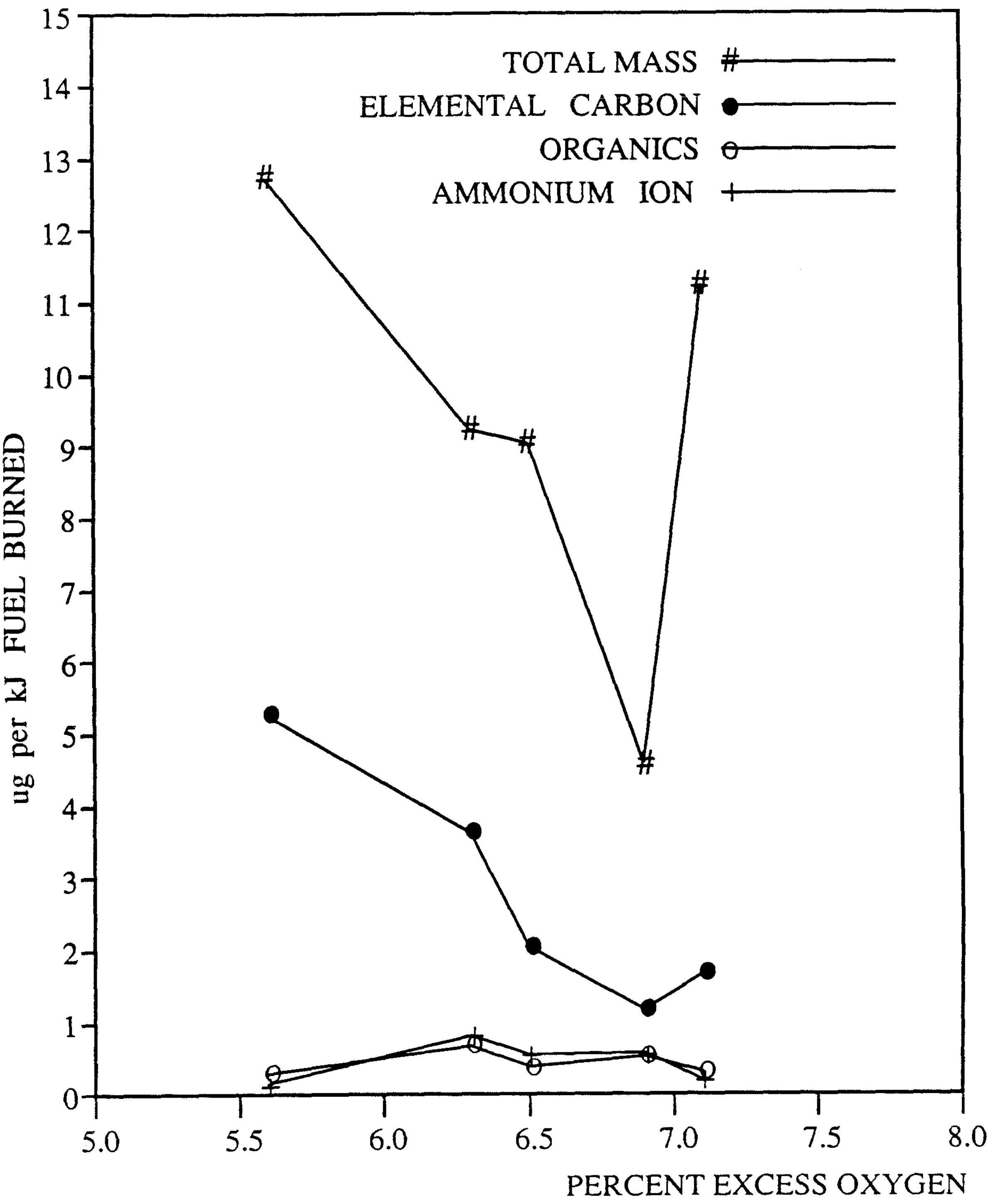


Figure 3.4. Fine aerosol emissions vs. excess oxygen measured during distillate oil combustion in an industrial-scale boiler.

variations in the elemental carbon emissions rate contribute greatly to the variation in total fine particulate emissions with excess oxygen that is seen in Figure 3.4. In a previous study, Goldstein and Siegmund (1976) observed a distinct minimum in total particulate emissions from combustion of residual fuel oil when a 1.8 GJ/hr boiler was operated at around 8% excess oxygen. In the present test program, a minimum in the aerosol mass emission rate is seen at about 7% excess oxygen.

The major chemical species found in the fine particulate emissions from the distillate oil-fired boiler were sulfates, elemental carbon, ammonium ion, and organics. The fine particle emission rate averaged over the five tests was 9 (±3) μg/kJ of fuel burned. In Figure 3.5a, it is seen that the fine particulate emissions averaged over all 5 tests consisted of about 32% sulfates, 29% elemental carbon, 6% organics, 6% NH_4^+, and 3% other ionic species and oxidized trace elements (consisting mainly of SiO_2, Al_2O_3, Fe_2O_3, and Na^+). The average chemical composition of the aerosol emissions measured for the five tests, contained in Table 3.6, will be of use to those interested in receptor modeling based on trace metals concentrations. (Results for each individual test are contained in Appendix C.) The other 24% of the emitted mass was not identified chemically, but is believed to include some water in the form of hydrolyzed compounds. For comparison, a previously published material balance on the chemical composition of the aerosol emissions from an industrial-scale boiler burning distillate fuel oil (Taback *et al.*, 1979) was based on the $<1\mu$m filter catch plus analysis of the residue remaining after evaporation of the impinger catch from a SASS train. In those tests, the aerosol composition was reported to consist of 25% sulfates, 15% total carbon, 4% nitrates, and 56% "other" material denoted as including O_2, Si, Mg and Al. In another study collecting fine particulate matter from a distillate oil-fired furnace using a hot filter maintained at 60–65 C, the ≤ 2.5 μm size fraction showed an average composition (sampling three furnaces for a total of six measurements) of 18 ± 23% elemental carbon, 18 ± 6% organic carbon, 13 ± 9% $SO_4^=$, 4% other species, and 46 ± 26% unidentified material (Watson, 1979).

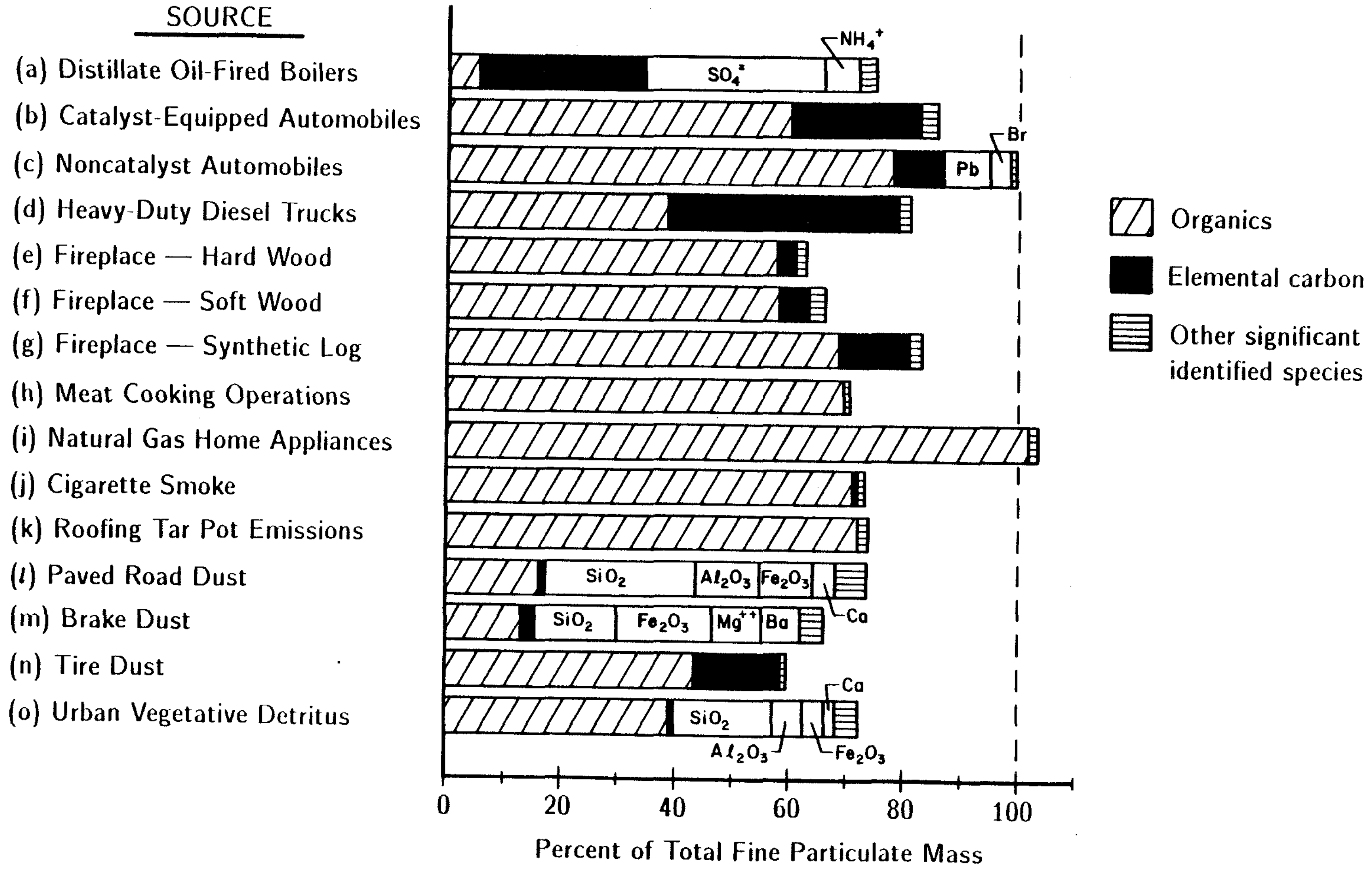


Figure 3.5. Average chemical composition of fine particulate emissions from various source types. (a) distillate oil-fired industrial boiler (avg. of 5 exps.); (b) catalyst-equipped automobiles (avg. of 7 vehicles); (c) noncatalyst automobiles (avg. of 6 vehicles); (d) heavy-duty diesel trucks (avg. of 2 vehicles); (e) hardwood combustion in a fireplace (avg. of 3 exps.); (f) softwood combustion in a fireplace (avg. of 2 exps.); (g) synthetic log combustion in a fireplace; (h) meat cooking operations (avg. of 4 exps.); (i) natural gas home appliances (avg. of 3 exps.); (j) cigarette smoking (avg. of 4 exps.); (k) roofing tar pot; (l) Pasadena-area road dust; (m) organo-metallic brake dust; (n) radial tire dust; and (o) vegetative detritus (avg. of 2 exps.).

Table 3.6. Chemical Characteristics Measured in Source Tests‡

	No.2 Fuel Oil Boiler (5 exps.) (% ± S.D.)	Catalyst Automobiles (7 vehicles) (% ± S.D.)	NonCatalyst Automobiles (6 vehicles) (% ± S.D.)	Heavy-Duty Diesel Trucks (2 vehicles) (% ± S.D.)	Soft Wood Fire (2 exps.) (% ± S.D.)	Hard Wood Fire (3 exps.) (% ± S.D.)	Synthetic Log Fire (1 exp.) (% ± S.D.)	Natural Gas Home Appliances (3 exps.) (% ± S.D.)
Al	0.42 ± 0.13 *	0.07 ± 0.44	0.73 ± 0.41 *	0.052± 0.062	0.015± 0.005*	0.011± 0.006*	0.26 ± 0.02 *	0.23 ± 0.58
Si	0.89 ± 1.08	0.29 ± 0.40	0.39 ± 0.25 *	0.59 ± 0.14 *	0.034± 0.009*	0.13 ± 0.10 *	0.058± 0.008*	0.28 ± 0.77
P	0.17 ± 0.06 *	0.17 ± 0.28	0.48 ± 0.37 *	0.028± 0.040	0.021± 0.013*	0.025± 0.017*	0.034± 0.021	0.03 ± 0.27
S	9.10 ± 3.01 *	0.00 ± 1.56	0.00 ± 0.87	0.00 ± 0.22	0.081± 0.020*	0.10 ± 0.05 *	0.11 ± 0.03 *	0.73 ± 2.15
Cl	-.002± 0.022	0.04 ± 0.65	0.01 ± 0.22	-.005± 0.090	0.54 ± 0.07 *	0.52 ± 0.22 *	0.52 ± 0.03 *	-.09 ± 0.74
K	0.002± 0.008	0.42 ± 0.77	0.09 ± 0.14	0.056± 0.045*	0.47 ± 0.11 *	0.88 ± 0.36 *	0.19 ± 0.01 *	0.17 ± 0.36
Ca	0.006± 0.008	0.63 ± 0.44 *	0.45 ± 0.20 *	0.16 ± 0.11 *	0.017± 0.003*	0.010± 0.009*	0.005± 0.003	1.04 ± 0.78 *
Ti	0.001± 0.003	0.01 ± 0.11	0.044± 0.051	0.030± 0.018*	0.001± 0.001	0.000± 0.001	0.002± 0.002	0.10 ± 0.14
V	0.001± 0.003	-.022± 0.085	-.005± 0.016	0.007± 0.017	0.000± 0.001	0.000± 0.001	0.001± 0.001	0.02 ± 0.10
Cr	0.002± 0.004	-.030± 0.095	0.011± 0.019	0.018± 0.018*	0.001± 0.001*	0.002± 0.003	0.002± 0.001	0.05 ± 0.11
Mn	0.000± 0.003	-.04 ± 0.11	0.90 ± 0.51 *	0.009± 0.017	0.000± 0.001	0.000± 0.001	0.010± 0.002*	0.02 ± 0.13
Fe	0.13 ± 0.05 *	0.15 ± 0.40	0.75 ± 0.59 *	0.13 ± 0.12 *	0.009± 0.003*	0.009± 0.011	0.022± 0.004*	0.09 ± 0.66
Ni	0.000± 0.002	0.04 ± 0.21	-.03 ± 0.12	0.027± 0.036	0.003± 0.002*	0.002± 0.002	0.002± 0.001	0.09 ± 0.14
Cu	0.001± 0.007	1.12 ± 1.33	0.61 ± 0.39	-.24 ± 0.38	0.013± 0.017	0.000± 0.001	0.44 ± 0.02 *	-.21 ± 2.13
Zn	0.001± 0.003	1.06 ± 0.88 *	0.60 ± 0.10 *	-.07 ± 0.26	0.017± 0.009*	0.022± 0.010	0.000± 0.003	-.16 ± 1.43
Se	0.002± 0.003	-.021± 0.078	0.002± 0.017	-.004± 0.013	0.000± 0.001	0.000± 0.001	0.000± 0.001	0.06 ± 0.15
Br	0.005± 0.007	0.04 ± 0.12	3.38 ± 1.33 *	0.011± 0.019	0.002± 0.001*	0.007± 0.007*	0.002± 0.002	0.04 ± 0.19
Rb	0.001± 0.004	-.12 ± 0.19	0.008± 0.054	-.001± 0.019	0.000± 0.001	0.001± 0.001	-.001± 0.002	0.02 ± 0.19
Sr	0.000± 0.006	-.08 ± 0.23	0.014± 0.044	-.008± 0.023	0.000± 0.001	0.000± 0.001	0.000± 0.002	-.15 ± 0.46
Ba	-.06 ± 0.19	0.12 ± 6.03	-.48 ± 1.43	0.00 ± 0.83	-.005± 0.027	-.006± 0.049	-.012± 0.087	-.23 ± 6.94
Pb	0.032± 0.031*	0.19 ± 0.50	8.66 ± 2.17 *	0.000± 0.051	0.019± 0.014*	0.011± 0.011*	0.000± 0.005	0.00 ± 0.46
EC	28.9 ±11.4 *	22.6 ±18.7 *	8.01 ± 5.57 *	40.5 ± 5.6 *	5.23 ± 2.96 *	2.86 ± 0.65 *	12.5 ± 0.8 *	6.7 ±20.9
OC	4.80 ± 3.34 *	50.1 ±25.7 *	65.5 ±12.9 *	32.3 ± 4.7 *	48.4 ± 4.7 *	48.4 ± 3.1 *	57.0 ± 3.1 *	84.9 ±39.3 *
Backup OC	0.89 ± 0.80 *	10.4 ±22.0	22.5 ±17.1 *	12.1 ± 3.7 *	0.96 ± 0.26 *	2.71 ± 0.29 *	3.53 ± 0.44 *	61.7 ±37.1 *
Mg^{++}	0.013± 0.022	-2.73 ± 5.50	-.44 ± 1.31	-.77 ± 1.07	0.025± 0.046	-.015± 0.041	-0.013± 0.007	-1.51 ± 7.96
Na^+	0.25 ± 0.26	1.50 ± 2.27	0.52 ± 0.79	0.17 ± 0.26	0.095± 0.090*	0.020± 0.032	0.032± 0.045	2.13 ± 3.91
Cl^-	0.056± 0.089	2.45 ± 3.01	0.85 ± 1.05	0.28 ± 0.34	0.90 ± 0.20 *	0.64 ± 0.23 *	0.29 ± 0.06 *	3.88 ± 5.16
NO_3^-	0.24 ± 0.35	1.81 ± 2.78	0.63 ± 0.97	0.33 ± 0.29 *	0.13 ± 0.03 *	0.25 ± 0.07 *	0.004± 0.055	3.41 ± 4.57
$SO_4^=$	31.5 ± 6.6 *	3.59 ± 5.11	0.45 ± 0.87	0.22 ± 0.53	0.15 ± 0.07 *	0.25 ± 0.07 *	-0.071± 0.056	12.6 ±15.8
NH_4^+	6.20 ± 4.83 *	0.00 ± 1.55	0.00 ± 0.54	0.08 ± 0.22	0.19 ± 0.04 *	0.15 ± 0.02 *	0.039± 0.035	0.44 ± 2.64
Fine Mass Emission Rate	9.4 ± 3.1 μg/kJ burned	11.1 ± 4.5 mg/km driven (w/o Vega)	59.4 ± 35.9 mg/km driven	408 ± 74 mg/km driven	13.0 ± 4.1 g/kg wood	5.3 ± 0.8 g/kg wood	12.0 ± 4.0 g/kg wood	45.8 ± 28.5 ng/kJ burned

(cont.)

Table 3.6. Chemical Characteristics Measured in Source Tests‡ (cont.)

	Charbroiled Meat (2 exps.) (% ± S.D.)	Fried Meat (2 exps.) (% ± S.D.)	Cigarette Smoke (4 exps.) (% ± S.D.)	Paved Road Dust (1 exp.) (% ± S.D.)	Brake Dust (1 exp.) (% ± S.D.)	Vegetative Detritus (4 exps.) (% ± S.D.)	Tire Dust (1 exp.) (% ± S.D.)	Tar Pot Emissions (1 exp.) (% ± S.D.)
Al	0.080± 0.043*	-.06 ± 0.43	0.007± 0.005*	5.89 ± 0.91 *	0.033± 0.021	2.57 ± 0.46 *	0.047± 0.011	0.018± 0.002*
Si	0.11 ± 0.07 *	-.25 ± 0.25	0.000± 0.004	12.4 ± 1.9 *	6.79 ± 0.73 *	8.35 ± 1.95 *	0.18 ± 0.02	0.017± 0.002*
P	0.10 ± 0.04 *	-.05 ± 0.21	0.006± 0.004*	0.072± 0.018*	0.000± 0.006	0.30 ± 0.07 *	0.000± 0.004	0.000± 0.001
S	0.06 ± 0.11	1.54 ± 2.46	0.14 ± 0.02 *	0.56 ± 0.02 *	1.28 ± 0.09 *	0.62 ± 0.10 *	0.11 ± 0.02	0.36 ± 0.02 *
Cl	0.088± 0.048*	0.35 ± 1.30	0.23 ± 0.04 *	0.17 ± 0.02 *	0.15 ± 0.02 *	0.33 ± 0.07 *	0.052± 0.012	0.73 ± 0.04 *
K	0.16 ± 0.15 *	0.36 ± 0.26 *	0.41 ± 0.04 *	1.87 ± 0.24 *	0.019± 0.007*	1.67 ± 0.42 *	0.038± 0.006	0.001± 0.001
Ca	0.057± 0.056*	0.15 ± 0.26	0.000± 0.003	4.44 ± 0.24 *	0.11 ± 0.01 *	2.29 ± 0.26 *	0.20 ± 0.01	0.000± 0.001
Ti	0.010± 0.015	-.01 ± 0.17	0.000± 0.001	0.56 ± 0.07 *	0.36 ± 0.19	0.27 ± 0.03 *	0.056± 0.005	0.000± 0.001
V	0.003± 0.005	-.011± 0.073	0.000± 0.001	0.027± 0.008*	0.066± 0.066	0.018± 0.009*	0.000± 0.002	0.000± 0.001
Cr	-.001± 0.006	0.15 ± 0.16	0.000± 0.001	0.017± 0.003*	0.12 ± 0.06	0.054± 0.042*	0.003± 0.001	0.000± 0.001
Mn	-.001± 0.006	0.04 ± 0.10	0.000± 0.001	0.12 ± 0.01 *	0.17 ± 0.01 *	0.061± 0.011*	0.010± 0.002	0.000± 0.001
Fe	0.071± 0.061*	0.24 ± 0.44	0.000± 0.001	6.23 ± 0.66 *	11.5 ± 0.6 *	2.77 ± 0.64 *	0.46 ± 0.03	0.001± 0.001
Ni	0.007± 0.007*	0.049± 0.086	0.000± 0.001	0.012± 0.001*	0.066± 0.004*	0.073± 0.090	0.005± 0.002	0.000± 0.001
Cu	0.34 ± 0.36	-.09 ± 1.08	0.008± 0.009	0.056± 0.042	0.037± 0.002*	2.25 ± 4.15	0.049± 0.004	0.007± 0.001*
Zn	0.22 ± 0.24	-.07 ± 0.58	0.006± 0.007	0.15 ± 0.03 *	0.027± 0.002*	1.34 ± 2.37	0.043± 0.004	0.005± 0.001*
Se	0.001± 0.007	0.006± 0.083	0.000± 0.001	0.001± 0.001	0.002± 0.001	0.003± 0.002*	0.002± 0.001	0.000± 0.001
Br	0.009± 0.010	0.084± 0.098	0.003± 0.001*	0.005± 0.001*	0.004± 0.001*	0.007± 0.003*	0.002± 0.001	0.000± 0.001
Rb	-.001± 0.012	0.09 ± 0.15	0.000± 0.001	0.013± 0.002*	0.005± 0.001*	0.008± 0.003*	0.000± 0.002	0.000± 0.001
Sr	0.004± 0.013	0.01 ± 0.28	0.000± 0.001	0.13 ± 0.01 *	0.074± 0.004*	0.026± 0.005*	0.004± 0.002	0.000± 0.001
Ba	0.20 ± 0.42	0.46 ± 4.74	-.009± 0.033	0.076± 0.064	7.44 ± 0.67 *	0.31 ± 0.24 *	0.037± 0.092	0.004± 0.012
Pb	0.027± 0.048	0.20 ± 0.44	0.000± 0.002	0.11 ± 0.01 *	0.005± 0.002*	0.18 ± 0.25	0.016± 0.005	0.001± 0.001
EC	-.40 ± 1.87	-6.1 ±19.6	0.49 ± 0.23 *	1.06 ± 0.23 *	2.61 ± 0.25 *†	0.94 ± 0.55 *	15.3 ± 2.9 *	0.013± 0.025
OC	58.8 ± 7.4 *	57.4 ±25.3 *	59.5 ± 4.5 *	13.5 ± 1.0 *	10.7 ± 0.7 *†	32.4 ± 3.9 *	36.0 ± 7.4 *	60.3 ± 5.4 *
Backup OC	5.40 ± 4.63 *	22.6 ±21.6 *	2.96 ± 0.90 *	0.65 ± 0.12 *	0.51 ± 0.13 *	2.97 ± 0.72 *	——	0.80 ± 0.36 *
Mg^{++}	0.91 ± 1.63	-3.82 ± 5.71	0.006± 0.036	0.17 ± 0.01 *	8.30 ± 0.62 *	0.50 ± 0.33 *	0.036± 0.013*	0.000± 0.001
Na^+	0.23 ± 0.38	0.45 ± 3.76	0.009± 0.026	0.15 ± 0.02 *	-.008± 0.039	0.05 ± 0.13	0.068± 0.033*	0.011± 0.006
Cl^-	0.37 ± 0.52	3.52 ± 3.61	0.28 ± 0.03 *	0.15 ± 0.02 *	0.15 ± 0.03 *	0.09 ± 0.14	0.060± 0.017*	0.70 ± 0.01 *
NO_3^-	0.02 ± 0.41	2.08 ± 4.10	0.071± 0.028*	0.25 ± 0.02 *	0.16 ± 0.04 *	0.38 ± 0.19 *	0.15 ± 0.02 *	0.012± 0.007
$SO_4^=$	0.21 ± 0.40	0.91 ± 3.67	0.059± 0.047*	1.20 ± 0.11 *	3.34 ± 0.28 *	0.39 ± 0.21 *	0.25 ± 0.05 *	0.091± 0.008*
NH_4^+	0.00 ± 0.23	0.00 ± 2.21	0.040± 0.010*	0.053± 0.019*	0.003± 0.007	0.019± 0.058	0.019± 0.005*	0.34 ± 0.01 *
Fine Mass Emission Rate	39.8 ± 1.3 g/kg meat (for reg. beef)	1.3 ± 0.3 g/kg meat	20.4 ± 4.2 mg/cigarette	——	——	——	——	——

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‡ Ga, As, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, La, and Hg also measured, but not found to be significant for any of the source types tested.

* Measurement is considered to be significant. For sources represented by a single experiment, the S.D. represents the uncertainty in the analytical method, and is the value is considered significant if it is greater than twice the S.D. For sources represented by more than one experiment, the S.D. value is calculated as the square root of the square of the S.D. of the values from the different experiments plus the square of the average S.D. resulting from uncertainties in the analytical result. The result is considered significant if it is greater than the S.D.

† For brake dust, division of carbon between EC and OC is uncertain due to interference of metals with laser transmittance.

Aerosol carbon collection on quartz fiber filters is known to be affected by artifacts resulting from filter adsorption of gas-phase organics and/or volatilization of a portion of the collected organic aerosol. Research is still underway to develop accurate methods of evaluating the magnitude of these artifacts (Appel, Cheng and Salamayeh, 1987; Fitz, 1987). In the boiler experiment, a second quartz fiber filter was located downstream of a quartz fiber filter used for aerosol collection in order to obtain a rough estimate of the magnitude of the potential organic aerosol sampling artifacts. For No. 2 fuel oil combustion, the mass of organics collected on the downstream filter (listed in Table 3.6 as "Backup" OC) averaged 22% of the fine organic aerosol mass collected upstream. For purposes of comparison, the organic material collected on such a backup filter when sampling fine organic aerosol from ambient Los Angeles air averages about 17 ± 11% of the organic aerosol collected on the upstream particle filter (Gray, *et al.*, 1986).

A review of the published literature was undertaken to identify previous measurements of particulate emissions from industrial-scale boilers (those with capacities roughly between 10 and 100 GJ/hr) burning No. 2 fuel oil. Two types of measurements were found in the literature. "Solid" particulate matter is measured by combining the solid material collected by high temperature filtration with the catch from any cyclones in the system, plus extracts from rinses of the probe, filter, and cyclones. This procedure is in accordance with U.S. Environmental Protection Agency recommendations (USEPA, 1984). In other references, measurements are reported that we will call "total" particulate matter, in which the extract from the impinger condensate is added to the "solid" particulate catch. Whether or not the impinger extract represents true particulate matter or consists mostly of artifact material formed due to chemical reactions and condensation of gas-phase species in the impinger is still a matter of considerable debate. The measurement of "solid" particulate matter may underrepresent the real aerosol mass emitted, because a significant fraction of the organic material that will condense into the aerosol phase at ambient temperature is in the gas phase at elevated temperatures and will not be collected. The "total" particulate matter measurement may overestimate aerosol mass emissions by capturing organic material that would exist in the gas phase under ambient conditions. Organic material may also be lost during the standard extraction procedure used to obtain the "total" particulate matter emissions value, since that procedure involves a solvent evaporation step.

Aerosol mass emission rates reported in previously published studies of boilers with capacities between 8 and 140 GJ/hr are summarized in Table 3.7, where they are compared with the results of the present set of dilution sampler experiments. The previous studies (Barrett *et al.*, 1973; Carter *et al.*, 1978; Cato *et al.*, 1974, 1976; Surprenant *et al.*, 1980, 1981; Taback *et al.*, 1979; USEPA, 1982) all used variations of either an EPA Method 5 sampling system or the SASS train to collect particulate matter. It should be noted that these two methodologies collect all particulate matter regardless of size. However, 96% by mass of particulate emissions from distillate fuel-burning industrial-scale boilers has been found to be $< 1\mu$m in diameter (Taback *et al.*, 1979), so it is reasonable to compare these total particulate measurements with the fine aerosol emissions measured in the present study.

For No. 2 fuel oil combustion, the mean particulate emission rate obtained in the present study by dilution sampling falls between the lower values previously obtained for "solid" particulate matter and the higher values reported for "total" particulate matter. This is exactly the result that one would expect, since hot filtration of the stack exhaust to obtain only solid aerosol understates the aerosol formation potential of condensible organics, while impinger trains can be expected to collect condensible materials that would not ordinarily form aerosol under normal conditions in a plume downwind of a combustion source.

3.3.2 Automobiles.

Seven catalyst-equipped and six noncatalyst automobiles were tested in as-received condition (see Table 3.2 for description of vehicles). Substantial variations in emissions were seen in the different automobile experiments. (See Appendix C for individual test results.) The organic carbon emitted ranged from 38 to 75% of the total measured fine mass, while elemental carbon emissions contributed from 4 to 37% of the total. The trace elements and ionic species

Table 3.7. Summary of published mass emission rates from industrial-scale boilers

Fuel	Particulate Emissions (μg/kJ)	
	Range	Mean ± S.D.
No. 2 Fuel Oil		
Previous Studies(a)		
—Solid Particles(b)	1—19	6 ± 4
—Total Particles(c)	4—24	11 ± 6
This Study	5—13	9 ± 3

(a) Summarized from references Barrett *et al.*, 1973; Carter *et al.*, 1978; Cato *et al.*, 1974, 1976; Surprenant *et al.*, 1980, 1981; Taback *et al.*, 1979; and USEPA, 1982.

(b) Solid = filter and cyclone catches, plus extracts of filter holder, cyclones and probe rinses.

(c) Total = "Solid" sample plus residue from impinger catch.

emitted also varied substantially from vehicle to vehicle, indicating the necessity of averaging results over as many different vehicle tests as possible in order to obtain results representative of the vehicle fleet on the road.

The average emission rates for the catalyst-equipped and noncatalyst fleets are shown in Table 3.6. A few systematic differences between the catalyst-equipped and noncatalyst vehicles can be observed. The noncatalyst automobiles tend to emit more particulate matter per distance driven than the catalyst-equipped cars. The high emissions of Pb and Br observed for the noncatalyst vehicles result from using leaded fuel. Premium gasoline with a lower lead content than the regular leaded gasoline was used in the last pair of noncatalyst vehicles tested, and correspondingly lower emissions of lead were measured. The fine particulate emissions from catalyst-equipped vehicles contain a larger relative proportion of elemental carbon than the emissions from noncatalyst cars.

The six noncatalyst vehicles tested showed average fine aerosol emission rates of 59 ± 35 mg/km driven, while the seven catalyst-equipped vehicles averaged 18 ± 12 mg/km. However, one of the catalyst-equipped vehicles tested (the Vega) had an exceptionally high particulate matter emission rate that was not considered representative of the catalyst-equipped vehicle fleet. If the experiment that included the Vega is excluded from computation of the fleet average, the other catalyst-equipped vehicles showed an average fine particulate emissions rate of 11 ± 2 mg/km driven.

A comparison of these emission rates with some previously measured values (Schuetzle, 1983; Muhlbaier and Williams, 1982; Braddock, 1977; Miller *et al.*, 1976; Laresgoiti and Springer, 1977; Ter Haar *et al.*, 1972) is presented in Table 3.8. Measurements from the present experiments are for fine aerosols only ($d_p < 2\mu m$) while the earlier tests reported are for total suspended particulate matter including coarse particle deposits reentrained from the inside of the vehicle tailpipe. Remarkable agreement is seen between the various emission rate measurements for the catalyst vehicles, which can be attributed in part to the fact that dilution tunnels have been used traditionally for motor vehicle source tests, and that most

Table 3.8. Measured Mass Emission Rates for Catalyst and Noncatalyst Vehicles

	Catalyst (mg/km)	Noncatalyst (mg/km)	Comments
Present Study	11±4	59±36	Fine emissions only Four catalyst cars, 1977–83 Five noncat. cars, 1965–76
Schuetzle (1983)	11±2	62±19	Average of data contained in eight 1980–81 references
Muhlbaier and Williams (1982)			
—Low Altitude	9	74	Five catalyst cars, 1978–79 Four noncat. cars, 1970–78
—High Altitude	12±4	94±49	Five catalyst cars, 1975–78 Five noncat. cars, 1972–74
Braddock (1977)	13±11		Six 1975 catalyst cars 0.036% S in fuel
Miller *et al.* (1976)	15	104	One 1970 car with catalyst One 1970 noncatalyst car
Laresgoiti & Springer (1977)	8		One 1970 car with catalyst 0.1% S in fuel
Ter Haar *et al.* (1972)			All 1966–70 cars
—Less than 1000 miles		94	Six low mileage cars
—More than 30000 miles		211	16 high mileage cars

aerosols emitted from catalyst-equipped cars are in the fine particle size range. The lower values for the noncatalyst vehicles tested in the present study (relative to earlier measurements) is at least partly due to the fact that only fine aerosol was measured.

To gauge the magnitude of the organic gas phase adsorption artifact onto the quartz filters in this (and subsequent) series of tests, a quartz filter downstream of a Teflon filter was also analyzed for organic carbon. The results of these measurements are again presented as "Backup OC" in Table 3.6. As seen in Table 3.6, the upper-bound estimate for the amount of organic gases adsorbed onto the quartz filters in these automobile tests averaged between 20 and 33% of the fine organic material collected.

The average chemical composition of the aerosol collected from the catalyst-equipped and noncatalyst automobiles tested is presented in Figure 3.5bc. Due to the small number of vehicles tested and the large test-to-test variations seen, it cannot be assumed immediately that these results are an accurate representation of the entire automobile fleet. However, a comparison of these results with a concurrent measurement program conducted by Cooper *et al.* (1988) that used comparable collection and measurement techniques shows similar results. Cooper's study measuring fine particulate emissions during an FTP cycle averaged 59.0 ± 11.9% organics and 38.6 ± 8.1% elemental carbon for six catalyst-equipped vehicles burning unleaded gasoline, and 37.6 ± 23.8% organics and 15.1 ± 2.4% elemental carbon for four noncatalyst vehicles burning leaded gasoline. Other previous measurements of the elemental and organic carbon content of automobile aerosol emissions have been reported. Muhlbaier and Williams (1982), measuring total particulate emissions, found 8.4% OC and 3.0% EC in the aerosol emissions from 5 noncatalyst cars, and 21.4% OC and 17.9% EC from 4 catalyst-equipped vehicles. For the fine particulate fraction, Watson (1979) measured 50% OC and 2% EC emitted during a single test of a catalyst-equipped vehicle burning unleaded fuel, and 28 ± 24% OC and 4 ± 2% EC for two tests of a noncatalyst automobile burning leaded fuel. Both Watson (1979) and Cooper *et al.* (1988) also report the trace elemental composition of emissions for automobiles, as did Pierson and Brachaczek (1983), Ondov *et al.* (1982), and Braddock (1977).

3.3.3 Heavy-Duty Trucks.

Two late-model, low-mileage heavy-duty diesel trucks (see Table 3.2) were tested while running under load on a truck dynamometer. The average fine particulate emission rate for the two tests was 0.41 g/km, or 1.32 g/l of fuel. In Table 3.9, these results are compared with emission rates measured in some previous studies (Baines, Somers and Harvey, 1979; Dietzmann, Parness and Bradow, 1981; Shuetzle, 1983; Szkarlat and Japar, 1983; Pierson and Brachaczek, 1983). The lower emission rates measured in the present study most likely result from two factors: (1) the trucks available here are newer and in better condition than the average heavy-duty diesel truck found on the highway, and (2) the dynamometer available cannot induce a large number of engine transients that may lead to higher soot production rates.

Table 3.6 contains the average chemical characteristics of the fine aerosol emissions measured for the two trucks. (See Appendix C for individual test results.) As seen in Figure 3.5d, 41% of the fine aerosol emitted was elemental carbon, and another 39% was organic material. These results should be considered "best case" in terms of the elemental carbon emissions, due to the factors mentioned previously. A recent study by Cooper *et al.* (1988) using two 1982 heavy-duty diesel vehicles measured fine aerosol emissions containing 52.1% elemental carbon, and an earlier study by Watson (1979) found that 68% of the fine aerosol emissions were evolved as elemental carbon. Both studies found that about one-third of the fine mass collected consisted of organic carbon, quite similar to the present study. Two other studies using solvent-extraction procedures found that 35–45% of the total particulate matter consisted of extractable organics (Williams and Chock, 1980; Rodriguez, Fischer and Johnson, 1980).

Previous analyses for trace elements in diesel exhaust have been performed by several groups (Dietzmann, Parness and Bradow, 1981; Pierson and Brachaczek, 1983; Watson, 1979; Cooper *et al.*, 1988). The present experiments found levels of

Table 3.9. Measured Mass Emission Rates for Heavy-Duty Diesel Trucks

	No. of Tests	Particulate Emissions (g/km)	Particulate Emissions (g/l fuel)	Comments
Present Study	2	0.41	1.32	Fine emissions
Baines *et al.* (1979)		0.6	1.72	4-stroke engines 13-mode SS FTP
Dietzmann *et al.* (1981)				
—1979 Caterpillar	8	0.57	2.01	Chassis
—1979 Mack	9	1.21	2.55	1983
—1979 Cummins	10	1.02	2.00	Transient
—1979 DD	8	1.99	3.12	Procedure
Schuetzle (1983)				
—Highway Composite		0.81		Average of results
—Dilution tube		1.04		from 8 papers
Szkarlat and Japar (1983)	20	0.89		Allegheny Tunnel
Pierson & Brachaczek (1983)		0.87±0.16		Tuscarora Mtn. Tunnel

Si, Ca, Fe, K, Ti, Cr and NO_3^- that were above detection limits in the diesel truck emissions (see Table 3.6).

3.3.4 Fireplace.

Six experiments involving the fireplace combustion of wood were conducted under the conditions presented in Table 3.10. Average fine particulate emission rates measured for the 3 hardwood, 2 softwood and 1 synthetic log combustion experiments are listed in Table 3.11, and are compared to the range of emission rates found in the publicly-available literature on fireplace combustion of wood (Muhlbaier, 1981ab; Kosel, 1980; DeAngelis *et al.*, 1980; Snowden, *et al.*, 1975; PEDCo, Inc., 1977) using EPA Method 5 (USEPA, 1971, 1984) or the Source Assessment Sampling System (Blake, 1978). The wide range of results shown for the previous studies is due to many differences in the various experimental protocols used. Differences between studies include the size of the wood pieces burned, the stage of the fire sampled, the mass of wood burned per unit time, and the presence or absence of damping mechanisms such as fireplace doors. Keeping these differences in mind, it can at least be said that the present tests lie in the middle of the range established by previous experiments.

The average chemical composition of the fine aerosol emissions from each of the three types of wood burned are presented in Table 3.6. (Results for individual tests are contained in Appendix C.) When the standard deviations are considered, the bulk chemical characteristics of soft and hard wood combustion are quite similar. However, synthetic log emissions are substantially higher in elemental carbon content than the natural wood fires. In addition, emissions of aluminum and copper from combustion of the synthetic log are over an order of magnitude higher than those from natural wood; most likely, this is the result of chemicals added to the synthetic log to produce colored flames in the fire.

Figure 3.5ef shows that fine particle emissions from fireplace combustion of natural wood contain about 58% organics and 3 to 5% elemental carbon. Several previous studies have also examined the bulk chemical characteristics of fine aerosol emissions from wood combustion. Collecting fine emissions from fireplaces burning

Table 3.10. Experimental Conditions for Fireplace Tests

Wood Type	Wood Burned (kg)	Sampling Time (min)	Burning Rate (g/min)	Stack Temp. (C)	Oxygen in Stack (%)	CO in Stack (ppm)	CO_2 in Stack (%)
Pine	12.53	220	57	—	—	—	—
Pine	15.18	162	94	75–110	19.8–20.2	410–580	0.6–1.0
Oak	16.23	175	93	75–140	18.8–19.8	560–1190	0.8–1.7
Almond	20.25	170	119	95–195	18.6–20.0	520–1300	0.3–2.0
Almond	19.29	159	121	80–130	19.5–20.4	330–950	0.5–1.3
Synthetic Log	2.27	200	11	30– 90	20.0–20.7	74–480	0.2–0.8

Table 3.11. Summary of Published Mass Emission Rates from Residential Fireplaces

	Particulate Emissions	
	Range	Mean ± S.D.
Wood	g/kg wood	g/kg wood
Hard Wood		
This Study	4.7—6.2	5.3 ± 0.9
Previous Studies(a)		
—Solid Particles(b)	0.8—13.0	4.3 ± 2.6
—Total Particles(c)	2.0—63.5	14.1 ±10.7
Soft Wood		
This Study	10.1—15.8	13.0 ± 4.1
Previous Studies(a)		
—Solid Particles(b)	1.8—11.6	4.2 ± 2.5
—Total Particles(c)	3.7—23.1	11.2 ± 5.2
Synthetic Logs		
This Study	12.0	
Previous Studies(a)		
—Solid Particles(b)	3.2—16.3	8.5 ± 5.9
—Total Particles(c)	4.4—19.9	12.2 ± 8.2

(a) Summarized from references Muhlbaier, 1981ab; Kosel, 1980; DeAngelis, 1980; Snowden *et al.*, 1975; PEDCo, Inc., 1977.

(b) Solid = filter and cyclone catches, plus extracts of filter holder, cyclones and probe rinses.

(c) Total = "Solid" sample plus residue from impinger catch.

a mixture of softwood and hardwood, Watson (1979) measured 46% organic carbon and 13% elemental carbon, while Rau (1989) found 54% organic carbon and 7% elemental carbon. For a woodstove/fireplace composite, the measurements of DeCesar and Cooper (1981) averaged 48% organic carbon and 13% elemental carbon, while Edgerton and coworkers (1986) found 50% organic carbon and 9% elemental carbon. The fraction of organic carbon measured in all studies is remarkably similar, despite differences in sampling methodology.

The fine potassium emissions in woodsmoke measured in this study also compare well to previously reported values. Muhlbaier (1981b) reported that potassium constituted 0.4–0.9% of the aerosol emissions from soft wood combustion and 0.8–1.3% from hard wood combustion, quite similar to the differences between hardwood and softwood potassium emissions seen in the present study. Other investigators (DeCesar and Cooper, 1981; Watson, 1979; Edgerton *et al.*, 1986; Rau, 1989) have reported values of 0.5 to 0.9% potassium in fine emissions from wood combustion, along with measurements of other trace elements.

3.3.5 Meat-Cooking Operations.

Charbroiling regular hamburger meat produced fine aerosol emissions totalling 40 g/kg of meat cooked, while charbroiling extra-lean meat generated 7 g/kg. In contrast, frying the same two types of meat generated fine aerosol emissions of only 1 g/kg meat. The chemical composition of the fine aerosol emissions measured for each of the four meat-cooking experiments is shown in Figure 3.5h. Between 68 and 73% of the fine mass emitted consisted of organics, with little or no elemental carbon present. Emissions of most of the trace chemical species varied substantially between experiments. As shown in Table 3.6, potassium was the only metal emitted in above-detection limit amounts during both frying and charbroiling. (Individual test results are presented in Appendix C.) The significance of potassium being emitted during meat-cooking operations has been discussed elsewhere (Hildemann and Cass, 1989; see Appendix A). Other source tests directly comparable to those conducted here for meat cooking operations are simply not available in the literature. One previous study in which aerosol emissions were measured while frying hamburger meat in oil found that detectable amounts of S and Cl were emitted (Sexton *et al.*, 1986). Another study, which collected emissions while cooking a single beefsteak in a broiling pan over charcoal (by drawing smoke and air through an inverted funnel onto a filter held 30cm away from the meat) collected 0.3 g of smoke condensate per kg of meat (Nagao *et al.*, 1977).

3.3.6 Natural Gas Home Appliances.

Particulate emissions from residential natural gas combustion when tested by dilution sampling were found to be *extremely* low, ranging from 23 to 72 ng/kJ of fuel burned. By comparison, an earlier study (Muhlbaier and Williams, 1982) measured a total particulate emission rate (using filters sampling emissions at 90 C) of 90 ng/kJ from combustion of 93% methane in a residential-sized furnace. Other studies measured fine particulate emission rates of 410 ± 190 ng/kJ from a stovetop burner (Traynor, Anthon and Hollowell, 1982), and 6 to 300 ng/kJ (submicron) from several gas-fired space heaters (Girman *et al.*, 1982).

Organic carbon accounted for between 83 and 91% of the measured fine aerosol mass emitted during these home appliance tests. (See Appendix C for individual test results.) When the organic carbon emissions are converted to an estimate of the total organic compounds emitted, $\geq$99% of the total fine particulate mass can be attributed to organic material. However, analysis of organics collected on a quartz filter downstream of a Teflon filter attached to the dilution sampling system indicated that over half of this organic mass could be due to adsorption of gas phase organics onto the quartz fiber rather than capture of fine particulate material. (For further discussion of artifact organic aerosol collection, see Gray *et al.*, 1986). The relatively high percentage of the emissions attributed to the adsorption artifact is due to the extremely low emission of actual aerosol from these gas-fired appliances. A previous study (Muhlbaier and Williams, 1982) measuring total carbonaceous aerosol emissions from residential furnaces under a variety of operating conditions measured 40% organic carbon and 8% elemental carbon when cycling the furnace in a residential setting. A study of fine aerosol emissions from a gas stovetop burner (Traynor, Anthon and Hollowell, 1982) reported 54% total carbon.

Due to the low mass emission rates, the error bounds on the chemical composition of these emissions were higher than usual. Table 3.6 presents the average chemical composition measured for the three natural gas appliance experiments (see also Figure 3.5i). Two previous studies have also measured detectable amounts of aerosol sulfur compounds from natural gas home appliances (Traynor, Anthon and Hollowell, 1982, Sexton *et al.*, 1986), which can be expected to vary depending on the sulfur content of the natural gas burned.

3.3.7 Cigarettes.

The fine mass emission rate measured for each of the four types of cigarettes smoked for this study, presented in Table 3.12, ranged from 17 to 23 mg per cigarette smoked. Surprisingly, the measured mass emission rate per cigarette is almost the same for all types of cigarettes smoked except the "light" cigarettes. However, when the length of cigarette actually smoked is considered in each case, the mass emission rate per length of cigarette is substantially higher for the regular cigarettes than for the filter-tipped cigarettes, as expected. The length of the cigarette, the presence or absence of a filtertip, and individual tastes determine how much of the total length of a cigarette is actually smoked, but more of the tobacco in a non-filtertip cigarette is traditionally left unsmoked. As shown in Table 3.12, the fine mass emission rates measured in the present study are lower than previous measurements where undiluted total particulate matter was collected (*e.g.*, Keith and Tesh, 1965; Schmeltz and Hoffmann, 1976), but somewhat higher than another study that sampled total diluted emissions from a cigarette (Girman *et al.*, 1982).

The bulk chemical composition of the fine emissions from cigarette smoking was quite similar for the four types of cigarettes. Figure 3.5j shows that the average chemical composition observed consisted mainly of organics. The organic compound content estimate of 71% represents a lower-bound; using a factor of 1.4 to convert from organic carbon to organic compounds would yield a sample containing 83% organics. As seen in Table 3.6, significant trace amounts of elemental carbon, potassium, sulfate and chloride were also measured. (See Appendix C for results of individual experiments.) A previous study (Norman, 1977) that examined the trace

Table 3.12. Mass Emission Rates from Cigarette Smoking

	Aerosol Mass Emitted per Cigarette Smoked (mg/cigarette)	Average Length Smoked (mm)	Aerosol Mass Emitted per Length of Cigarette Smoked (μg/mm)
Present Study (fine aerosol mass)			
—Regulars, 85 mm	22	66	330
—Filtertips, 85 mm	22	81	270
—Menthols, 100 mm	23	96	240
—Lights, 85 mm	14	81	170
Previous Studies (total aerosol mass)			
—Keith and Tesh (1965)(a)	40.6	55	741
—Schmeltz and Hoffman (1975)(a)	31.5		
—Girman *et al.* (1982)	10.8		

(a) Sampled without dilution; includes condensed water.

metal constituents in cigarette smoke measured significant quantities of K, Na, Zn, Pb, Al, Cu and Cd.

3.3.8 Tar Pots.

The fine aerosol emissions measured from an in-use roofing tar pot also were predominantly organic in nature, with trace amounts of sulfate, ammonium and chlorine (see Table 3.6). As shown in Figure 3.5k, identified species account for approximately three-quarters of the measured fine aerosol mass. The filter samples taken from this source were completely colorless, in contrast to the blackness of the tar itself, suggesting that tar pot emissions represent the distillation of lower boiling point organics from the roofing tar material rather than aerosolization of the bulk roofing tar. While many previous studies have examined the exposure of roofing workers to specific organic compounds emitted from tar pots, no previous work was found that examined the bulk chemical composition of tar pot emissions.

3.3.9 Road Dust.

The springtime grab sample of Pasadena-area fine road dust was composed of a large group of chemical species. As shown in Figure 3.5*l*, the sample was found to consist of 27% SiO_2, 17% organics, 11% Al_2O_3, 9% Fe_2O_3, and 4% Ca. The total chemical composition measured in this study (see Table 3.6) agrees well with concurrent measurements of various Los Angeles-area paved road dusts completed by Cooper and coworkers (1988) in terms of the relative amounts of the different trace metals. The data of Cooper *et al.* (1988) show substantial variations in the amount of organic material measured at different sites, with organic carbon fractions ranging from 7 to 20%.

3.3.10 Brake Dust.

The fine fraction of the organo-metallic brake dust grab sample consisted mainly of Fe_2O_3, SiO_2, organics, magnesium, and barium (see Figure 3.5m). The chemical characteristics measured are listed in Table 3.6. About 13% of the fine particle mass of the brake dust sample consisted of organic compounds, and identified species accounted for 68% of the measured mass.

Only limited previous studies of the chemical composition of brake dust have been performed. Average chemical composition data for asbestos brake linings (Lynch, 1968; Bush, Rowson and Warren, 1972; Ondov, 1974; Taback *et al.*, 1979) have been published, and Bush and coworkers (1972) have chemically analyzed the particulate matter generated from the attrition of asbestos brake linings. For the parent organo-metallic brake lining material, Lohrer and Berlin (1983) list a typical composition of 60–70% metals, 15–25% graphite, 7–10% binders, and 0–5% Al_2O_3 and SiO_2. Analysis of a sample of semi-metal brake pad dust (Cooper *et al.*, 1988) gave a composition of 46% Fe, 3.5% Ba, 2.1% Cu, 0.7% Sn, and 0.4% Mo.

3.3.11 Tire Dust.

About half of the total particulate mass in the tire wear dust grab sample was composed of organic compounds (see Figure 3.5n), with another one-sixth being elemental carbon. An early estimate by Friedlander (1973) based on the composition of tire rubber suggested that tire wear particles should contain about 29% EC, 58% OC, and 1.5% zinc. Gray (1986) estimated a carbonaceous content of 67% organic carbon and 33% elemental carbon. A complete list of the chemical species measured in the tire dust sampled is included in Table 3.6; however, the trace metals content of the dust from the tires is not considered to be representative of the typical vehicle tire. In particular, zinc, which often constitutes about 1% of the tire rubber, is much lower in this sample. Neutron activation analysis of various brands of tires by Pierson and Brachaczek (1974) yielded an average value of 1% zinc. Other measurements of various trace elements in tire tread (Ondov, 1974; Fukuzaki, Yanaka and Urushiyama, 1986; Cooper *et al.*, 1988) have all measured zinc at 0.8 to 1.0% of the total sample.

3.3.12 Vegetative Detritus.

The chemical compositions of the vegetative detritus released from the composite leaf samples is shown in Figure 3.5o. In many respects, the green and dead leaf samples were found to be very similar. As seen from the average chemical characteristics shown in Table 3.6, *urban* vegetative detritus is represented, with an urban dry deposition component similar in its characteristics to paved road dust superimposed on a background of organics and phosphorus contributed from the leaf material. (Individual results for the two types of vegetation are contained in Appendix C.) The mechanical processes that release plant waxes into the atmosphere will also resuspend the urban particulate matter deposited on the leaf surfaces.

Past studies of vegetative detritus have collected organic material by dipping plant leaves in solvent, and have focused on organic chemical characteristics like the alkanes and fatty acids content of the extracts (*e.g.*, Eglington and Hamilton, 1963; Simoneit and Mazurek, 1982). The present study is the first known experiment in which the fine particulate matter collected was released from leaves through a mechanical agitation process intended to simulate the movement of leaves in a wind. The absolute mass emission rates applicable to an urban landscape cannot be deduced from the procedure used; however, it was observed experimentally that the release of detritus from dead leaves was substantially higher than the release of green leaf detritus when agitating comparable quantities of leaf material.

3.4 CONCLUSIONS

A program of organic aerosol source sampling has been undertaken that will lead to characterization of many of the major organic aerosol emission sources in urban areas. In the present paper, both the absolute emission rates (mass per unit of activity) and bulk chemical characteristics of a variety of urban sources were examined. The uniform approach used for sampling and analysis of the fine aerosol from these sources enables accurate comparisons to be made between sources.

This study shows that for many of the sources, a majority of the fine mass emitted consists of organic material. Table 3.13 summarizes the fraction of the fine mass emitted from each source sampled that was emitted as organic compounds.

The fine organic aerosol source inventory for Los Angeles used as the basis for source selection in this project (Cass, Boone and Macias, 1982; Gray, 1986) also can be revised based on these results. Table 3.14 presents a revised inventory.

Table 3.13. Summary of Organic Fraction Contained in the Fine Aerosol Mass Emitted from Each Source Sampled

Source	Organic Fraction of Fine Aerosol Mass (%)
STATIONARY INDUSTRIAL SOURCES	
Distillate Oil Industrial Boiler	6
MOBILE SOURCES	
Catalyst Automobiles	63
Non-Catalyst Automobiles	79
Heavy-Duty Diesel Trucks	32
DISTRIBUTED AREA SOURCES	
Fireplace (natural wood)	58
Meat Cooking	70
Natural Gas Home Appliance	99
Cigarettes	71
Road Dust	17
Tire Dust	49
Brake Dust	13
Tar Pot	72
Urban Vegetative Detritus	37

Table 3.14. Revised Estimate of the Major Sources of Fine Aerosol Organic Carbon Emissions within an 80 x 80 km Heavily Urbanized Area Surrounding Los Angeles (for 1982)

Source Type	Organic Carbon Emitted (kg/day)	% of Organic Carbon Emissions	Notes(a)
1) Paved road dust	4798	15.1	(b)
2) Meat Cooking Operations			(c)
— Charcoal broiling	5937	18.7	(b),(d)
— Frying	1716	5.4	(b),(d),(e)
3) Noncatalyst gasoline vehicles			
— Automobiles	2098	6.6	(b),(d)
— Other vehicles	1372	4.3	
4) Diesel vehicles			
— Heavy-duty trucks	1229	3.9	(b),(d)
— Other vehicles	617	1.9	
5) Brake lining	696	2.2	(b)
6) Surface coating	1433	4.5	
7) Cigarettes	1347	4.3	(b),(d)
8) Fireplaces	4174	13.2	(b),(d)
9) Forest fires	877	2.8	
10) Roofing tar pots	556	1.8	(b)
11) Natural gas combustion			
— Residential sources	31	0.1	(b),(d)
— Other sources	262	0.8	
12) Organic chemical processes	692	2.2	
13) Tire wear	472	1.5	(b)
14) Misc. industrial point sources	393	1.2	
15) Catalyst-equipped gasoline vehicles			
— Automobiles	637	2.0	(b),(d)
— Other vehicles	79	0.2	
16) Nonrefinery petroleum industries	278	0.9	
17) Primary metallurgical processes	228	0.7	
18) Railroad (diesel oil)	211	0.7	
19) Residual oil stationary sources	206	0.7	
20) Refinery gas combustion	195	0.6	
21) Secondary metallurgical processes	167	0.5	
22) Mineral industrial processes	158	0.5	
23) Other organic solvent use	106	0.3	
24) Jet aircraft	92	0.3	
25) Asphalt roofing	81	0.3	
26) Coal burning	76	0.2	
27) Wood processing	74	0.2	
28) Residual oil-fired ships	66	0.2	
29) Structural fires	63	0.2	
30) Distillate oil stationary sources			
— Industrial	13	0.04	(b),(d)
— Other	23	0.07	
Other sources	226	0.7	
TOTAL	31679		

(a) Except where otherwise noted, values are drawn from Gray (1986).
(b) Fraction of organic carbon in fine emissions estimated from present study.
(c) Revised mass emission rates include both commercial and domestic cooking.
(d) Fine mass emission rate estimated from present study.
(e) New emission source not included in original inventory.

The results of the present study show that primary organic aerosol emissions are probably about 15% greater than originally estimated. Meat-cooking operations are an even more important source of fine organic aerosol than originally thought, accounting for almost one-quarter of the organic aerosol emissions inventoried in the Los Angeles Basin. Fireplace emissions of fine organic aerosol are also higher than previously projected, due to the higher fine mass emission rates measured, especially for softwood combustion. Additionally, the organic carbon emissions from catalyst-equipped automobiles were higher than expected (even though the Vega was excluded), due both to higher measured mass emission rates and a larger measured fraction of organic carbon in the fine aerosol. Finally, in contrast, natural gas home appliances were found to burn much more cleanly than originally estimated.

From ^{14}C dating of ambient aerosol samples (Currie, 1980), it has been noted that a significant fraction of the Los Angeles area organic aerosol is composed of contemporary carbon that is not derived from fossil fuel components. Currie (1980) reports that approximately 54% of the carbonaceous aerosol in Los Angeles is contemporary.

At first glance, these high percentages are surprising because Los Angeles usually is viewed as having a vehicle-dominated pollution problem and is not the site of large amounts of wood burning for home heating purposes. One might speculate then that this high fraction of contemporary carbon in the aerosol indicates that a large fraction of the organic aerosol is due to natural sources. Close examination of Table 3.14, however, shows that one need not invoke a high natural organic aerosol background level in order to explain the high fraction of contemporary carbon in the Los Angeles aerosol. Nearly 45% of the direct primary emissions of organic aerosols to the Los Angeles atmosphere are contributed by man-caused air pollution sources that are known to consist of contemporary carbon (*i.e.*, cooking operations, cigarettes, fireplace combustion of wood, etc.). To this is added that fraction of the tire dust derived from natural rubber, that fraction of surface coating emissions that are natural components, and a portion of the vehicle-reentrained road dust.

The total aerosol carbon burden in Los Angeles area fine particles consists of about two-thirds organic carbon and one-third elemental carbon (Gray *et al.*, 1986). On that basis, at least 30% of the total fine aerosol carbon could be contributed by man-caused emissions of contemporary organic carbon aerosol.

3.5 REFERENCES

Appel, B.R., Cheng, W., and Salamayah, F. (1987). Sampling Errors in Filter Collection of Atmospheric Particulate Carbon. Presented at the Third International Conference on Carbonaceous Particles in the Atmosphere, Berkeley, California, October 5–8, 1987.

Baines, T.M., Somers, J.H., and Harvey, C.A. (1979). Heavy Duty Diesel Particulate Emissions Factors. *J. Air Pollut. Control Assoc.* 29:616–621.

Barrett, R.E., Miller, S.E., and Locklin, D.W. (1973). Field Investigation of Emissions from Combustion Equipment for Space Heating. EPA-R2-73-084a (PB-223 148), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Blake, D.E. (1978). Source Assessment Sampling System: Design and Development. EPA-600/7-78-018, U.S. Environmental Protection Agency, Washington, D.C.

Bolleter, W.T., Bushman, C.T., and Tidell, P.W. (1961). Spectrophotometric Determination of Ammonium as Indophenol. *Anal. Chem.* 33:592–594.

Braddock, J.N. (1977). Gaseous, Particulate, and Sulfur-Related Emissions from Non-Catalyst and Catalyst Equipped Vehicles. EPA600/2-77-237 (PB 276 601), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Bush, H.D., Rowson, D.M., and Warren, S.E. (1972). The Application of Neutron Activation Analysis to the Measurement of the Wear of a Friction Material. *Wear* 20:211–225.

Carpenter, K.A. (1978). The Design and Development of a Dilution Tunnel for the Physical and Chemical Characterization of Diesel Particulate Matter. M.S. Thesis, Michigan Technological University, Houghton, Michigan.

Carter, W.A., Buening, H.J., and Hunter, S.C. (1978). Emission Reduction on Two Industrial Boilers with Major Combustion Modifications. EPA-600/7-78-099a (PB-283 109), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cass, G.R., Boone, P.M., and Macias E.S. (1982). Emissions and Air Quality Relationships for Atmospheric Carbon Particles in Los Angeles. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 207–240.

Cato, G.A., Buening, H.J., DeVito, C.C., Morton, B.G., and Robinson, J.M. (1974). Field Testing: Application of Combustion Modifications to Control Pollutant

Emissions from Industrial Boilers — Phase I. EPA-650/2-74-078a (PB 238 920), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cato, G.A., Muzio, L.J., and Shore, D.E. (1976). Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers — Phase II. EPA-600/2-76-086a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cooper, J.A., Redlone, D.C., Sherman, J.R., Valdovinos, L.M., Pollard, W.L., Scavone, L.C., and Badgett-West, C. (1988). Appendix V - G. PM10 Source Profile Library for the South Coast Air Basin. Draft. South Coast Air Quality Management District, El Monte, California.

Currie, L.A. (1980). Contemporary Particulate Carbon. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 245–260.

DeAngelis, D.G., Ruffin, D.S., and Reznik, R.B. (1980). Preliminary Characterization of Emissions from Wood-Fired Residential Combustion Equipment, EPA-600/7-80-040, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

DeCesar, R.T., and Cooper, J.A. (1981). Medford Aerosol Characterization Study (MACS). Final Report to Oregon Department of Environmental Quality from Oregon Graduate Center, Beaverton, Oregon (as cited in Cooper *et al.*, 1988).

Dietzmann, H.E., Parness, M.A., and Bradow, R.L. (1981). Emissions from Trucks by Chassis Version of 1983 Transient Procedure. Paper No. 801371, *SAE Trans.* 89:4313–4328.

Duleep, K.G., and Dulla, R.G. (1980). Survey and Analysis of Automotive Particulate Sampling. In *Health Effects of Diesel Engine Emissions: Proceedings of an International Symposium* (W.E. Pepelko, R.M. Danner and N.A. Clarke, eds.). EPA-600/9-80-057a, U.S. Environmental Protection Agency, Cincinnati, Ohio, pp. 93-111.

Edgerton, S.A., Khalil, M.A.K., and Rasmussen, R.A. (1986). Source Emission Characterization of Residential Wood-Burning Stoves and Fireplaces: Fine Particle/Methyl Chloride Ratios for Use in Chemical Mass Balance Modeling. *Environ. Sci. Technol.* 20:803–807.

Eglinton, G., and Hamilton, R.J. (1963). The Distribution of Alkanes. In *Chemical Plant Taxonomy* (T. Swain, ed.). Academic Press, New York, pp. 187–217.

Fitz, D. (1987). Reduction of the Positive Organic Artifact on Quartz Filters. Presented at the Third International Conference on Carbonaceous Particles in the Atmosphere, Berkeley, California, October 5–8, 1987.

Friedlander, S.K. (1973). Chemical Element Balance and Identification of Air Pollution Sources. *Environ. Sci. Technol.* 7:235–240.

Fukuzaki, N., Yanaka, T., and Urushiyama, Y. (1986). Effects of Studded Tires on Roadside Airborne Dust Pollution in Niigata, Japan. *Atmos. Environ.* 20:377–386.

Girman, J.R., Apte, M.G., Traynor, G.W., Allen, J.R., and Hollowell, C.D. (1982). Pollutant Emission Rates from Indoor Combustion Appliances and Sidestream Cigarette Smoke. *Environ. Inter.* 8:213–221.

Goldstein, H.L. and Siegmund, C.W. (1976). Influence of Heavy Fuel Oil Composition and Boiler Combustion Conditions on Particulate Emissions. *Environ. Sci. Technol.* 10:1109–1114.

Gray, H.A. (1986). Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, California.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1984). Elemental and Organic Particle Concentrations: A Long-Term Perspective. *Sci. Total Env.* 36:17–25.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1986). Characteristics of Atmospheric Organic and Elemental Carbon Particle Concentrations in Los Angeles. *Environ. Sci. Technol.* 20:580–89.

Hildemann, L.M., and Cass, G.R. (1989). Meat Cooking Operations: A Significant Source of Fine Potassium Emissions to the Urban Atmosphere. *submitted for publication.* [See Appendix A.]

Hildemann, L.M., Cass, G.R., and Markowski, G.R. (1989). A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests. *Aerosol Sci. Technol.* 10:193–204. [See Chapter 2.]

House of Representatives, Committee on Energy and Commerce, Subcommittee on Health and the Environment (1982). Comprehensive Smoking Prevention Education Act. Hearings, March 5, 11 and 12, 1982. Serial No. 97-106 (Depository No. Y4.EN2/3:97-106), pp. 421–438.

Huntzicker, J.J., Johnson, R.L., Shah, J.J., and Cary, R.A. (1982). Analysis of Organic and Elemental Carbon in Ambient Samples by a Thermal Optical

Method. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 79–85.

John, W., and Reischl, G. (1980). A Cyclone for Size-Selective Sampling of Ambient Air. *J. Air Pollut. Control Assoc.* 30:872–876.

Johnson, R.L., Shah, J.J., Cary, R.A., and Huntzicker, J.J. (1981). An Automated Thermal-Optical Method for the Analysis of Carbonaceous Aerosols. In *Atmospheric Aerosols: Source/Air Quality Relationships* (E.S. Macias and P.K. Hopke, eds.). American Chemical Society, Washington D.C.

Keith, C.H., and Tesh, P.G. (1965). Measurement of the Total Smoke Issuing from a Burning Cigarette. *Tobacco Science* 9:61–64.

Kosel, P.H. (1980). Emissions from Residential Fireplaces. Report No. C-80-027, California Air Resources Board, Sacramento, California.

Laresgoiti, A., and Springer, G.S. (1977). Sulfate and Particulate Emissions from an Oxidation Catalyst Equipped Vehicle. *Environ. Sci. Technol.* 11:285–292.

Lohrer, W., and Berlin, M. (1983). Substitution of Asbestos in Friction Linings – Problems and Trends. (In German.) *Staub Reinhalt. Luft* 43:78–83.

Lynch, J.R. (1968). Brake Lining Decomposition Products. *J. Air Pollut. Control Assoc.* 18:824–826.

Mazurek, M.A., and Simoneit, B.R.T. (1984). Characterization of Biogenic and Petroleum-Derived Organic Matter in Aerosols over Remote, Rural and Urban Areas. In *Identification and Analysis of Organic Pollutants in Air* (L.H. Keith, ed.). Ann Arbor Science/Butterworth Publishers, Boston, Massachusetts, pp. 353–370.

Mazurek, M.A., Simoneit, B.R.T., Cass, G.R., and Gray, H.A. (1987). Quantitative High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Analyses of Carbonaceous Fine Aerosol Particles. *Intern. J. Environ. Anal. Chem.* 29:119–139.

Mazurek, M.A., Cass, R.G., and Simoneit, B.R.T. (1989). Interpretation of High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Data Acquired from Atmospheric Organic Aerosol Samples. *Aerosol Sci. Technol.* 10:408–420.

Miller, D.F., Levy, A., Pui, D.Y.H., Whitby, K.T., and Wilson, W.E., Jr. (1976). Combustion and Photochemical Aerosols Attributable to Automobiles. *J. Air Pollut. Control Assoc.* 26:576–581.

Miller, P.R., and Winer, A.M. (1984). Composition and Dominance in Los Angeles Basin Urban Vegetation. *Urban Ecology* 8:29–54.

Muhlbaier, J.L. (1981a). Particulate and Gaseous Emissions from Residential Fireplaces. GMR-3588, General Motors Research Laboratories, Warren, Michigan.

Muhlbaier, J.L. (1981b). A Characterization of Emissions from Wood-Burning Fireplaces. GMR-3730, General Motors Research Laboratories, Warren, Michigan.

Muhlbaier, J.L., and Williams, R.L. (1982). Fireplaces, Furnaces and Vehicles as Emission Sources of Particulate Carbon. In *Particulate Carbon: Atmospheric Lifecycles* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 185–198.

Nagao, M., Honda, M., Seino, Y., Yahagi, T., and Sugimura, T. (1977). Mutagenicities of Smoke Condensates and the Charred Surface of Fish and Meat. *Cancer Letters* 2:221–226.

Norman, V. (1977). An Overview of the Vapor Phase, Semivolatile and Nonvolatile Components of Cigarette Smoke. *Recent Advances in Tobacco Science* 3:28–51.

Ondov, J.M. (1974). A Study of Trace Elements on Particulates from Motor Vehicles. Ph.D. Thesis, University of Maryland (as cited in Cooper *et al.*, 1988).

Ondov, J.M., Zoller, W.H., and Gordon, G.E. (1982). Trace Element Emissions on Aerosols from Motor Vehicles. *Environ. Sci. Technol.* 16:318–328.

PEDCo-Environmental, Inc. (1977). Source Testing for Fireplaces, Stoves, and Restaurant Grills in Vail, Colorado. EPA Contract No. 68-01-1999, U.S. Environmental Protection Agency, Denver, Colorado. (Results drawn from DeAngelis, Ruffin, Peters and Reznik (1980). Source Assessment: Residential Combustion of Wood. EPA600/2-80-042b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.)

Pierson, W.R., and Brachaczek, W.W. (1974). Airborne Particulate Debris from Rubber Tires. *Rubber Chemistry & Technol.* 47:1275–1299.

Pierson, W.R., and Brachaczek, W.W. (1983). Particulate Matter Associated with Vehicles on the Road. II. *Aerosol Science Technol.* 2:1–40.

Rau, J.A. (1989). Composition and Size Distribution of Residential Wood Smoke Particles. *Aerosol Sci. Technol.* 10:181–192.

Rodriguez, C.F., Fischer, J.B., and Johnson, D.E. (1980). Characterization of Organic Constituents in Diesel Exhaust Particulates. In *Particulate Carbon:*

Atmospheric Life Cycle (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 34–48.

Schmeltz, I., and Hoffman, D. (1976). Chemical Studies on Tobacco Smoke. XXXVIII. The Physicochemical Nature of Cigarette Smoke. In *Proceedings of the 3rd World Conference on Smoking and Health, New York City, June 2–5, 1975. Smoking and Health. I. Modifying the Risk for the Smoker* (E.L. Wynder, D. Hoffmann, and G.B. Gori, eds.). U.S. Department of Health, Education, and Welfare, Public Health Service, National Institutes of Health, National Cancer Institute, DHEW Publication No. (NIH) 76-1221, pp. 13–34.

Schuetzle, D. (1983). Sampling of Vehicle Emissions for Chemical Analysis and Biological Testing. *Environ. Health Perspec.* 47:65–80.

Sexton, K., Webber, L.M., Hayward, S.B., and Sextro, R.G. (1986). Characterization of Particle Composition, Organic Vapor Constituents, and Mutagenicity of Indoor Air Pollutant Emissions. *Environ. Inter.* 12:351–362.

Simoneit, B.R.T., and Mazurek, M.A. (1982). Organic Matter of the Troposphere — II. Natural Background of Biogenic Lipid Matter in Aerosols over the Rural Western United States. *Atmos. Environ.* 16:2139–2159.

Snowden, W.D., Alguard, D.A., Swanson, G.A., and Stolberg, W.E. (1975). Source Sampling Resiential Fireplaces for Emission Factor Development. EPA-450/3-76-010, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Solomon, P.A., Fall, T., Salmon, L., Cass, G.R., Gray, H.A., and Davidson, A. (1989). Chemical Characteristics of PM_{10} Aerosols Collected in the Los Angeles Area. *J. Air Pollut. Control Assoc.* 39:154–163.

Surprenant, N.F., Battye, W., Roeck, D., and Sandberg, S.M. (1981). Emissions Assessment of Conventional Stationary Combustion Systems: Volume V. Industrial Combustion Sources. EPA-600/7-81-003c (PB81-225559), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Surprenant, N.F., Hung, P., Li, R., McGregor, K.T., Piispanen, W., and Sandberg, S.M. (1980). Emissions Assessment of Conventional Stationary Combustion Systems: Volume IV. Commercial/Institutional Combustion Sources. EPA-600/7-81-003b (PB81-145187), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Szkarlat, A.C. and Japar, S.M. (1983). Optical and Chemical Properties of Particle Emissions from On-Road Vehicles. *J. Air Pollut. Control Assoc.* 33:592–597.

Taback, H.J., Brienza, A.R., Macko, J., and Brunetz, N. (1979). Fine Particle Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin. Final Report and Appendices. NTIS Nos. PB 293 922 and PB 293 923.

Ter Haar, G.L., Lenane, D.L., Hu, J.M., and Brandt, M. (1972). Composition, Size and Control of Automotive Exhaust Particulates. *J. Air Pollut. Control Assoc.* 22:39–46.

Traynor, G.W., Anthon, D.W., and Hollowell, C.D. (1982). Technique for Determining Pollutant Emissions from a Gas-Fired Range. *Atmos. Environ.* 16:2979–2987.

U.S. Environmental Protection Agency (1982). Fossil Fuel-Fired Industrial Boilers — Background Information. EPA-450/3-82-006b, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

U.S. Environmental Protection Agency (1971). Method 5—Determination of Particulate Emissions from Stationary Sources. *Federal Register* 36(247):24888–24890.

U.S. Environmental Protection Agency (1984). Method 5—Determination of Particulate Emissions from Stationary Sources. CFR, Title 40, Part 60, pp. 436–455. Superintendent of Documents, Washington, D.C.

Watson, J.G., Jr. (1979). Chemical Element Balance Receptor Model Methodology for Assessing the Sources of Fine and Total Suspended Particulate Matter in Portland, Oregon. Ph.D. Thesis, Oregon Graduate Center, Beaverton, Oregon.

Williams, R.L., and Chock, D.P. (1980). Characterization of Diesel Particulate Exposure. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 3–32.

Winer, A.M., Fitz, D.R., and Miller, P.R. (1983). Investigation of the Role of Natural Hydrocarbons in Photochemical Smog Formation in California. Statewide Air Pollution Research Center, University of California, Riverside, California. Final Report to the California Air Resources Board, Sacramento, California, under agreement no. A0-056-032.

Chapter 4

Quantitative Characterization of Organic Aerosol Sources by High-Resolution Gas Chromatography

4.1 INTRODUCTION

Most of the existing data on the organic aerosol emissions from sources are derived from bulk chemical analyses that quantify the total amount of organic carbon present. Total aerosol carbon emissions have been measured by combustion techniques for a large variety of sources (*e.g.*, Cooper *et al.*, 1988; Watson, 1979). Gravimetric procedures have been used to quantify the amount of extractable organic material in sources such as boilers (*e.g.*, Surprenant *et al.*, 1979, 1980, 1981), motor vehicles (*e.g.*, Laresgoiti, Loos and Springer, 1977; Pierson *et al.*, 1983; Szkarlat and Japar, 1983; Japar *et al.*, 1984), and fireplaces (*e.g.*, DeAngelis, Ruffin and Reznik, 1980; Dasch, 1982). Some separation of the organic species present on the basis of their vaporization temperature has also been achieved by using thermal evolution analysis to produce "thermograms" (Muhlbaier, 1981; Muhlbaier and Williams, 1982; Kowalczyk and Greene, 1982; Hering, Miguel and Dod, 1984; Daisey and Gundel, 1988). These approaches provide little or no information about the underlying molecular structure of the organic aerosol compounds emitted.

Other researchers have used costly, time-consuming procedures to identify specific organic compounds (like the polycyclic aromatic hydrocarbons) through such approaches as gas chromatography coupled with mass spectrometry (GC/MS) and high-pressure liquid chromatography with fluorescence detection. Daisey and coworkers (1986) have published a thorough review of the literature between 1972 and 1986 that identifies specific organic compounds in source emissions. The individual compounds identified typically account for only a few percent of the total organic mass emitted, and hence these data are of limited use in designing pollution abatement programs that must account for changes in the total amount of aerosol present.

Aerosol carbon emissions arise from a large number of different source types. Recent studies in Los Angeles (Hildemann, Markowski and Cass, 1989; Gray, 1986) have shown that about 14 different source types must be considered in order to account for close to 80% of the primary organic aerosol emissions in that airshed. Identification of the effect of these emission sources on ambient air quality via receptor modeling techniques requires at the very least that there be more distinctive attributes of the organic aerosol than there are different source types. Verification of the predictions of transport-oriented models for source contributions to the ambient organic aerosol likewise requires that the emission sources be characterized in sufficient detail that the model predictions can be tested. In both air quality modeling applications, a procedure is needed for characterizing the organic aerosol emissions sources that is more economical than gas chromatography/mass spectronomy analysis yet that can provide a fuller description of the differences between the source types than is possible from bulk carbon analysis. In the present study, gas chromatography (GC) analyses alone will be used to characterize the organic aerosol emissions from sources in a way that reveals the distinctive features of the different source types using a quantitative, multi-parameter description. This approach holds promise as an effective tool for uniquely characterizing organic emissions in a way that can be used to better support air quality modeling studies.

4.2 EXPERIMENTAL SECTION

4.2.1 Sample Collection

Fine organic aerosol (particle diameter $d_p < 2\mu m$) was collected from combustion sources using a dilution stack sampling system, and other sources were sampled using grab sampling techniques. The source types tested and the number of tests conducted are itemized in Table 4.1. Details of the sampling procedures used for each of the sources have been described elsewhere (Hildemann, Markowski and

TABLE 4.1. Characteristics of Elutable Organics from the Various Sources

Source (no. of samples analyzed)	Organics Eluted on GC (%)	Unresolved:Resolved Ratio Acid+Neutral	Unresolved:Resolved Ratio Neutral
Boiler, No.2 Fuel Oil (3)	57–67	3.8–4.2	3.1–3.8
Fireplace			
—natural wood (2)	45–51	3.0–3.4	3.2–3.9
—synthetic log (1)	77⁽¹⁾	3.7	3.4
Vehicles			
—catalyst cars (1)	133	16.5	14.5
—noncatalyst cars (1)	142	9.0	7.9
—diesel trucks (1)	93	8.3	8.2
Home appliance, natural gas (1)	185	1.3	1.0
Hamburger cooking			
—Charbroiling (extra-lean) (1)	43	4.1	5.2
—Charbroiling (regular) (1)	27	3.9	7.4
—Frying (1)	60	5.5	4.7
Road dust (1)	30	5.3	12.7
Brake dust (1)	3⁽²⁾	4.6	7.0
Vegetative detritus			
—Dead leaves (1)	18	0.8	0.9
—Green leaves (1)	27	1.1	1.5
Cigarettes (1)	87	2.3	2.9
Tire dust (1)	49⁽¹⁾	6.8	10.1
Tar pot (1)	171	7.7	7.6

(1) GC programming extended to a run time of 120 minutes for this sample.

(2) Delineation between EC and OC uncertain due to interference with laser.

Cass, 1989), and the design of the stack sampler has been documented previously (Hildemann, Cass and Markowski, 1989). Briefly, hot stack gases were diluted many-fold with dilution air that had passed through an activated carbon bed and an absolute filter. During the dilution process, the source effluent was cooled to ambient temperature, causing the aerosol-forming organic vapors present to condense onto preexisting aerosol as would normally occur in the plume downwind of the stack. The diluted emissions passed through a 2μm size-cut cyclone, and the fine particulate matter then was collected on prebaked quartz fiber filters (Pallflex 2500 QAO). The filters were stored in annealed glass jars with Teflon-lined lids at -25 C until extraction.

4.2.2 Extraction

The isolation and quantification procedures used in the extraction of the organic source samples have been described elsewhere in detail (Mazurek *et al.*, 1987). Each set of filters was spiked with a known aliquot of a perdeuterated standard ($\underline{n}$-$C_{24}D_{50}$ for source samples, a suite of standards for the blanks) in order to quantify the extraction efficiency and recovery of organic compounds from the filters. The source samples varied greatly in composition, consisting of from 1 to 45 filters, and containing anywhere from 300 μg to 20 mg of organic carbon. To ensure that an appropriate amount of standard(s) was added to each sample, a trial organic filter sample that was collected concurrently with the actual sample to be analyzed was spiked, extracted and analyzed before beginning extraction of the main source sample. In this manner it was determined what the appropriate volume of standard to be added was in proper proportion to the amount of organic material in each source sample. The typical sample, which consisted of 15 filters and contained about 1 mg of organic carbon, was spiked with 50 μl of $\underline{n}$-$C_{24}D_{50}$ at a concentration of 154 ng/μl.

Sequential additions of hexane (2 x 60 ml additions) and benzene/isopropanol (2:1) (3 x 60 ml additions) were used to extract the organics from the filters under ultrasonic agitation. Following filtration and combination of the extracts, each sample was reduced to a volume of 200—500 μl for gas chromatographic analysis.

4.2.3 Gas Chromatographic Analysis

The concentrated organic extracts were analyzed using a Varian 4600 high resolution gas chromatograph (GC) equipped with a Grob splitless injector, a 30-meter fused silica OV-1701 column (bonded 86% dimethyl-[14%]-cyanopropyl phenyl polysiloxane, 25 μm film thickness, 0.32 mm i.d., J & W Scientific, Rancho Cordova, California), and a flame ionization detector (FID). Peak integration was performed electronically using a Varian Vista 402 computerized data system. The extracts were introduced onto the capillary column by a flash vaporization technique and with an injection temperature of 300 C (Mazurek *et al.*, 1987). Temperature programming consisted of the following steps: (1) isothermal hold at 65 C for 10 minutes; (2) temperature ramp of 10 C/minute to 275 C; and (3) isothermal hold at 275 C for 49 minutes.

The GC trace obtained when the organic extract was injected without derivatization was considered to represent the non-polar or neutral fraction of the organic compounds present in the extract. An aliquot of the extract was derivatized through the addition of diazomethane to convert labile organic acids to their methyl ester analogs and acidic hydroxy compounds to their methyl ether analogs. This derivatized aliquot also was injected, giving a GC trace representing the acid plus neutral ("acid+neutral") fraction of the organic extract. The acidic fraction, which was determined as the mass difference between the results of the neutral and the acid+neutral fractions, contained oxidized polar compounds which were soluble in benzene.

Resolved component mass contributions were determined by recalculation of the raw data at elevated signal-to-noise (SN) ratios to exclude the portion of the GC trace that contained no resolved peaks. The unresolved mass component was calculated by the difference in area counts between the results at SN=1 and at the elevated SN ratio.

Regular injections of a 17-component $\underline{n}$-alkane standard suite ($\underline{n}$-C_{10} to $\underline{n}$-C_{36} homologues) throughout the course of the source analysis program were used to subdivide the GC traces into elution zones that corresponded to the retention times occurring between the standard n-alkane homologues. Area counts for compounds eluting between each pair of adjacent n-alkanes were summed in order to define the relative mass distribution of compounds in each sample. For some source extracts, homologous series with retention times corresponding to the n-alkanes were clearly visible in the GC trace of the source sample and could be used directly. For other source extracts, the retention times obtained from an n-alkane standard injection were used to locate the peaks corresponding to the n-alkanes within a particular sample. A similar approach has been used previously (Black and High, 1979; Pierson *et al.*, 1983) to analyze the relative mass distribution of organics in diesel exhaust.

4.2.4 Mass Quantification

Conversion of area counts to organic mass must account for the FID response to the particular injection, as well as any losses that occurred during sample extraction and concentration. It has been observed from standard injections of homologous series in both the present and previous studies (*e.g.*, Hauser and Pattison, 1972) that instrument response for a given mass of a component in a series varies with retention time, becoming less sensitive for the higher molecular weight components in the series. Hence, it was also desired to account for this variable sensitivity.

Two standard suites of homologous series, the n-alkanes and the n-fatty acid methyl esters, were injected regularly during the source analysis program. As will be shown in the results section of this study, for most of the source extracts, the majority of area counts were contributed by neutral compounds, so it was decided that the instrument response to the n-alkane series would be used to quantify the aerosol organic carbon mass concentration in the subregions. The mass of organics eluting between adjacent alkanes was calculated as follows:

$$\begin{aligned}\text{Mass between } C_n \text{ and } C_{n+1} &= \frac{\text{Mass } \underline{\text{n}}\text{-}C_{24}D_{50} \text{ spiked onto sample}}{\text{Counts } \underline{\text{n}}\text{-}C_{24}D_{50}} \\ &\times \frac{\text{Counts between } C_n \text{ and } C_{n+1}}{\text{RRF}_{\underline{\text{n}}\text{-}C_{24}D_{50}}} \times \text{RRF}_{C_n} \qquad (1)\end{aligned}$$

where RRF_A = Relative Response Factor for compound A

Multi-level calibration procedures were used to determine the RRF values. The RRF for n-$C_{24}D_{50}$ was calculated from regular injections of the n-$C_{24}D_{50}$ standard with 1-phenyldodecane at two standard concentrations, while the RRFs for the n-alkanes were calculated from repeated injections of the standard n-alkane suite with 1-phenyldodecane, also at two standard concentrations. The RRF values were calculated as:

$$\mathrm{RRF_A} = \frac{\text{Counts 1-phenyldodecane}}{\text{Mass 1-phenyldodecane}} \times \frac{\text{Mass A}}{\text{Counts A}} \qquad (2)$$

4.2.5 Analytical Blanks

Rigorous quality control is a vital part of trace organic analytical procedures. Two types of blanks were analyzed in conjunction with this project.

With each group of 10 to 12 source samples, a sample containing blank, baked quartz fiber filters was also spiked, extracted and analyzed to monitor the extraction procedures and identify any contaminants present. As shown in Figure 4.1, the few significant contaminants seen were identified via GC/MS as low molecular-weight solvent impurities and degradation products. These solvent by-products also appeared in the source sample GC traces, and their resolved area counts were subtracted from the data set, along with the resolved area counts of the perdeuterated standards.

Samples obtained by filtration of the precleaned dilution air were collected before each source type was sampled with the dilution stack sampler. These system blanks, which were intended to identify any contaminants in the dilution air and any residual contamination remaining after cleaning the sampler's components, were extracted and analyzed in the same way as the source samples.

4.3 RESULTS

4.3.1 Total vs. Elutable Organics

Not all of the particulate organic material collected is extractable, and not all of the extracted organics will elute on a GC column. For air quality modeling and emission control purposes, it is of interest to determine the fraction of the total organics in each source sample that is represented by the GC trace.

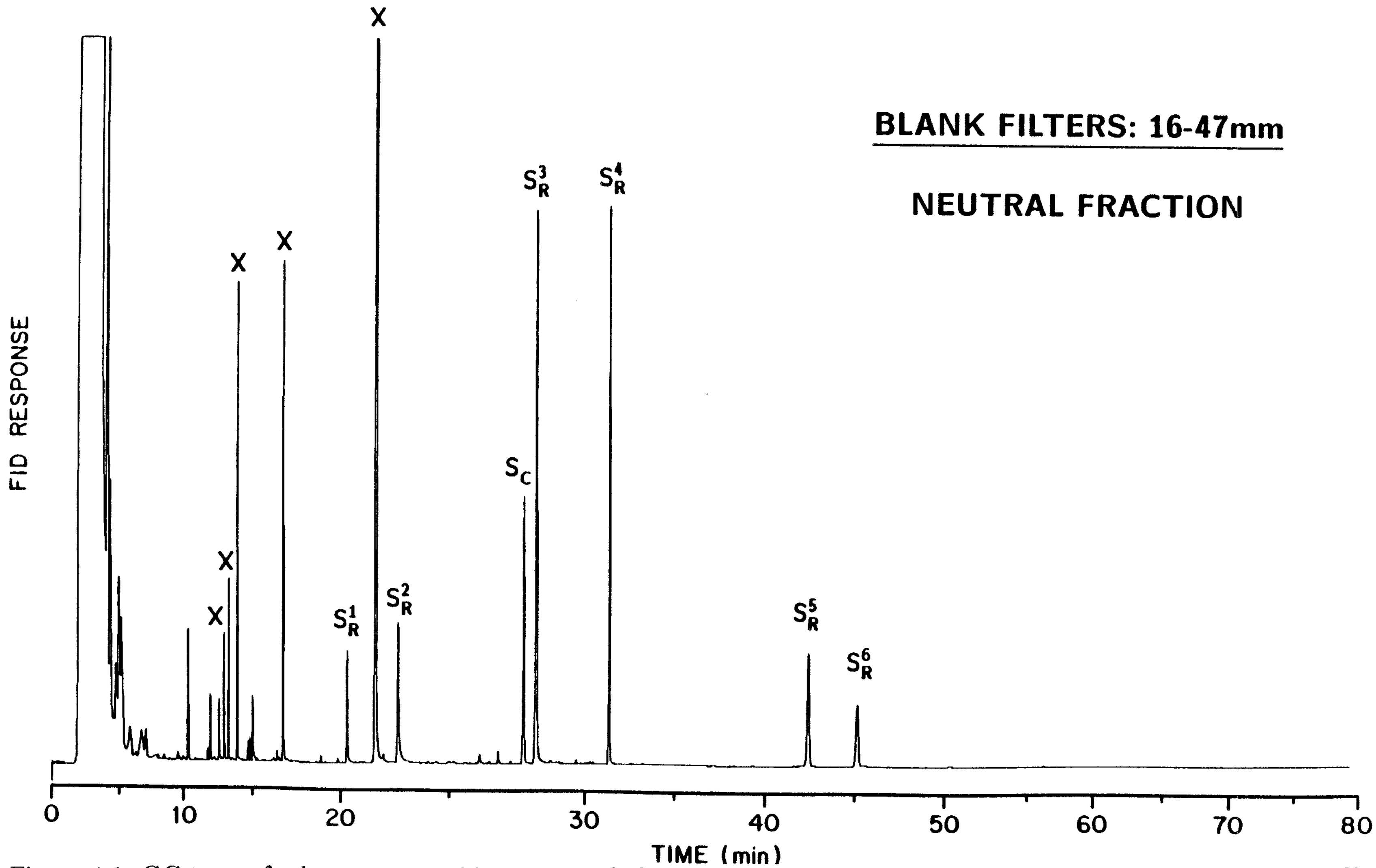

Figure 4.1 GC trace of solvent-extractable compounds from a spiked blank filter composite containing sixteen 47-mm filters. "X" denotes a known solvent artifact; "S_C" is the coinjection standard, 1-phenyl dodecane; and "S_R" denotes the recovery standards (S_R^1 = isoquinoline, S_R^2 = n-dodecanol, S_R^3 = anthracene-d_{10}, S_R^4 = n-$C_{24}D_{50}$, S_R^5 = n-$C_{32}D_{66}$, and S_R^6 = perylene-d_{12}).

The total amount of fine organic carbon collected from each source type was analyzed separately via a thermal evolution and combustion technique (Huntzicker *et al.*, 1982; Johnson *et al.*, 1981). The emission rate of fine organic compounds measured from each source type is reported in Hildemann, Markowski and Cass (1989). To determine the fraction of the total organic carbon present that is observed during GC analysis, the total concentration of organics obtained by integration under each GC trace was divided by the total concentration of organics as measured by the thermal evolution and combustion technique, using a factor of 1.2 to estimate total organics from total organic carbon (Gray *et al.*, 1984).

As seen in Table 4.1, the fraction of the total organics emitted from each source (as measured by combustion analysis) that eluted on the GC during the 80-min elution cycle varied substantially between sources. For the tar pot, natural gas home appliances and automobiles, a high fraction of the total fine organics collected were elutable. (Recoveries of greater than 100% most likely are due to an underestimate of the total organics based on the organic carbon measurement; a factor of 1.4 has also been used to convert from organic carbon to organics.) In contrast, a very small fraction of the brake dust organics eluted on the GC. Organics that did not elute may have been insoluble in the solvents used, too acidic or basic in composition to migrate through the capillary column, thermally unstable, or of too high a molecular weight to elute during the 80-min cycle.

4.3.2 Unresolved:Resolved Ratios

The ratio of unresolved components to resolved components (U:R) observed during GC analysis of atmospheric organic aerosol samples has been utilized in past studies as a qualitative indicator of the degree of anthropogenic contribution to the organic portion of airborne particulate matter (Simoneit and Mazurek, 1982; Mazurek and Simoneit, 1984; Mazurek, 1985; Cox, Mazurek and Simoneit, 1982). Petroleum and combustion products exhibit a large hump of unresolved compounds, and hence have high U:R ratios. Urban atmospheres have exhibited neutral fraction U:R ratios of 2.6 to 25, while rural atmospheres dominated by vegetation-derived organic aerosols characteristically have had ratios of less than 2.0 (Mazurek, Cass and Simoneit, 1989). From the results of the present study, the

U:R ratio characteristic of each major source type can be determined. These data then can be used in later studies that seek to explain the differences in U:R ratio between air basins on a cause and effect basis.

GC trace characteristics of the emissions from source types with high U:R ratios and with low U:R ratios are shown in Figure 4.2. Results for the catalyst-equipped cars (Figure 4.2a) show a large hump of unresolved compounds and a complete lack of any predominant single peaks, yielding a high U:R ratio of 14.5. Fireplace combustion of pine wood provides a less extreme case (Figure 4.2b), with a few important resolved peaks between C19 and C21 and between C25 and C26, but still exhibiting an intermediate U:R of 3.9. In contrast, both vegetative detritus (U:R = 1.4) and natural gas combustion emissions from home appliances (U:R = 1.0) (Figure 4.2cd) contain most of their organic mass in a few predominant peaks, giving both sources a low U:R ratio.

Table 4.1 also lists the range of U:R ratios observed for each of the sources measured in this study. Petroleum products (tar pot, tire dust) had ratios of 7–10, while vehicular emissions showed ratios of 8–17. Somewhat lower values were observed for other types of petroleum combustion, with distillate oil-fired boiler emissions having ratios from 3.1 to 4.2, and synthetic log combustion (containing petroleum waxes) ranging from 3.4 to 3.7. Combustion of plant material (fireplace combustion of natural wood, cigarettes) also gave elevated U:R ratios, between 2.3 and 3.9. The other anthropogenic sources tested likewise showed elevated U:R ratios, with the exception of natural gas combustion, which produced U:R ratios in the range 1.0–1.3. The natural source tested, vegetative detritus, showed low U:R ratios as expected, ranging between 0.8 and 1.5.

These measurements of the U:R ratio confirm that emissions from petroleum products and their combustion, as well as combustion of *some* other types of carbonaceous materials, give U:R ratios greater than 2.0, while vegetative detritus has a lower U:R ratio. However, the low ratio obtained for natural gas combustion emphasizes that the U:R ratio should only be used as a qualitative indicator of the anthropogenic content of an organic aerosol sample unless the airmass has been studied to account for the presence of anthropogenic sources with a low U:R ratio.

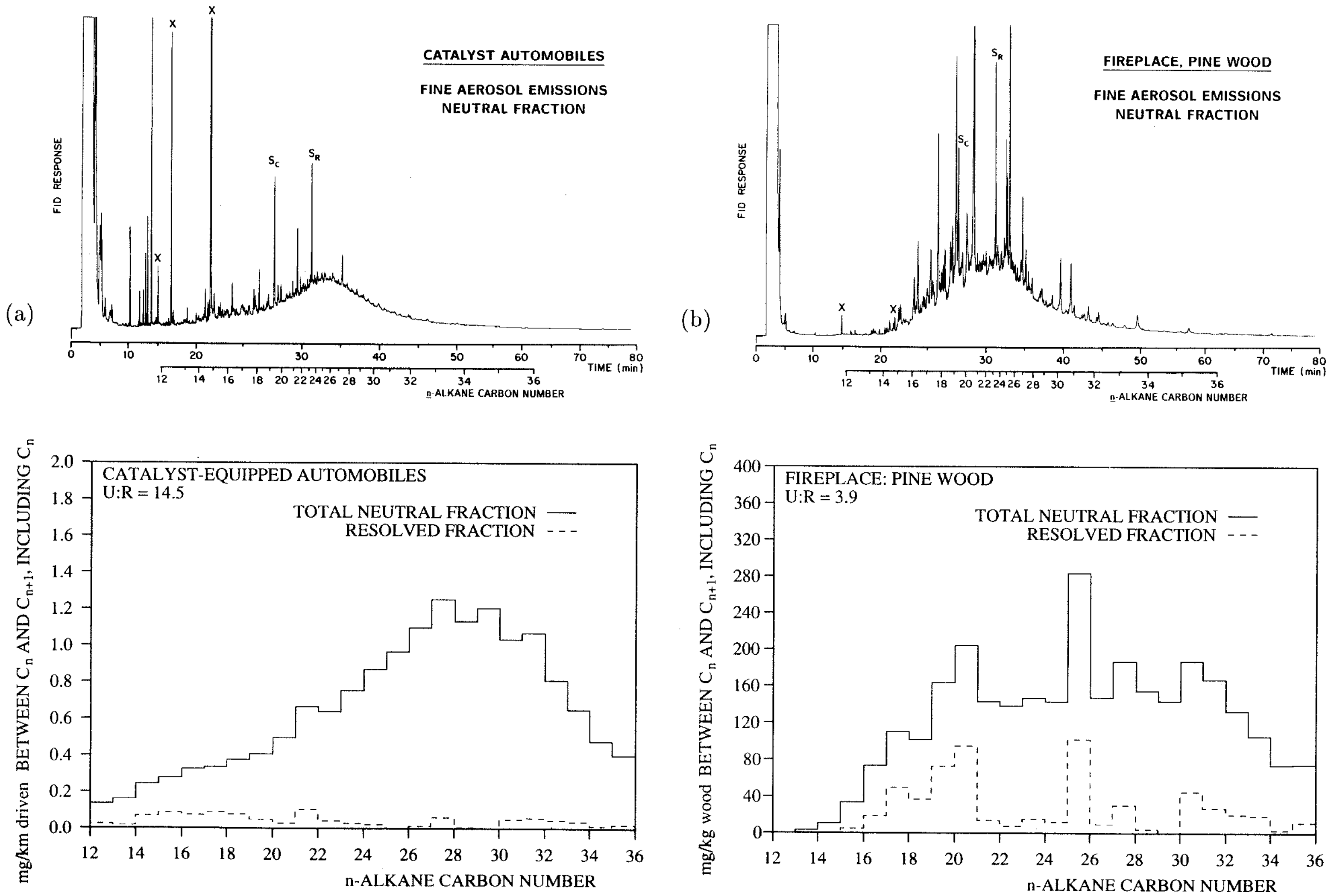

Figure 4.2 Unresolved vs. resolved organic mass distributions. Peaks marked with "X" and "S" are (respectively) contaminants and standards that are not included in area count summations. (a) Catalyst automobiles; (b) fireplace burning pine wood. (cont.)

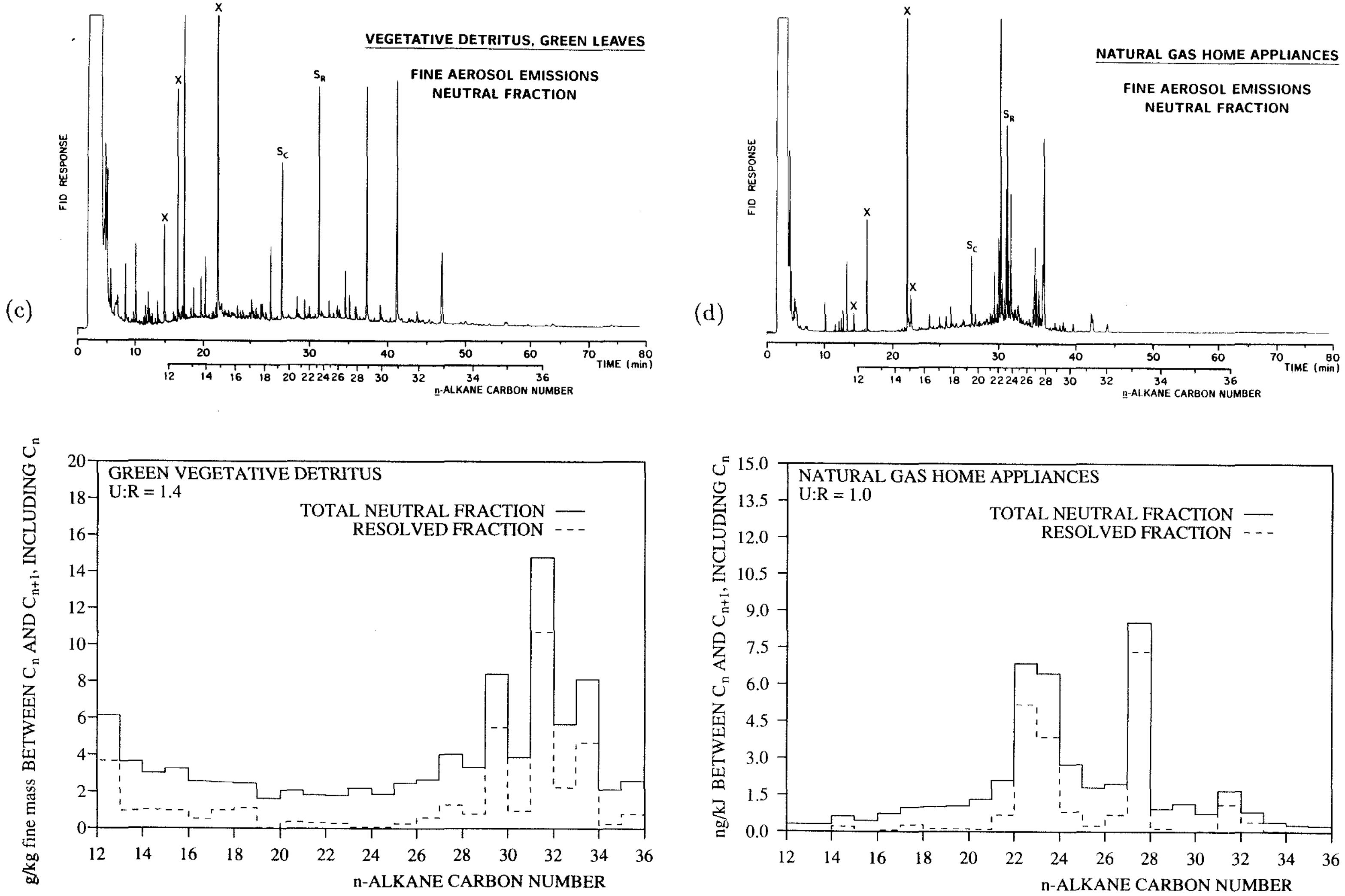

Figure 4.2 Unresolved vs. resolved organic mass distributions (cont.). Peaks marked with "X" and "S" are (respectively) contaminants and standards that are not included in area count summations. (c) Vegetative detritus, green leaves; (d) natural gas home appliances.

4.3.3 Organic Mass Distributions

Gas chromatographic analysis of source samples often yields GC traces that possess hundreds of peaks corresponding to the different compounds that are present. While the identity of many of these compounds cannot be determined by gas chromatography alone, it is still possible to characterize each source by summing the total mass of organic compounds that elute between well-defined points in each gas chromatogram. In the present work, source fingerprints characteristic of the organic compound distribution emitted by each source will be assembled by summing the quantity of organic material that elutes between each of the normal alkanes in the range C_{12} – C_{36} under the experimental conditions cited previously.

4.3.3.1 Replicate Analyses. Before drawing comparisons between dissimilar sources, it is useful to determine the reproducibility with which the organic compound distribution from a single source can be characterized by the methods used here. In Figure 4.3, the derivatized mass distributions obtained from pairs of separately-extracted and analyzed samples for six different source types are presented, using the percent of the total elutable organic mass that elutes between adjacent n-alkanes as the unit of measurement. The cigarette smoke data (Figure 4.3a) represent an exact analytical replicate, with each of the two samples containing the same number of simultaneously-collected filters. The tire dust and paved road dust sample pairs (Figure 4.3bc) represent separate resuspensions of the same grab sample, giving somewhat different mass loadings between the two samples. The pairs of green and dead vegetative detritus samples (Figure 4.3de) were also resuspended in separate experiments, using the same vegetation. Finally, the tar pot emissions (Figure 4.3f) were collected in consecutive experiments performed on the same day sampling the same tar pot.

Each step in the mass distributions of Figure 4.3 was treated as a single observation. It was assumed that the value of an observation was generated by the actual value plus an independent Gaussian error term, the variance of the error term being the same for all observations. For replicate values, then, the difference between them would be Gaussian with a variance twice the variance of the error associated with a single observation. Thus the variance of the error term for a

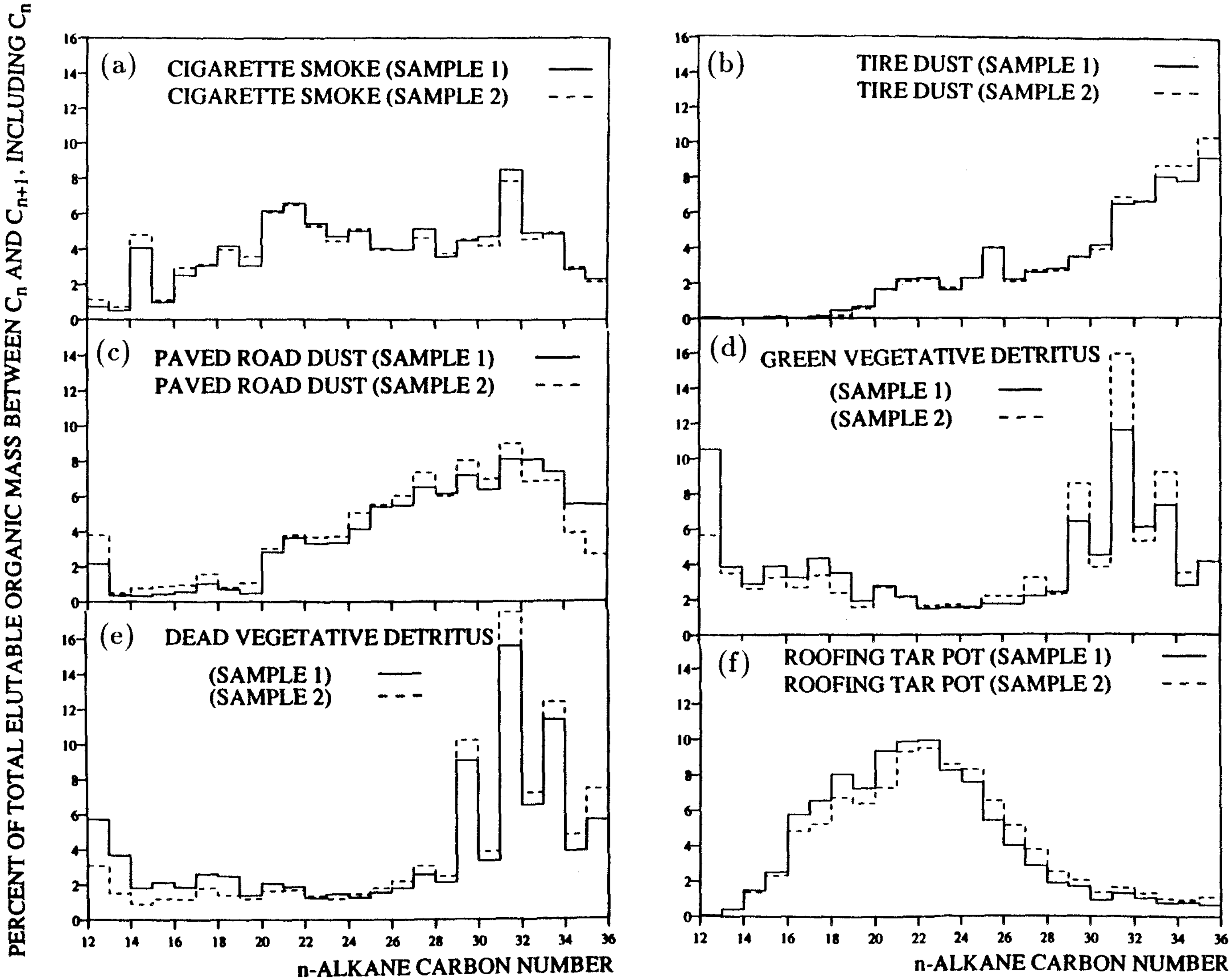

Figure 4.3 Organic mass distributions obtained from replicate sample analyses. (a) Cigarette smoke; (b) tire dust; (c) paved road dust; (d) green vegetative detritus; (e) dead vegetative detritus; and (f) roofing tar pot.

single observation could be estimated. (The hypothesis of the difference of zero means also was tested and could not be rejected.) By pooling all 144 replicate observations and using the percent of total eluted mass falling between adjacent alkanes as the common unit of measurement, it was estimated that the standard deviation associated with a single such measurement was equal to 0.66% of the total eluted organic mass in the entire source sample.

4.3.3.2 Oil-Fired Boiler Emissions. Emissions from an industrial-scale boiler (Babcock & Wilcox, with steam production capacity of 53 x 10^6 kJ/hr) burning No. 2 fuel oil were measured under several different experimental conditions (Hildemann, Markowski and Cass, 1989), and samples from three of the experiments were analyzed by gas chromatography. Results indicated that essentially all of the organics eluted were in the neutral fraction of the source extracts. In Figure 4.4, the GC traces for the neutral extract fraction obtained from the three experiments are presented, along with the mass distributions calculated for each GC data set.

The GC trace in Figure 4.4a (experiment 5) represents the effluent from the oil-fired boiler when tested by the full dilution sampling system described earlier (Hildemann, Cass and Markowski, 1989). In this case, the fine aerosol sample was withdrawn from the residence time chamber at the far downstream end of the sampling system. A simultaneously collected sample withdrawn from the main dilution tunnel in the sampler gave results that were not significantly different. Figure 4.4b shows the results of a second residence time chamber sample collected on a different day, using a different batch of fuel oil and containing a different percentage of excess oxygen in the emissions. In Figure 4.4d, the mass distributions of the organics collected are compared. Both samples have a primary mass peak between C20 and C22, with a secondary peak between C17 and C18. They also both exhibit a slight "sawtooth" pattern between C23 and C30, with alternating high and low values between adjacent segments.

The dilution sampler-based tests of Figure 4.4ab can be compared to results obtained if one uses the hot filter portion of EPA Method 5 (USEPA, 1971, 1984) as the means for collecting an organic aerosol sample from this boiler. In figure 4.4cd, it is seen that the EPA Method 5 hot filter collects much less organic aerosol

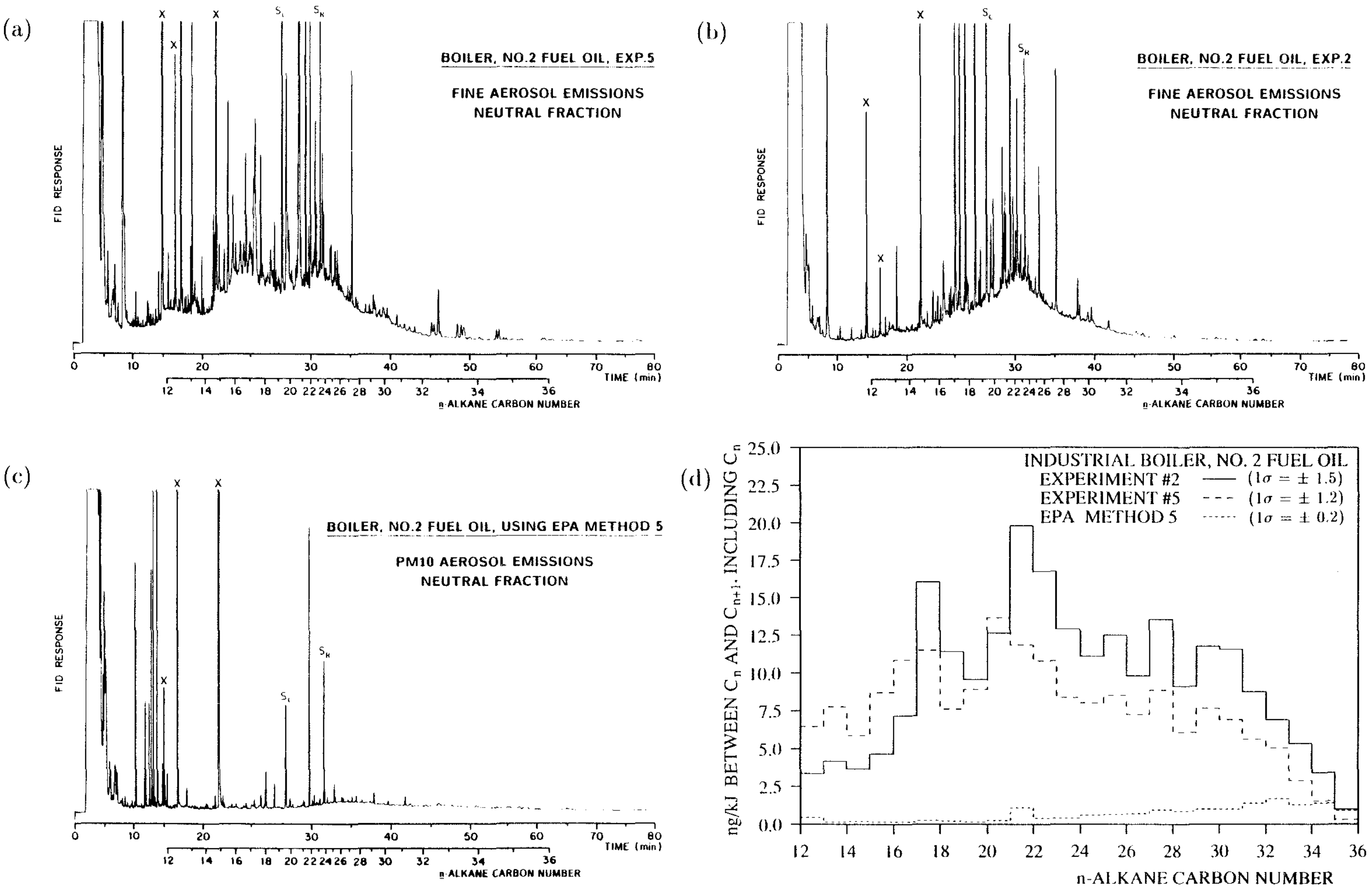

Figure 4.4 GC results for industrial boiler burning No. 2 fuel oil. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace from experiment No. 5; (b) Neutral GC trace from experiment No. 3; (c) Neutral GC trace from experiment using EPA Method 5; (d) Neutral fraction mass distributions obtained for 3 boiler experiments.

than does the dilution sampler, particularly at the lighter molecular weight end of the mass distribution. This is consistent with the expectation that filtration of undiluted exhaust at higher temperature (120 C) will fail to collect the lower molecular weight condensible organic compounds that are still in the vapor phase under stack conditions.

4.3.3.3 Motor Vehicle Emissions. Aerosol samples from each of three types of motor vehicles were analyzed by gas chromatography. The three samples were composites representing seven catalyst-equipped cars, six noncatalyst cars, and two heavy-duty diesel trucks. The automobile emissions were sampled during a Federal Test Procedure urban driving cycle, while a simpler cycle involving transitions between three speeds was used for the diesel trucks. The general characteristics seen in the GC traces for each of the vehicular sources were similar, with a smoothly varying, substantial-sized hump of unresolved organics and relatively little resolved mass (see Figure 4.5abc), which is consistent with the character of the petroleum used in fuels and lubricants. Essentially all of the elutable organics from these samples were found in the neutral organics fraction.

For the catalyst-equipped cars, the peak in the mass distribution fell between C27 and C30, while for the noncatalyst cars, the peak occurred earlier in the elution schedule, between C23 and C27 (see Figure 4.5d). The diesel truck exhaust exhibited a more complex mass distribution, with two peaks, one between C20 and C23, and the other between C27 and C31. The later peak, which is not obvious in the unresolved hump of the GC trace (Figure 4.5c), occurs because there are several significant resolved peaks with elution times later than the peak of the unresolved hump, which become emphasized when the larger relative response factors (RRFs) for the higher alkanes are applied to convert the area counts to organic mass concentrations.

4.3.3.4 Roofing Tar Pot. Fine organic particulate emissions from an in-use tar pot containing petroleum-based roofing asphalt was collected using a small dilution sampling system. The GC trace (Figure 4.6a) shows a large hump of unresolved organic material that elutes quite early, and a homologous series of peaks with retention times corresponding to the n-alkanes. It is clear that this

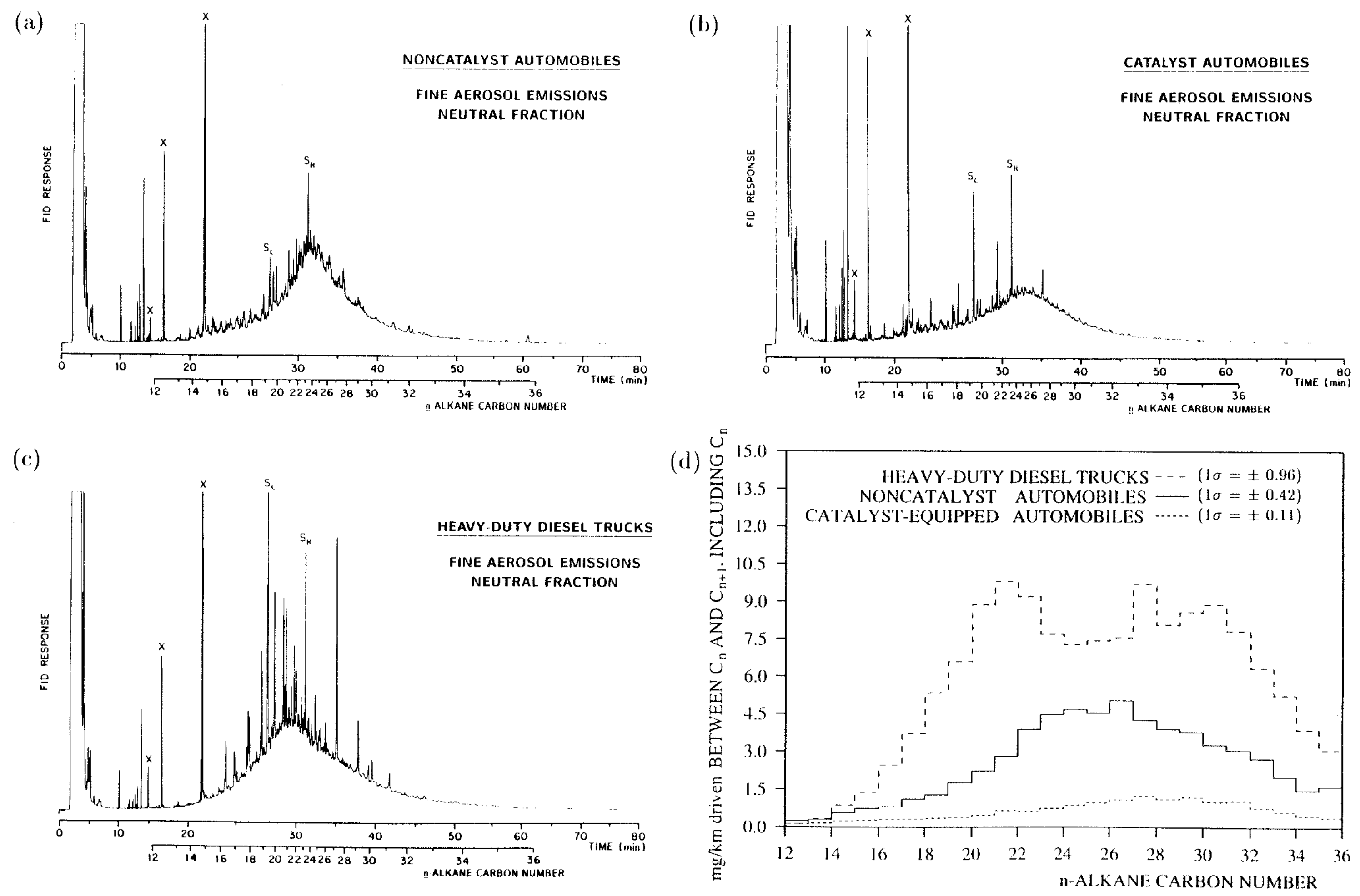

Figure 4.5 GC results for vehicle emissions. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace from composite of 7 noncatalyst automobiles; (b) Neutral GC trace from composite of 6 catalyst-equipped automobiles; (c) Neutral GC trace from composite of 2 heavy-duty diesel trucks; (d) Neutral fraction mass distributions obtained for 3 types of vehicles.

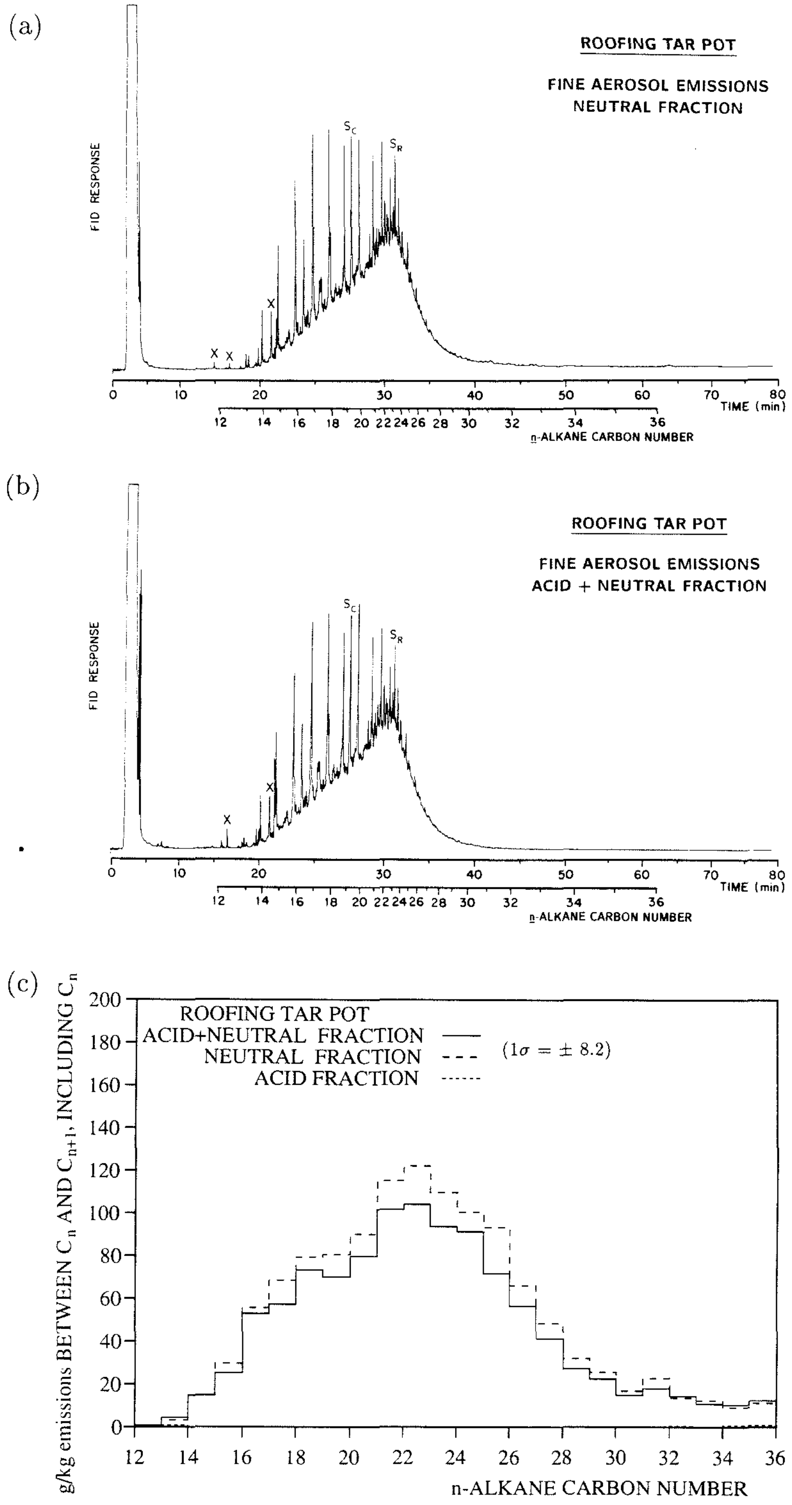

Figure 4.6 GC results for roofing tar pot emissions. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace; (b) Acid+neutral GC trace; (c) Organic mass distributions.

sample represents the distillation of low molecular weight hydrocarbons found in the roofing tar itself. The appearance of peaks in this series with retention times that are as early as C14 indicates that substantial gas-phase emissions of organics also occurred, because emissions of alkanes under C18 have been observed mainly in the vapor phase (Black and High, 1979).

The mass distribution computed for the tar pot emissions (Figure 4.6b) shows that essentially none of the elutable organics were acidic. The peak in the mass distribution occurs early on, between C21 and C23, and the distribution varies smoothly with no other distinctive features.

4.3.3.5 Tire Dust. For the tire dust sample, difficulties were encountered in obtaining a sample of the fine ($d_p < 2\mu m$) fraction of the dust, and a total aerosol sample was extracted instead for GC analysis. In Figure 4.7a and b, the GC traces obtained for the neutral and acid+neutral fractions are presented. A few additional peaks appear in the derivatized sample, indicating the presence of some acidic compounds. Again for this petroleum product, a homologous series of peaks is evident, and the retention times again correspond to the n-alkane series. The hump of unresolved material extended past 80 minutes, so the programming of the GC was extended to 120 minutes to allow more of the slow-eluting material to make it through the column. It was estimated (based on the RRF for C36) that 27–29% of the total elutable mass eluted after C36.

The mass distribution for the tire dust is presented in Figure 4.7c, and it is seen that the mass distribution for this source is quite different from the other petroleum derived sources studied. The peak in the mass distribution occurred at or beyond C36, emphasizing that most of the elutable tire dust organics were (not surprisingly) high molecular weight compounds. Approximately 6% of the sample was acidic, and most of the acidic fraction eluted between C20 and C26. The peak seen in the mass distribution between C25 and C26 was due to the appearance of two strong peaks in the derivatized fraction.

4.3.3.6 Fireplace Combustion of Wood. Emissions from combustion of three types of wood in a brick fireplace (located in an older single family home) were analyzed by gas chromatography. Results of these analyses (see Figure 4.8)

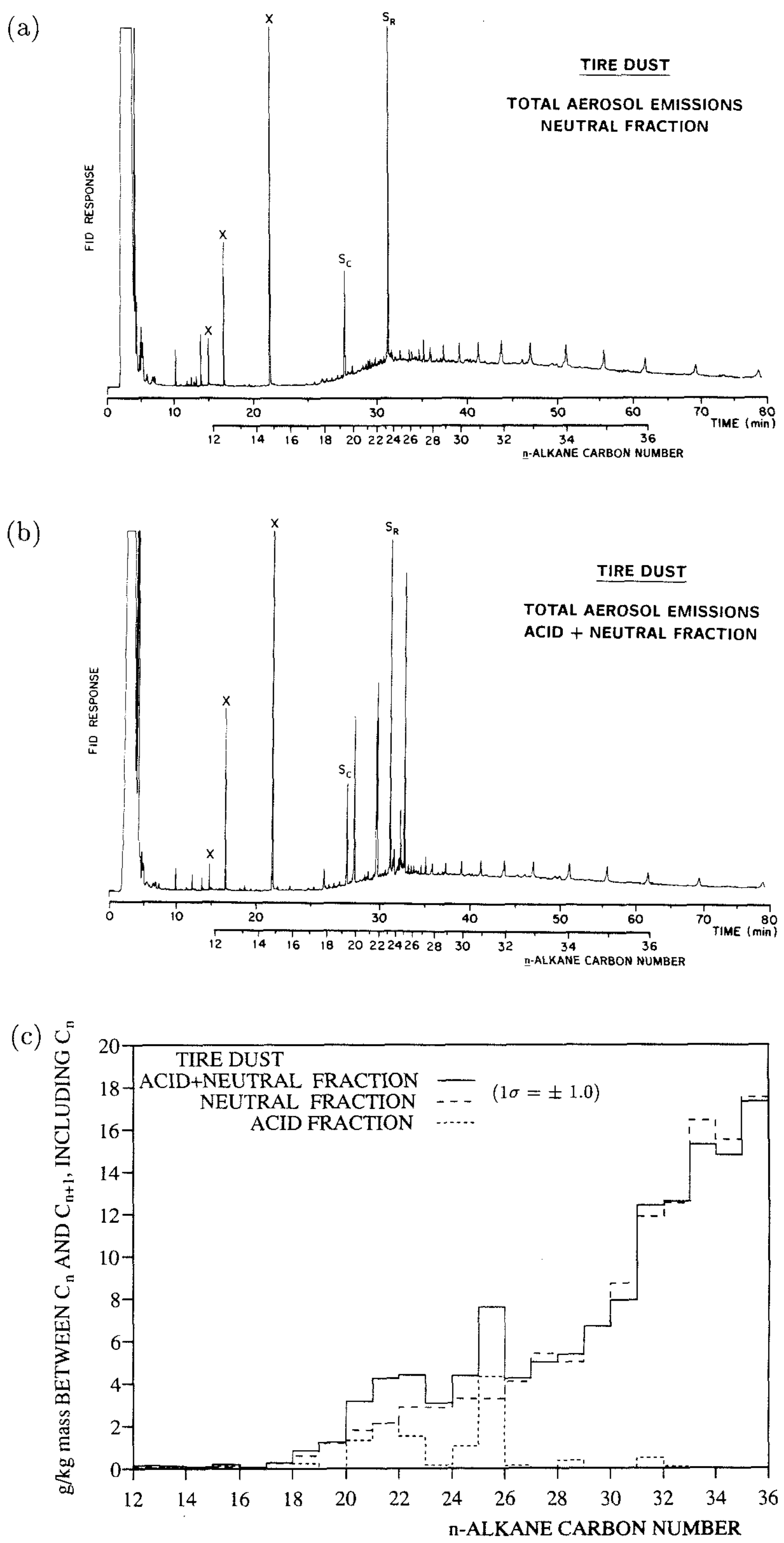

Figure 4.7 GC results for tire dust. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace; (b) Acid+neutral GC trace; (c) Organic mass distributions.

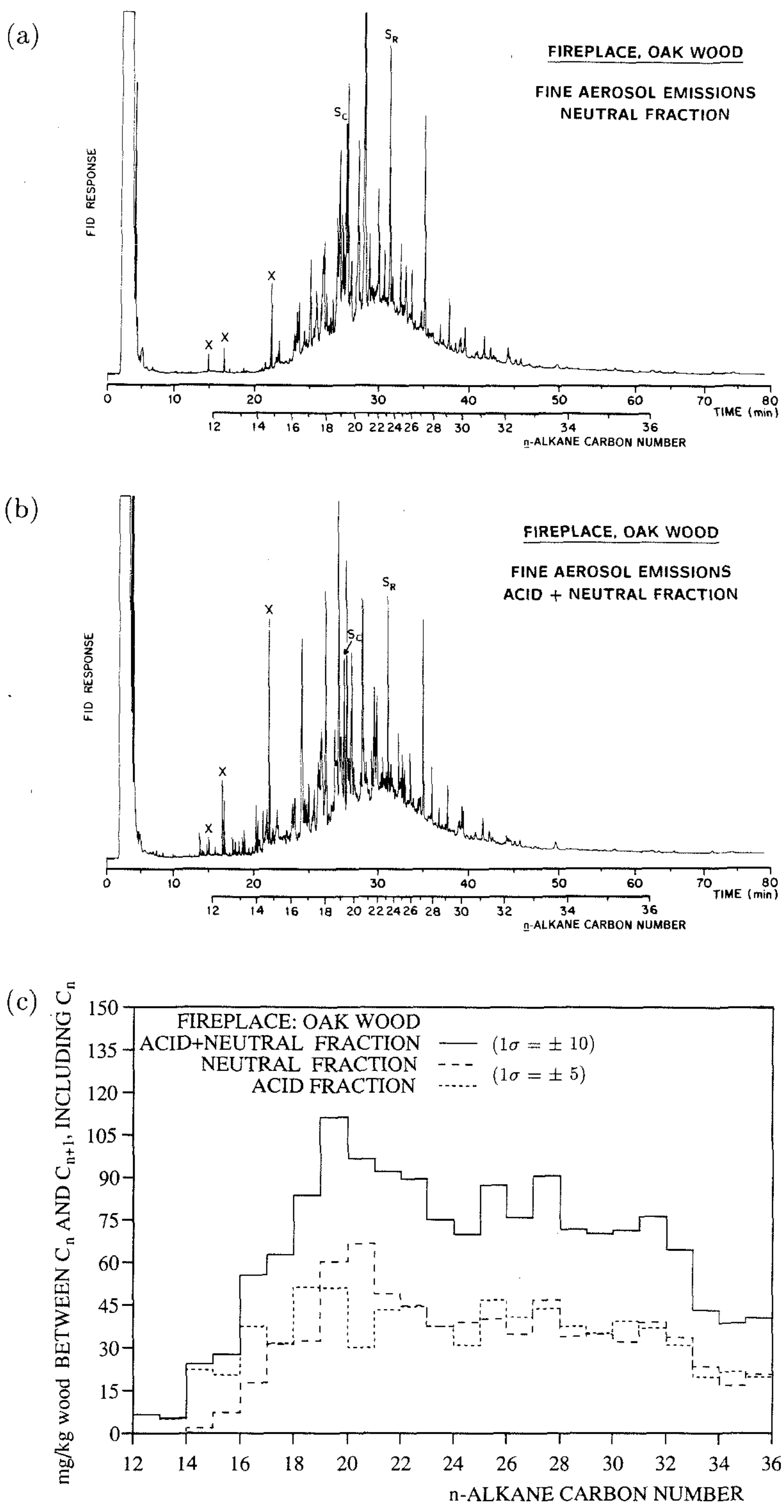

Figure 4.8 GC results for fireplace combustion of wood. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace for oak wood; (b) Acid+neutral GC trace for oak wood; (c) Organic mass distributions for oak wood; (cont.)

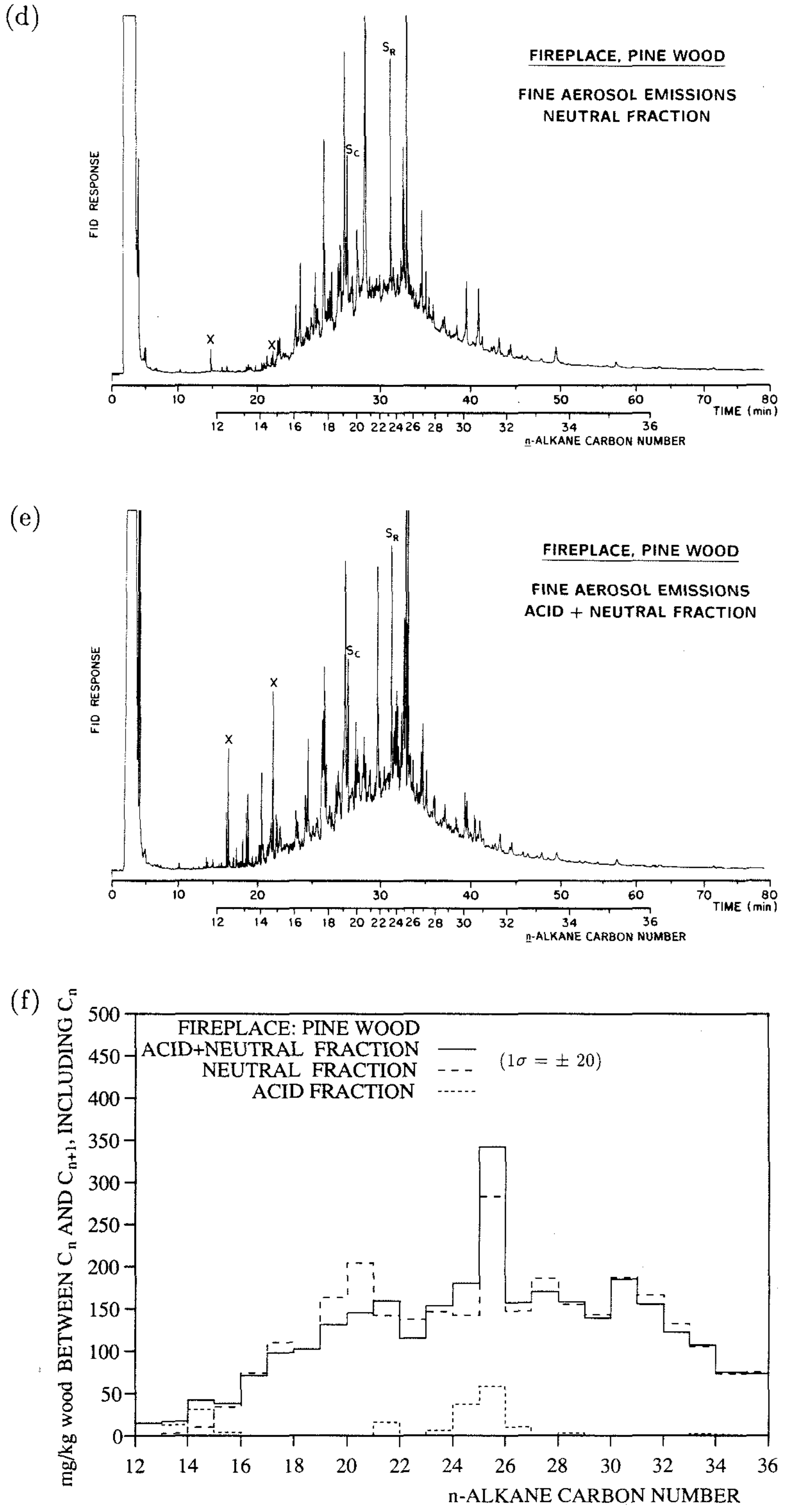

Figure 4.8 GC results for fireplace combustion of wood (cont.). Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (d) Neutral GC trace for pine wood; (e) Acid+neutral GC trace for pine wood; (f) Organic mass distributions for pine wood; (cont.)

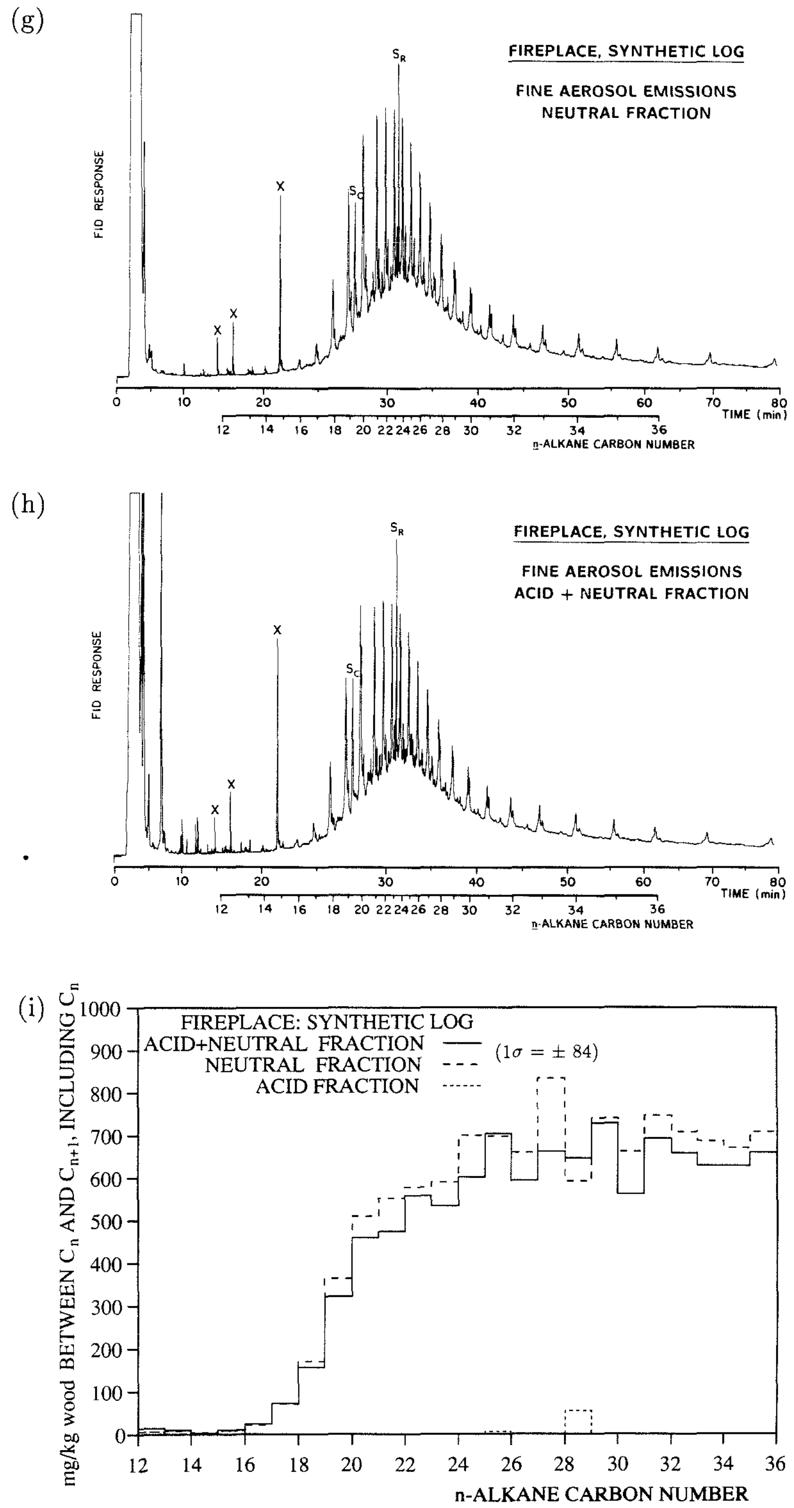

Figure 4.8 GC results for fireplace combustion of wood (cont.) Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (g) Neutral GC trace for synthetic log; (h) Acid+neutral GC trace for synthetic log; (i) Organic mass distributions for synthetic log.

exhibit marked differences in the organic characteristics of emissions from oak wood, pine wood, and a synthetic log. As shown in Figure 4.8ab, approximately half of the eluted organics emitted during combustion of oak were contained in the benzene-soluble acidic fraction. In contrast, benzene-soluble acidic organics from the combustion of pine only accounted for a few percent of the total (Figure 4.8cd). However, unlike most of the other samples analyzed in this study, substantial additional polar organic material present in the pine and oak emissions was not benzene-soluble. This additional material was found to be extremely polar, and is suspected to consist of higher-molecular weight complex organic acids. Finally, essentially all of the emissions from combustion of the synthetic log were found in the neutral fraction of the sample extract (Figure 4.8ef).

The organic mass distribution for oak combustion emissions exhibits a peak between C20 and C21, with a secondary peak between C27 and C28. Substantial similarities are seen in Figure 4.8b between the mass distributions for the neutral and acidic fractions. For combustion of pine, a single, very strong peak in the mass distribution occurs between C25 and C26 (Figure 4.8d) due to the appearance of three strong resolved peaks between these two alkanes. The majority of the acidic organic mass from pine combustion also occurs in this area, between C24 and C26.

The characteristics of the aerosol organics emitted from the combustion of the synthetic log show few similarities to the emissions from natural wood combustion. As seen in Figure 4.8f, the mass distribution rises steadily from C16 to C26, reaching a plateau from about C26 onward. In addition, unlike the natural woods, the GC trace of the synthetic log (Figure 4.8e) is dominated by a homologous series that has retention times corresponding to the n-alkane standard series. It is likely that this results from the use of paraffin waxes (a petroleum product) to mold together sawdust to form synthetic logs. Finally, significant peaks were seen to elute near the 80-min end of the normal GC alanysis cycle, so the GC elution time was extended to 120 minutes in order to observe these later peaks. It was found that approximately 12% of the total elutable organics mass from the synthetic log combustion experiment (based on the C36 RRF) eluted after C36 (and hence is not shown in Figure 4.8f), while for both the natural wood samples only 2% of the organics mass eluted after C36.

4.3.3.7 Cigarette Smoke. Samples containing both sidestream and mainstream smoke from four different types of cigarettes were composited for GC analysis, forming a sample representing smoke from regular cigarettes (43%), filtertip cigarettes (29%), "light" cigarettes (21%), and menthol cigarettes (7%). This composited sample is a close representation of the market share for each of these types of cigarettes in 1981 (House of Representatives, 1982). Almost all of the elutable organic material was found in the neutral fraction of the extract. However, as was the case for wood combustion, substantial polar organic material insoluble in benzene was present in the cigarette smoke extract. Again, this extremely polar fraction is suspected to consist of complex, high-molecular weight organic acids.

As seen in Figure 4.9a and b, the largest additional peaks eluting after derivatization appear near the top of the unresolved hump and fall between the retention times for n-alkanes C20 and C23 (see Figure 4.9c). The mass distribution for this sample, shown in Figure 4.9c, is very complex. A strong peak appears between C31 and C32, a second peak occurs between C20 and C23, and a notable isolated peak occurs between C14 and C15.

4.3.3.8 Meat-Cooking Operations. Two types of hamburger meat, regular and extra-lean, each were cooked by both frying and charbroiling in separate experiments using a commercial-scale cooking facility. The emissions from each of the charbroiling tests were analyzed separately on the GC, while the samples from the two frying experiments were combined prior to extraction (due to the smaller amount of material collected in the latter cases).

The results of the GC analyses, presented in Figure 4.10, show that the three organic extracts had quite similar characteristics, despite large differences in the mass emission rates of organic aerosol between these tests. The meat-cooking samples contained an acidic component that represented 13 to 24% of the total acid+neutral fraction, and most of the acidic fraction (55 to 68%) eluted between C20 and C25. When comparing the neutral vs. acid+neutral GC traces, this acidic mass can be seen in the form of additional resolved peaks that appear near the top of the unresolved hump (see Figure 4.10). Both samples of the effluent from charbroiling meat show a strong narrow peak in the mass distribution between C21

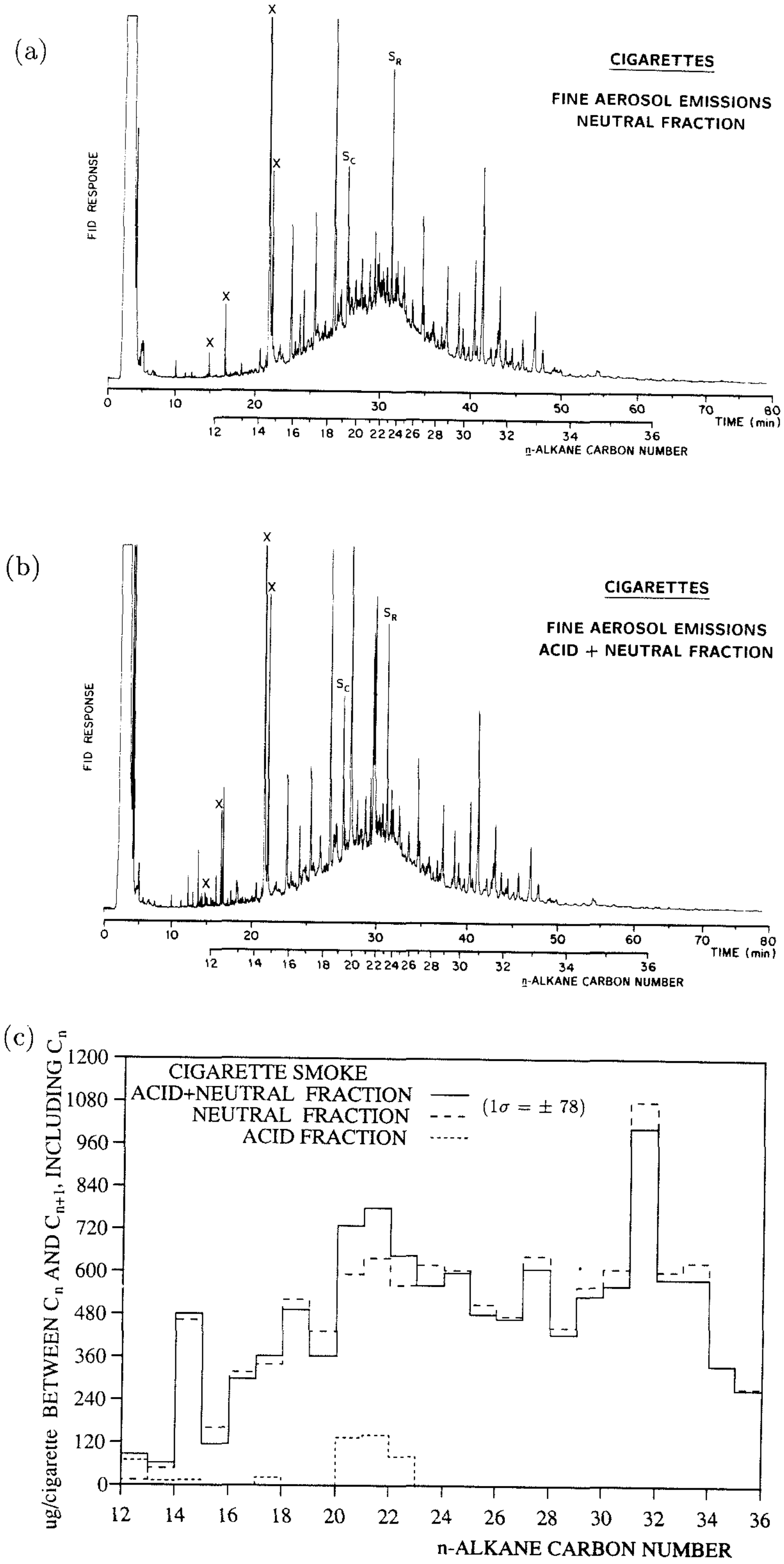

Figure 4.9 GC results for cigarette smoke. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace; (b) Acid+neutral GC trace; (c) Organic mass distributions.

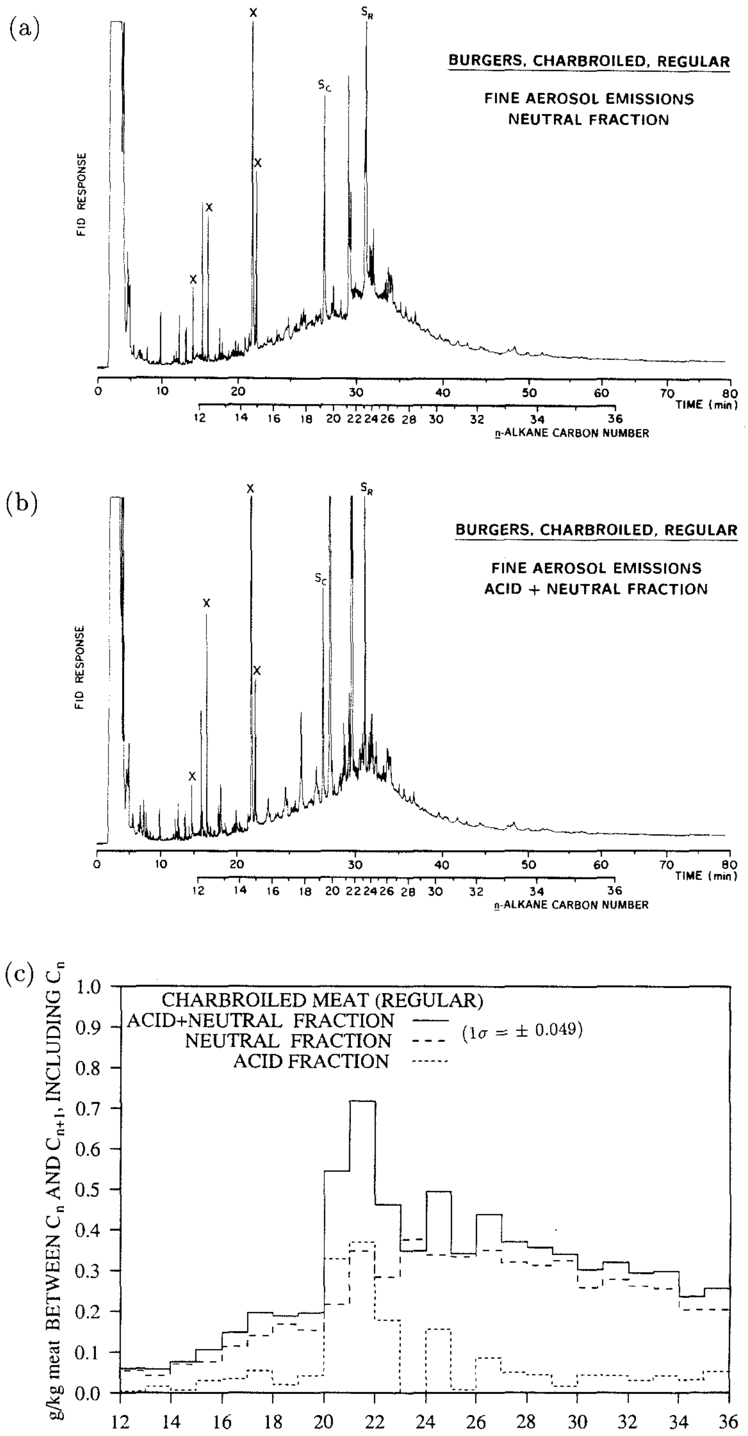

Figure 4.10 GC results for meat-cooking operations. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace for regular, charbroiled hamburger meat; (b) Acid+neutral GC trace for regular, charbroiled hamburger meat; (c) Organic mass distributions for regular, charbroiled hamburger meat; (cont.)

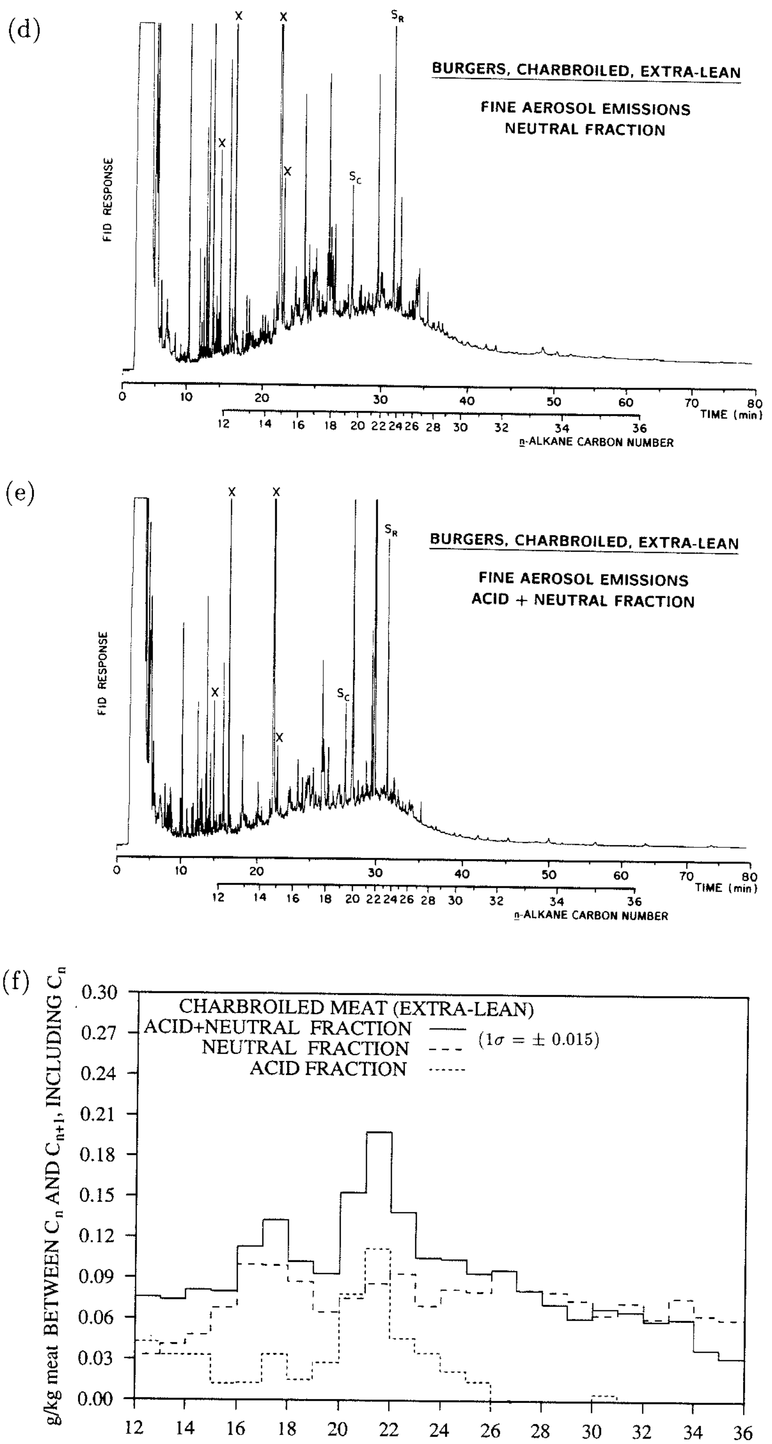

Figure 4.10 GC results for meat-cooking operations (cont.). Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (d) Neutral GC trace for extra-lean, charbroiled hamburger meat; (e) Acid+neutral GC trace for extra-lean, charbroiled hamburger meat; (f) Organic mass distributions for extra-lean, charbroiled hamburger meat; (cont.)

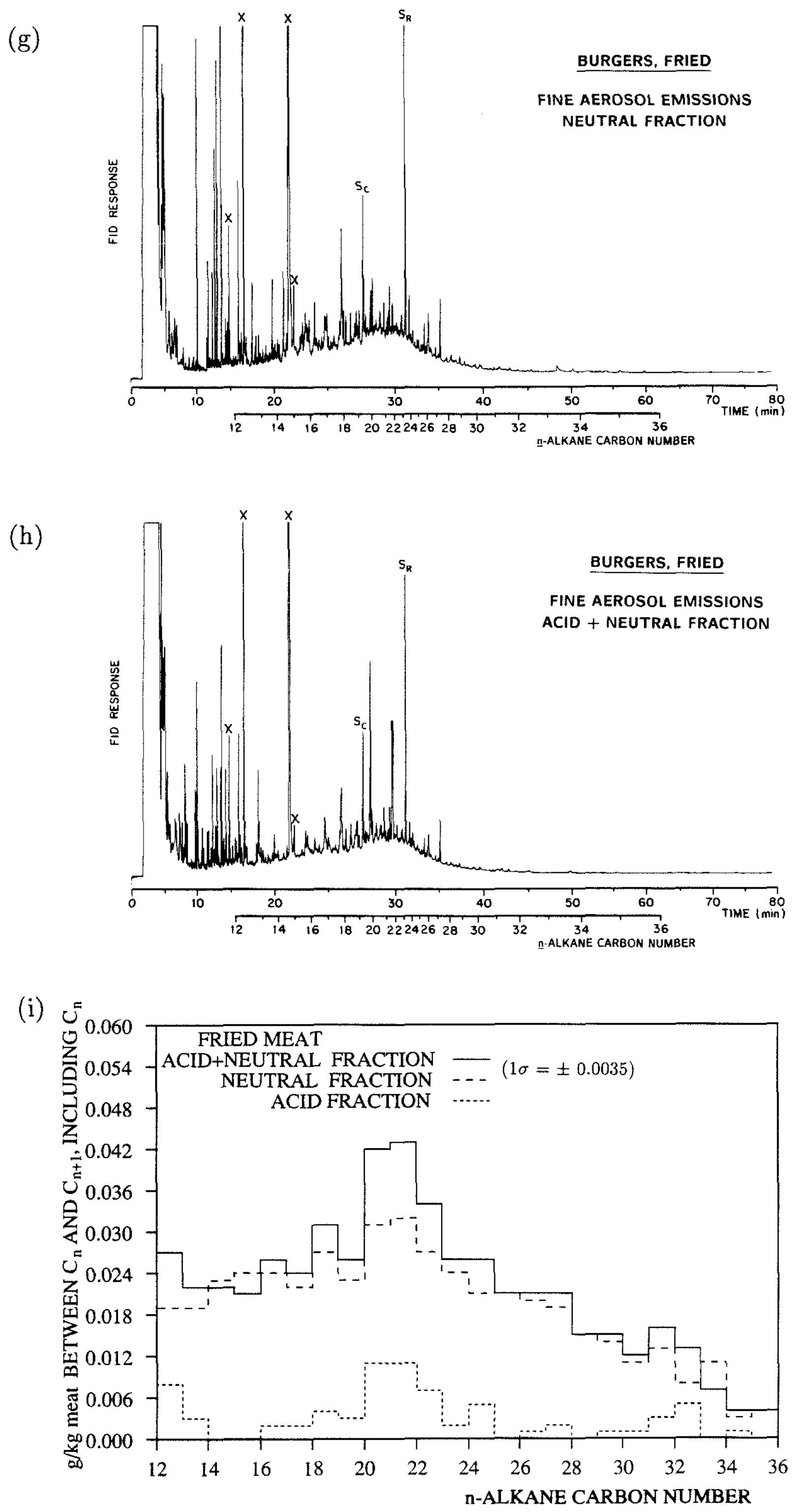

Figure 4.10 GC results for meat-cooking operations (cont.) Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (g) Neutral GC trace for fried hamburger meat; (h) Acid+neutral GC trace for fried hamburger meat; (i) Organic mass distributions for fried hamburger meat.

and C22, while the peak for the fried meat is a little wider, falling between C20 and C22.

4.3.3.9 Brake Dust. A grab sample of organometallic brake dust was resuspended and drawn through a cyclone separator prior to analysis in order to capture just the fine aerosol fraction. The GC analyses showed that acidic organics constituted about 13% of the elutable acid+neutral fraction. As seen in Figure 4.11a and b, these acidic compounds appear both as resolved peaks, and as additional unresolved species that elute near the end of the unresolved hump. The mass distribution for this source (Figure 4.11c) shows a broad distribution of organics mass over most of the subareas defined between the elution times for the n-alkanes, with the peak of the distribution spread between C21 and C28. Most of the acidic fraction falls between C20 and C34.

4.3.3.10 Natural Gas Home Appliance Emissions. Fine particulate emissions measured from combustion of natural gas by a space heater and water heater in a single family home were extremely low, requiring sampling periods of up to 12 hours to collect quantities of organic material that were adequate for GC analysis. Because of the small quantities of actual aerosol and the long sampling times, adsorption of gas phase organics by the quartz fiber filter or vaporization of collected aerosol from the quartz fiber filter were considered to be potential interferences, and a second set of quartz fiber filters was placed downstream of the set destined for GC analysis in order to evaluate these possible sampling artifacts. In addition, the low emissions rates encountered in these experiments made it more likely that organic contaminants in the dilution air might constitute a significant part of the total sample. Therefore, results of the GC analysis of the dilution air blank collected prior to sampling the home appliances were also compared with the results from the fine particulate sample.

The GC results for the particulate sample indicated that the elutable organics collected were essentially all found in the neutral fraction of the extract. The GC trace obtained for the neutral particulate organic fraction is presented in Figure 4.12a, while those obtained for the adsorbed gas-phase organics and the dilution air blank are shown in Figure 4.12b and c, respectively. The mass distributions

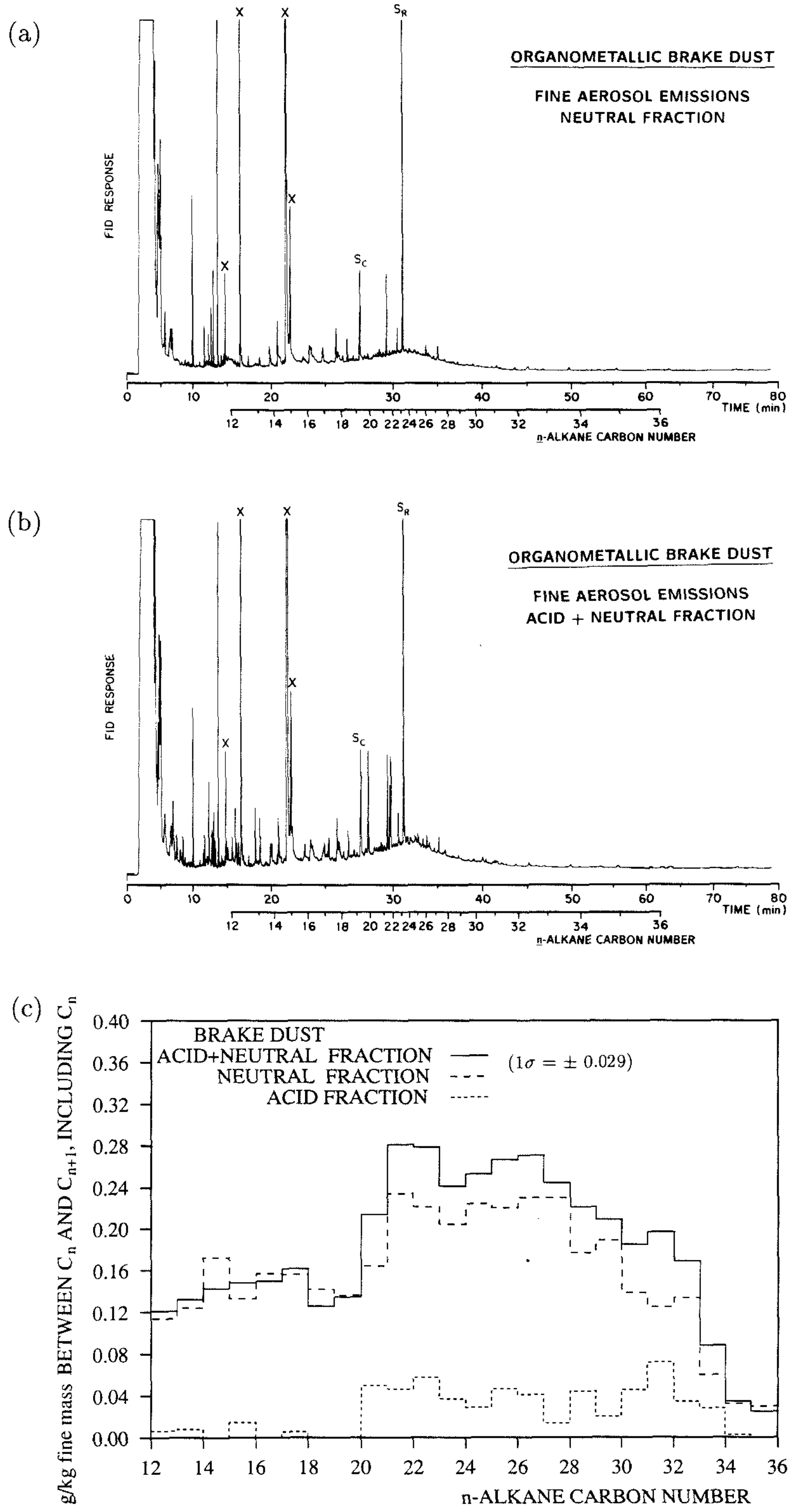

Figure 4.11 GC results for organometallic brake dust. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace; (b) Acid+neutral GC trace; (c) Organic mass distributions.

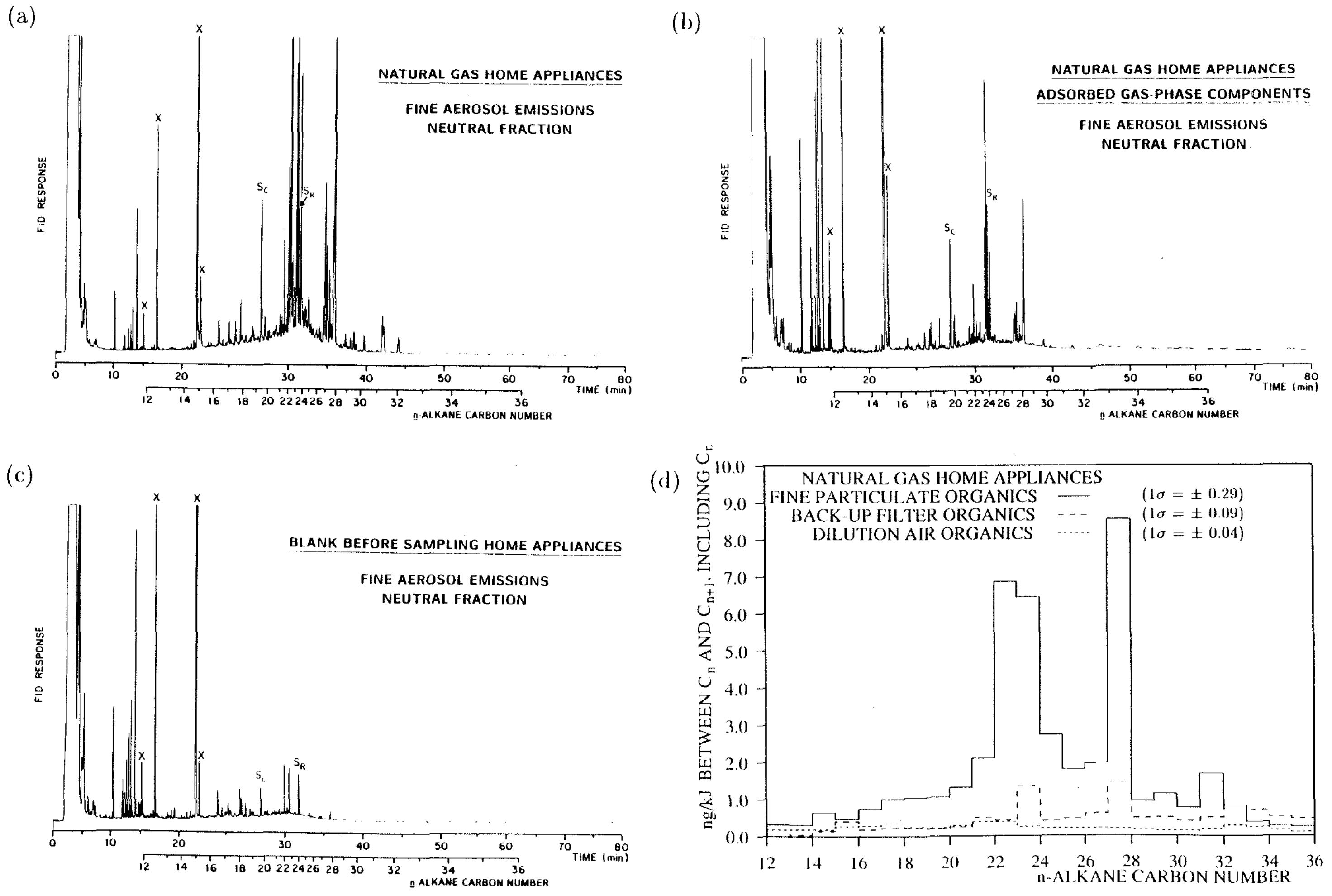

Figure 4.12 GC results for natural gas home appliance emissions. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace for fine particulate emissions; (b) Neutral GC trace for material collected on backup filters; (c) Neutral GC trace for material collected from dilution air; (d) Neutral fraction mass distributions for natural gas home appliance samples.

for each of these three GC traces are shown in Figure 4.12d. The distribution of organic emissions from the home appliances shows two strong peaks, one between C22 and C24, the other between C27 and C28. The contribution of the dilution air to the total elutable organics in the sample is quite small, even for under this "worst case" sampling condition. However, the collection of organics on the second quartz filter located downstream of the aerosol sample accounts for about one-fourth of the total mass of particulate organics collected. Separate organic carbon measurement by combustion of a quartz fiber filter located downstream of a Teflon filter from this experiment indicates that approximately half of the total organic carbon material collected may be attributable to adsorption of gas-phase organics, or to vaporization of particulate matter from the Teflon filter. Nonetheless, it appears that the two distinctive peaks that appear in the mass distribution of the particulate organic emissions collected are mostly attributable to particulate matter, and can still be used to characterize the emissions.

4.3.3.11 Detritus from Urban Leaf Surfaces. Both green and dead leaf samples were agitated in a Teflon bag to dislodge plant waxes and other material present on the leaf surfaces as would naturally occur due to sloughing and mechanical abrasion processes. The vegetation sample was especially prepared to represent a composite of Los Angeles area vegetation, as is described elsewhere (Hildemann, Markowski and Cass, 1989). The GC traces for each of these two samples, shown in Figure 4.13, show very similar characteristics, with little unresolved mass and a very distinctive pattern of the resolved peaks. In particular, the last 3 large peaks in each sample have retention times corresponding to odd-numbered n-alkanes C29, C31 and C33. While absolute confirmation of these identifications must await GC/MS analysis, this odd-numbered alkane predominance for vegetation has been observed in other studies (Simoneit, Chester and Eglinton, 1977; Simoneit and Mazurek, 1981, 1982; Mazurek and Simoneit, 1984), along with a predominance of even-numbered normal fatty acids. The prevalence of these compounds in plant wax emissions results from the compound-selective biosynthetic pathways found in plants.

Since most of the elutable organics mass from the vegetation samples consisted of a few resolved peaks, the mass distribution pattern for these samples closely

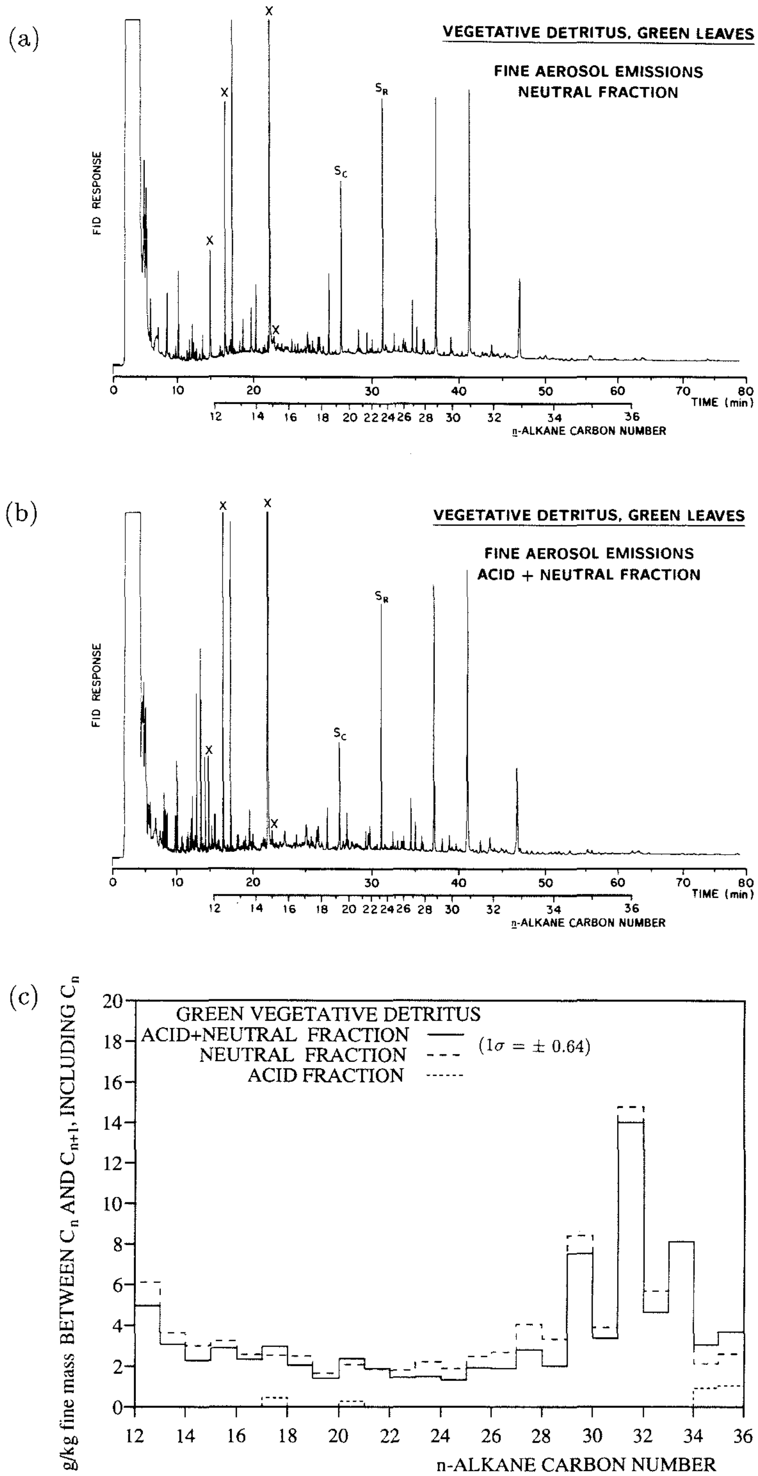

Figure 4.13 GC results for vegetative detritus. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace for green leaf vegetative detritus; (b) Acid+neutral GC trace for green leaf vegetative detritus; (c) Organic mass distributions for green leaf vegetative detritus; (cont.)

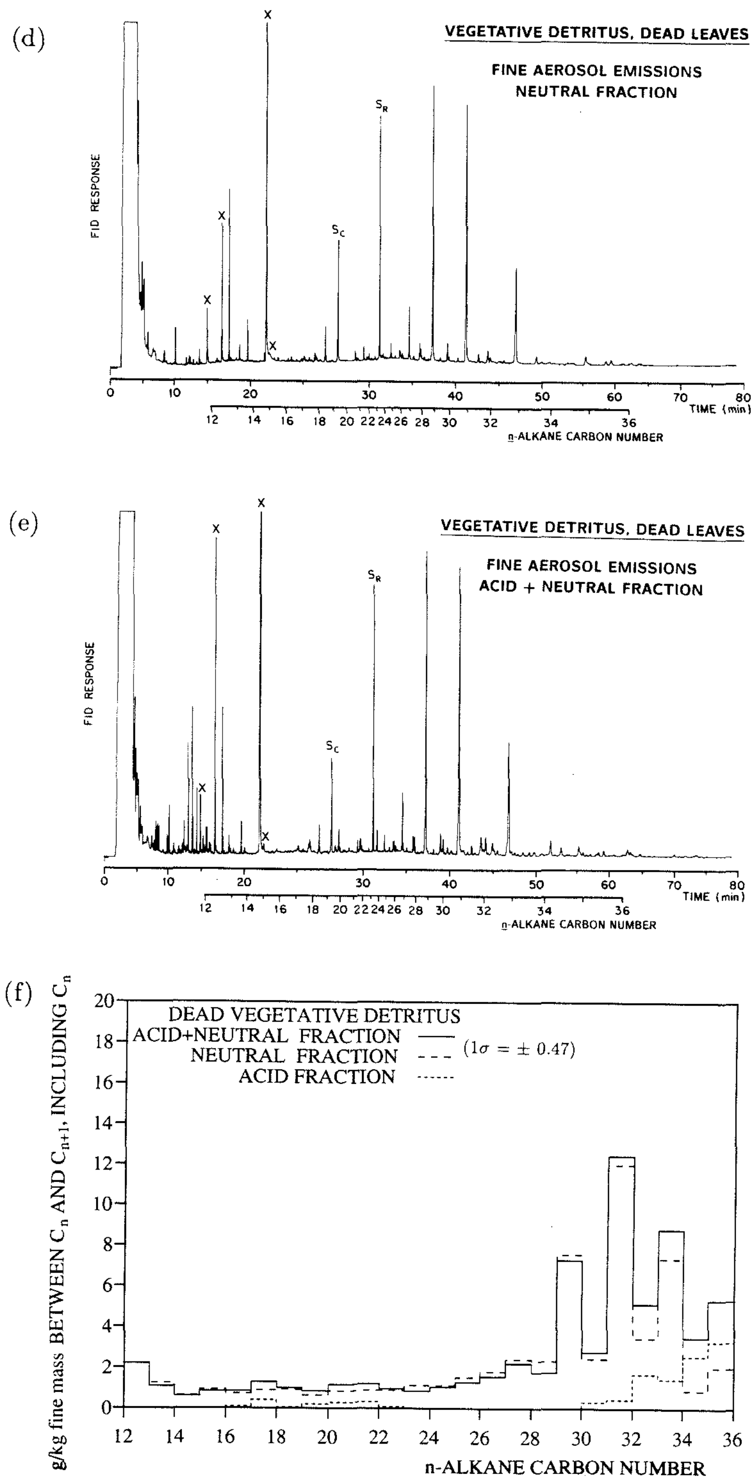

Figure 4.13 GC results for vegetative detritus (cont.). Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (d) Neutral GC trace for dead leaf vegetative detritus; (e) Acid+neutral GC trace for dead leaf vegetative detritus; (f) Organic mass distributions for dead leaf vegetative detritus.

follows the pattern of the GC trace. In both Figure 4.13c and d, a sawtooth pattern is evident between C27 and C36. The peak in the mass distribution between C31 and C32 is contributed mainly by the mass contained in the single compound peak that has the retention time corresponding to C31. Only a small amount of acidic organics were present. Peaks with retention times corresponding the the C28 and C30 fatty acids appeared in the derivatized fractions of both samples, but were more prevalent in the dead leaf sample than in the green leaf sample. These fatty acid peaks were not sufficiently intense for the difference to be apparent in Figure 4.13cd.

4.3.3.12 Paved Road Dust. Fine Pasadena-area paved road dust, collected with a small vacuum sweeper truck, also was isolated for GC analysis by resuspending a grab sample followed by sample collection downstream of a cyclone separator. Organic analysis on the GC (Figure 4.14) showed that almost all of the sample was found in the neutral fraction of the extract, with a few acidic compounds that had retention times corresponding to the C16 and C18 fatty acids appearing between the elution times for C20 and C23 n-alkanes (Figure 4.14c). The peak in the neutral mass distribution occurred late in the elution schedule, between C31 and C32, and about 8% of the mass eluted after C36 (and hence is not shown in Figure 4.14c). A sawtooth pattern between C27 and C32 supports the contention that this sample contained some plant-derived organic matter, while the hump of unresolved material seen in the GC traces of Figure 4.14ac is characteristic of petroleum or combustion derived (anthropogenic) organic material.

4.4 DISCUSSION

Gas chromatographic analysis of aerosol source samples can be employed in order to define features of the organic aerosol that distinguish one source type from another. A 52-parameter description of each source is obtained, based on the fraction of the emitted organics that will elute on the GC column, the ratio of the unresolved to resolved organics present, and the distribution of the acid and neutral organic compounds that have elution times falling between the elution times of specific n-alkanes in the range C12 to C36 and after C36.

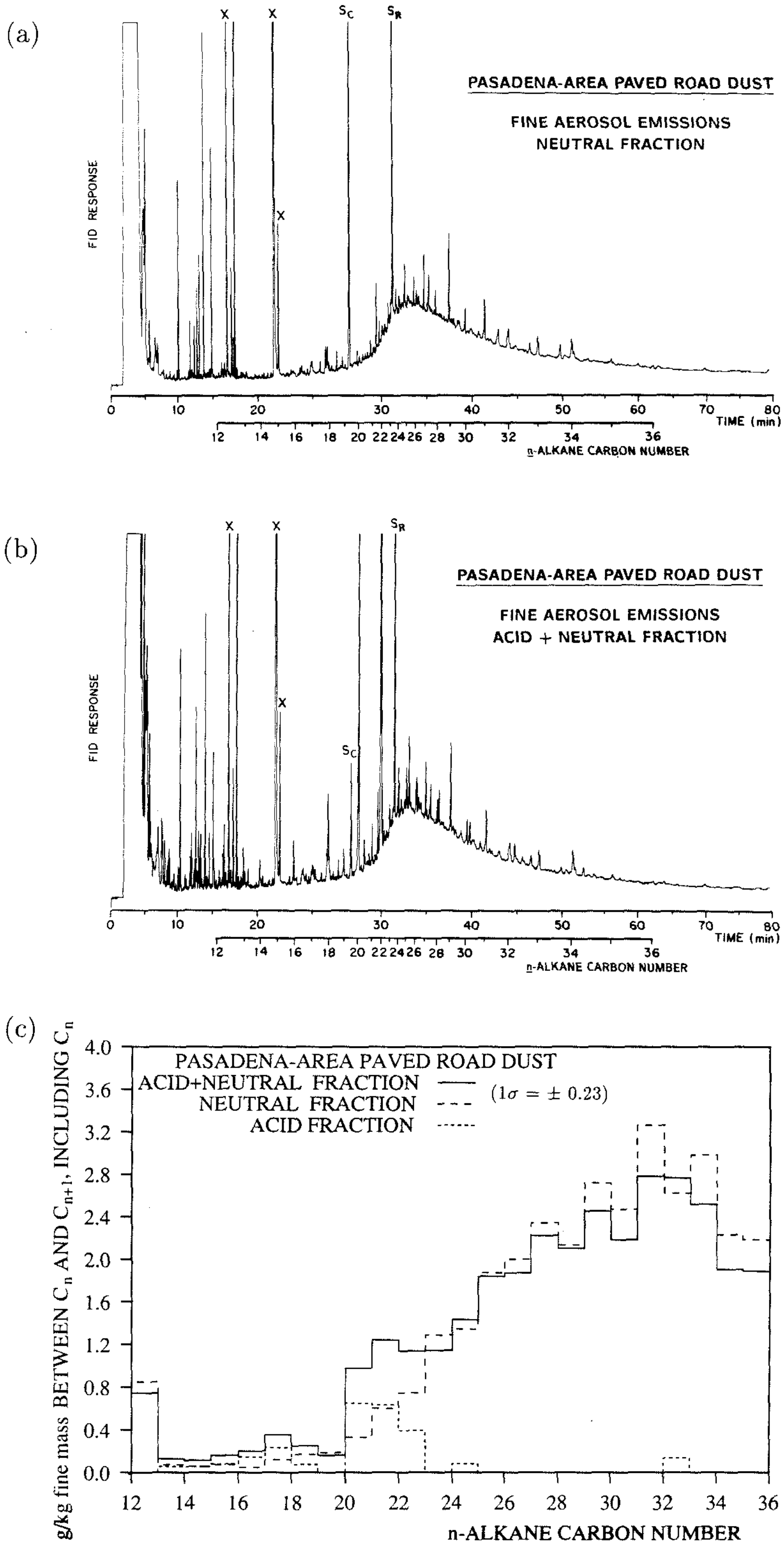

Figure 4.14 GC results for Pasadena-area paved road dust. Contaminant peaks (marked with "X") and standard peaks (marked with "S") are not included in area count summations. (a) Neutral GC trace; (b) Acid+neutral GC trace; (c) Organic mass distributions.

Nineteen source types that contribute close to 80% of the primary organic carbon aerosol to the Los Angeles area atmosphere have been characterized by these methods in order to obtain a nearly comprehensive picture of the difference between the organic aerosol sources present in a complex urban area. It is confirmed that man-caused aerosol sources usually emit a mixture of organics with a ratio of unresolved to resolved compounds (U:R) greater than 2.0, while the natural organic aerosol contributed by vegetative detritus (*e.g.*, plant waxes) show U:R values in the range 0.8–1.5. One notable exception to this rule was found: the natural gas-fired home appliances tested emit mostly resolved organics with a low U:R value of 0.6–1.3.

Further distinctions between the anthropogenic sources can be drawn based on the quantitative distribution of organic materials that elute between the elution times for known standard compounds, in this case the homologous series of the n-alkanes. In Figure 4.15, the data for all sources tests have been displayed on a common basis, showing the neutral and acidic organic compound mass concentrations that elute in each subrange of the GC trace, each expressed as a percentage of the total quantity of elutable acid+neutral organics observed. From the data on the neutral organic fraction, certain sources are readily distinguished from each other. Combustion of the synthetic log tested produces high molecular weight materials eluting at long retention times; these are not seen in natural wood combustion. Tire dust shows a progressive trend toward increasing quantities of material at the longer elution times, in contrast to vehicle tailpipe emissions that show a progressive decline in emissions with long elution times. Diesel exhaust is distinctly different from catalyst-equipped automobile exhaust. Sources such as combustion of pine wood, cigarettes and natural gas show prominent single peaks in their mass distribution that may be diagnostic markers for those sources. Vegetative detritus shows neutral organics with a predominance of material in the elution zone between C27 and C33.

From Figure 4.15, it is seen that organic acids are emitted in significant quantities from a minority of the sources tested: combustion of hard wood, meat-cooking operations and brake dust. This helps to distinguish those sources from sources that emit largely neutral organics. Since it is seen that organic acids

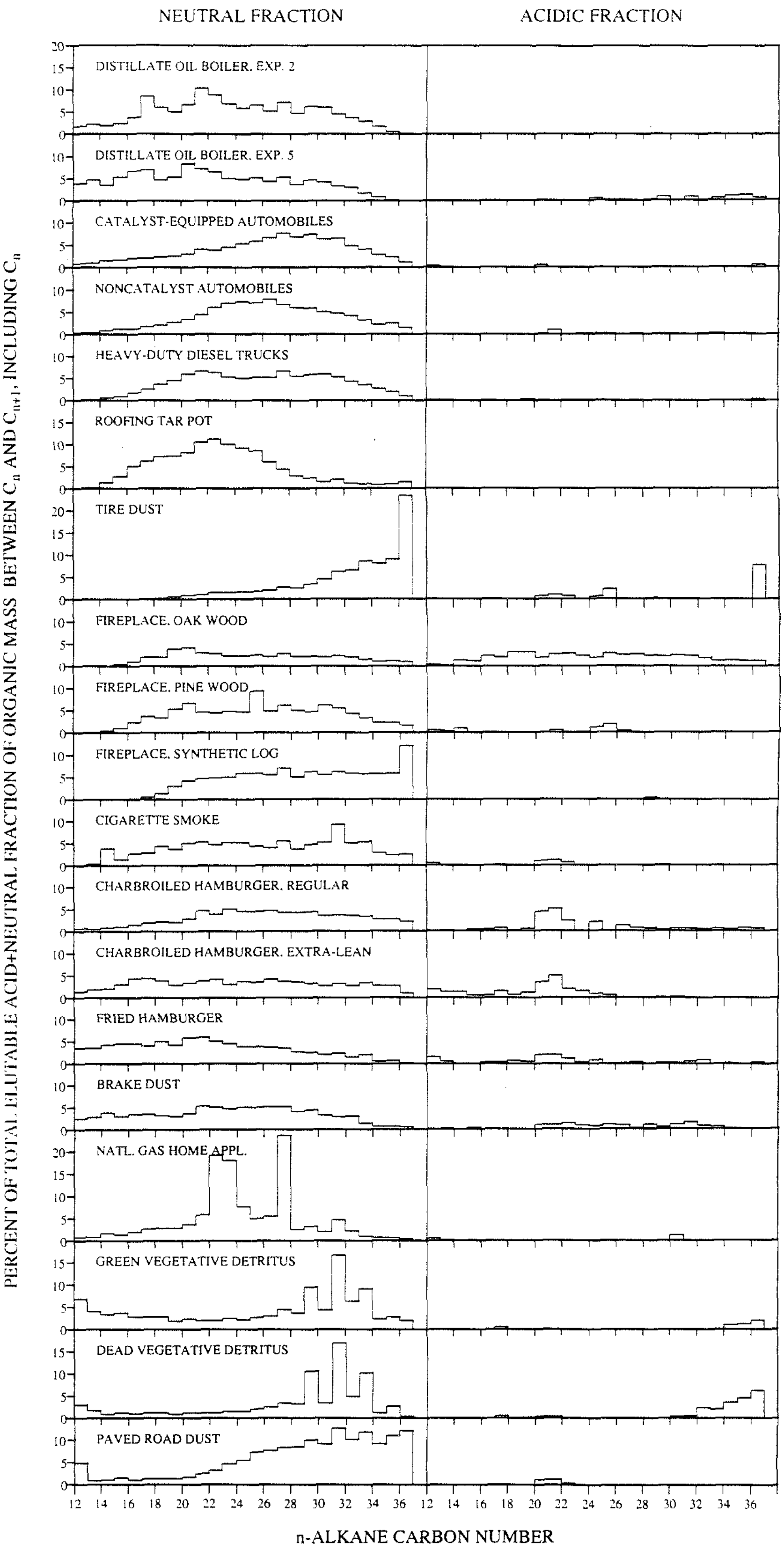

Figure 4.15 Summary of mass distribution profiles.

are emitted directly from some primary organic aerosol sources, careful analysis will be needed to determine the fraction of the organic acids in the atmosphere that arise from primary emission sources vs. atmospheric chemical reaction processes.

To qualitatively evaluate the degree of similarity or difference between the organic mass distributions obtained for each of the individual source types, a hierarchical cluster analysis was performed on the nineteen source signatures obtained. Separate organic mass distributions obtained for the neutral and acidic fractions of each source sample were appended together to form a sequence of 50 groups of organic compounds. These mass emissions rates for each compound group were normalized by the total elutable acid+neutral organic aerosol emission rate from the relevant source in order to compute the percentage of the total elutable organics emissions from that source falling into each of the 50 compound groups. Using this relative compound distribution, each of the source signatures was assigned to a location in a 50-dimensional space, and the source samples were clustered together according to their proximity to each other in a step-by-step approach, using the squared Euclidean distance between adjacent samples in this 50-dimensional space as a measure of proximity.

The computer program used to perform this analysis was the CLUSTER package within the SPSS-X software package. At the first step in the cluster analysis, the two source samples closest to each other in this space were grouped, creating eighteen clusters containing the nineteen source types. The distance between these eighteen clusters next was evaluated, and the consolidation process continued step by step until the two surviving clusters were combined into a single final cluster. At each step, the distance between the centroids of the clusters being combined was recorded. The hierarchy formed by this analysis is shown in Figure 4.16, including the distance between the clusters combined at each step.

The hierarchical cluster analysis (shown in Figure 4.16) reveals that the organic aerosol compound distributions obtained for vegetative detritus (green and dead leaves combined), tire dust, paved road dust and natural gas home appliances were among the most distinct, with relative distance measures of over 500 between those sources and the closest source cluster. (The *maximum* possible proximity value, assuming that no more than 20% of the total mass occurs in a single subregion

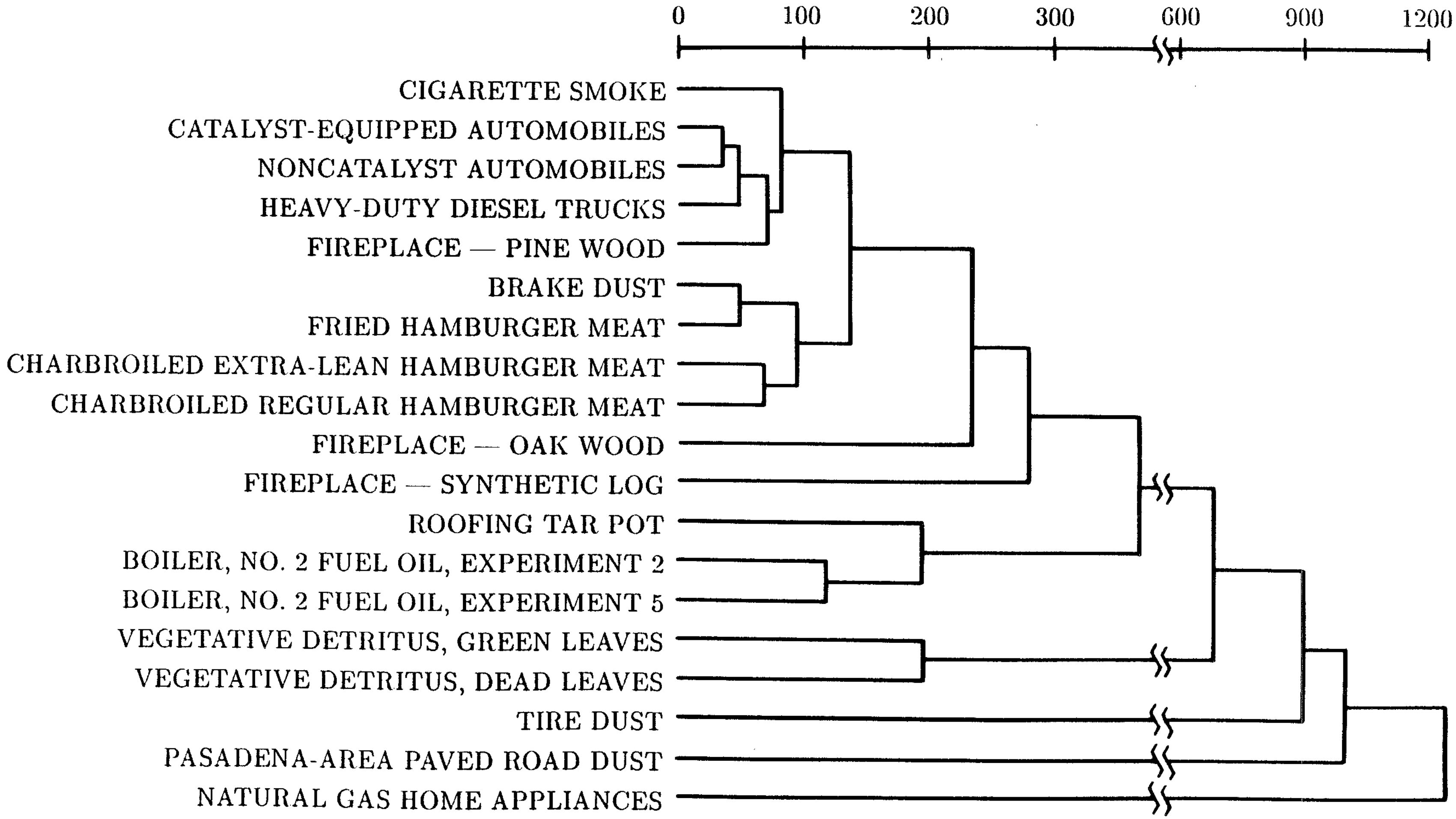

Figure 4.16 Cluster analysis hierarchy for source samples.

of the 50-parameter source signature, would be 4000.) In addition, some of the source signatures that were expected to be similar were indeed found to be in close Euclidean proximity to one another: the motor vehicles had proximities of less than 50, and the two types of charbroiled hamburger meat had a separation distance of 65. Two other sources, brake dust and fried hamburger meat, also were found to be closely spaced, with a proximity of 46.

To estimate the magnitude of the proximity values that might be indicative of clusters that are indistinguishable, the distance measures for several replicate samples from the same source type also were evaluated. The proximity of the two cigarette samples had a value of 13 in the unit system chosen, the distance between the two tire dust samples had a value of 26, and the two tar pot samples had a proximity value of 33. On the basis of these replicate samples, a proximity value of 100 was chosen as a *tentative* dividing line between source that are much more different from each other than is the case for replicate samples from the same source type. At this relative distance, the source signatures are grouped into 12 clusters. The 3 meat-cooking experiments forn one cluster along with the brake dust sample, and the 3 vehicle experiments form a second cluster along with cigarette smoke and fireplace combustion of pine wood. The other 10 source types are still in separate clusters at this level, indicating that their organic mass distributions contain characteristics that clearly distinguish them from the other sources based solely on the distribution of compounds between the 50 compound groups defined earlier.

4.5 REFERENCES

Black, F., and High, L. (1979). Methodology for Determining Particulate and Gaseous Diesel Hydrocarbon Emissions. SAE paper no. 790422, Society of Automotive Engineers, Warrendale, Pennsylvania.

Cooper, J.A., Redlone, D.C., Sherman, J.R., Valdovinos, L.M., Pollard, W.L., Scavone, L.C., and Badgett-West, C. (1988). Appendix V – G. PM10 Source Profile Library for the South Coast Air Basin. Draft. South Coast Air Quality Management District, El Monte, California.

Cox, R.E., Mazurek, M.A., and Simoneit, B.R.T. (1982). Lipids in Harmattan Aerosols of Nigeria. *Nature* 296:848–849.

Daisey, J.M, and Gundel, L.A. (1988). A Simple and Inexpensive Tracer Method for Receptor Source Apportionment of Indoor Aerosols. Paper no. 8C.3 presented at the 1988 AAAR Conference, Chapel Hill, North Carolina.

Daisey, J.M., Cheney, J.L., and Lioy, P.J. (1986). Particulate Emissions from Air Pollution Sources: Status and Needs for Receptor Source Apportionment Modeling. *J. Air Pollut. Control Assoc.* 36:17–33.

Dasch, J.M. (1982). Particulate and Gaseous Emissions from Wood-Burning Fireplaces. *Environ. Sci. Technol.* 16:639–645.

DeAngelis, D.G., Ruffin, D.S., and Reznik, R.B. (1980). Preliminary Characterization of Emissions from Wood-Fired Resiential Combustion Equipment. EPA-600/7-80-040, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1984). Elemental and Organic Carbon Particle Concentrations: A Long-Term Perspective. *Sci. Total Env.* 36:17–25.

Gray, H.A. (1986). Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, California.

Hauser, T.R., and Pattison, J.N. (1972). Analysis of Aliphatic Fraction of Air Particulate Matter. *Environ. Sci. Technol.* 6:549–555.

Hering, S.V., Miguel, A.H., and Dod, R.L. (1984). Tunnel Measurements of the PAH, Carbon Thermogram and Elemental Source Signature for Vehicular Exhaust. *Sci. Total Environ.* 36:39–45.

Hildemann, L.M., Cass, G.R., and Markowski, G.R. (1989). A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests. *Aerosol Sci. Technol.* 10:193–204. [See Chapter 2.]

Hildemann, L.M., Markowski, G.R., and Cass, G.R. (1989). Chemical Characterization of Fine Aerosol Emissions from Important Sources of Organic Aerosol. *in preparation.* [See Chapter 3.]

House of Representatives, Committee on Energy and Commerce, Subcommittee on Health and the Environment (1982). Comprehensive Smoking Prevention Education Act. Hearings, March 5, 11 and 12, 1982. Serial No. 97-106, pp. 421–438.

Huntzicker, J.J., Johnson, R.L., Shah, J.J., and Cary, R.A. (1982). Analysis of Organic and Elemental Carbon in Ambient Samples by a Thermal Optical Method. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 79–85.

Japar, S.M., Szkarlat, A.C., Gorse, R.A., Jr., Heyerdahl, E.K., Johnson, R.L., Rau, J.A., and Huntzicker, J.J. (1984). Comparison of Solvent Extraction and Thermal-Optical Carbon Analysis Methods: Application to Diesel Vehicle Exhaust Aerosol. *Environ. Sci. Technol.* 18:231–234.

Johnson, R.L., Shah, J.J., Cary, R.A., and Huntzicker, J.J. (1981). An Automated Thermal-Optical Method for the Analysis of Carbonaceous Aerosols. In *Atmospheric Aerosols: Source/Air Quality Relationships* (E.S. Macias and P.K. Hopke, eds.). American Chemical Society, Washington D.C., pp. 223–233.

Kowalczyk, J.F., and Greene, W.T. (1982). New Techniques for Identifying Ambient Air Impacts from Residential Wood Heating. In *Residential Solid Fuels. Environmental Impacts and Solutions* (J.A. Cooper and D. Malek, eds.). Proceedings of 1981 International Conference, June 1–4, 1981, Portland, Oregon. Oregon Graduate Center, Beaverton, Oregon.

Laresgoiti, A., Loos, A.C., and Springer, G.S. (1977). Particulate and Smoke Emission from a Light Duty Diesel Engine. *Environ. Sci. Technol.* 11:973–978.

Mazurek, M.A. (1985). Geochemical Investigations of Organic Matter Contained in Ambient Aerosols and Rainwater Particulates. Ph.D. Thesis, University of California (Los Angeles), 372 pp.

Mazurek, M.A., Cass, G.R., and Simoneit, B.R.T. (1989). Interpretation of High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Data Acquired from Atmospheric Organic Aerosol Samples. *Aerosol Sci. Technol.* 10:408–420.

Mazurek, M.A., and Simoneit, B.R.T. (1984). Characterization of Biogenic and Petroleum-Derived Organic Matter in Aerosols over Remote, Rural and Urban Areas. In *Identification and Analysis of Organic Pollutants in Air* (L.H. Keith, ed.), Ann Arbor Science/Butterworth Publishers, Woburn, Massachusetts, pp. 353–370.

Mazurek, M.A., Simoneit, B.R.T., Cass, G.R., and Gray, H.A. (1987). Quantitative High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Analyses of Carbonaceous Fine Aerosol Particles. *Intern. J. Anal. Chem.* 29:119-139.

Muhlbaier, J.L. (1981). A Characterization of Emissions from Wood-Burning Fireplaces. Report No. GMR-3730, General Motors Research Laboratories, Warren, Michigan.

Muhlbaier, J.L., and Williams, R.L. (1982). Fireplaces, Furnaces and Vehicles as Emission Sources of Particulate Carbon. In *Particulate Carbon: Atmospheric Life Cycles* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 185–198.

Pierson, W.R., Gore, R.A., Jr., Szkarlat, A.C., Brachaczek, W.W., Japar, S.M., Lee, F.S.C., Zweidinger, R.B., and Claxton, L.D. (1983). Mutagenicity and Chemical Characteristics of Carbonaceous Particulate Matter from Vehicles on the Road. *Environ. Sci. Technol.* 17:31-44.

Simoneit, B.R.T., Chester, R., and Eglinton, G. (1977). Biogenic Lipids in Particulates from the Lower Atmosphere over the Eastern Atlantic. *Nature* 267:682–685.

Simoneit, B.R.T., and Mazurek, M.A. (1981). Air Pollution: The Organic Components. *CRC Critical Reviews in Environmental Control* (May 1981), pp. 219–276.

Simoneit, B.R.T., and Mazurek, M.A. (1982). Organic Matter of the Troposphere–II. Natural Background of Biogenic Lipid Matter in Aerosols over the Rural Western United States. *Atmos. Environ.* 16:2139–2159.

Surprenant, N.F., Battye, W., Roeck, D., and Sandberg, S.M. (1981). Emissions Assessment of Conventional Stationary Combustion Systems: Volume V. Industrial Combustion Sources. EPA-600/7-81-003c (PB81-225559), U.S. Environmental Protection Agency, Washington D.C.

Surprenant, N.F., Hall, R.R., McGregor, K.T., and Werner, A.S. (1979). Emissions Assessment of Conventional Stationary Combustion Systems: Volume I. Gas- and Oil-Fired Residential Heating Sources. EPA-600/7-79-029b, U.S. Environmental Protection Agency, Washington D.C.

Surprenant, N.F., Hung, P., Li, R., McGregor, K.T., Piispanen, W., and Sandberg, S.M. (1980). Emissions Assessment of Conventional Stationary Combustion Systems: Volume IV. Commercial/Institutional Combustion Sources. EPA-600/7-81-003b (PB81-145187), U.S. Environmental Protection Agency, Washington D.C.

Szkarlat, A.C., and Japar, S.M. (1983). Optical and Chemical Properties of Particle Emissions from On-Road Vehicles. *J. Air Pollut. Control Assoc.* 33:592–597.

U.S. Environmental Protection Agency (1971). Method 5—Determination of Particulate Emissions from Stationary Sources. *Federal Register* 36(247):24888–24890. December 23, 1971.

U.S. Environmental Protection Agency (1984). Method 5—Determination of Particulate Emissions from Stationary Sources. Code of Federal Regulations, Title 40—Protection of Environment, Part 60, pp. 436–455. Revised July 1, 1984. Superintendent of Documents, Washington, D.C.

Watson, J.G., Jr. (1979). Chemical Element Balance Receptor Model Methodology for Assessing the Sources of Fine and Total Suspended Particulate Matter in Portland, Oregon. Ph.D. Thesis, Oregon Graduate Center, Beaverton, Oregon.

Chapter 5

Mathematical Modeling of Organic Aerosol Characteristics: Features Observable by High-Resolution Gas Chromatography

5.1 INTRODUCTION

Determination of the source origin of the atmospheric organic aerosol poses serious challenges for both chemical analysis in the laboratory and for atmospheric modeling. Many of the problems encountered arise because the sources to be considered are so diverse. Carbon-containing particles are emitted directly from more than seventy different types of air pollution sources (Cass, Boone and Macias, 1982). Production of secondary organic aerosols resulting from atmospheric chemical reactions (Grosjean and Friedlander, 1975; Schuetzle *et al.*, 1975; Cronn *et al.*, 1977) further complicates source reconciliation studies.

Source-receptor relationships could be sought by receptor-oriented modeling approaches, in which stable organic compounds characteristic of particular source types are used as tracers to quantify the presence of a particular source's effluent in an ambient aerosol sample. Alternatively, source-oriented mathematical models for atmospheric transport and dilution could be used to calculate the combination of primary aerosol emissions that should be present at a particular air monitoring site. Even more advanced models could be envisioned that would account for gas-to-particle conversion processes that form secondary organics.

Progress towards development of each of these modeling approaches has been severely hampered by the lack of adequate data for testing model performance. Large differences exist in the methodologies that have been used by different research groups to collect, store and analyze both ambient aerosol samples and organic source emission samples (Daisey, Cheney and Lioy, 1986). Use of receptor models in which the easily measured polycyclic aromatic hydrocarbons (PAH) are employed to identify source contributions to ambient samples have been proposed (Friedlander, 1981). However, investigations into the chemical stability of commonly-measured organic species like the PAHs have given conflicting results, making the usefulness of these compounds for modeling work uncertain. Some investigators have found that flyash-adsorbed PAHs are relatively stable (Korfmacher *et al.*, 1979, 1980; Natusch and Taylor, 1980), while others have found substantial reactivity using diesel particulate PAHs (Van Vaeck and Van Cauwenberghe, 1984; Albrechcinski, Michalovic and Gibson, 1985) and wood smoke PAHs (Kamens *et al.*, 1985). Half lives on the order of days have been measured for ambient PAHs under exposure to ambient air (Miguel, 1983), NO_x (Butler and Crossley, 1981), and NO_2 (Brorstrom, Grennfelt and Lindskog, 1983), but another study showed no evidence of transformations of PAHs under exposure to NO_2, SO_2 or ozone (Grosjean, Fung and Harrison, 1983).

In the present study, the transport model developed by Cass (1977, 1981) and modified by Gray (1986) will be used to compute the mixture of organic aerosol contributed at Pasadena, downtown Los Angeles, and West Los Angeles by primary aerosol sources. The modeling study by Gray (1986) provides information on source-to-receptor transport relationships for each major organic aerosol source type in Los Angeles. Since these calculations are linear in emissions source strengths, the results may be rescaled on a source-by-source basis to reflect revised emission rate data for each source type, in order to compute source-to-receptor relationships for other scalar quantities that describe characteristics of the primary organic aerosol.

The model will be used to transport those characteristics of the primary organics sources that can be discerned from high resolution gas chromatography (HRGC) analysis of source emissions samples. Instead of relying on individual organic species that may be severely depleted by atmospheric chemical reactions, the approach taken here is to subdivide the entire extractable organic aerosol in both source emissions and in ambient samples into 48 independent groups of organic compounds (see Hildemann, Mazurek and Cass, 1989, for details), each of which will be tracked by the air quality model. Calculations are conducted as if the emissions are nonreactive, and discrepancies that could be due to atmospheric transformation are sought. Predictions based on source measurements of the amount of primary organic aerosol that is extractable and elutable under the HRGC conditions studied will be compared to HRGC analysis of the ambient fine organic aerosol samples. Model results will be presented separately for primary non-polar (neutral) and primary acidic organics. An upper limit on the amount of secondary organic aerosol present will be quantified, based on the difference between the fine aerosol organic acids fraction present in ambient samples versus the fine acidic fraction concentration due to direct primary organic aerosol emissions from sources. Then model predictions of the distribution of organic compounds due to primary source emissions will be compared to the distribution of compounds seen by HRGC analysis of ambient organic aerosol samples.

5.2 MODELING APPROACH

To predict the effect of primary organic aerosol emissions sources on ambient organics characteristics at sites in Los Angeles, the air quality model developed by Cass (1977, 1981) and modified by Gray (1986) will be used. In this model, ambient aerosol concentrations due to primary emissions sources are computed by a Lagrangian particle-in-cell technique.

Single mass points marked with the mass emission rate of organic carbon aerosol and elemental carbon aerosol are released to the atmosphere at measured time intervals from each source in the air basin. Depending on the plume rise characteristics of each source, the particles may be inserted either above or below the base of an elevated temperature inversion. Exchange of air parcels between the stable layer above the inversion base and the zone below the inversion base occurs as inversion base height changes on an hourly basis. For air parcels inserted below the inversion base, three different regimes are used to define the vertical distribution of pollutant particles: (1) sufficiently near a point source, the inversion base has no influence on the concentration distribution of emissions from that source, and pollutant concentrations assume a Gaussian distribution in the vertical domain; (2) far from the source, the emitted particles become fully mixed in the vertical dimension beneath the inversion base; and (3) between these two extremes, the inversion base influences the concentration profile of the emitted airborne particles. In the horizontal domain, trajectories of successive particles released from a source form streaklines downwind of that source, computed from the time sequence of the hourly ground level wind speed and direction observations plus a simulation of the effect of horizontal diffusion. Particle losses due to dry deposition also are computed.

The horizontal displacement of each particle at each hour then is paired with its probable location in the vertical dimension, and organic aerosol mass concentrations are computed by summing the contributions of all particles residing within the ground-level layer above a matrix of receptor cells that forms a grid over the air basin. Monthly average pollutant concentration increments, $\overline{\langle c \rangle}$, are computed for each source type at each receptor site, as follows:

$$\overline{\langle c(\mathbf{x};T,t_s)\rangle} = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\left[\frac{1}{T}\int_{t_s}^{t_s+T}\int_{0}^{\infty} Q(\mathbf{x},t|\mathbf{x}',t-\tau)\,\omega(t-\tau)\,d\tau\,dt\right]\bar{S}(\mathbf{x}')\,d\mathbf{x}' \qquad (5.1)$$

where

$Q(\mathbf{x},t\|\mathbf{x}',t-\tau)$	is the transition probability density function that describes the probability that a pollutant particle will be found in the small air volume $(\Delta x_1, \Delta x_2, \Delta x_3)$ surrounding location $\mathbf{x}$ at present time t given that it was released from location $\mathbf{x}'$ at time $t-\tau$;
$\omega(t-\tau)$	is the normalized diurnal variation in the emission rate for the source type of interest;
$\bar{S}(\mathbf{x}')$	is the spatial distribution of the monthly average pollutant emissions from the source class of interest;
t_s	is the starting time for the long time period over which concentrations will be averaged; and
T	is the length of that averaging time; in this case T equals one month.

By repeating this calculation for each source class in the air basin and then superimposing the results onto an estimate of aerosol carbon background air quality, a multiple source urban air quality model for long-term average primary aerosol carbon concentrations is obtained. Superposition is permitted because the primary aerosol carbon particle concentrations are modeled in a form that is linear in emissions.

In the study by Gray (1986), the mathematical model just described was applied to compute monthly average elemental carbon and total carbon concentrations over the western coastal plain of the Los Angeles Basin. Primary aerosol carbon emissions from 70 classes of mobile and stationary sources were estimated for each of 625 grid cells located within the 80 x 80 km study area shown in Figure 5.1.

The primary aerosol carbon increment due to each source type was computed based on hourly wind speed and direction data observed over central Los Angeles plus hourly mixing depths estimated from the morning and afternoon mixing depths reported by the South Coast Air Quality Management District. Concentration increments from all source types were summed, then added to the background aerosol carbon content of marine air measured upwind of the city at San Nicholas Island. Model predictions for elemental carbon concentrations were compared to ambient observations at seven monitoring sites in the study area, and good agreement between model predictions of primary aerosol concentrations and ambient observations was found. The emissions data, modeling procedures used, and comparison of model predictions to observations are thoroughly documented in the study by Gray (1986). Model results at Pasadena, CA have been published previously by Larson and co-workers (1989).

In the present study, characteristics of the ambient primary organic aerosol that are observable by high-resolution gas chromatography (HRGC) analysis were predicted by substituting the HRGC properties of the emissions source effluent into the source term $\bar{S}(\mathbf{x}')$ of the air quality model just described. Source tests conducted by dilution sampling and grab sampling for fourteen classes of primary organic aerosol sources provided samples that represent close to 80% of the primary emissions of fine organic aerosol to the Los Angeles atmosphere (see Hildemann, Markowski and Cass, 1989, for the source test program and mass emissions rate data). The fine organic particulate emissions from various sources were characterized by solvent extraction of the organic material, followed by high resolution gas chromatography. (See Hildemann, Mazurek and Cass, 1989, for details.) Two fractions of the organic extract were analyzed: one fraction analyzed by HRGC without derivatization was considered to represent the neutral (nonpolar) fraction; a second fraction, derivatized to convert acidic components to their methyl ester equivalents, also was injected to characterize the acid+neutral fraction. The difference between the results obtained from these two injections was considered

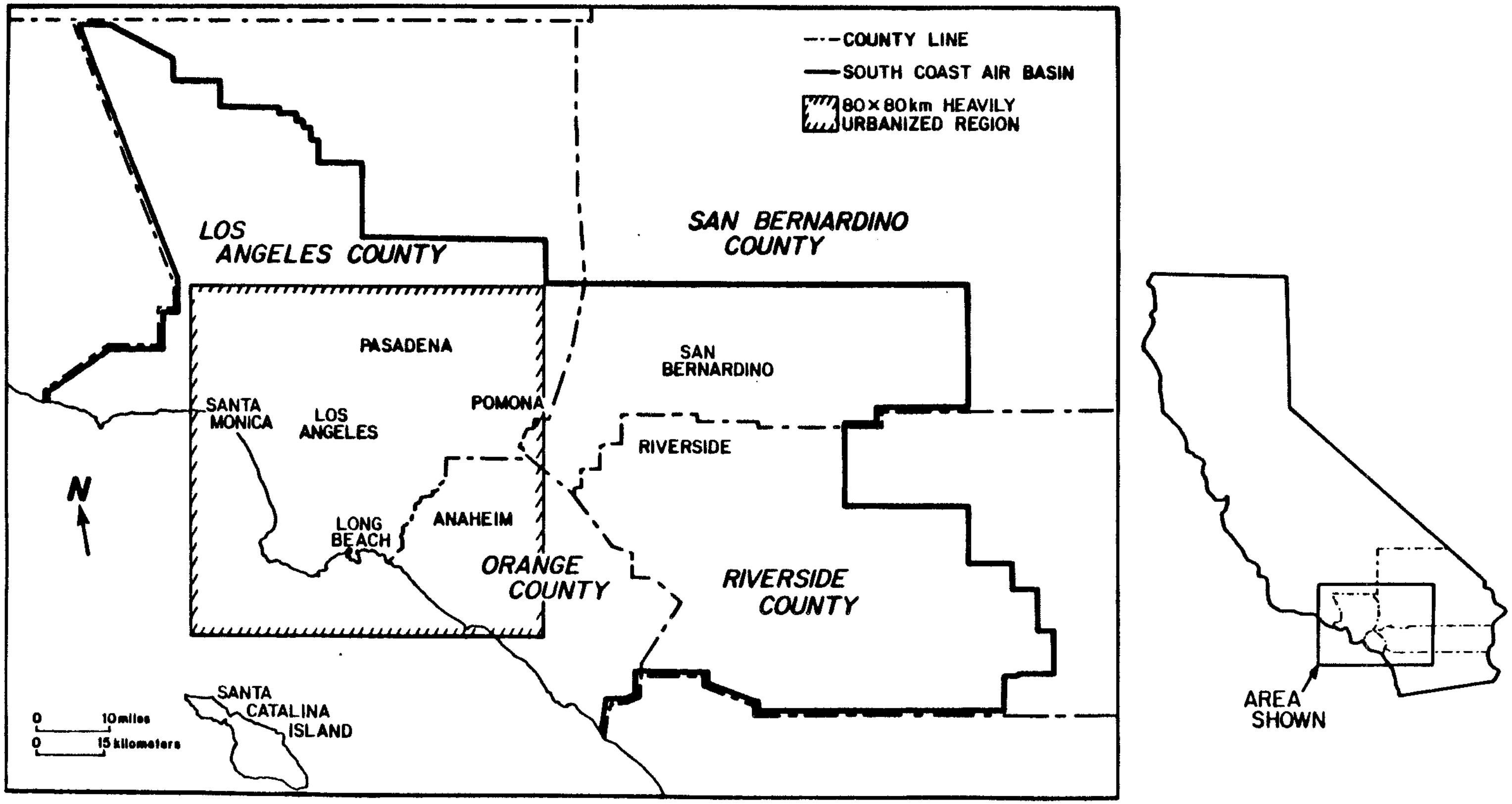

Figure 5.1 Los Angeles Basin modeling area (80 x 80 km).

to represent the acidic organic aerosol alone. The complex pattern of peaks representing hundreds of separate compounds emitted from each source was broken into subareas using the elution points of the C_{12} to C_{36} n-alkane series as dividing lines, and the organic mass contained in each subarea was calculated by summing the masses between each of the adjacent alkanes (see Hildemann, Mazurek and Cass, 1989). In this manner, the extractable organics mass emission rate from each source was broken down into 48 independent groups of neutral and acidic compounds.

Emission rate data then were supplied to the air quality model for each major source type, using emission source activity data from Gray's inventory (1986) (*e.g.*, the spatial distribution of km driven per day by catalyst-equipped automobiles) together with extractable organic mass emission rates from the present study (*e.g.*, μg fine neutral elutable organic aerosol between C12 and C13 emitted per km driven by catalyst-equipped automobiles). The model was used to compute the ambient fine particle concentrations at Pasadena, downtown Los Angeles and West Los Angeles for each month of the year 1982 that would be expected if primary emissions in each of the 48 categories of organic compounds were transported without chemical reaction. An estimate of background fine organic aerosol concentrations in 1982 for each group of organic compounds then was added to the source increments, based on characterization of the organic aerosol measured upwind of Los Angeles during 1982 at San Nicholas Island. Filter samples of the San Nicholas Island fine aerosol collected by Gray and co-workers (1986) were employed for this purpose. Due to the low levels of organic aerosol found there, filters collected over a period of several months were composited to give adequate organic concentrations for HRGC analysis. The San Nicholas Island (SNI) composite containing filters collected during the months of July, August and September, 1982, was used in the model to characterize April through September, while the composite consisting of filters collected during October, November and December was used to characterize the colder months of the year 1982.

Ambient fine aerosol samples for comparison to the air quality model predictions were prepared, using 24-hr average filter samples collected at 6-day intervals during 1982 by Gray *et al.* (1986). Monthly composites of ambient samples taken at Pasadena, downtown Los Angeles, and West Los Angeles were extracted, derivatized and quantified by HRGC, as described previously (Mazurek *et al.*, 1987, 1989). Organic compound concentrations falling into the 48 groups of nonpolar and acidic compounds defined between the elution points of the C_{12} to C_{36} n-alkane series were computed for comparison to the source-oriented air quality model results.

5.3 RESULTS

Source contributions to a large number of attributes of the primary organic aerosol can be evaluated by comparison of air quality model results to ambient data on the same aerosol attributes. First, the extent to which primary emissions of aerosol organic carbon can account for ambient organic aerosol carbon levels as measured by combustion techniques will be examined. Next, source–receptor relationships will be developed for that fraction of the primary organic aerosol that is solvent-soluble and that will elute from a HRGC column under the conditions of our experiments. Finally, the ability of the model to account for the distributions of organic compounds found in the ambient aerosol will be tested.

5.3.1 Organic Carbon.

In the study by Gray (1986), air quality model predictions for ambient elemental carbon and total carbon concentrations were compared to ambient observations at seven sites in the Los Angeles area for each month of the year 1982. Elemental carbon concentrations were closely reproduced by the model, as would be expected since fine particle elemental carbon concentrations are due entirely to direct primary emissions of carbon particles to the atmosphere. Surprisingly, air quality model predictions for total aerosol carbon also were in fairly close agreement with observed ambient concentrations.

If elemental carbon concentrations are subtracted from total aerosol carbon concentrations, the results of Gray (1986) also can be presented as modeled and measured ambient values of primary *organic* aerosol. Using the fine organic aerosol carbon inventory of Gray (1986), Figure 5.2 shows the results of the model on a month-by-month basis for the three ambient sites of interest here. (The vertical bars shown in Figure 5.2 represent the standard deviation of the 5 to 6 ambient samples collected during each month.) The seasonal variations measured, with peak levels in winter months, are reproduced fairly well by the model. The modeled concentrations

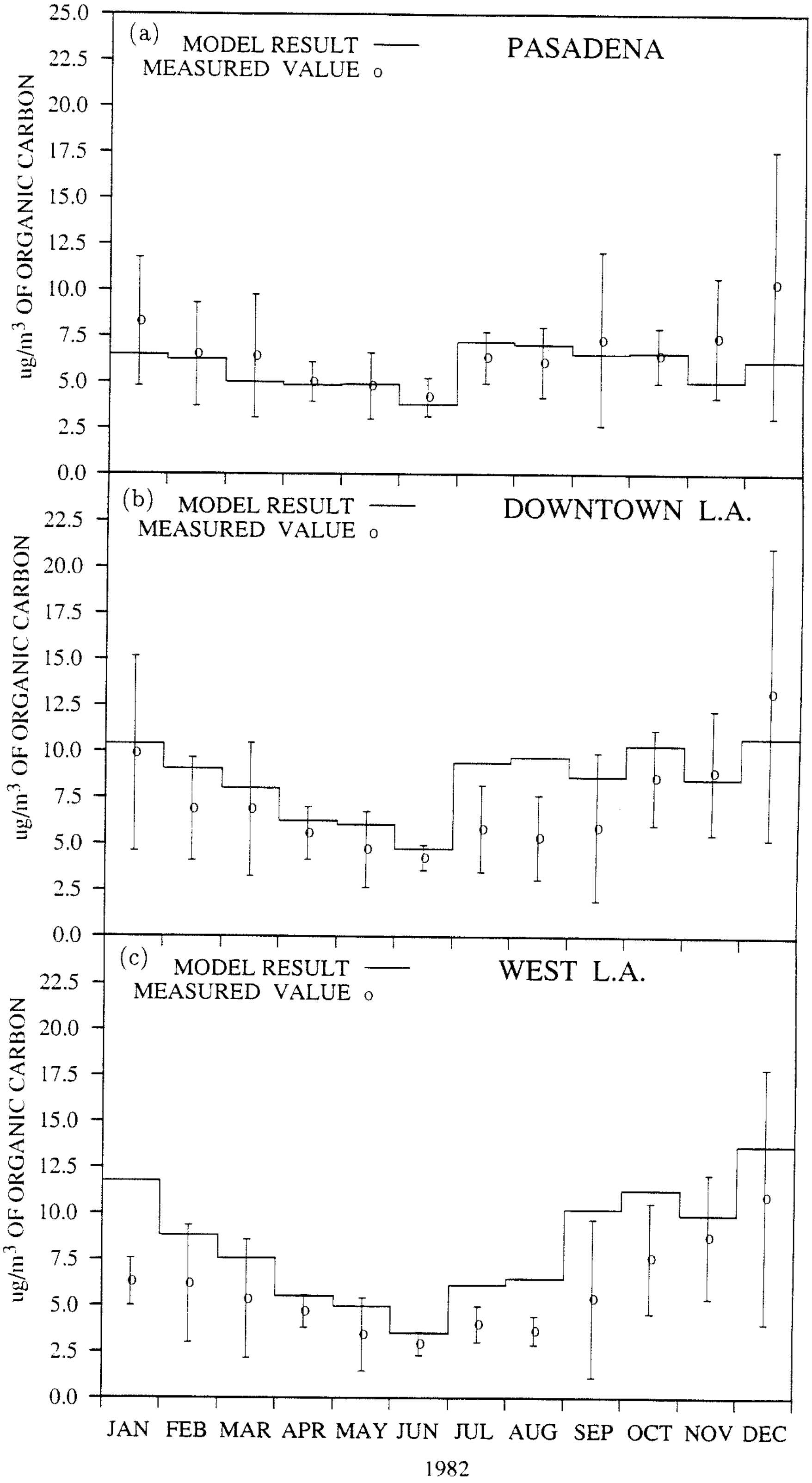

Figure 5.2 Modeled vs. measured monthly concentrations of total fine organic carbon at Los Angeles Basin ambient sites. (a) Pasadena; (b) Downtown Los Angeles; and (c) West Los Angeles.

agree well with measurements made at Pasadena, but tend to be higher than observations made at downtown Los Angeles and West Los Angeles. The absence of any obvious deficit in primary organic aerosol carbon concentrations computed by the transport model when compared to ambient organics concentrations suggests that most of the total aerosol organic carbon concentrations observed over long averaging times during 1982 were due to primary emissions of organic carbon particles rather than to secondary organic aerosol formation.

5.3.2 Elutable Organics.

A similar comparison can be presented for the fine organic particulate matter emissions that will elute through a GC column under the conditions of our experiments. This provides a separate test of model performance because for some sources, like the cigarettes and tar pot emissions, essentially all of the organic carbon is elutable, while for other sources, only a small fraction of the total fine organic carbon elutes through the column. In this case, however, only those sources contained in the model that were actually tested can be included in the modeled results; Table 5.1 lists the sources used in the model. The organic carbon emission inventory of Chapter 3 can be used along with the air quality model to calculate the fraction of the *organic carbon* that is represented by these measured sources. According to the inventory and the model, the combination of the background levels measured at San Nicholas Island plus the organic sources actually tested should account on an annual basis for 76% of the primary organic carbon at downtown Los Angeles, 79% at West Los Angeles, and 83% at Pasadena. If the source tests were applied to wider categories (for example, by using the compound distribution in natural gas home appliance emissions to represent all types of natural gas combustion, or the emissions from heavy-duty diesel trucks to represent all diesel engines), the fraction of the primary organic carbon represented by GC traces within the model would total 88% at downtown Los Angeles, 89% at West Los Angeles, and 91% at Pasadena.

Using the more conservative approach in which only those sources actually tested are represented within the model, model predictions for elutable organic aerosol are compared with ambient observations in Figure 5.3. In Figure 5.3abc, the neutral elutable organic material is plotted, while in Figure 5.3def, the acid+neutral

Table 5.1. Sources Used in the Modeling Calculations

Source Type	Used in Model	Notes
Distillate oil stationary sources		
— Industrial	X	
— Other		
Catalyst-equipped gasoline vehicles		
— Automobiles	X	
— Other vehicles		
Noncatalyst gasoline vehicles		
— Automobiles	X	
— Other vehicles		
Diesel vehicles		
— Heavy-duty trucks	X	
— Other vehicles		
Fireplaces		
— Soft wood	X	
— Hard wood	X	
— Synthetic log		(b)
Natural gas combustion		
— Residential sources	X	
— Other sources		
Meat Cooking Operations		
— Charcoal broiling	X	(a)
— Frying		(b)
Paved road dust	X	
Brake lining	X	
Cigarettes	X	
Roofing tar pot	X	
Tire wear	X	(c)
Vegetative detritus		(b)

(a) Only commercial cooking emissions were used by the model.

(b) This source was not used by the model.

(c) A total particulate matter sample was used for this source.

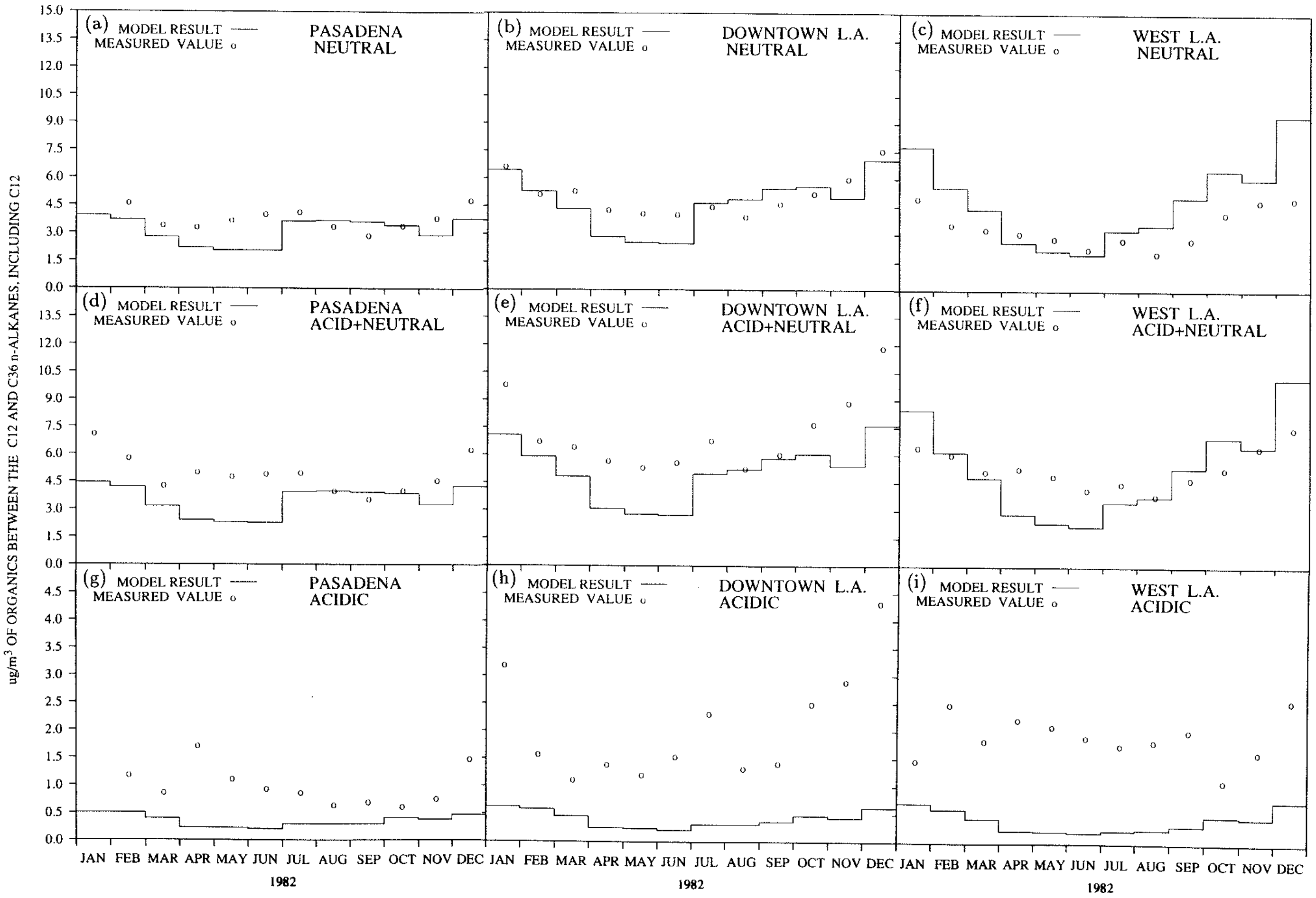

Figure 5.3 Modeled vs. measured monthly concentrations of elutable fine organics between the C12 and C36 n-alkanes at Los Angeles Basin ambient sites. (a) Pasadena, neutral fraction; (b) Downtown Los Angeles, neutral fraction; (c) West Los Angeles, neutral fraction; (d) Pasadena, acid+neutral fraction; (e) Downtown Los Angeles, acid+neutral fraction; (f) West Los Angeles, acid+neutral fraction; (g) Pasadena, acidic fraction; (h) Downtown Los Angeles, acidic fraction; and (i) West Los Angeles, acidic fraction.

fraction of the organic aerosol is shown. The results for both of these fractions show reasonable agreement between the modeled and the measured values, with a seasonal peak in the concentrations seen in the winter months for both the measurements and the model predictions. In Figure 5.3ghi, the results for the acidic fraction alone (computed as the difference between the neutral and acid+neutral fractions) are shown. For this fraction, the agreement between the modeled and measured values is poor. The model, based solely on primary emissions, consistently and substantially underpredicts the concentrations of aerosol organic acids. This indicates that, for the sources measured, the acidic organics emitted as primary material are not sufficient to account for the concentrations of acidic aerosol organics measured at these ambient sites. Even if *all* the organic material emitted by the unmeasured sources were in the form of elutable acidic organics, there would not be sufficient primary emissions to account for the large differences between modeled primary and ambient aerosol organic acids seen at downtown Los Angeles and West Los Angeles. Hence, it appears that secondary processes in the atmosphere plus the organic acids present in airborne vegetative detritus (for which emission rates are not known) are contributing substantially to the acidic fraction of the organic aerosol seen at the ambient sites.

Primary organic acids concentrations computed from the air quality model can be subtracted from the measured ambient fine organic acids aerosol concentrations, as shown in Table 5.2. From the data obtained, it is possible to place an upper limit on the long-term average organic acids concentration that could be due to formation of fine secondary organic aerosol.

On an annual basis, the difference between modeled primary and total measured acids in the fine aerosol averages 0.6, 1.6, and 1.5 μg m^{-3} at Pasadena, downtown Los Angeles and West Los Angeles, respectively. This can be compared to an average concentration of *total* fine organics (1.2 x OC measured by combustion) of 8.0, 8.6, and 6.9 μg m^{-3}, respectively, showing that secondary organic acids constitute no more than 9%, 19% and 26% of the total fine organic aerosol present on an annual basis at these three sites. This finding is consistent with the inference of Gray and co-workers (1986), based on total carbon to elemental carbon ratios, that secondary organic aerosol constituted on average no more than 27 to 38% of the total fine organics present at Los Angeles area monitoring sites during 1982.

Table 5.2. Extent of Excess Ambient Elutable Acidic Organic Aerosol

SITE Month	Excess of Elutable Organic Acids $^{(a)}$ ($\mu g/m^3$)	Total Fine Ambient Organic Aerosol $^{(b)}$ ($\mu g/m^3$)	Fine Elutable (Acid+Neutral) Ambient Organic Aerosol ($\mu g/m^3$)	Excess / Total Fine Ambient Organic Aerosol (%)	Excess / Fine Elutable Ambient Organic Aerosol (%)
PASADENA					
Jan	—	9.94	7.07	—	—
Feb	0.67	7.85	5.76	8.5	11.6
Mar	0.46	7.73	4.24	6.0	10.8
Apr	1.46	6.07	4.98	24.0	29.3
May	0.88	5.78	4.74	15.2	18.6
Jun	0.71	5.06	4.88	14.0	14.5
Jul	0.55	7.66	4.95	7.2	11.1
Aug	0.34	7.37	3.97	4.6	8.6
Sep	0.39	8.82	3.51	4.4	11.1
Oct	0.20	7.78	3.97	2.6	5.0
Nov	0.37	8.93	4.53	4.1	8.2
Dec	0.99	12.42	6.21	8.0	15.9
Average	0.64	7.95	4.90	9.0	13.2
DOWNTOWN L.A.					
Jan	2.37	11.88	9.81	19.9	24.2
Feb	0.96	8.28	6.70	11.6	14.3
Mar	0.66	8.26	6.41	8.0	10.3
Apr	1.16	6.72	5.67	17.3	20.5
May	0.97	5.69	5.32	17.1	18.2
Jun	1.32	5.16	5.57	25.6	23.7
Jul	2.06	7.03	6.78	29.3	30.4
Aug	1.05	6.46	5.25	16.3	20.0
Sep	1.07	7.15	6.02	15.0	17.8
Oct	1.98	10.39	7.68	19.1	25.8
Nov	2.42	10.70	8.86	22.6	27.3
Dec	3.53	15.86	11.83	22.3	29.8
Average	1.63	8.63	7.16	18.7	21.9
WEST L.A.					
Jan	0.83	7.56	6.40	11.0	13.0
Feb	1.88	7.44	6.02	25.3	31.2
Mar	1.38	6.43	5.13	21.5	26.9
Apr	1.98	5.64	5.30	30.8	37.4
May	1.87	4.15	4.93	45.0	37.9
Jun	1.70	3.53	4.15	48.2	41.0
Jul	1.46	4.80	4.53	30.4	32.2
Aug	1.52	4.39	3.86	34.6	39.4
Sep	1.66	6.48	4.77	25.6	34.8
Oct	0.66	9.10	5.30	7.3	12.5
Nov	1.22	10.51	6.48	11.6	18.8
Dec	1.95	13.14	7.52	14.8	25.9
Average	1.51	6.94	5.37	25.5	29.3

(a) Calculated as the difference between the measured ambient concentration and the model prediction.

(b) Calculated as 1.2 x the organic carbon concentration as measured by combustion analysis.

Alternatively, this deficit in acidic organics can be compared to *elutable* fine organics measured at these three sites, which averaged 4.9, 7.2, and 5.4 μg m^{-3}. On this basis, secondary organic acids constitute no more than 13%, 22%, and 29% of the elutable fine organic aerosol present on a yearly average at the three sites. Both of these approaches demonstrate that the bulk of the fine organic aerosol in the Los Angeles Basin over long averaging times during 1982 was primary in origin, explaining why the monthly model predictions using primary organic aerosol emissions are in good agreement with ambient aerosol measurements, both using total fine organic carbon (Figure 5.2) and fine elutable organics (Figure 5.3).

5.3.3 Mass Distribution of Elutable Organics.

Monthly composites of ambient organic aerosol samples from each of the three monitoring sites studied were analyzed by HRGC. The mass concentration of organic species that elute between each of the normal alkanes in the range C_{12} to C_{36} was determined for both the neutral and the acid+neutral fractions previously described for the source samples. Since most of the source samples were taken in or near Pasadena, the Pasadena air monitoring site was selected to be examined in detail. Figure 5.4 presents the mass distribution results for the Pasadena site for each month of the year 1982. It is observed that both the neutral and the acid+neutral fractions display a bimodal distribution, with the peak of the first mode occurring between C16 and C23, and the second mode peaking between C25 and C32. The previously-observed wintertime peak in elutable organics concentrations is due mainly to the substantial fluctations seen in the intensity of the second mode. A substantial quantity of acidic organics is also observed, with most of the acidic organics mass concentration occurring in the C16 to C23 range.

The mass distribution of elutable organics due to primary aerosol sources was computed from the air quality model at the Pasadena site for each month of the year 1982. Results for the neutral and acid+neutral fractions for each month are presented in Figure 5.5. The degree of agreement between model results and ambient measurements of the neutral fraction mass distributions is encouraging, especially if one adjusts the modeled distributions vertically by the amount necessary to adjust for the differences between measured and modeled *total* elutable organics that are shown in Figure 5.3. (Recall that the modeled concentrations are based on transport

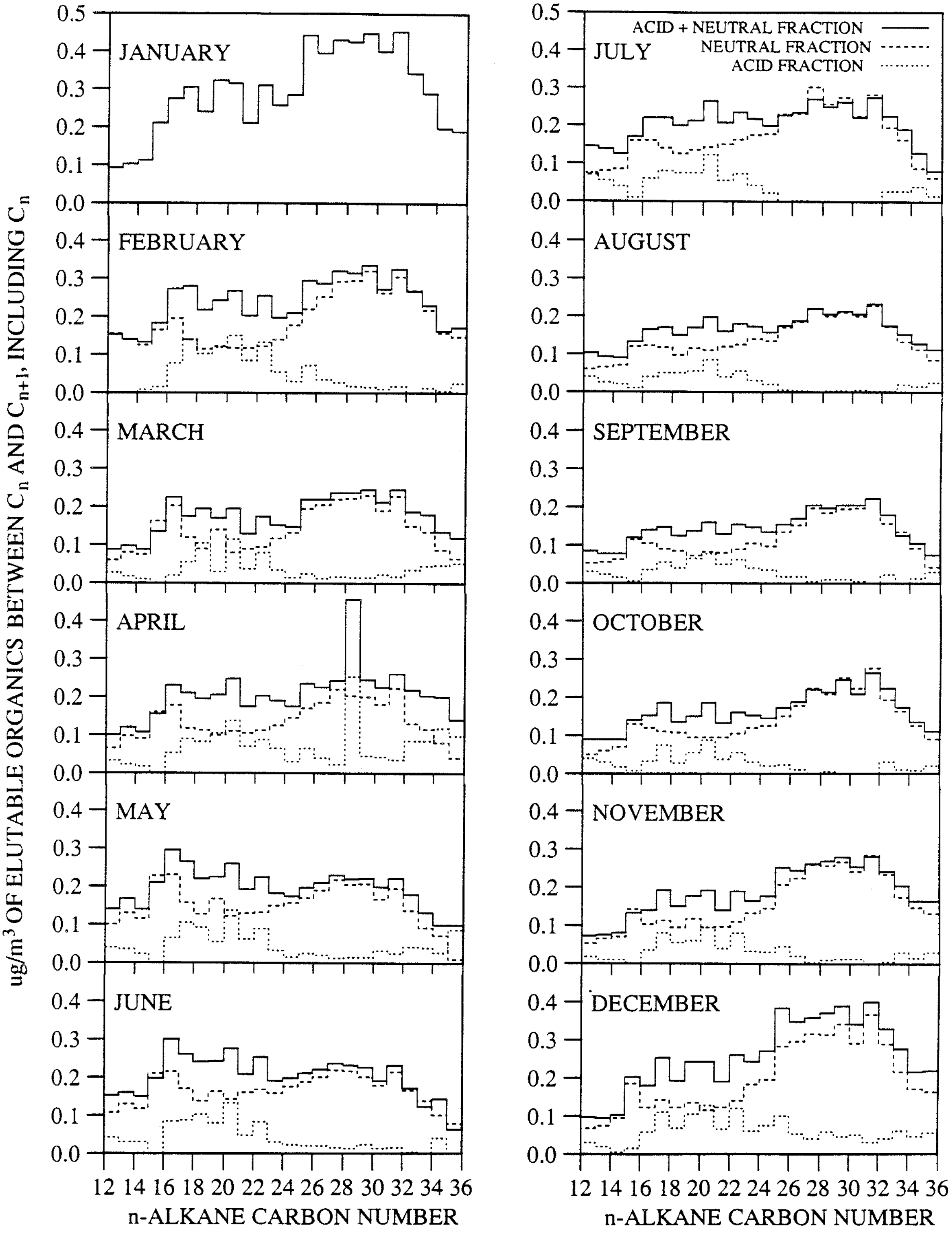

Figure 5.4 Measured monthly elutable fine organic mass distributions for Pasadena in 1982.

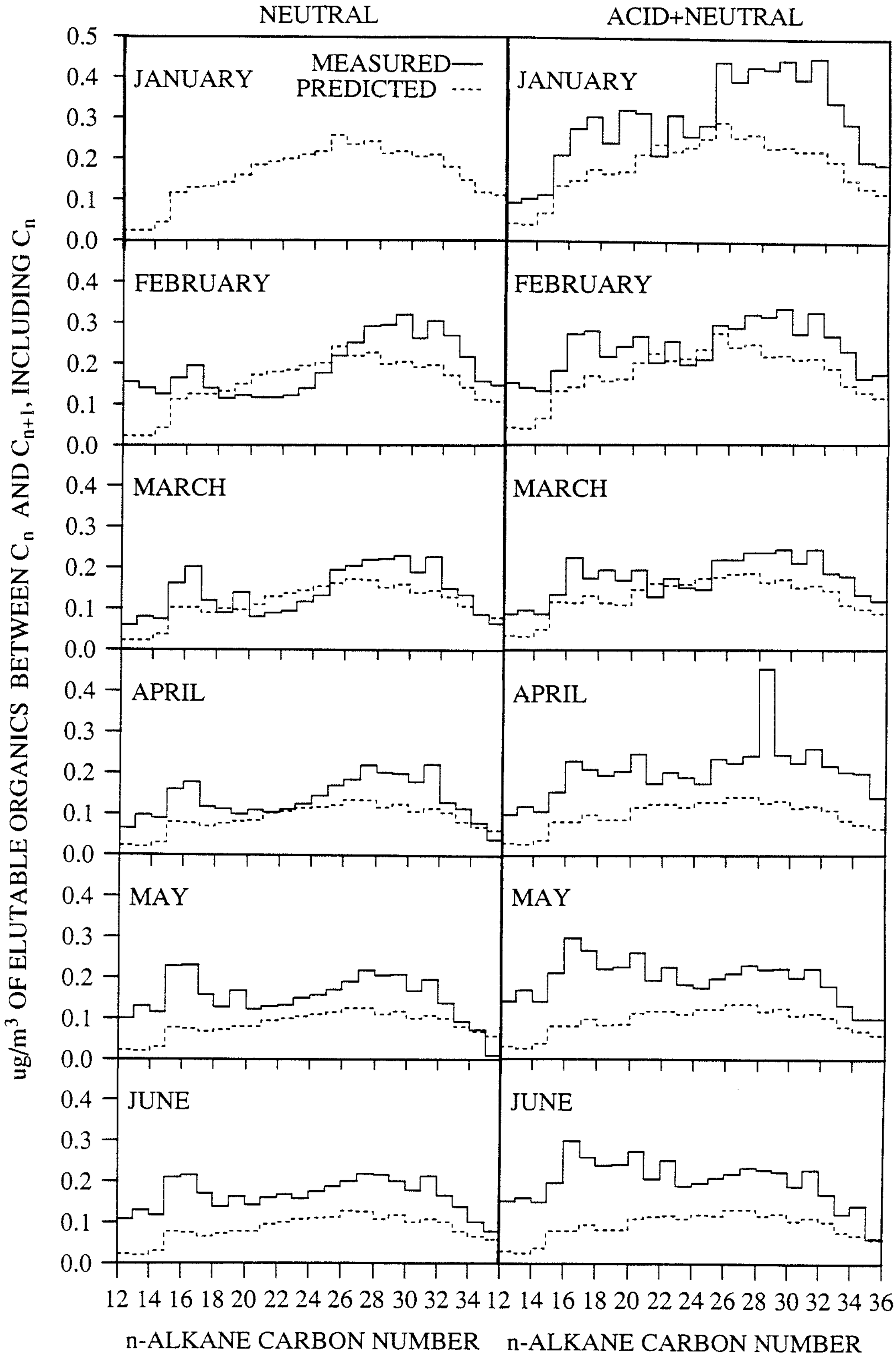

Figure 5.5 Comparison between modeled and measured organic mass distributions for Pasadena in 1982: neutral and acid+neutral fractions.

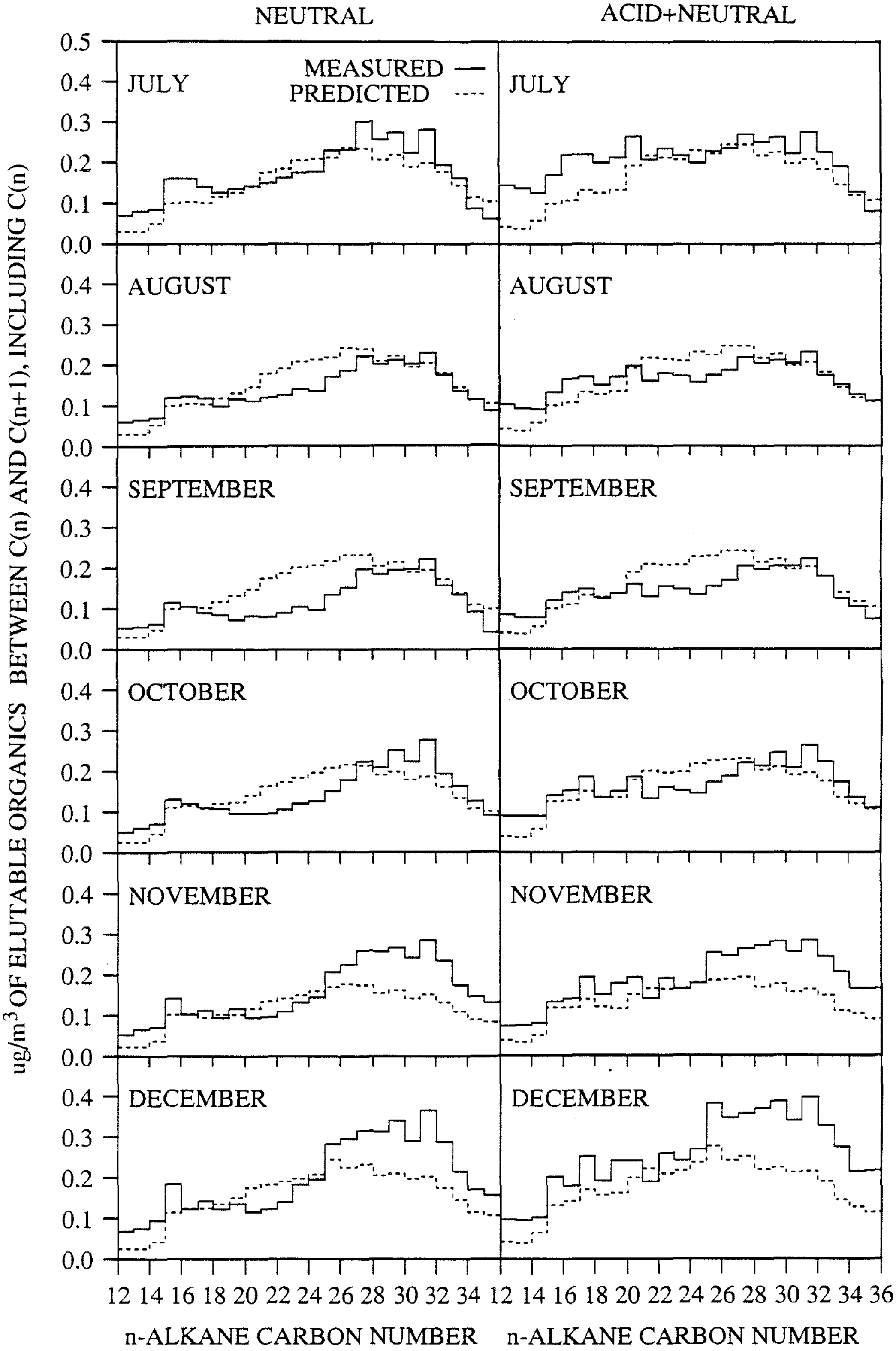

Figure 5.5 Comparison between modeled and measured organic mass distributions for Pasadena in 1982: neutral and acid+neutral fractions (cont.).

calculations for each hour of the month while measured concentratison represent a composite of only six days of the month; hence perfect agreement on total mass concentration is not expected.) Thus, the model predictions for September are higher than observed, while the May, June and December model results may be expected to be somewhat lower than the observations. The general shape of the modeled neutral fraction mass distributions is quite close to observations during March, July, August and October when both the measured and modeled total elutable organics concentrations are in close agreement.

Some characteristic differences between the model predictions and the ambient measurements for the Pasadena site can be discerned. The neutral modeled mass distributions tend to be lower than observations in the C12 to C18 range. As a result, the model does not show the bimodal distribution apparent in the ambient samples. Also for the neutral fraction, the model tends to overpredict the amount of organics mass between C20 and C25. (While agreement between the two results for the acid+neutral fraction plots appears to be better between C20 and C25, the model predicts that most of the organics in that region are neutral, while the measured values indicate that a significant portion of the organics mass in that region consists of acidic organics.)

The model results for the acidic fraction, shown in Figure 5.6, significantly underestimate the amount of acidic organics present in the Pasadena atmosphere. In particular, the high concentration of acidic organics that elute between the C16 and C23 n-alkanes in the ambient samples are not represented by primary emission sources that are included in the model. Primary emissions from most of the sources tested contained little or no acidic organics; hence, most of the acidic organic material appearing in the modeled result is attributable to background aerosol as measured at San Nicholas Island (see Figure 5.6).

Three hypotheses can be offered to account for the difference between measured acidic organics vs. the modeled contribution due to anthropogenic primary emissions plus background. First, the organics acids needed to complete a material balance on the acidic aerosol could result from reactions of gas-phase molecules to form aerosol phase products that elute in the acidic fractions. This is the traditional view that secondary aerosol from gas-phase precursors is responsible for most of the organic acids (Grosjean and Friedlander, 1975; Schuetzle *et al.*,

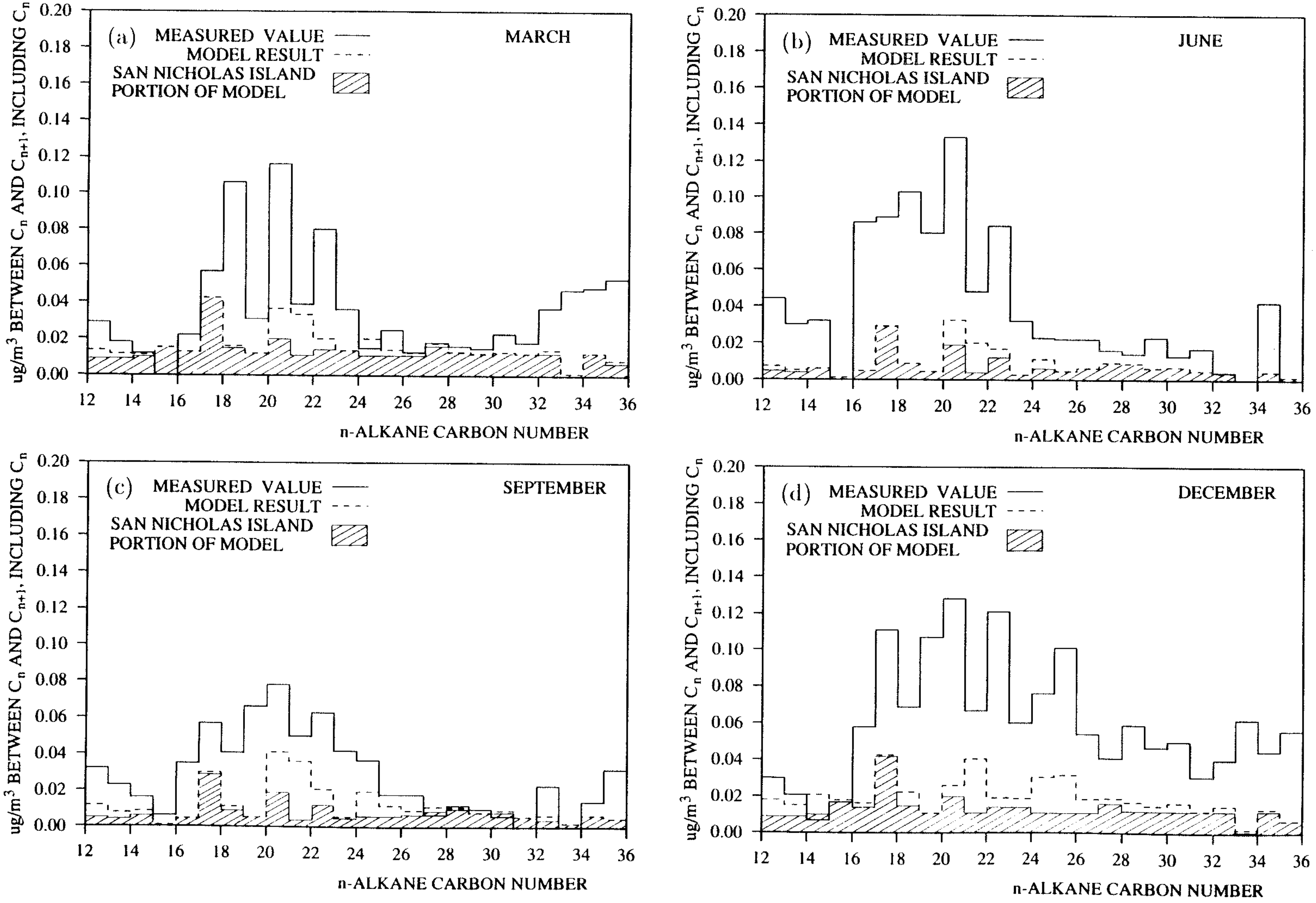

Figure 5.6 Comparison between modeled and measured organic mass distributions for Pasadena in 1982: acidic fraction. (a) March; (b) June; (c) September; and (d) December.

1975; Cronn *et al.*, 1977). However, two other possibilities also exist. Since the tendancy of the model is to overpredict the neutral mass between C20 and C25, it is possible that the primary particulate emissions of neutral organics in this region are especially reactive, and react in the atmosphere to form acidic aerosol products. Finally, acids contributed by the primary emission of organic vegetative detritus due to leaf abrasion have been noted as a further important contributor to the primary aerosol (Mazurek, Cass and Simoneit, 1989; Hildemann, Mazurek and Cass, 1989), but those emission are not included in the transport model because their emission rate is not known.

5.3.4 Source Contributions to Model Predictions.

The contributions of elutable fine organic particulate matter from the different sources to the model predictions can also be examined. In Figure 5.7, the sources contributing to the elutable organics mass predicted for each month are shown for each of the three sites.

One important factor influencing the predicted organics mass concentration at an ambient site on a given month is the meteorological conditions. The model reflects the fact that some sources, like motor vehicles, emit at a nearly constant rate throughout the year, yet the contributions of motor vehicle emissions to the predicted ambient concentrations of elutable organics can be seen to vary by a factor of two to four over the year. In the Los Angeles Basin, two meteorological phenomena influence the seasonal concentrations of primary carbonaceous aerosol at ambient monitoring sites. First, the early morning inversion base height tends to be substantially lower in the winter months than during the summer. As a result, the emissions that occur during morning rush hour traffic remain more highly concentrated during the winter. Secondly, air mass motion in the Basin is from the ocean to the land during the hot summer months, but reverses its direction in the wintertime. In Pasadena, these factors work in opposing directions: while the lower winter morning inversion base tends to concentrate ground-level source emissions, the reversal of the net wind direction tends to transport fewer emissions from upwind areas into Pasadena in the winter than in the summer. In contrast, for the West Los Angeles site, these factors work together to make pollutant concentrations much higher in the wintertime than during the summer: West Los Angeles is downwind

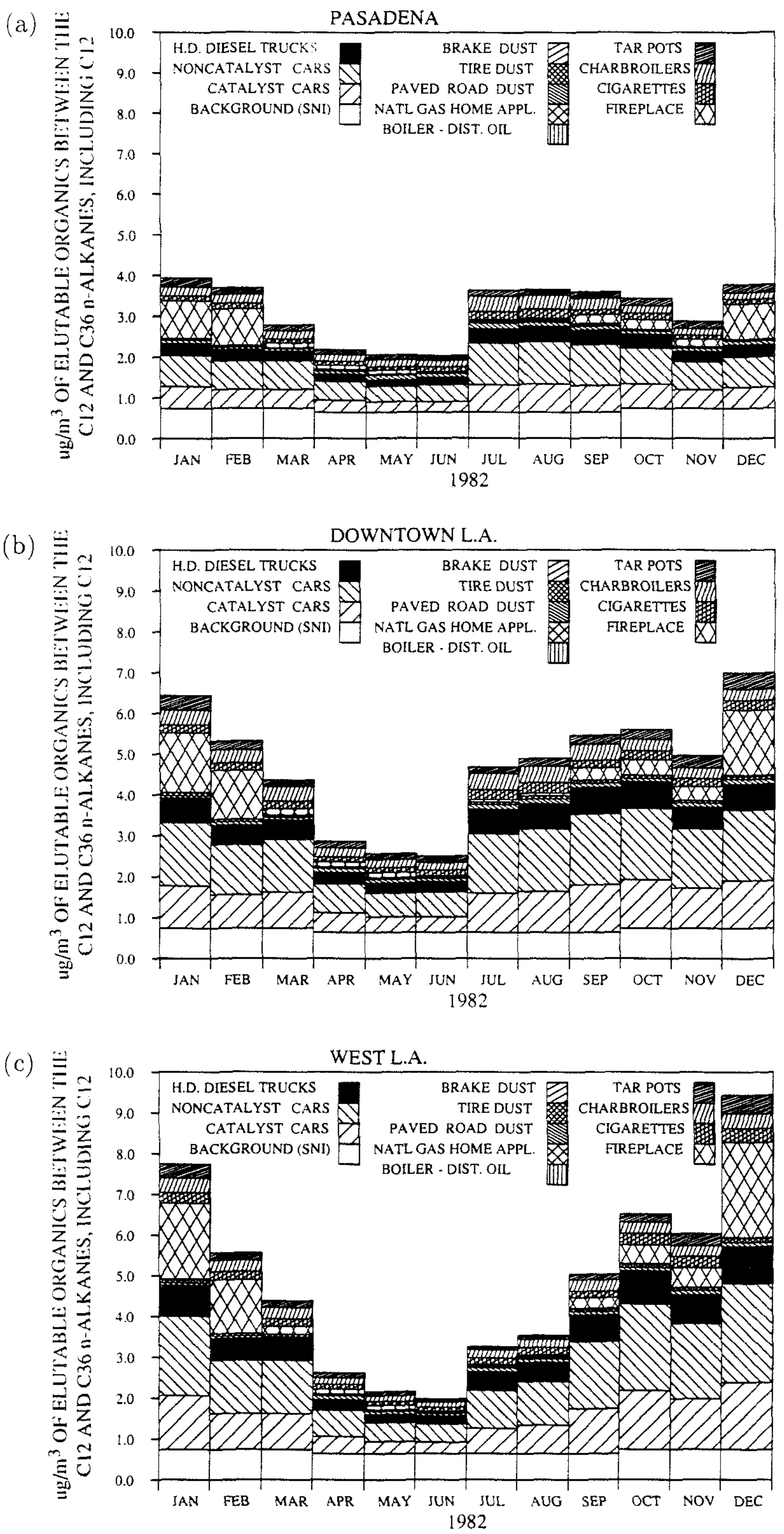

Figure 5.7 Contributions of sources to modeled concentrations of elutable acid+neutral organics at Los Angeles Basin ambient sites in 1982. (a) Pasadena; (b) Downtown Los Angeles; and (c) West Los Angeles.

of the City of Los Angeles during the winter. As can be seen in Figures 5.2 and 5.7, the seasonal variations in the model predictions and in measured air quality are extreme at the West Los Angeles site, while there is little seasonal variation at the Pasadena site.

A second factor influencing the predicted seasonality of the elutable organics mass concentrations in ambient air is the variation of some source emissions with season. As seen in Figure 5.7, emissions from fireplaces contribute a substantial fraction of the total modeled elutable organics in the winter months, but are almost nonexistant contributors to the aerosol during the summer months. Due to the net offshore flow of the Basin airmass in the wintertime, the impact of fireplace emissions on ambient air quality is most apparent at the West Los Angeles site.

The influence of the different emission sources on the actual distribution of the extractable organics mass between C12 and C36 also can be determined. In Figure 5.8, the sources contributing to the organics mass distribution predicted for Pasadena are shown for 4 different months of the year. Surprisingly, the organics found between C15 and C17 are mainly the result of background organics already present in the air mass as it passes over San Nicholas Island. As the model underpredicts aerosol concentrations in the elution range of the C15 to C17 n-alkanes, it may be that additional organics like those found in San Nicholas Island background air (*e.g.*, from grasses, which cover the island) may be added to air parcels as they move inland over the Los Angeles area. The appearance of a hump in the modeled mass distribution with a peak around C27 is seen to result mainly from automotive emissions. This hump becomes even more pronounced in the December plot as the fireplace emissions become a significant part of the total elutable organics mass concentration.

5.4 CONCLUSIONS

An atmospheric transport model was used to predict the organic characteristics of fine primary particulate matter at ambient monitoring sites in the Los Angeles area, as they would appear if the primary organic aerosol emissions are transported without further chemical reaction. The source samples and ambient aerosol samples

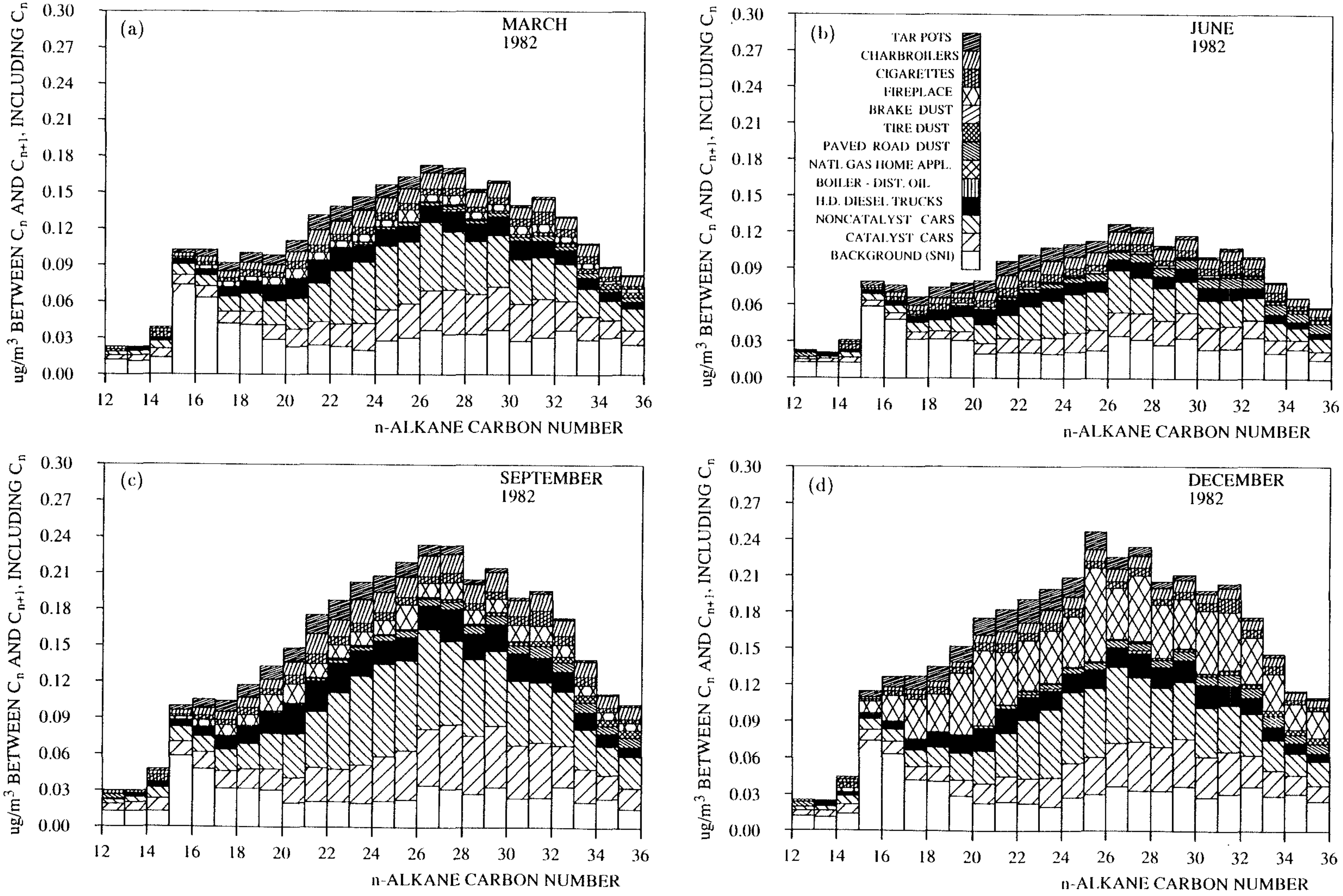

Figure 5.8 Contributions of elutable acid+neutral organics from sources to modeled organic mass distributions for Pasadena in 1982. (a) March; (b) June; (c) September; and (d) December.

were collected and analyzed by compatible methods so that accurate comparisons can be drawn between predicted and observed organic aerosol properties.

The neutral fraction of the organic aerosol can be attributed with reasonable accuracy to known primary emissions sources plus background air quality. Results show that the model tracks the seasonal variations observed in the neutral fraction of the ambient organics measurements. The predicted concentrations obtained are close to observed values. However, model calculations do overpredict the amount of neutral organics that elute in the range between the elution points of the C20 and C25 n-alkanes. Finally, the model results show a hump of elutable organics that peak in the elution range of the C27 n-alkane, which is shown to result mainly from inputs from motor vehicles. This hump becomes more pronounced in the winter months, when emissions from fireplaces become significant.

Although some organic acids are emitted from primary aerosol sources (see Hildemann, Mazurek and Cass, 1989), these primary emissions are insufficient to account for the ambient organic acids concentrations measured during this study. The anthropogenic primary source contributions to the Los Angeles ambient acidic organic aerosol has been quantified in the course of this work. Primary organic aerosol from the anthropogenic aerosol sources studied here is estimated to contribute only 0.35, 0.42, and 0.41 $\mu g/m^3$ to the 0.97, 2.06, and 1.92 $\mu g/m^3$ of acidic organics measured at Pasadena, downtown Los Angeles and West Los Angeles, respectively, during the year 1982. Organic acids present in background air as measured at San Nicholas Island contributed 0.19 $\mu g/m^3$ to the annual average elutable fine organic acids in the aerosol phase. Some of the apparent excess of ambient organic acid aerosols will be explained once the contribution of plant fragments to the aerosol has been determined based on matching the biomarkers present in vegetative source samples to their abundance in the ambient aerosol (see Mazurek, Cass and Simoneit, 1988, 1989; Hildemann, Mazurek and Cass, 1989). The remaining acidic organics needed to explain the ambient organic acids concentrations result from reactions in the atmosphere, involving either gas-phase reactants or perhaps apparent excess neutral aerosol organics that elute in the range between the C20 and C25 normal alkanes.

5.6 REFERENCES

Albrechcinski, T.M., Michalovic, J.G., and Gibson, T.L. (1985). A Smog Chamber Study of Polycyclic Aromatic Hydrocarbons in Diesel Particulates. In *Polycyclic Aromatic Hydrocarbons: Mechanisms, Methods and Metabolism* (M. Cooke and A.J. Dennis, eds.). Batelle Press, Columbus, Ohio, pp. 69–86.

Brorstrom, E., Grennfelt, P., and Lindskog, A. (1983). The Effect of Nitrogen Dioxide and Ozone on the Decomposition of Particle-Associated Polycyclic Aromatic Hydrocarbons During Sampling From the Atmosphere. *Atmos. Environ.* 17:601–605.

Butler, J.D., and Crossley, P. (1981). Reactivity of Polycyclic Aromatic Hydrocarbons Adsorbed on Soot Particles. *Atmos. Environ.* 15:91–94.

Cass, G.R. (1977). Methods for Sulfate Air Quality Management with Applications to Los Angeles. Ph.D. thesis, California Institute of Technology, Pasadena, California.

Cass, G.R. (1981). Sulfate Air Quality Control Strategy Design. *Atmos. Environ.* 15:1227–1249.

Cass, G.R., Boone, P.M., and Macias E.S. (1982). Emissions and Air Quality Relationships for Atmospheric Carbon Particles in Los Angeles. In *Particulate Carbon: Atmospheric Life Cycle* (G.T. Wolff and R.L. Klimisch, eds.). Plenum Press, New York, pp. 207–240.

Cronn, D.R., Charlson, R.J., Knights, R.L., Crittenden, A.L., and Appel, B.R. (1977). A Survey of the Molecular Nature of Primary and Secondary Components of Particles in Urban Air by High-Resolution Mass Spectrometry. *Atmos. Environ.* 11:929–937.

Daisey, J.M., Cheney, J.L., and Lioy, P.J. (1986). Particulate Emissions from Air Pollution Sources: Status and Needs for Receptor Source Apportionment Modeling. *J. Air Pollut. Control Assoc.* 36:17–33.

Friedlander, S.K. (1981). New Developments in Receptor Modeling Theory. In *Atmospheric Aerosol: Source/Air Quality Relationships* (E.S. Macias and P.K. Hopke, eds.). American Chemical Society, Washington, D.C., pp. 1–19.

Gray, H.A. (1986). Control of Atmospheric Fine Primary Carbon Particle Concentrations. EQL Report 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, California.

Gray, H.A., Cass, G.R., Huntzicker, J.J., Heyerdahl, E.K., and Rau, J.A. (1986). Characteristics of Atmospheric Organic and Elemental Carbon Particle Concentrations in Los Angeles. *Environ. Sci. Technol.* 20:580–589.

Grosjean, D., and Friedlander, S.K. (1975). Gas-Particle Distribution Factors for Organic and Other Pollutants in the Los Angeles Atmosphere. *J. Air Pollut. Control Assoc.* 25:1038–1044.

Grosjean, D., Fung, K., and Harrison, J. (1983). Interactions of Polycyclic Aromatic Hydrocarbons with Atmospheric Pollutants. *Environ. Sci. Technol.* 17:673–679.

Hildemann, L.M., Markowski, G.R., and Cass, G.R. (1989). Emissions from Important Sources of Organic Aerosol. *To be published.* [See Chapter 3.]

Hildemann, L.M., Mazurek, M.A., and Cass, G.R. (1989). Quantitative Characterization of Organic Aerosol Source by High-Resolution Gas Chromatography. *To be published.* [See Chapter 4.]

Korfmacher, W.A., Natusch, D.F.S., Taylor, D.R., Wehry, E.L., and Mamantov, G. (1979). Thermal and Photochemical Decomposition of Particulate PAH. In *Polynuclear Aromatic Hydrocarbons: Carcinogenesis and Mutagenesis* (P.W. Jones and P. Leber, eds.). Batelle Press, Columbus, Ohio, pp. 165–170.

Korfmacher, W.A., Wehry, E.D., Mamantov, G., and Natusch, D.F.S. (1980). Resistance to Photochemical Decomposition of Polycyclic Aromatic Hydrocarbons Vapor-Adsorbed on Coal Fly Ash. *Environ. Sci. Technol.* 14:1094–1099.

Kamens, R., Bell, D., Dietrich, A., Perry, J., Goodman, R., Claxton, L., and Tejada, S. (1985). Mutagenic Transformations of Dilute Wood Smoke Systems in the Presence of Ozone and Nitrogen Dioxide. Analysis of Selected High Pressure Liquid Chromatography Fractions from Wood Smoke Particle Extracts. *Environ. Sci. Technol.* 19:63–69.

Larson, S.M., Cass, G.R., and Gray, H.A. (1989). Atmospheric Carbon Particles and the Los Angeles Visibility Problem. *Aerosol Sci. Technol.* 10:118–130.

Mazurek, M.A., Cass, G.R., and Simoneit, B.R.T. (1988). Quantification of the Source Contributions to Organic Aerosols in the Remote Desert Atmosphere. Final Report to the Electric Power Research Institute, Palo Alto, California.

Mazurek, M.A., Cass, G.R., and Simoneit, B.R.T. (1989). Interpretation of High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Data Acquired from Atmospheric Organic Aerosol Samples. *Aerosol Sci. Technol.* 10:408–420.

Mazurek, M.A., Simoneit, B.R.T., Cass, G.R., and Gray, H.A. (1987). Quantitative High-Resolution Gas Chromatography and High-Resolution Gas Chromatography/Mass Spectrometry Analyses of Carbonaceous Fine Aerosol Particles. *Intern. J. Anal. Chem.* 29:119-139.

Miguel, A.H. (1983). Atmospheric Reactivity of Polycyclic Aromatic Hydrocarbons Associated with Aged Urban Aerosols. In *Polycyclic Aromatic Hydrocarbons: Formation, Metabolism and Measurement* (M. Cooke and A.J. Dennis, eds.). Batelle Press, Columbus, Ohio, pp. 897–904.

Natusch, D.F.S., and Taylor, D.R. (1980). Environmental Effects of Western Coal Combustion: Part IV — Chemical and Physical Characteristics of Coal Fly Ash. EPA-600/3-80-094, U.S. Environmental Protection Agency, Duluth, Minnesota.

Schuetzle, D., Cronn, D., Crittenden, A.L., and Charlson, R.J. (1975). Molecular Composition of Secondary Aerosol and its Possible Origin. *Environ. Sci. Technol.* 9:838–845.

Van Vaeck, L., and Van Cauwenberghe, K. (1984). Conversion of Polycyclic Aromatic Hydrocarbons on Diesel Particulate Matter upon Exposure to PPM Levels of Ozone. *Atmos. Environ.* 18:323–328.

Chapter 6

Conclusions

6.1 SUMMARY OF RESULTS

A dilution stack sampler specifically intended to collect fine organic aerosol emissions from combustion sources was designed to simulate atmospheric cooling and dilution processes, so that organic vapors which condense under ambient conditions would be collected as particulate matter. Comparison of this sampler with EPA Method 5, a traditionally-used method of stack sampling, showed that the dilution stack sampler collected approximately 10 times as much organic aerosol as the hot filter portion of EPA Method 5. Tests were conducted using the new sampling system to measure organic aerosol emissions from eighteen major source types that constitute approximately 80% of the fine organic aerosol emitted to the Los Angeles atmosphere. The fine organic aerosol emission inventory for the Los Angeles area was revised based on these measurements. It was found that paved road dust, meat-cooking operations, and fireplace emissions are among the most important sources of fine organic aerosol, and that over 45% of the organic aerosol emitted consists of contemporary (non-fossil) carbonaceous material. To define quantitative characteristics of the organic aerosol samples that can be used to distinguish the effluent from different sources, a new approach utilizing high-resolution gas chromatography alone was developed. With this protocol, a quantitative, 50-parameter characterization of the elutable fine organic aerosol emitted from each of 18 source types was obtained. Comparison of these organic source signatures using hierarchical cluster analysis showed that organic aerosol emissions from many of the sources are sufficiently different that they can be distinguished from one another on the basis of the characteristics identified here.

Using a transport model, the distribution of organic compounds that would exist at ambient sites in the Los Angeles area *if* the primary emissions were transported without chemical reaction were predicted. Differences found between ambient measurements and model predictions were used to assess the degree of secondary organic aerosol formation. For the neutral organic fraction, reasonable agreement between ambient measurements and model predictions was found, suggesting that most of the neutral ambient organic aerosol is emitted directly as aerosol from the sources tested during this research effort. For the acidic fraction of the atmospheric organic aerosol, the model significantly underpredicted the ambient concentrations, indicating that much of the acidic ambient organic aerosol fraction may be formed by chemical reactions in the atmosphere. Based on the difference between predicted and measured concentrations of acidic organics, it was estimated that 15 to 25% of the total elutable organic aerosol present in the Los Angeles area may consist of atmospheric transformation products.

6.2 FUTURE RESEARCH

While this research project has revealed many interesting findings, it has also raised new questions, and identified other areas where further work is needed. In this chapter, some of the more promising areas identified for future research will be discussed. These areas include both experimental and theoretical work, and have both fundamental and practical implications.

6.2.1 Dilution Sampling Equipment for Organic Aerosols

A dilution stack sampler specifically designed for the sampling of organic aerosol was constructed and tested, as discussed in Chapter 2. Use of this sampler in the field has verified that it collects organic aerosol without contributing artifact organic compounds either from the dilution air or from the sampler itself. However, the fieldwork also has identified some attributes of this prototype design that could be improved.

The large size of the sampler itself has led to difficulties. In some cramped locations, substantial time was spent planning an appropriate arrangement of the equipment within a confined space. In addition, the time needed to clean the sampler between uses was longer than desirable, due to the many pieces involved and the large size of some of the sampler parts. Finally, the electrical power consumption requirements of the sampler have sometimes been difficult to meet in the field, necessitating long extension cords and special arrangements. Construction of a smaller sampling device would alleviate these problems. While additional sampling time might sometimes be necessary to collect a sample of adequate size at a site, the time needed for cleaning the sampler between consecutive tests would be reduced, and the time required for planning and setup at a given site would also be shorter. Hence, more source types could be sampled in a given amount of time. In addition, while the present sampling system requires two "sturdy" people to assemble and operate it, a smaller sampler could be designed to be manageable by a single person, reducing the manpower needed to use the sampler in the field. However, a smaller sampler would also have its drawbacks. In particular, the problem of particle losses within the sampler might worsen considerably due to the increased surface-to-volume ratio of the sampler interior.

A few improvements to the present sampler's design would also be beneficial. The venturi that monitors the flowrate of the source emissions into the sampler is also the source of the largest particle losses in the system, due to its narrow throat. If a reliable alternate method for measuring the flowrate in this part of the system could be found, particle losses in the sampler would be significantly reduced. The present cooling system for the dilution air, which consists of copper tubing in an large icebath, requires a substantial supply of ice. Development of a more sophisticated heat exchange system could eliminate the logistical problems involved in hauling ice to the field site on a daily basis. Finally, regulation of the flowrates in the sampler is accomplished at present through frequent adjustments by the sampler operator based on pressure drop readings. It should be possible to automate this procedure, allowing the flowrates to be fine-tuned more frequently and accurately.

6.2.2 Source Sampling Program

In Chapters 3 and 4, the results of the source sampling program undertaken as part of this research project were presented. This project tested one or a few examples of each of fourteen important types of organic aerosol emission sources, and treated the particulate emissions obtained as representative of that source type.

It is already known from the results of this project that there are substantial variations in the emissions characteristics of different examples of a single source type. Fine particulate emissions from a single industrial-scale boiler were observed to vary from day to day, influenced by factors including the batch of fuel oil being burned, the excess oxygen level in the boiler, and perhaps even the operator in charge. Emissions from motor vehicles also showed tremendous variation, due to factors like the age, type and maintenance condition of the vehicle, and the fuel being burned. It is likely that some of the other source types that were tested also exhibit substantial variations in their particulate emissions.

As a next step, additional examples of each source type should be sampled to more accurately determine the *average* emissions characteristics of each source type, as well as to quantify the variability from one source to the next. This work (which would be a less daunting prospect if a smaller sampling device were used) would provide an accurate measure of the uncertainty in the fine particulate emissions characteristics from each source type. With this information, further refinement of the organic aerosol emissions inventory (as well as perhaps other emissions inventories) could be achieved, with accompanying improvement in the air quality modeling results.

6.2.3 Identification of Organic Characteristics

In Chapter 4, the fine organic aerosol emissions from the various source types sampled were characterized using high-resolution gas chromatography (GC). The objective of this work was to uniquely characterize each of the types of organic emission sources. The results obtained show marked differences between many of the sources, but in a few cases two sources would appear to be similar if only GC analysis was available to distinguish between them. Several strategies appear promising for further characterizing the sources in order to achieve a unique chemical fingerprint for each source type.

First, using data already collected during this research project, inorganic chemical characteristics (*e.g.*, trace elemental concentrations) could be added to the organic characterizations already obtained for each source. With this approach, dissimilar sources like brake dust and fried hamburger meat, which have similar organic mass distributions, could be readily distinguished from each other on the basis of trace elemental compositions. It is possible that with the addition of just a few of the trace elemental species, a unique chemical characterization could be achieved for each of the organic aerosol sources tested.

However, some caution must be exercised: the source types tested during this research project were selected because they were thought to be major sources of *organic* aerosol. It is quite likely that there are other untested urban sources which are major contributors of some of the trace elemental species found in the atmosphere. Thus, the data set generated for this project should **not** be considered to be comprehensive for the trace elemental species. The addition of trace species concentrations to the modeling approach utilized will not accurately predict ambient trace elemental concentrations until the other important sources of the trace species being used are tested and included in the model.

Additional distinguishing features of the emission sources tested could be determined if these samples were analyzed further using high-resolution gas chromatography/mass spectrometry (GC/MS). While this approach is time-consuming, it allows identification of individual organic chemical species, making it possible to search for unique chemical tracers in the source emissions.

6.2.4 Investigation of Secondary Organic Aerosols

In Chapter 5, an investigation was conducted of the nature and extent of secondary organic aerosols by comparing the characteristics of primary organic particulate matter source emissions with the organic characteristics of the ambient aerosol in the Los Angeles area. This analysis can be extended if GC/MS techniques are used to compare the chemical compounds found in ambient aerosol samples with those present in the primary organic aerosol source emissions. Comparison of the emission rates of specific compounds to their prevalence in the ambient air, during both winter and summer months, would enable identification of compounds that are depleted in the atmosphere relative to their source emissions (due to photochemistry and to other mechanisms), as well as compounds that are enriched in the ambient air and hence may be the reaction products of directly emitted compounds. With this information, a more accurate evaluation of the extent and nature of secondary organic aerosol could be obtained. In addition, new reaction pathways could be proposed for reactive organic compounds, providing insight into their origin.

6.2.5 Identification of Control Strategies

The practical motivation for accurately measuring and modeling pollutant emissions from sources is to provide a basis for testing the effectiveness of control strategies for reducing pollutant concentrations in the urban environment in advance of the adoption of an expensive control program. This may be of particular importance for the fine organic aerosols: besides the detrimental effect that they have on visibility, certain organic compounds known to be present in ambient aerosol also have been found to be carcinogenic or mutagenic.

At present, no goals have been established for reducing the concentrations of organic aerosols in urban areas. Potential control strategy goals for an organic aerosol control program could include reduction in the total concentrations of fine organic material in the air (for visibility improvement), decrease in the amounts of certain types of organics that are suspected to be especially harmful (like the chlorinated organics), or reduction of the emissions of specific organic compounds that are already known to be carcinogenic.

In the event that a program of organic aerosol mass concentration reduction is considered, the results obtained in this research will be directly applicable to testing the likely effects of the proposed controls. If certain organic compounds are specifically identified as the subject of an abatement program, then the methods developed here can be coupled with more extensive chemical analysis in order to provide predictions of the effect of proposed emission controls strategies.

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To understand is to complicate.

Lucien Lefebvre
Combats pour l'histoire

Strange how much you've got to know
Before you know how little you know.

Author unknown

Appendix A

Meat-Cooking Operations: A Significant Source of Fine Particulate Potassium Emissions to the Urban Atmosphere

A.1 INTRODUCTION

In an effort to simplify the identification of source contributions to airborne particulate matter using receptor modeling calculations, many attempts have been made to identify easily detectable chemical characteristics that are unique to one or a few emission sources. Some investigators have focused on fine particulate potassium as a potential tracer for the presence of woodsmoke in ambient aerosol samples. Chemical signatures used to quantify the contributions of woodsmoke to ambient samples have included: the ratios of potassium to iron (Mukai and Ambe, 1986; Wolff *et al.*, 1981), potassium to soot (elemental carbon) (Raemdonck, Maenhaut and Andreae, 1986; Andreae, 1983) and potassium to total mass Sexton *et al.*, 1985; Dasch, 1982); potassium concentrations with soil-derived potassium subtracted through the use of calcium (Andreae, 1983), silicon (Lewis, Baumgardner and Stevens, 1986), or iron (Dasch, 1982; Lewis and Einfeld, 1985; Lewis *et al.*, 1988ab); and nighttime potassium concentrations (Stevens, 1985).

However, insufficient data exist to conclude that any of these tracer techniques can be used to accurately quantify the amount of woodsmoke aerosol in an urban atmosphere. In fact, limited data indicate that there may be many sources of airborne potassium that are as significant as woodsmoke. A trace metals emissions inventory conducted for the 4-county South Coast Air Basin (SoCAB) that surrounds Los Angeles (see figure A.1) considered source emissions of particulate matter less than 10 μm in diameter (Cass and McRae, 1981). Despite many

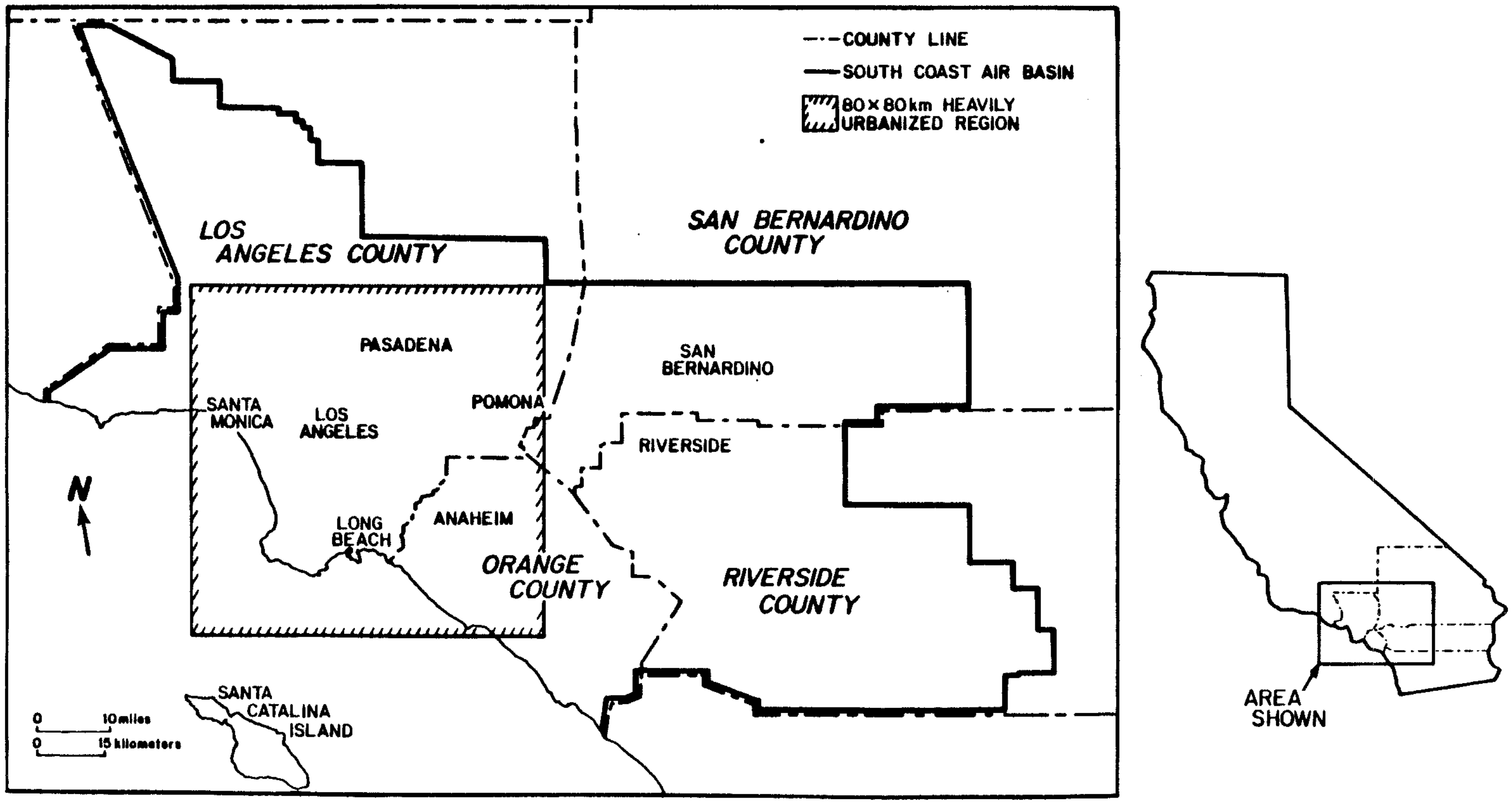

Figure A.1. Geographical outline of the South Coast Air Basin Showing an 80x80 km square area that contains 83% of the air basin's population.

data gaps in the inventory for potassium (and the absence of charbroiling in the list of source types), 14.5% of the potassium emissions were due to sources besides soil dust (83.3%) and wood combustion (2.2%). Other significant sources of potassium identified included sea salt (8.1%), metallurgical industries (4.9%), combustion of residual fuel oil (0.5%), and glass furnaces (0.3%). In addition to these sources of particulate potassium, the present note shows that one must include the contributions from meat-cooking operations.

Meat-cooking operations have received some attention as a potentially significant source of particulate matter in urban areas (Bornstein, 1978; Francis and Lipinski, 1977). Commercial charbroiling of meats in the restaurant industry has been estimated to account for 3% of the fine ($d_p < 2.1\mu m$) mass emissions and 12% of the fine organic carbon emissions to the atmosphere of the SoCAB (Gray, 1986).

In the present study, a dilution stack sampling system was used to measure the quantity and composition of the fine particulate emissions from meat cooking operations and from the fireplace combustion of wood. This dilution stack sampling system has been designed specifically to collect those source emissions that would condense into the fine particulate phase under normal ambient conditions, while minimizing particle loss and contamination problems (Hildemann, Cass and Markowski, 1989).

Substantial amounts of potassium were found to be emitted during meat-cooking operations, especially during charbroiling of regular hamburger meat. These potassium emissions are comparable in magnitude to the potassium emitted from the fireplace combustion of wood in the Los Angeles area. This suggests that it is inappropriate to use fine potassium as if it were a nearly unique tracer for presence of woodsmoke in the ambient aerosol samples. The use of fine potassium data along with ^{14}C-based contemporary carbon aerosol data likewise may fail to identify woodsmoke uniquely, as meat-cooking operations also emit contemporary (non-fossil) aerosol carbon.

A.2 EXPERIMENTAL SECTION

General source sampling and quality assurance procedures used with this sampling system have been described elsewhere (Hildemann, Markowski and Cass, 1989). Total fine aerosol mass was determined gravimetrically by weighing the filters before and after sampling, while potassium was analyzed by x-ray fluorescence. A complete description of the chemical composition of these source samples will be given elsewhere (Hildemann, Markowski and Cass, 1989); this brief note focuses on the potassium data.

A.2.1 Meat Cooking.

Source tests were conducted at the commercial-scale kitchen attached to the California Institute of Technology's Chandler Cafeteria complex. The aerosol emissions released from cooking two different kinds of hamburger meat were studied: (1) regular grade beef (about 21% fat); and (2) extra-lean beef (about 10% fat). Each type of meat was cooked by two methods: by charbroiling over a natural gas flame, and by frying.

In each of the four experiments, 80 quarter-pound (113 g) hamburger patties were cooked until they were medium to well-done, eight at a time, over a time period of 70–80 min. The aerosol generated during cooking was withdrawn through a 14,000 cfm (6.6 m^3 sec^{-1}) overhead exhaust hood. The commonly-used baffle-type grease extractor, which has been estimated to be approximately 60 percent efficient at removing airborne cooking grease on a mass basis (Bornstein, 1978), was present at the entrance to the exhaust duct. Source sampling was conducted on the roof of the kitchen, with samples withdrawn at the exit to the exhaust duct. The air flow rate through the exhaust vent was verified through pitot probe measurements.

A.2.2 Home Fireplace Emissions.

Woodsmoke emissions were sampled from the brick fireplace chimney in an older single family home. An access hole was bored into the side of the chimney about halfway up the flue, and samples were taken by traversing across the long axis of the flue through this hole. Both hard (oak) and soft (pine) wood fires were examined separately, and each fire was sampled from ignition to ember stage over a

3–4 hr sampling period. The fire was periodically stirred and wood was occasionally added in an attempt to mimic the course of a typical home fireplace fire.

A.3 RESULTS AND DISCUSSION

Table A.1 shows the measured mass emission rate of fine particulate potassium for each of the four hamburger cooking experiments. The values shown have been corrected for minor contributions of potassium from the dilution air. The largest emission rate by far for fine aerosol potassium was measured for charbroiling of regular hamburger meat.

These emission rates are also compared (Table A.1) with the potassium content estimated for raw and cooked hamburger meat (Anderson, Lauderdale and Hoke, 1986). It appears that up to 33% of the potassium "lost" during cooking may be emitted as airborne particulate matter.

To provide a common basis for comparison, woodsmoke emissions of fine potassium, based on measurements of fireplace emissions taken with the same dilution sampling system, are shown in Table A.2 along with the meat-cooking measurements. For the SoCAB, home fireplaces account for an estimated 96% of the woodsmoke emissions that occur on a daily basis, while structural fires account for the remainder (Gray, 1986). Woodsmoke emissions from seasonal forest fires are excluded from these calculations, as these fires are unusual events that occur on an occasional basis.

As mentioned in the introduction to this note, some previous source attribution studies have used the ratio between potassium and other elements in the aerosol to trace woodsmoke. Several of these diagnostic ratios between potassium and other elements are presented in Table A.2, both for hamburger cooking and for wood combustion. The ratio of potassium to mass is very similar for the two source types, indicating that this ratio is not a unique indicator of the presence of woodsmoke. Due to the low amount of elemental carbon emitted during meat cooking, the potassium to elemental carbon ratio is much higher for meat cooking than for wood combustion. Woodsmoke, however, is only one of several important sources of atmospheric elemental carbon; diesel engine emissions are the largest

Table A.1. Comparison of the Potassium Content of Meat Before and After Cooking with Measured Potassium Aerosol Emissions

	Fine Aerosol Potassium Emitted[(a)]	Potassium Content of Raw Meat[(b)]	Potassium Content of Cooked Meat[(b)]	Potassium "Lost" During Cooking
	(mg/kg raw meat)			
REGULAR MEAT				
Charbroiled	106.7	2280	1960	320
Fried	4.4	2280	2030	250
EXTRA-LEAN MEAT				
Charbroiled	4.4	2840	2290	550
Fried	5.1	2840	2340	500

(a) This study, particle diameter $< 2.1\ \mu m$.

(b) Values obtained from Anderson, Lauderdale and Hoke (1986).

Table A.2. Fine Aerosol Potassium Emissions and Signatures from Meat-Cooking Operations and from Fireplaces

	Fine Aerosol Potassium Emitted[(a)] (mg/kg raw mat'l)	Fine Aerosol Ratios [(a)]		
		K/Mass	K/Elemental C	K/Fe
REGULAR MEAT				
Charbroiled	106.7	0.0027	2.28	8.67
Fried	4.4	0.0038	—(b)	0.73
EXTRA-LEAN MEAT				
Charbroiled	4.4	0.0006	—(b)	0.55
Fried	5.1	0.0036	—(b)	—(b)
FIREWOOD				
Pine (soft)	55.6	0.0055	0.17	79.2
Oak (hard)	49.0	0.0079	0.27	164.

(a) This study, particle diameter $< 2.1\ \mu m$.

(b) Denominator was below the detection limit.

contributor of elemental carbon to the Los Angeles atmosphere (Gray, 1986). Therefore the potassium to elemental carbon ratio found in atmospheric aerosol samples may be difficult to connect to differences in the woodsmoke vs. charbroiler content of an ambient aerosol. The ratio of potassium to iron varies greatly over the various meat cooking tests, making it difficult to compare with firewood emissions.

It is of interest to compare the particulate potassium emissions to the Los Angeles area atmosphere from woodsmoke with those from meat-cooking operations. Based on an emissions inventory developed for the SoCAB in 1982 (Gray, 1986), regional fine particulate potassium emissions can be estimated both for meat-cooking operations and for fireplace combustion of wood.

Bornstein (1978) estimates that 40% of all meat is cooked in restaurants, and that 9% of all commercially-cooked meat is charbroiled. It is assumed that the rest of the commercially-cooked meat is fried. In addition, it is assumed that the ratio of charbroiled to fried meat applies to meat cooked in the home as well as in restaurants. (Backyard charcoal grilling of meat is a common practice in Southern California.) Ground meat is estimated to represent over 50% of the meat served (Bornstein, 1978), so for simplicity, regular hamburger meat is assumed to be representative of all meat cooked in terms of emissions.

Table A.3 presents the results of these calculations. Even though only about one-tenth of all meat is charbroiled, the fine particulate emissions from charbroiling of meat are much higher than those resulting from meat frying. It appears that fine potassium emissions into the entire SoCAB atmosphere in 1982 from meat-cooking operations are of the same order of magnitude as those from fireplace combustion of wood. Within the 80 x 80 km square area shown in figure 1 that contains 83% of the SoCAB's population, Table A.3 shows that potassium emissions from the two sources are comparable for this heavily urbanized area. These results indicate that in similar urban areas, fine particulate potassium cannot be used as if it were a unique tracer for the presence of woodsmoke due to the possibility of substantial potassium emissions from other sources, including meat-cooking operations.

Table A.3. Emissions of Potassium into the Los Angeles Area Atmosphere in 1982 from Meat Cooking and Fireplaces

HEAVILY URBANIZED REGION OF METROPOLITAN LOS ANGELES AREA
(80 x 80 km area shown in Figure A.1)

Raw Material	Estimated Amount of Raw Material Consumed(a) (kg/day)	Fine Particulate Emissions(b) (mg/kg raw mat'l)	Potassium in Fine Emissions(b) (%)	Fine Particulate Potassium Emissions (kg/day)
MEAT COOKING				
Charbroiling	211,000	39,800	0.27	22.7
Frying	2,129,000	1,140	0.38	9.2
			TOTAL	31.9
FIREPLACES				
Softwood	529,000	10,100	0.55	29.4
Hardwood	327,000	6,160	0.79	15.9
			TOTAL	45.3

ENTIRE SOUTH COAST AIR BASIN

Raw Material	Estimated Amount of Raw Material Consumed(a) (kg/day)	Fine Particulate Emissions(b) (mg/kg raw mat'l)	Potassium in Fine Emissions(b) (%)	Fine Particulate Potassium Emissions (kg/day)
MEAT COOKING				
Charbroiling	253,000	39,800	0.27	27.2
Frying	2,561,000	1,140	0.38	11.1
			TOTAL	38.3
FIREPLACES				
Softwood	973,000	10,100	0.55	54.1
Hardwood	1,213,000	6,160	0.79	59.0
			TOTAL	113.1

(a) Meat consumption calculated using per capita meat consumption figures (retail weight, excluding meat byproducts) for the U.S. in 1982 (Rogers, 1983), and 1980 population figures for the area of interest (Gray, 1986). Firewood consumption taken from Gray (1986).

(b) This study; total aerosol mass emitted with particle diameter $< 2.1\ \mu m$.

A.4 REFERENCES

Anderson, B.A., Lauderdale, J.L., and Hoke, I.M. (1986). *Composition of Foods: Beef Products, Raw, Processed, Prepared.* Agriculture Handbook No. 8–13, U.S. Department of Agriculture, Human Nutrition Information Service, Washington, D.C.

Andreae, M.O. (1983). Soot Carbon and Excess Fine Potassium: Long-Range Transport of Combustion-Derived Aerosols. *Science* 220:1148–1151.

Bornstein, M.I. (1978). Study to Develop Background Information for the Direct Meat-Firing Industry. EPA-450/3-78-027 (PB282-486), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cass, G.R., and McRae, G.J. (1981). Source-Receptor Reconciliation of South Coast Air Basin Particulate Air Quality Data. NTIS PB82-250093, California Air Resources Board, Sacramento, California.

Dasch, J.M. (1982). Particulate and Gaseous Emissions from Wood-Burning Fireplaces. *Environ. Sci. Technol.* 16:639–645.

Francis, G.Z., and Lipinski, R.E. (1977). Control of Air Pollution from Restaurant Charbroilers. *J. Air Poll. Control Assn.* 27:643–647.

Gray, H.A. (1986). Control of Atmospheric Fine Primary Carbon Particle Concentrations. PhD Thesis, California Institute of Technology, Pasadena, California. Also available as Report No. 23, Environmental Quality Laboratory, California Institute of Technology, Pasadena, California.

Hildemann, L.M., Cass, G.R., and Markowski, G.R. (1989). A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests. *Aerosol Sci. Technol.* 10:193–204. [See Chapter 2.]

Hildemann, L.M., Markowski, G.R., and Cass, G.R. (1989). Emissions from Important Sources of Fine Organic Aerosol. *To be submitted.* [See Chapter 3.]

Lewis, C.W., Baumgardner, R.E., and Stevens, R.K. (1986). Receptor Modeling Study of Denver Winter Haze. *Environ. Sci. Technol.* 20:1126–1136.

Lewis, C.W., Baumgardner, R.E., Stevens, R.K., Claxton, L.D., and Lewtas, J. (1988a). Contribution of Woodsmoke and Motor Vehicle Emissions to Ambient Aerosol Mutagenicity. *Environ. Sci. Technol.* 22:968–971.

Lewis, C.W., and Einfeld, W. (1985). Origins of Carbonaceous Aerosol in Denver and Albuquerque During Winter. *Environ. Int.* 11:243–247.

Lewis, C.W., Stevens, R.K., Baumgardner, R.E., Zweidinger, R.B., Cuppitt, L.T., Highsmith, V.R., Claxton, L.D., and Lewtas, J. (1988b). Receptor Modeling Results frm the Integrated Air Cancer Project. EPA/600/D-38/127 (PB88-218433), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Mukai, H., and Ambe, Y. (1986). Characterization of a Humic Acid-Like Brown Substance in Airborne Particulate Matter and Tentative Identification of Its Origin. *Atmos. Environ.* 20:813–819.

Raemdonck, H., Maenhaut, W., and Andreae, M.O. (1986). Chemistry of Marine Aerosol Over the Tropical and Equatorial Pacific. *J. Geophys. Res.* 91:8623–8636.

Rogers, A. (1983). *Food Consumption, Prices, and Expenditures.* Bulletin No. A 1.34:702, U.S. Department of Agriculture, Economic Research Service, Washington D.C.

Sexton, K., Liu, K.S., Hayward, S.B., and Spengler, J.D. (1985). Characterization and Source Apportionment of Wintertime Aerosol in a Wood-Burning Community. *Atmos. Environ.* 19:1225–1236.

Stevens, R.K. (1985). Sampling and Analysis Methods for Use in Source Apportionment Studies to Determine Impact of Wood Burning on Fine Particle Mass. *Environ. Int.* 11:271–283.

Wolff, G.T., Countess, R.J., Groblicki, P.J., Ferman, M.A., Cadle, S.H., and Muhlbaier, J.L. (1981). Visibility-Reducing Species in the Denver "Brown Cloud" — II. Sources and Temporal Patterns. *Atmos. Environ.* 15:2485–2502.

Appendix B

Submicron Aerosol Mass Distributions of Emissions from Boilers, Fireplaces, Automobiles, Diesel Trucks, and Meat-Cooking Operations

B.1 INTRODUCTION

Mathematical modeling of atmospheric aerosol processes is currently limited by a lack of detailed information on the size distribution of the many primary aerosol emissions sources. Without such information, the rate of change of the atmospheric aerosol size distribution due to condensation of secondary aerosol material onto the primary particles emitted directly from sources cannot be computed. Likewise, ambient aerosol coagulation and deposition calculations cannot be supported without an accurate assessment of the size distribution of the initial aerosol emitted to the atmosphere.

For most source types, little information is presently available on the size distribution of the submicron fraction of the primary aerosol emissions. Some measurements using an electrical aerosol analyzer (EAA) have been made for diesel vehicles, either by sampling immediately behind a travelling diesel vehicle (Kittelson *et al.*, 1988), using a dilution tunnel in the laboratory (Khatri and Johnson, 1979; Verrant and Kittelson, 1978; Groblicki and Begeman, 1980; Kittelson *et al.*, 1979; Raunemaa *et al.*, 1984), or sampling downwind of a truckstop (Kittelson *et al.*, 1988). EAA measurements of the size distribution of the aerosol emitted from gasoline-powered automobiles on a dynamometer also have been made (Miller *et al.*, 1976). Several investigators have attempted to measure the size distribution of fresh traffic aerosol by sampling in the vicinity of heavily-trafficked areas using cascade impactors (Berner *et al.*, 1984, Berner and Reischl, 1983, Berner and Lurzer, 1980, Berner *et al.*, 1979) or EAAs and optical particle counters (Wilson *et al.*, 1977, Whitby *et al.*, 1975, Hidy *et al.*, 1975). The size distributions of aerosol emissions from industrial-scale boilers burning No. 2 fuel oil have been measured using cascade impactors (Cato, Muzio and Shore, 1976; Carter, Buening and Hunter, 1978), sequential cyclone catches (Taback *et al.*, 1979), and electron microscope examination of filter catches (Cato *et al.*, 1974). A few measurements also have been made for fireplace emissions, using parallel impactors (Rau, Huntzicker and Edgerton, 1987; Rau, 1989) and EAA instrumentation (Dasch, 1982). Finally, Sexton and co-workers (1986) have measured an aerosol size distribution produced while frying hamburger meat in cooking oil. However, substantial differences in sampling methodology between the various studies frustrate comparison between sources.

The objective of the research reported here was to determine the size distribution of the submicron fraction of the direct aerosol emissions from a variety of the major combustion sources found in urban areas. A portable dilution source sampling system was used (Hildemann, Cass and Markowski, 1989). In this system, condensible vapors present at high temperature in the combustion source exhaust are cooled and diluted to ambient conditions, causing condensation onto the solid particles in the exhaust, thus approximating the effective primary aerosol size distribution found in the plume in the atmosphere immediately downwind of the source. The uniform method of sampling provided by this system allows size distributions from disparate sources to be quantitatively compared. Size distribution measurements of the cooled, diluted exhaust aerosol were taken using an EAA, and in addition, fine particulate matter was collected by filtration, providing a separate measure of the amount of fine aerosol mass. This allowed comparison of aerosol mass emission rates calculated using two different measurement methods.

B.2 EXPERIMENTAL SECTION

The design of the dilution stack sampling system has been described in detail previously (Hildemann, Cass and Markowski, 1989). Briefly, a heated inlet line was used to withdraw the hot exhaust from the sources tested, traversing the stack where appropriate to obtain a representative sample. The exhaust was then diluted and cooled to near-ambient temperature by mixing with cooled dilution air that had passed through an activated carbon bed and a HEPA filter to remove pollutants from the dilution air. A small portion of the diluted sample was withdrawn for aerosol size distribution measurement by a TSI Model 3030 Electrical Aerosol Analyzer (EAA). For the motor vehicle tests reported, an additional stage of exhaust dilution preceeded the use of the dilution stack sampler. Without this pre-dilution step, abrupt changes in vehicle operation cause large changes in the volumetric flow rate of the exhaust that cannot be tracked by the dilution stack sampler. With the pre-dilution step, a constant volumetric flowrate was achieved, enabling the dilution sampler to withdraw an exhaust sample that was representative of the emission rate of the vehicle at any time, regardless of engine speed.

Because gaseous components in the diluted emissions sample (such as SO_2) might have an effect on the EAA charger operation (and perhaps greatly reduce charger life), the EAA was modified so that filtered ambient air was used for charger sheath air while sample gas was used in the mobility analyzer. Ambient air could not be used for the mobility analyzer since the different composition, especially the organic content and relative humidity, could easily cause significant changes in aerosol size. (The ratio of mobility analyzer air to aerosol sample volume was about 12.5 to 1.) The use of ambient air for the sheath air supply was not expected to cause a problem, since it represented only 2% of the total flow.

Rapid fluctuations were apparent in the aerosol size distribution emitted at all sources tested. To reduce the effect of these short-term fluctuations in source characteristics, an averaging bottle was placed in-line just upstream of the EAA. For most of the sources, a 4-liter averaging bottle was used; in a few cases (such as the automobiles undergoing a variable driving cycle), an 8-liter bottle was used. Results were scaled upward by 10% to adjust for wall losses in the averaging bottle.

For sources that produced high concentrations of submicron aerosol even after dilution in the stack sampler, an additional dilution step was introduced upstream of the EAA to bring the measurements into the range of the EAA. This dilution step was achieved by plumbing an absolute filter and a small orifice in parallel and inserting the unit either immediately before or immediately after the averaging bottle.

Groups of sequential EAA measurements were averaged over the duration of the various combustion conditions studied. STWOM, Markowski's combination of Twomey's inversion routine with a smoothing algorithm (Markowski, 1987), was used to invert the EAA size distribution measurements. Some distributions, when inverted, had spurious tails at one or both ends of the EAA's particle size range. These tails were due to limitations in the accuracy of the EAA at the extremes of its nominal range (due both to measurement noise and to difficulties in defining the true instrument response matrix needed by the inversion algorithm), and were deleted from the data base. Estimates of submicron mass emission rates were made by integration of the EAA data assuming a particle density of 1 g/cm^3 for all sources. Adjustments to the mass emission rates reported here can be made easily if the reader wishes to assume an alternate density value for the particles emitted from a particular source.

The fine fraction of the aerosol mass was collected on Teflon filters downstream of AIHL cyclones, which were operated at a flowrate designed to remove particles with an aerodynamic diameter of greater than 2 μm (John and Reischl, 1980). The filters were weighed before and after collection on a Mettler balance (Model M-55-A) in a constant temperature and relative humidity environment.

B.3 RESULTS AND DISCUSSION

B.3.1 Industrial-Scale Boiler.

The size distribution of aerosol emissions from an industrial-scale boiler (Babcock & Wilcox dual fuel FM-type watertube, with a steam production capacity of 53 x 10^6 kJ/hr) burning No. 2 fuel oil was measured. Diluted flue gas from combustion of No. 2 fuel oil under steady-state conditions showed a strong bimodal mass distribution with a nucleation mode peak near 0.05 μm particle diameter and an larger mode peak near 0.5 μm. Size distributions measured at different positions in the stack were similar. The submicron ($d_p < 0.7$ μm) mass emission rate of

8 μg/kJ of fuel burned estimated using the EAA measurements agrees well with the 11 μg/kJ fine ($d_p < 2$ μm) aerosol emission rate measured gravimetrically for this particular experiment.

Figure B.1 shows the aerosol mass distribution after two different residence times in the dilution sampler. These distributions, while not measured simultaneously, were from the same sampling experiment with the probe at comparable locations in the stack. The order-of-magnitude reduction seen in the particle number density and the shift in the size distribution toward larger sizes with longer residence time within the dilution sampler both suggest that coagulation plays an important role in the observed shift in the size distribution. The increase in apparent aerosol mass emission rate with increased residence time suggests that more condensation may be occurring, but the change is not pronounced enough to be conclusive. These results indicate that the aerosol size distribution continues to evolve within the dilution stack sampler. When matching the results of these measurements to an environmental model, care should be taken to insert the measured aerosol size distribution at that portion of the hypothetical plume downwind of the source that best matches the retention time and degree of dilution achieved during these experiments. The time and dilution history of the size distributions for all tests presented in this paper are listed in Table B.1.

Artifact aerosol formation has been observed in the EAA when high ppm quantities of SO_2 are present (Stelson, 1989a). Since fuel oil contains sulfur, the magnitude of this potential artifact was evaluated for the test of the industrial-scale boiler burning 0.4% S distillate fuel oil. The diluted sample entering the EAA could have contained up to 9 ppm SO_2 (if all sulfur was emitted in the form of SO_2), and the relative humidity of the emissions after dilution with dry air was measured at less than 5%. Using these values as a worst-case condition, it was found that the only part of the EAA signal potentially affected was the output of channel 3 during the long residence time sample shown in Figure B.1. In the inversion algorithm, channel 3 of the EAA distribution is represented by the lowest three steps in the distribution curve (solid line), which in this case may have included up to 17% artifact aerosol generated from SO_2. None of the other EAA channel readings were

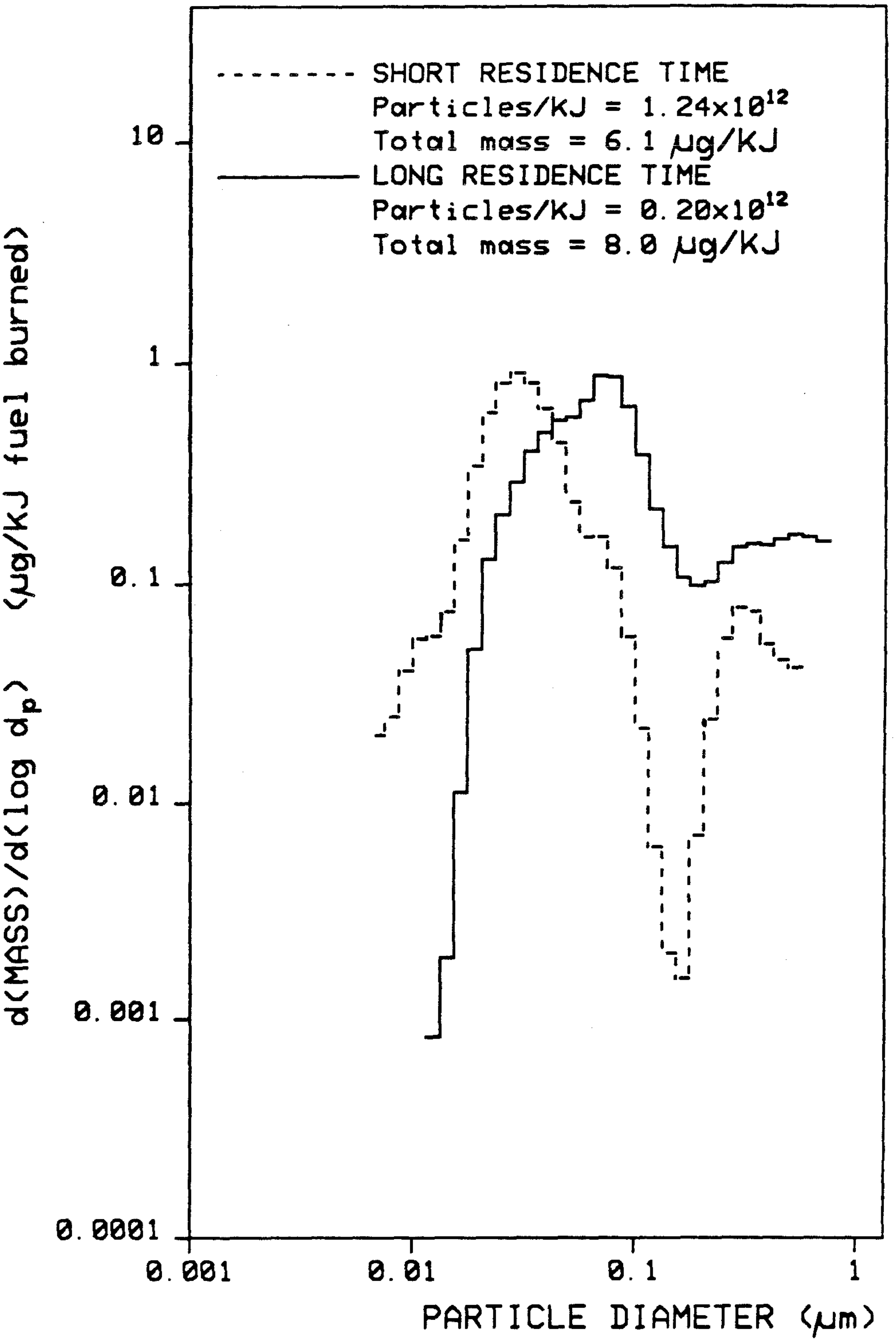

Figure B.1. Mass distribution of aerosol emissions from midsize industrial boiler burning No. 2 fuel oil.

Table B.1. Time and Dilution History of Emissions[a]

Source	t_1 (sec)	D_1 [b]	t_2 (sec)	D_2 [b]	t_s (sec)
Industrial Boiler					
—No. 2 Fuel Oil, Tunnel	0.5	35.3x	2.3	9.44x	59.3
—No. 2 Fuel Oil, Res.Ch.	0.5	35.3x	42.1	21.9x	99.1
Fireplace					
—Seasoned Pine (exp. 1)	0.3	31.1x	58.9	22.4x	59.1
—Seasoned Pine (exp. 2)	0.3	44.4x	58.9	23.0x	59.1
—Seasoned Oak	0.3	47.0x	58.9	28.0x	59.1
Catalyst Automobiles					
—Toyota	0.1	21.7x	0.7	26.0x	116.3
—Omni	0.1	20.7x	0.7	26.0x	116.3
—Honda 1500	0.1	22.3x	0.7	26.2x	116.3
—Vega	0.1	20.5x	0.7	26.2x	116.3
—Malibu	0.1	17.1x	0.7	26.2x	116.3
—Honda 150	0.1	23.2x	0.7	26.4x	116.3
—Datsun	0.1	20.2x	0.7	26.4x	116.3
Noncatalyst Automobiles					
—Mustang	0.1	13.7x	0.7	26.5x	116.3
—Pinto	0.1	20.5x	0.7	26.5x	116.3
—Caprice	0.1	11.4x	0.7	27.1x	116.3
—VW	0.1	22.1x	0.7	27.1x	116.3
—Mercury	0.1	12.4x	0.7	27.5x	116.3
—Buick	0.1	13.4x	0.7	27.5x	116.3
Heavy-Duty Diesel Trucks					
—GMC (Cycle 1, Idle)	11.5	2.99x	12.0	27.9x	127.6
—GMC (Cycle 1, NonIdle)	3.5	2.99x	4.0	27.9x	119.6
—GMC (Cycle 2, Idle)	11.5	2.99x	12.0	27.9x	70.8
—GMC (Cycle 2, NonIdle)	3.5	2.99x	4.0	27.9x	62.8
—Ford (Idle)	11.5	2.92x	12.0	29.8x	70.8
—Ford (NonIdle)	3.5	2.92x	4.0	29.8x	62.8
Hamburger Cooking					
—Regular Meat, Charbr.	0.1	22.9x	115.5	5.8x	115.7
—Extra-Lean Meat, Charbr.	0.1	23.0x	–	–	58.9
—Regular Meat, Fried	0.1	22.4x	–	–	58.9
—Extra-Lean Meat, Fried	0.1	22.6x	–	–	58.9

(a) At time $t=0$, emissions exit the stack or tailpipe. At time t_1, emissions are diluted by a factor of D_1. At time t_2, emissions are diluted a second time by a factor of D_2, yielding a total cumulative dilution of $D_1 \times D_2$. At time t_s, emissions are analyzed by the EAA.

(b) D = (Concentration before dilution)/(Concentration after dilution) potentially affected by more than 1–2%, so the presence of SO_2 did not significantly influence the size distribution results obtained for No. 2 fuel oil combustion.

These calculations were performed under the worst-case assumption that only SO_2 was available to react with the hydroxyl radicals generated within the EAA. In reality, other gas-phase species (*e.g.*, NO_x) are present that would scavenge some of the radical species, reducing aerosol formation from SO_2 (Stelson, 1989b).

B.3.2 Residential Fireplace.

Emissions from seasoned pine burning in a traditional residential brick fireplace were measured throughout the course of a 3-hr fire. Figure B.2 shows the variations in the submicron mass emission rate with changes in the fire. Over a 10-fold difference in mass emissions was seen between a period in the middle of the fire when more wood was added and a later time when the fire was in the ember stage.

Size distribution measurements for four different stages during this pine fire are shown in Figure B.3. For all stages of the fire, a very broad aerosol mass distribution was obtained with a peak around 0.1 to 0.2 μm particle diameter. Only the intensity of the peak changed with the stage of the fire. Between 1.3 and 14 g of submicron mass were emitted per kg of wood burned at various stages of the fire (based on the average rate of wood combustion in the fire), with an overall average emission rate of 6.9 g/kg wood ($d_p < 0.7$ μm). By comparison, filter masses indicated an average fine aerosol emission rate (over all conditions) of 10 g/kg wood ($d_p < 2$ μm). A second experiment burning pine gave similar results, with an estimated submicron mass emission rate from the EAA data of 10 g/kg ($d_p < 0.7$ μm) vs. fine filter mass results of 16 g/kg ($d_p < 2$ μm).

Size distribution measurements were also taken during combustion of seasoned oak in the same fireplace. Mass distributions for four different stages of the fire are shown in Figure B.4. Again, over a 10-fold difference is seen between an active stage of the fire and the ember stage. For oak, at some times a bimodal-type mass distribution was seen, with peaks near 0.05 and 0.2 μm particle diameter. At other times, a single, much broader distribution was observed, with a peak near 0.1 μm

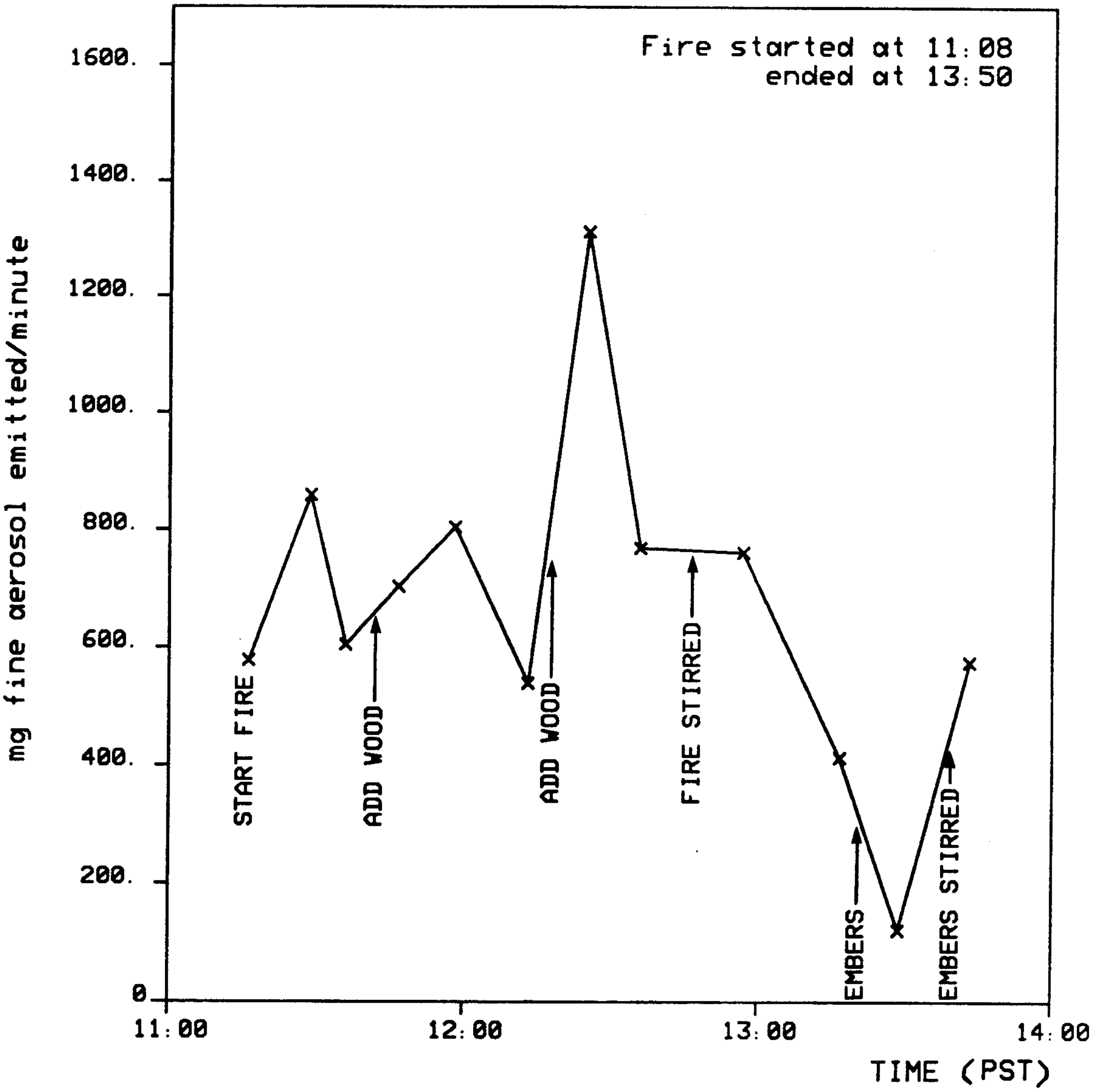

Figure B.2. Mass emissions from fireplace combustion of seasoned pine.

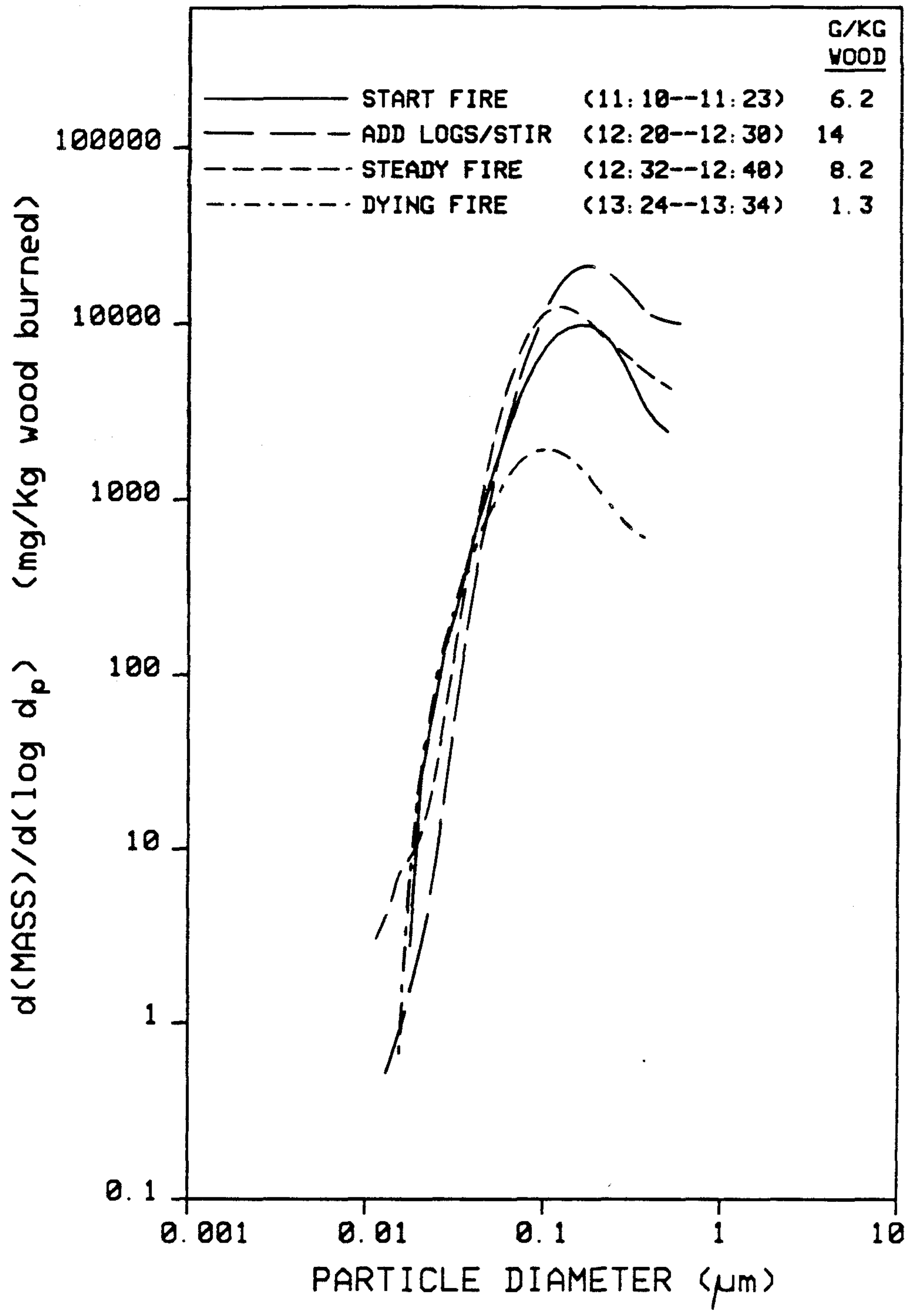

Figure B.3. Mass distribution of aerosol emissions from fireplace combustion of seasoned pine.

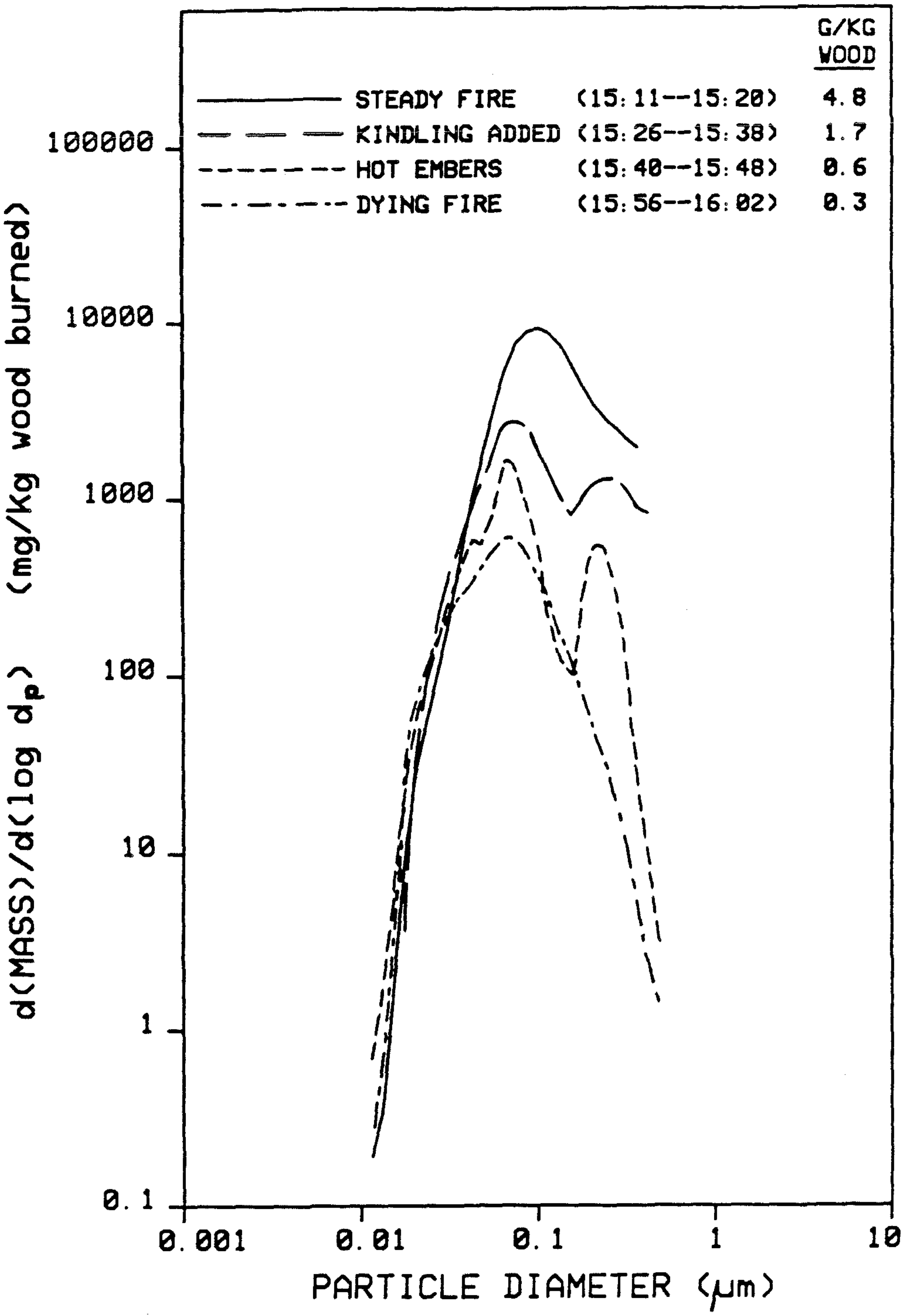

Figure B.4. Mass distribution of aerosol emissions from fireplace combustion of seasoned oak.

particle diameter. The submicron mass emission rates of 0.3 to 4.8 g/kg wood were measured using the EAA only during the last hour of a 3-hr fire, so the average value of 1.6 g/kg wood may be somewhat low. The gravimetrically-measured fine mass emission rate over the entire 3-hr fire was 6 g/kg wood.

B.3.3 Automobiles.

Emissions from thirteen automobiles were sampled during both a Federal Test Procedure (FTP) city driving cycle, and under steady state conditions at idle, 40 km/hr, and 90 km/hr. The FTP cycle is shown in Figure B.5. Both catalyst and noncatalyst vehicles were tested, using both domestic and foreign models. The cars were tested in as-received condition. The noncatalyst autos were fueled with leaded gasoline containing 58 or 90 mg of lead per liter of fuel, while the catalyst-equipped cars burned unleaded gasoline. A list of the vehicles appears in Table B.2.

Figure B.6 shows the average submicron mass emission rates for each of these cars, as measured by the EAA over the course of the 32 min FTP cycle. In customary units of mass emitted per distance driven, automobiles with large engines and/or poor fuel economy tended to register the highest emission rates. A dramatic difference is seen between the catalyst and noncatalyst vehicles: the noncatalyst cars have emission rates 10 to 30 times higher than most catalyst cars. The only catalyst automobile with a high mass emission rate was manufactured near the beginning of the introduction of catalytic converters into the vehicle fleet. Marked improvements are seen in the performance of the newer catalyst-equipped automobiles.

The mass distribution of submicron emissions under steady-state conditions was compared with the average distribution measured over the course of the FTP cycle. Figure B.7a–d shows mass distributions measured for four vehicles (2 catalyst, 2 noncatalyst) under different driving conditions, all plotted on the same scale.

Results typical of those obtained for many catalytic vehicles are shown in Figure B.7a. A single-modal, broad mass distribution is seen, with a peak between 0.1 and 0.3 μm particle diameter. The submicron emissions during the test cycle were about 10-fold higher than those measured under steady-state conditions.

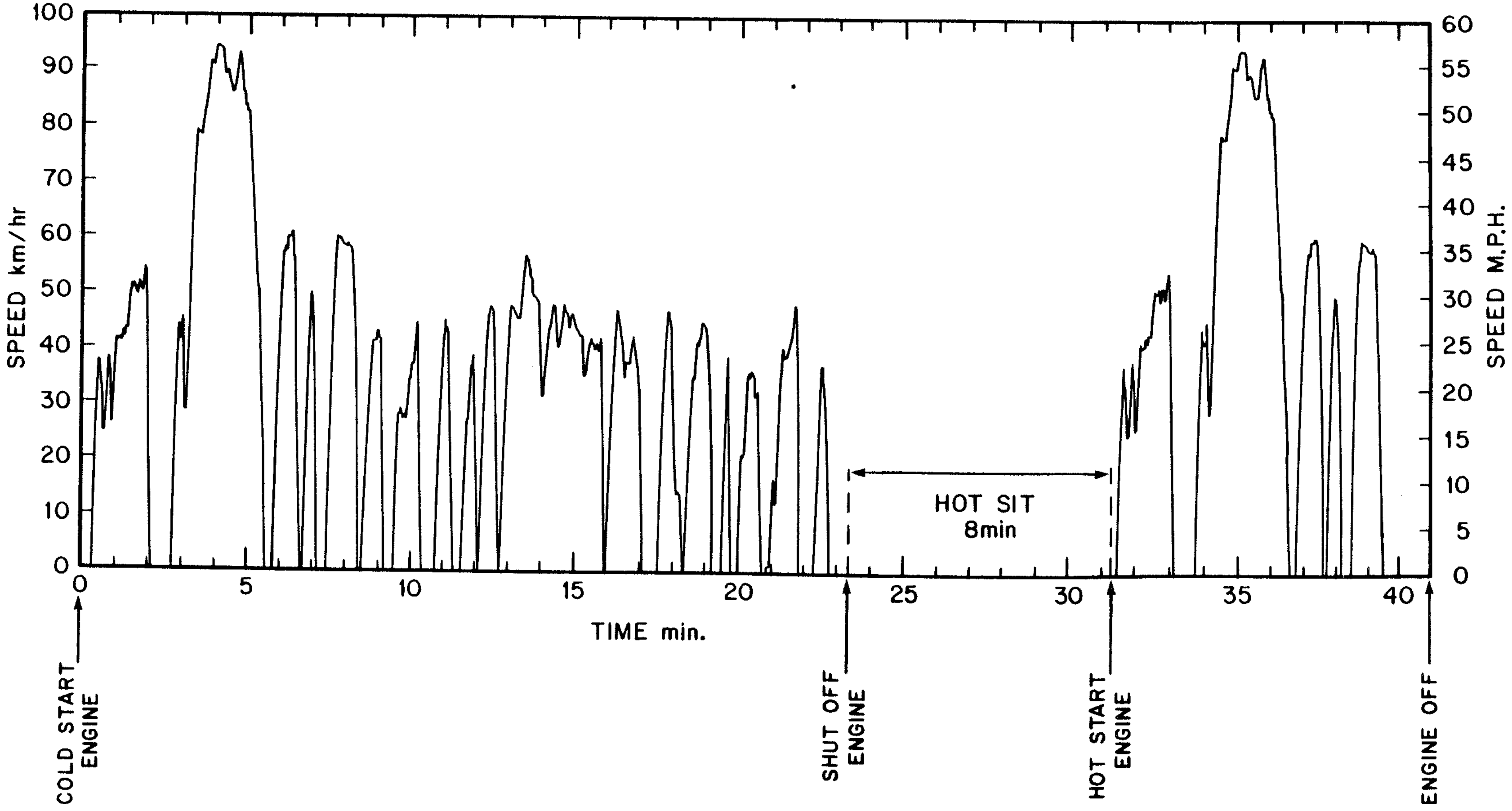

Figure B.5. Federal Test Procedure urban driving cycle.

Table B.2. Characteristics of Vehicles Tested

	Number of Cylinders	Engine Displacement (cu in)	Odometer Reading (miles)	FTP Fuel Economy (mi/gal)
NONCATALYST AUTOMOBILES				
1965 Mercury Monterey	8	390	139192	10.7
1969 Ford Mustang	8	302	141843	14.7
1970 Buick Skylark	8	350	88726	13.0
1972 Chevrolet Caprice	8	400	147249	12.3
1974 Ford Pinto	4	140	107138	16.7
1976 Volkswagen Beetle	4	97	80876	26.6
CATALYST AUTOMOBILES				
1977 Chevrolet Vega	4	140	88598	22.0
1980 Honda Civic 150	4	91	83862	27.5
1980 Honda 1500	4	91	149424	28.0
1980 Toyota Corolla	4	108	66832	20.6
1981 Datsun 200SX	4	119	81541	24.6
1983 Chevrolet Malibu CL	6	231	38826	17.7
1983 Dodge Omni	4	135	27280	22.7
HEAVY-DUTY DIESEL TRUCKS				
1987 GMC Truck (2-axle)	8	636	2920	7.9(a)
1987 Ford Dump Truck (3-axle)	8	636	5581	7.2(a)

(a) Mileage is for the truck cycle shown in figure B.10.

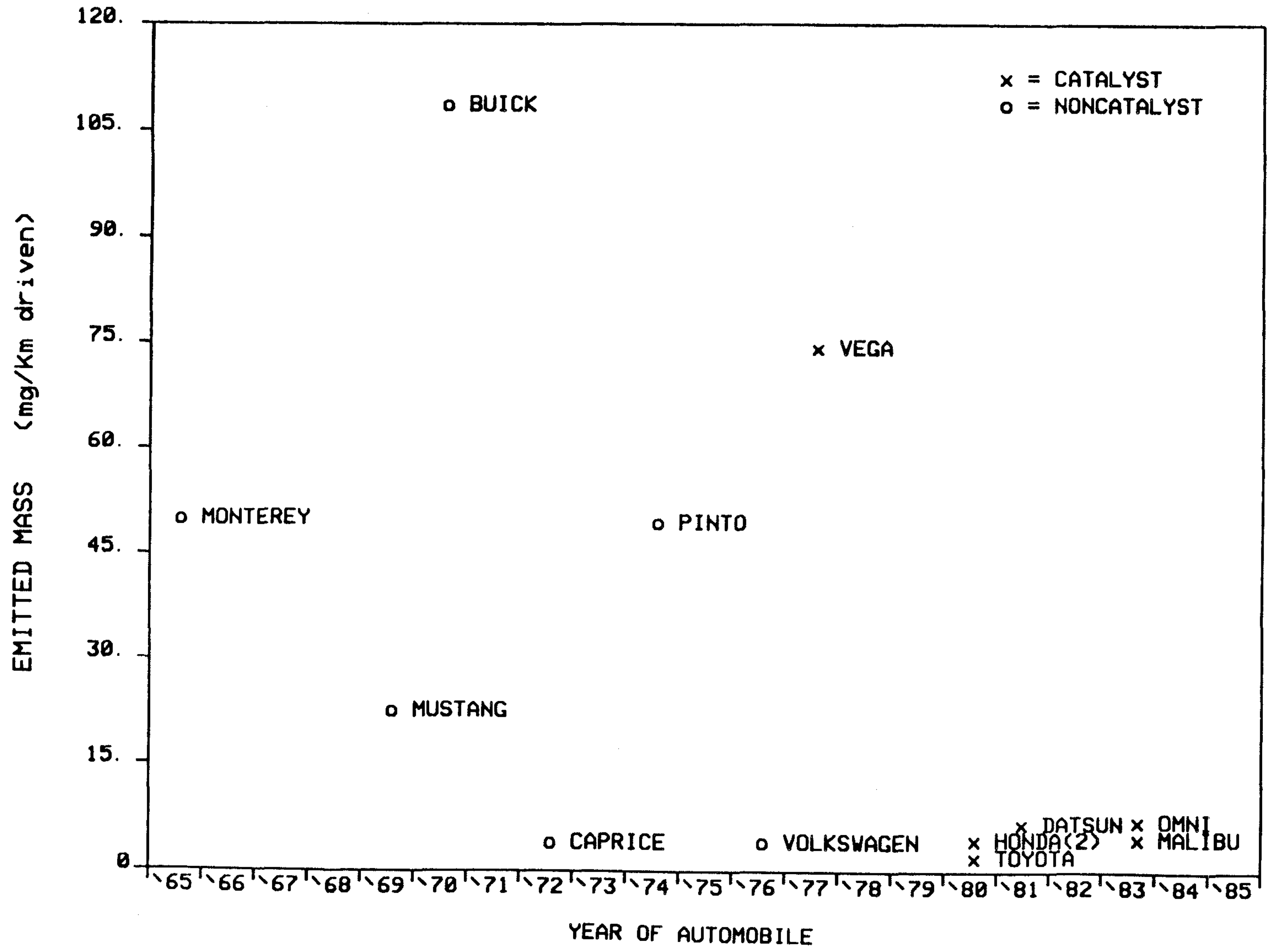

Figure B.6. Submicron aerosol emissions from catalyst and noncatalyst autos during Federal Test Procedure driving cycle.

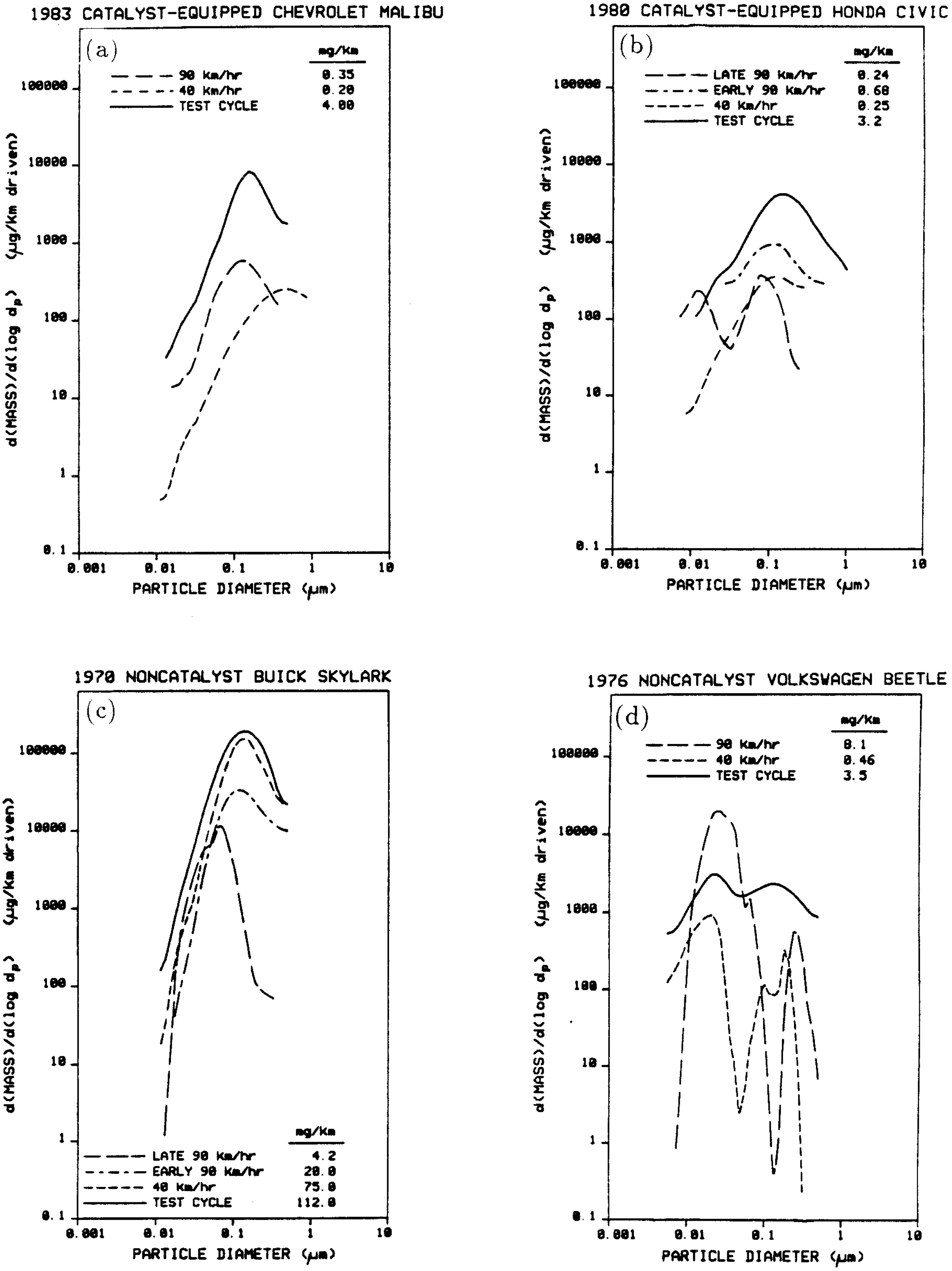

Figure B.7. Mass distribution of aerosol emissions from (a) 1983 catalyst-equipped Chevrolet Malibu; (b) 1980 catalyst-equipped Honda Civic; (c) 1970 noncatalyst Buick Skylark; and (d) 1976 noncatalyst Volkswagen Beetle.

For several of the catalyst-equipped autos, bimodal size distributions were obtained under certain conditions. For the vehicle plotted in Figure B.7b, substantial differences were seen between emissions at the beginning of the 90 km/hr steady state experiment vs. the later portion of the same experiment. Besides a significant drop in the mass emission rate, a second peak in the size distribution developed late in the 90 km/hr steady state test, with a peak value around 0.01 μm particle diameter.

Emissions were much higher from noncatalyst vehicles. Figure B.7c shows results typical of many of the noncatalyst vehicles tested, with the FTP test cycle producing the highest submicron aerosol emission rate. For the vehicle shown, substantial changes again are seen between the early and late stages of the steady state experiment at 90 km/hr. The lower emission rate seen in the later portion of the experiment could be due to greater engine efficiency once it has warmed up, or to less oil use once the piston rings have expanded.

Finally, Figure B.7d is shown to emphasize the complexity of the aerosol formation processes occurring in automobile emissions. This was one of several vehicles tested that produced atypical size distribution curves. In this case, the 90 km/hr steady state experiment led to the highest submicron aerosol emission rates. In addition, a definite bimodal distribution is seen under all conditions, with inconclusive indications of an occasional third peak in the distribution.

It is interesting to examine the average distributions gotten for the 7 catalyst and 6 noncatalyst vehicles tested. The small sample size poses a significant problem for averaging the catalyst-equipped automobiles. As was shown in Figure B.6, the 1977 Vega tested had an emission rate 10 to 20 times higher than the other 6 catalyst-equipped automobiles. In order to determine an aerosol mass distribution typical of the catalyst-equipped fleet of vehicles, the Vega was excluded in calculating the average results for the catalyst-equipped cars.

Figure B.8 shows the average results obtained for the noncatalyst and for the "typical" catalyst-equipped vehicles for the FTP driving cycle. Both mass distributions show evidence of a shoulder between 0.03 and 0.05 μm particle diameter, reflecting the nucleation mode observed for some, but not all, of the

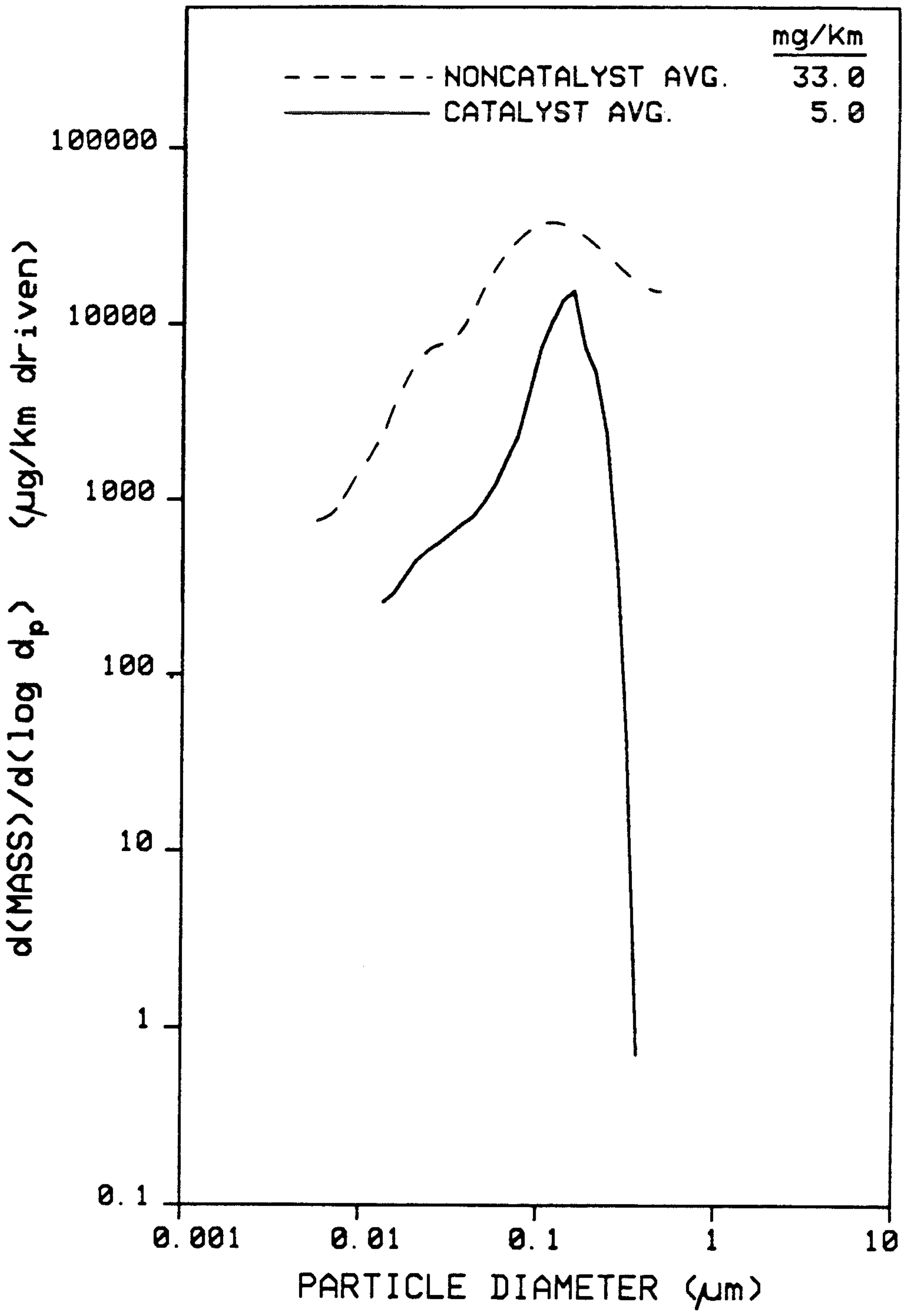

Figure B.8. Average mass distribution of aerosol emissions from catalyst and noncatalyst automobiles.

vehicles tested. A pronounced peak is seen in each mass distribution, at between 0.1 and 0.2 μm particle diameter.

B.3.4 Diesel Trucks.

Two heavy-duty diesel dump trucks also were tested while operating under load on a truck dynamometer. Due to limitations inherent in the truck dynamometer available, it was not possible to run the truck through a complicated driving cycle. Instead, the cycle shown in Figure B.9 was used. The transient acceleration/decelerations shown were included because of field observations that diesel truck emissions are most apparent when the truck is changing its operating mode.

The two trucks tested were both late model vehicles with low mileage (see Table B.2). Hence, the results should be considered to represent a best-case situation, both due to the excellent condition of the trucks and to the use of a driving cycle with a modest number of transient conditions.

The submicron aerosol mass distributions illustrated in Figure B.10 show a single mode with a peak around 0.2 μm particle diameter. The mass emission rate per distance driven is 10–100 times larger than that measured for the automobiles discussed earlier. Little difference is seen between the two pseudo-steady state vehicle speeds. The 460–470 mg/km submicron aerosol emission rate estimate obtained for the two trucks from integration of the EAA data is comparable to the 360–450 mg/km of fine mass measured gravimetrically.

B.3.5 Meat Cooking.

The size distribution of aerosol emissions from meat-cooking operations was measured during both frying and charbroiling of extra-lean and regular hamburger meat. For each of the four experiments, eighty 1/4-lb (113 g) patties were cooked, eight at a time, while sampling emissions from the exit to the kitchen vent above the cooking operations. A typical baffle-type grease extractor was in place in the hood above the meat cooking area (upstream of the sampling point), with an estimated removal efficiency of about 60% by mass (Bornstein, 1978).

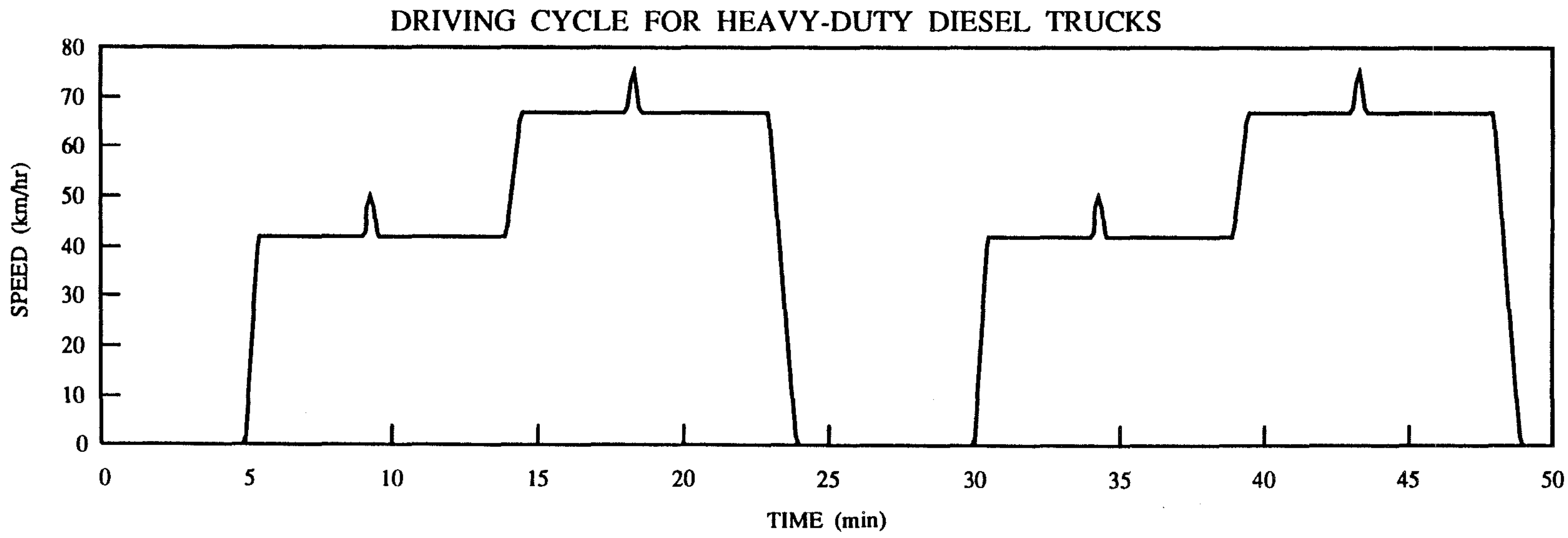

Figure B.9. Driving cycle for heavy-duty diesel trucks.

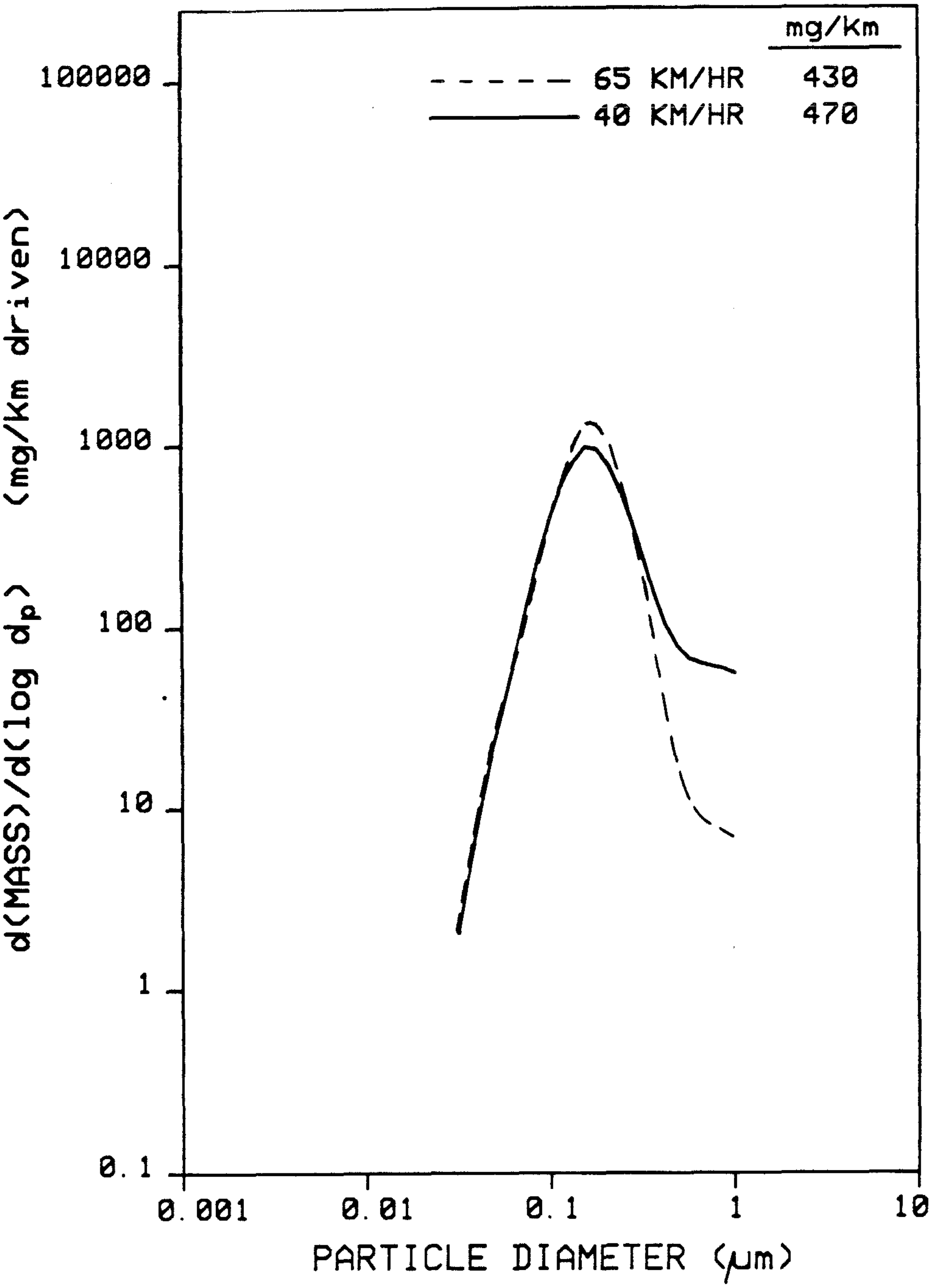

Figure B.10. Mass distribution of aerosol emissions from a 1987 heavy-duty Ford diesel dump truck.

Figure B.11 shows the size distributions measured during these experiments. A drastic difference was seen between charbroiling (with natural gas) and frying, with charbroiling producing 20 to 80 times as much submicron aerosol mass as frying. Charbroiling regular hamburger meat produced about 4 times as much submicron aerosol mass as charbroiling extra-lean meat. For frying, emissions from the two different types of meat were about the same. All measurements showed a broad, single-modal mass distribution with a peak around 0.2 μm particle diameter.

B.3.6 Mass Emission Rates.

A comparison between the mass emission rates calculated using the submicron aerosol size distributions and those measured gravimetrically using the fine (< 2 μm) aerosol collected on a Teflon filter is shown in Table B.3. Several of the automotive emissions tests are grouped because the filter samples were accumulated over the course of two or three consecutive tests.

For most of the sources, remarkably good agreement is obtained between the two methods. In all but a few cases, the differences in mass emission rate that do exist between the two measurement methods show lower estimates from the EAA data base than from the fine filter samples. This observation is consistent with the knowledge that the upper limit of the EAA size distributions reported is about 0.7 μm while the fine filter samples contain any additional aerosol that resides between 0.7 and 2 μm particle diameter. The assumption of unit particle density when reducing the EAA size distribution data may also lead to an underestimate of the submicron aerosol mass in some cases.

B.4 CONCLUSIONS

Measurement of the submicron aerosol size distributions of cooled, diluted emissions from some of the common combustion sources found in urban areas shows that the most prominant peaks in their primary submicron mass distributions occur at ≤ 0.2 μm particle diameter. By comparison, the submicron aerosol size distribution observed for Los Angeles area ambient aerosols (see for example Larson *et al.*, 1988) usually peaks at a larger particle size closer to 0.4 μm particle

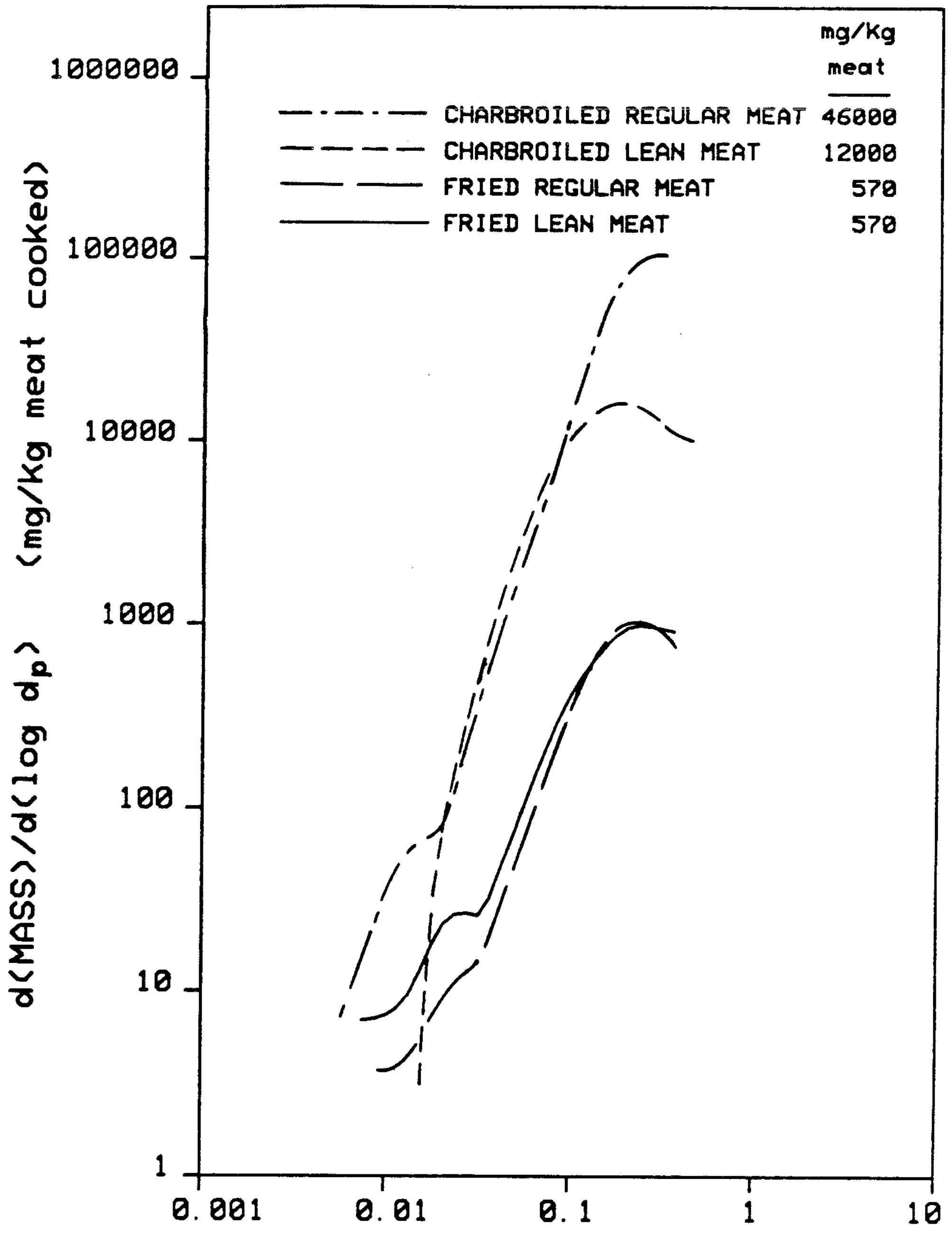

Figure B.11. Mass distribution of aerosol emissions from cooking hamburger meat.

Table B.3. Comparison of Submicron Mass Emission Rates Measured by an Electrical Aerosol Analyzer to Fine Mass Measurements Made by Filtration

Source	(units)	Submicron Mass Emission Rate from EAA	Fine Mass Emission Rate by Filtration
Industrial Boiler	(μg/kJ fuel burned)		
—No. 2 Fuel Oil		8	11
Fireplace	(g/kg wood burned)		
—Seasoned Pine (exp. 1)		10	16
—Seasoned Pine (exp. 2)		6.9	10
—Seasoned Oak		1.6(a)	6.2
Catalyst Automobiles	(mg/km driven)		
—Toyota, Omni		4.5	10
—Honda 1500, Vega, Malibu		27	31
—Honda 150, Datsun		4.0	12
Fleet Average (excl. Vega)		5.0	11(b)
Noncatalyst Automobiles	(mg/km driven)		
—Mustang, Pinto		37	61
—Caprice, VW		3.5	17
—Mercury, Buick		81	94
Fleet Average		33	57
Heavy-Duty Diesel Trucks	(mg/km driven)		
—GMC		470	360
—Ford		460	450
Hamburger Cooking	(g/kg meat cooked)		
—Regular Meat, Charbroiled		46	40
—Extra-Lean Meat, Charbroiled		12	7.1
—Regular Meat, Fried		0.6	1.1
—Extra-Lean Meat, Fried		0.6	1.4

(a) Based on last hour of fire only.

(b) Approximate value based on first and third samples only.

diameter, demonstrating that considerable modification of the primary aerosol mass distribution occurs due to subsequent atmospheric processes. In the present experiments, the same method of sampling was used for all source types, creating a data set that can be used with mathematical models to study the evolution of the atmospheric aerosol size distribution from the primary emissions.

1) For boiler emissions, combustion of No. 2 fuel oil produced a bimodal mass distribution with a nucleation mode peak between 0.02 and 0.06 μm and an larger mode peak near 0.3 μm.

2) For fireplace emissions, the size distribution varied greatly in intensity throughout the course of the fire, with mass emissions about 10 times higher when new wood was added than when the ember stage was reached. Typically, the emissions showed a single, broad mode in the mass distribution with a peak at 0.1 to 0.2 μm particle diameter.

3) For automobiles, considerable differences were seen in the aerosol size distributions of emissions from the different vehicles tested. Mass emission rates from noncatalyst cars were much higher than from catalyst cars. Emissions over a variable driving cycle were higher than under steady state conditions. Typically, a broad mass distribution having a single mode with a peak around 0.1 μm particle diameter was observed, but bimodal distributions also were seen for some cars.

4) Diesel trucks showed a submicron aerosol mass distribution with a single mode that peaked at about 0.2 μm particle diameter. The mass emission rates from these diesel trucks were 10 to 100 times higher than those of the automobiles tested.

5) Meat-cooking operations produced a broad mass distribution with a peak around 0.2 μm particle diameter. Charbroiling of hamburger meat produced emissions that were 20 to 80 times higher than from frying the same meat. Charbroiling extra-lean meat instead of regular meat reduced emissions by about 4-fold.

6) For most sources, the fine aerosol mass emission rates calculated by integration of the submicron aerosol size distributions assuming unit particle density agreed rather well with the fine mass emission rates measured gravimetrically by filtration of the diluted source effluent.

B.5 REFERENCES

Berner, A., Lurzer, C., Pohl, F., Preining, O., and Wagner, P. (1979). The Size Distribution of the Urban Aerosol in Vienna, *Sci. Total Environ.* 13:245–261.

Berner, A., and Lurzer, C. (1980). Mass Size Distributions of Traffic Aerosols at Vienna, *J. Phys. Chem.* 84:2079–2083.

Berner, A., and Reischl, G. (1983). Mass Size Distributions of Traffic Aerosols of Vienna, *J. Aerosol Sci.* 14:324–325.

Berner, A., Reischl, G., and Puxbaum, H. (1984). Size Distribution of Traffic Derived Aerosols, *Sci. Total Environ.* 36:299–303.

Bornstein, M.I. (1978). Study to Develop Background Information for the Direct Meat-Firing Industry, EPA-450/3-78-027 (PB282-486), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Carter, W.A., Buening, H.J., and Hunter, S.C. (1978). Emission Reduction on Two Industrial Boilers with Major Combustion Modifications, EPA-600/7-78-099a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cato, G.A., Buening, H.J., DeVivo, C.C., Morion, B.G., and Robinson, J.M. (1974). Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers - Phase I, EPA650/2-74-078a (PB238-920), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Cato, G.A., Muzio, L.J., and Shore, D.E. (1976). Field Testing: Application of Combustion Modifications to Control Pollutant Emissions from Industrial Boilers - Phase II, EPA600/2-76-086a, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

Dasch, J.M. (1982). Particulate and Gaseous Emissions from Wood-Burning Fireplaces, *Environ. Sci. Technol.* 16:639–645.

Groblicki, P.J., and Begeman, C.R. (1980). Particle Size Variation in Diesel Car Exhaust, Paper No. 790421, Society of Automotive Engineers, Warrendale, Pennsylvania.

Hidy, G.M., Appel, B.R., Charlson, R.J., Clark, W.E., Friedlander, S.K., Hutchison, D.H., Smith, T.B., Suder, J., Wesolowski, J.J., and Whitby, K.T. (1975). Summary of the California Aerosol Characterization Experiment, *J. Air Pollut. Control Assoc.* 25:1106–1114.

Hildemann, L.M., Cass, G.R., and Markowski, G.R. (1989). A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests, *Aerosol Sci. Technol.* 10:193–204. [See Chapter 2.]

John, W., and Reischl, G. (1980). A Cyclone for Size-Selective Sampling of Air, *J. Air Pollut. Control Assoc.* 30:872–876.

Khatri, N.J., and Johnson, J.H. (1979). Physical Size Distribution Characterization of Diesel Particulate Matter and the Study of the Coagulation Process, paper no. 780788, *SAE Transactions* 87:3023–3047.

Kittelson, D.B., Dolan, D.F., Diver, R.B., and Aufderheide, E. (1979). Diesel Exhaust Particle Size Distributions — Fuel and Additive Effects, paper no. 780787, *SAE Transactions* 87:3011–3022.

Kittelson, D.B., Kadue, P.A., Scherrer, H.C., and Lovrien, R.E. (1988). Characterization of Diesel Particles in the Atmosphere, Final Report to the Coordinating Research Council, AP-2 Project Group, Atlanta, Georgia.

Larson, S.M., Cass, G.R., Hussey, K.J., and Luce, F. (1988). Verification of Image Processing Based Visibility Models, *Environ. Sci. Technol.* 22:629–637.

Markowski, G.R. (1987). Improving Twomey's Algorithm for Inversion of Aerosol Measurement Data, *Aerosol Sci. Technol.* 7:127–141.

Miller, D.F., Levy, A., Pui, D.Y.H., Whitby, K.T., and Wilson, W.E., Jr. (1976). Combustion and Photochemical Aerosols Attributable to Automobiles, *J. Air Pollut. Control Assoc.* 26:576–581.

Rau, J.A. (1989). Composition and Size Distribution of Residential Wood Smoke Particles, *Aerosol Sci. Technol.* 10:181–192.

Rau, J.A., Huntzicker, J.J., and Edgerton, S.A. (1987). Size Distributed Receptor Modeling of Atmospheric Aerosol, Paper No. 87-14.4 presented at the 80th Annual Meeting of Air Pollution Control Association, June 21–26, 1987.

Raunemaa, T., Hyvonen, V., and Kauppinen, E. (1984). Submicron Size Particle Growth and Chemical Transformation in Gasoline Exhaust—I. Size Distribution and Transformation, *J. Aerosol Sci.* 15:335–341.

Sexton, K., Webber, L.M., Hayward, S.B., and Sextro, R.G. (1986). Characterization of Particle Composition, Organic Vapor Constituents, and Mutagenicity of Indoor Air Pollutant Emissions, *Environ. Int.* 12:351–362.

Stelson, A.W. (1989a). Theoretical and Experimental Evidence for Artifact Particulate Matter Formation in Electrical Aerosol Analyzers, *Environ. Sci. Technol.* 23:125–128.

Stelson, A.W. (1989b). Personal communication, Atlanta University Center, Inc., Atlanta, Georgia.

Taback, H.J., Brienza, A.R., Macko, J., and Brunetz, N. (1979). Fine Particulate Emissions from Stationary and Miscellaneous Sources in the South Coast Air Basin. Final Report and Appendices. NTIS Nos. PB 293 922 and PB 293 923.

Verrant, J.A., and Kittelson, D.A. (1978). Sampling and Physical Characterization of Diesel Exhaust Aerosols, paper no. 770720, *SAE Transactions* 86:2623–2636.

Whitby, K.T., Clark, W.E., Marple, V.A., Sverdrup, G.M., Sem, G.J., Willeke, K., Liu, B.Y.H., and Pui, D.Y.H. (1975). Characterization of California Aerosols—I. Size Distributions of Freeway Aerosol, *Atmos. Environ.* 9:463–482.

Wilson, W.E., Spiller, L.L., Ellestad, T.G., Lamothe, P.J., Dzubay, T.G., Stevens, R.K., Macias, E.S., Fletcher, R.A., Husar, J.D., Husar, R.B., Whitby, K.T., Kittelson, D.B., and Cantrell, B.K. (1977). General Motors Sulfate Dispersion Experiment: Summary of EPA Measurements, *J. Air Pollut. Control Assoc.* 27:46–51.

Appendix C

Bulk Chemical Analysis Results for Individual Source Tests

The following tables contain the results of the bulk chemical analyses for those sources where more than one experiment was performed. The values (except for the fine mass emission rates) are expressed as percent of the total fine particulate mass collected. The measurements have been corrected for the contribution of any trace species present in the dilution air, and as a result, negative values which are not statistically significant occasionally occur.

The standard deviation values listed with the individual measurements reflect the accuracy of the measurement methods. On the right side of each table, the mean of the multiple experimental values is calculated, along with the standard deviation of the mean. The value under the "Average of the S.D.s" column is the average standard deviation resulting from the measurement method used for that species. The "Overall S.D." value, which is calculated as the square root of the sum of the square of the measurement method standard deviation plus the square of the standard deviation of the mean, is considered to represent the total standard deviation of the mean measurement. An asterisk is used to mark those species with mean values that are greater than the overall standard deviation.

TABLE C.1. BOILER BURNING NO.2 FUEL OIL

	46x Dilution		49x Dilution		27x Dilution		94x Dilution		35x Dilution			S.D. of	Avg.of	Overall
	TEST 1 (% +- SD)		TEST 2 (% +- SD)		TEST 3 (% +- SD)		TEST 4 (% +- SD)		TEST 5 (% +- SD)		MEAN	MEAN	S.D.s	S.D.
AL	0.5696	0.0589	0.4990	0.0344	0.2485	0.0165	0.4211	0.0364	0.3644	0.0230	0.4205	0.1236	0.0336	0.1281 *
SI	0.4851	0.0443	0.4624	0.0304	0.2983	0.0176	2.8165	0.1481	0.3759	0.0224	0.8876	1.0808	0.0526	1.0821
P	0.2192	0.0474	0.2125	0.0441	0.1145	0.0231	0.1685	0.0344	0.1527	0.0309	0.1735	0.0434	0.0360	0.0564 *
S	12.0832	0.6444	11.6913	0.7121	4.8370	0.2480	8.9802	0.4734	7.9201	0.4296	9.1024	2.9662	0.5015	3.0083 *
CL	-0.0050	0.0383	0.0000	0.0224	-0.0020	0.0106	-0.0041	0.0246	0.0000	0.0151	-0.0022	0.0023	0.0222	0.0223
K	0.0000	0.0143	0.0000	0.0039	0.0000	0.0028	0.0097	0.0080	0.0021	0.0025	0.0024	0.0042	0.0063	0.0076
CA	0.0150	0.0093	-0.0034	0.0025	0.0062	0.0019	0.0086	0.0055	0.0021	0.0015	0.0057	0.0069	0.0041	0.0081
TI	0.0000	0.0060	0.0001	0.0017	0.0010	0.0012	0.0030	0.0033	0.0019	0.0009	0.0012	0.0013	0.0026	0.0029
V	0.0011	0.0051	0.0005	0.0013	-0.0008	0.0010	0.0024	0.0028	0.0000	0.0008	0.0006	0.0012	0.0022	0.0025
CR	0.0073	0.0054	0.0013	0.0014	0.0007	0.0010	0.0002	0.0031	0.0003	0.0008	0.0020	0.0030	0.0023	0.0038
MN	0.0000	0.0070	0.0000	0.0019	0.0000	0.0013	0.0000	0.0041	0.0000	0.0013	0.0000	0.0000	0.0031	0.0031
FE	0.2131	0.0186	0.1166	0.0084	0.0836	0.0054	0.1210	0.0100	0.0938	0.0059	0.1266	0.0513	0.0097	0.0522 *
NI	-0.0008	0.0047	0.0006	0.0012	-0.0006	0.0008	0.0023	0.0027	0.0006	0.0008	0.0004	0.0012	0.0020	0.0024
CU	-0.0111	0.0068	0.0035	0.0022	0.0032	0.0011	0.0065	0.0029	0.0048	0.0009	0.0012	0.0069	0.0026	0.0074
ZN	-0.0038	0.0045	0.0027	0.0017	0.0007	0.0008	0.0016	0.0021	0.0015	0.0007	0.0005	0.0025	0.0020	0.0032
GA	0.0008	0.0036	-0.0007	0.0010	0.0003	0.0007	-0.0005	0.0021	0.0002	0.0007	0.0000	0.0006	0.0016	0.0017
AS	0.0000	0.0157	0.0043	0.0043	0.0000	0.0032	0.0048	0.0084	0.0006	0.0028	0.0019	0.0024	0.0069	0.0073
SE	0.0046	0.0053	0.0009	0.0014	0.0018	0.0010	-0.0004	0.0032	0.0018	0.0009	0.0017	0.0018	0.0024	0.0030
BR	0.0150	0.0072	-0.0001	0.0019	0.0010	0.0013	0.0078	0.0042	0.0008	0.0013	0.0049	0.0065	0.0032	0.0072
RB	0.0005	0.0090	0.0027	0.0024	0.0000	0.0017	0.0023	0.0053	0.0001	0.0015	0.0011	0.0013	0.0040	0.0042
SR	0.0062	0.0110	-0.0025	0.0030	-0.0021	0.0021	0.0000	0.0064	0.0000	0.0020	0.0003	0.0035	0.0049	0.0060
Y	0.0225	0.0134	0.0009	0.0036	-0.0014	0.0025	-0.0048	0.0077	0.0017	0.0025	0.0038	0.0108	0.0059	0.0123
ZR	0.0034	0.0558	-0.0077	0.0150	-0.0085	0.0105	-0.0093	0.0322	-0.0037	0.0103	-0.0052	0.0052	0.0248	0.0253
MO	0.0000	0.0381	-0.0028	0.0102	-0.0028	0.0072	0.0200	0.0222	-0.0058	0.0069	0.0017	0.0104	0.0169	0.0199
PD	0.0059	0.0338	-0.0080	0.0093	0.0022	0.0064	0.0000	0.0198	0.0000	0.0063	0.0000	0.0051	0.0151	0.0160
AG	0.0193	0.0474	-0.0060	0.0127	0.0000	0.0089	-0.0015	0.0274	-0.0046	0.0089	0.0014	0.0103	0.0211	0.0234
CD	0.0117	0.0616	-0.0035	0.0166	0.0000	0.0114	-0.0215	0.0345	-0.0087	0.0112	-0.0044	0.0121	0.0271	0.0297
IN	-0.0017	0.0771	-0.0080	0.0209	-0.0051	0.0146	-0.0172	0.0443	0.0063	0.0142	-0.0051	0.0086	0.0342	0.0353
SN	-0.0153	0.0903	-0.0053	0.0243	0.0115	0.0172	0.0139	0.0539	-0.0019	0.0172	0.0006	0.0121	0.0406	0.0424
SB	0.0000	0.2037	0.0136	0.0539	0.0211	0.0376	0.0504	0.1203	0.0000	0.0380	0.0170	0.0207	0.0907	0.0930
BA	-0.2059	0.3776	-0.0754	0.1017	0.0000	0.0705	0.0000	0.2211	0.0000	0.0710	-0.0563	0.0898	0.1684	0.1908
LA	0.0000	0.6918	0.0000	0.1868	0.0000	0.1292	0.2380	0.4001	-0.0921	0.1283	0.0292	0.1234	0.3072	0.3311
HG	0.0019	0.0063	-0.0020	0.0017	-0.0012	0.0012	0.0007	0.0037	0.0003	0.0012	-0.0001	0.0016	0.0028	0.0032
PB	0.0826	0.0252	0.0217	0.0068	0.0247	0.0049	0.0146	0.0143	0.0158	0.0046	0.0319	0.0287	0.0112	0.0308 *
EC	25.9068	1.8270	22.6834	1.6198	41.3653	2.2830	39.5006	2.6779	15.1008	0.9820	28.9114	11.2448	1.8579	11.3972 *
OC	9.9046	1.1586	3.5424	0.5185	2.0351	0.3502	6.1411	0.9656	2.3908	0.3426	4.8028	3.2744	0.6671	3.3416 *
Backup filter OC	0.8426	0.7791	0.7795	0.3742	0.9787	0.3002	1.7988	0.7592	0.0361	0.2297	0.8871	0.6280	0.4885	0.7956 *
MG++	0.0471	0.0193	0.0171	0.0050	-0.0016	0.0037	0.0002	0.0098	0.0034	0.0032	0.0132	0.0203	0.0082	0.0219
NA+	0.1716	0.1330	0.0736	0.0344	0.2881	0.0264	0.6717	0.0675	0.0418	0.0219	0.2494	0.2549	0.0564	0.2611
CL-	0.1565	0.1633	0.0401	0.0422	0.0303	0.0312	0.0261	0.0822	0.0265	0.0269	0.0559	0.0565	0.0692	0.0893
NO3-	0.1159	0.1628	0.0297	0.0420	0.2189	0.0325	0.8333	0.0880	0.0196	0.0268	0.2435	0.3393	0.0704	0.3466
SO4=	35.4378	0.6152	36.2729	1.3171	22.6485	0.3425	26.2196	0.6146	36.9234	0.8578	31.5004	6.5941	0.7494	6.6366 *
NH4+	12.5708	0.3633	6.2779	0.3260	1.1671	0.0463	9.0837	0.4459	1.8776	0.0636	6.1954	4.8198	0.2490	4.8262 *
Fine Mass Emission Rate (ug/kJ burned)	4.5916	0.0492	9.0362	0.3023	12.7434	0.0259	9.2286	0.0926	11.2451	0.2107	9.3690	3.0765	0.1395	3.0795

TABLE C.2. AUTOMOBILE TESTS

	CATALYST CARS TEST 1 (% +- SD)		CATALYST CARS TEST 2 (% +- SD)		CATALYST CARS TEST 3 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.0000	0.7709	0.0000	0.1551	0.2090	0.3504	0.0697	0.1207	0.4255	0.4422
SI	-0.3748	0.5143	0.0000	0.0961	0.4961	0.3163	0.0404	0.4369	0.3089	0.5350
P	0.0000	0.3040	0.2708	0.2259	0.2420	0.1779	0.1709	0.1487	0.2369	0.2789
S	0.0000	2.8523	0.0000	0.5693	0.0000	1.2460	0.0000	0.0000	1.5559	1.5559
CL	0.1228	1.1947	0.0000	0.2399	-0.0092	0.5063	0.0379	0.0737	0.6470	0.6612
K	1.2149	0.6901	-0.0173	0.0959	0.0565	0.2191	0.4180	0.6911	0.3350	0.7680
CA	0.4758	0.4091	0.4107	0.0875	0.9906	0.4319	0.6267	0.3177	0.3095	0.4435 *
TI	-0.0161	0.1902	0.0044	0.0407	0.0554	0.0945	0.0149	0.0364	0.1085	0.1144
V	-0.0550	0.1462	0.0086	0.0299	-0.0185	0.0615	-0.0216	0.0319	0.0792	0.0854
CR	0.0136	0.1540	-0.0382	0.0326	-0.0647	0.0724	-0.0298	0.0398	0.0863	0.0951
MN	-0.0654	0.1916	-0.0148	0.0389	-0.0441	0.0869	-0.0414	0.0254	0.1058	0.1088
FE	0.4504	0.4523	-0.1690	0.0879	0.1602	0.2136	0.1472	0.3099	0.2513	0.3990
NI	-0.1190	0.1635	0.0051	0.0335	0.2381	0.1220	0.0414	0.1813	0.1063	0.2102
CU	0.0000	0.1992	0.8704	0.0786	2.4817	0.9855	1.1174	1.2691	0.4211	1.3277
ZN	0.3481	0.1944	0.8968	0.0734	1.9322	0.7662	1.0590	0.8044	0.3447	0.8751 *
GA	0.0000	0.1268	0.0000	0.0255	0.0000	0.0543	0.0000	0.0000	0.0689	0.0689
AS	0.0917	0.3997	-0.0456	0.0797	-0.1710	0.1865	-0.0416	0.1314	0.2220	0.2579
SE	-0.0424	0.1366	-0.0061	0.0281	-0.0153	0.0614	-0.0213	0.0189	0.0754	0.0777
BR	0.0819	0.1923	-0.0271	0.0389	0.0665	0.0890	0.0404	0.0590	0.1067	0.1220
RB	-0.2634	0.2570	-0.0045	0.0480	-0.1063	0.1099	-0.1247	0.1304	0.1383	0.1901
SR	-0.2677	0.3136	0.0099	0.0598	0.0227	0.1263	-0.0784	0.1641	0.1666	0.2338
Y	0.0000	0.3622	0.0000	0.0724	0.0746	0.1595	0.0249	0.0431	0.1980	0.2027
ZR	0.0000	1.5443	0.0000	0.3096	0.0000	0.6698	0.0000	0.0000	0.8412	0.8412
MO	1.0169	1.0764	-0.1677	0.2040	0.0647	0.4298	0.3046	0.6277	0.5701	0.8479
PD	-0.0238	0.9948	-0.0247	0.2009	0.2339	0.4460	0.0618	0.1490	0.5472	0.5672
AG	0.0000	1.4137	0.0000	0.2815	0.0000	0.6026	0.0000	0.0000	0.7659	0.7659
CD	0.0000	1.7502	0.0000	0.3503	0.4329	0.7881	0.1443	0.2499	0.9629	0.9948
IN	0.0000	2.1367	0.0000	0.4255	0.3782	0.9347	0.1261	0.2184	1.1656	1.1859
SN	0.0000	2.5868	-0.1850	0.5222	0.0000	1.1094	-0.0617	0.1068	1.4061	1.4102
SB	0.0000	5.7802	0.0000	1.1570	2.5102	2.7265	0.8367	1.4493	3.2212	3.5322
BA	0.0000	11.0548	0.0000	2.2210	0.3483	4.8005	0.1161	0.2011	6.0254	6.0288
LA	0.0000	19.2639	0.0000	3.8500	-0.5324	8.4870	-0.1775	0.3074	10.5336	10.5381
HG	0.0068	0.1670	-0.0101	0.0325	0.0402	0.0733	0.0123	0.0256	0.0909	0.0945
PB	0.0000	0.6791	0.0225	0.1368	0.5374	0.3633	0.1866	0.3040	0.3931	0.4969
EC	36.6434	22.5840	13.7613	4.0216	17.4135	15.6411	22.6061	12.2931	14.0822	18.6930 *
OC	37.5699	26.5490	68.6267	7.7449	44.0639	25.2486	50.0868	16.3810	19.8475	25.7344 *
Backup filter OC	-6.5662	21.2399	13.7930	4.8374	24.1186	20.2143	10.4488	15.6129	15.4305	21.9514
MG++	0.8674	0.5365	-0.2060	0.0929	-8.8511	3.4584	-2.7299	5.3282	1.3623	5.4996
NA+	2.2012	3.1107	0.4780	0.6364	1.8110	2.5144	1.4967	0.9036	2.0872	2.2744
CL-	3.6017	3.9138	0.7821	0.7821	2.9631	3.1812	2.4490	1.4784	2.6257	3.0133
NO3-	2.6680	3.8059	0.5794	0.7791	2.1950	3.0758	1.8141	1.0952	2.5536	2.7785
SO4=	8.4046	4.7741	0.4924	0.7778	1.8656	3.0385	3.5875	4.2278	2.8635	5.1063
NH4+	0.0000	2.3195	0.0000	0.4824	0.0000	1.8485	0.0000	0.0000	1.5501	1.5501
Fine Mass Emission Rate (mg/km driven)	9.939	3.530	31.063	1.346	12.363	4.802	17.765	11.562	3.226	12.004

TABLE C.2. AUTOMOBILE TESTS (CONT.)

	NONCATALYST CARS TEST 1 (% +- SD)		NONCATALYST CARS TEST 2 (% +- SD)		NONCATALYST CARS TEST 3 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.6441	0.2277	1.1060	0.3198	0.4496	0.1300	0.7332	0.3372	0.2258	0.4058 *
SI	0.3993	0.0775	0.5890	0.1587	0.1893	0.0506	0.3925	0.1999	0.0956	0.2216 *
P	0.6764	0.4213	0.3598	0.2820	0.4077	0.2648	0.4813	0.1707	0.3227	0.3650 *
S	0.0000	0.9482	0.0000	1.0846	0.0000	0.5862	0.0000	0.0000	0.8730	0.8730
CL	-0.0526	0.2118	0.0686	0.3047	0.0000	0.1240	0.0053	0.0608	0.2135	0.2220
K	-0.0032	0.0500	0.2326	0.1004	0.0506	0.0275	0.0933	0.1236	0.0593	0.1371
CA	0.5960	0.0805	0.4938	0.1229	0.2479	0.0421	0.4459	0.1789	0.0818	0.1968 *
TI	0.0220	0.0206	0.0967	0.0379	0.0141	0.0100	0.0443	0.0456	0.0228	0.0510
V	-0.0084	0.0148	-0.0024	0.0248	-0.0050	0.0071	-0.0053	0.0030	0.0156	0.0159
CR	0.0000	0.0148	0.0157	0.0267	0.0182	0.0083	0.0113	0.0099	0.0166	0.0193
MN	0.9437	0.1023	1.3881	0.0932	0.3787	0.0479	0.9035	0.5059	0.0811	0.5124 *
FE	0.4740	0.0711	0.3617	0.1025	1.4095	0.1762	0.7484	0.5753	0.1166	0.5870 *
NI	0.0093	0.0155	-0.1565	0.0407	0.0601	0.0125	-0.0290	0.1133	0.0229	0.1156
CU	0.1895	0.0318	0.9480	0.0764	0.6788	0.0853	0.6054	0.3845	0.0645	0.3899 *
ZN	0.6607	0.0736	0.6328	0.0570	0.5162	0.0643	0.6032	0.0767	0.0650	0.1005 *
GA	0.0083	0.0363	0.0881	0.0488	0.0082	0.0236	0.0349	0.0461	0.0362	0.0586
AS	0.1985	0.5241	-0.0531	0.5585	-0.0239	0.3446	0.0405	0.1376	0.4757	0.4952
SE	-0.0010	0.0149	0.0057	0.0267	0.0000	0.0076	0.0016	0.0036	0.0164	0.0168
BR	3.6693	0.3799	4.5140	0.2394	1.9614	0.2358	3.3816	1.3004	0.2850	1.3313 *
RB	0.0271	0.0533	0.0000	0.0724	-0.0019	0.0278	0.0084	0.0162	0.0512	0.0537
SR	-0.0076	0.0296	0.0492	0.0515	0.0000	0.0136	0.0139	0.0308	0.0316	0.0441
Y	0.0000	0.0492	0.0026	0.0723	0.0294	0.0274	0.0107	0.0163	0.0496	0.0522
ZR	0.0000	0.1522	-0.1098	0.2697	-0.0317	0.0710	-0.0472	0.0565	0.1643	0.1737
MO	0.0048	0.0986	0.0480	0.1722	-0.0115	0.0451	0.0138	0.0307	0.1053	0.1097
PD	-0.0172	0.0970	0.0746	0.1777	-0.0251	0.0471	0.0108	0.0554	0.1073	0.1207
AG	0.0000	0.1367	0.0000	0.2398	0.1041	0.0690	0.0347	0.0601	0.1485	0.1602
CD	0.0155	0.1712	0.0000	0.2984	0.0000	0.0790	0.0052	0.0089	0.1829	0.1831
IN	0.0083	0.2084	0.2813	0.3837	0.1184	0.0996	0.1360	0.1373	0.2306	0.2684
SN	0.0000	0.2521	-0.3380	0.4519	-0.0685	0.1177	-0.1355	0.1787	0.2739	0.3270
SB	-0.3083	0.5776	-0.4322	0.9955	0.0076	0.2604	-0.2443	0.2268	0.6112	0.6519
BA	0.0000	1.0788	-1.4295	1.9333	0.0000	0.5001	-0.4765	0.8253	1.1707	1.4324
LA	0.7085	1.9185	-3.9106	3.4312	0.5563	0.8960	-0.8819	2.6240	2.0819	3.3496
HG	-0.0029	0.0171	-0.0062	0.0323	-0.0065	0.0095	-0.0052	0.0020	0.0196	0.0197
PB	9.5995	0.9949	10.0484	0.5493	6.3320	0.7603	8.6600	2.0285	0.7682	2.1691 *
EC	9.3717	3.3488	4.0625	7.1697	10.6070	2.5382	8.0137	3.4772	4.3522	5.5707 *
OC	57.6146	7.9671	75.2600	11.3137	63.4949	8.5423	65.4565	8.9848	9.2744	12.9128 *
Backup filter OC	15.3935	4.3398	40.9456	9.8162	11.2201	2.9576	22.5197	16.0931	5.7045	17.0743 *
MG++	-1.9287	0.1876	0.5056	0.1845	0.1084	0.0495	-0.4382	1.3060	0.1405	1.3135
NA+	0.3771	0.5024	0.9428	1.2684	0.2461	0.3319	0.5220	0.3703	0.7009	0.7927
CL-	0.6170	0.6182	1.5427	1.5582	0.4026	0.4088	0.8541	0.6059	0.8617	1.0534
NO3-	0.4571	0.6150	1.1428	1.5528	0.2982	0.4063	0.6327	0.4488	0.8580	0.9683
SO4=	0.5714	0.6140	0.5142	1.5471	0.2535	0.4054	0.4464	0.1695	0.8555	0.8721
NH4+	0.0000	0.3880	0.0000	0.9879	0.0000	0.2549	0.0000	0.0000	0.5436	0.5436
Fine Mass Emission Rate (mg/km driven)	60.644	5.436	23.530	4.436	94.008	10.183	59.394	35.256	6.685	35.884

TABLE C.3. HEAVY-DUTY TRUCK TESTS

	H-D DIESEL TRUCK TEST 1 (% +- SD)		H-D DIESEL TRUCK TEST 2 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.0654	0.0839	0.0391	0.0363	0.0522	0.0186	0.0596	0.0624
SI	0.6639	0.0934	0.5153	0.0846	0.5896	0.1051	0.0890	0.1377 *
P	0.0115	0.0327	0.0450	0.0304	0.0283	0.0237	0.0316	0.0395
S	0.0000	0.3026	0.0000	0.1273	0.0000	0.0000	0.2149	0.2149
CL	0.0000	0.1271	-0.0099	0.0524	-0.0049	0.0070	0.0898	0.0900
K	0.0714	0.0549	0.0397	0.0228	0.0556	0.0224	0.0389	0.0449 *
CA	0.2272	0.0446	0.0831	0.0209	0.1551	0.1019	0.0327	0.1070 *
TI	0.0244	0.0217	0.0352	0.0101	0.0298	0.0076	0.0159	0.0176 *
V	0.0162	0.0152	-0.0017	0.0062	0.0073	0.0127	0.0107	0.0166
CR	0.0272	0.0171	0.0089	0.0072	0.0181	0.0129	0.0122	0.0178 *
MN	0.0151	0.0207	0.0028	0.0086	0.0090	0.0087	0.0147	0.0170
FE	0.2090	0.0480	0.0499	0.0200	0.1295	0.1125	0.0340	0.1175 *
NI	0.0501	0.0213	0.0031	0.0071	0.0266	0.0332	0.0142	0.0361
CU	-0.5017	0.0596	0.0271	0.0104	-0.2373	0.3739	0.0350	0.3755
ZN	-0.2522	0.0382	0.1130	0.0156	-0.0696	0.2582	0.0269	0.2596
GA	0.0000	0.0138	0.0000	0.0056	0.0000	0.0000	0.0097	0.0097
AS	0.0405	0.0428	-0.0102	0.0176	0.0152	0.0359	0.0302	0.0469
SE	-0.0101	0.0147	0.0016	0.0062	-0.0042	0.0083	0.0104	0.0133
BR	0.0204	0.0207	0.0022	0.0084	0.0113	0.0129	0.0146	0.0194
RB	0.0018	0.0258	-0.0045	0.0107	-0.0013	0.0045	0.0183	0.0188
SR	-0.0110	0.0318	-0.0052	0.0131	-0.0081	0.0041	0.0225	0.0228
Y	0.0094	0.0392	0.0000	0.0161	0.0047	0.0066	0.0277	0.0284
ZR	0.0000	0.1653	0.0000	0.0686	0.0000	0.0000	0.1169	0.1169
MO	0.0223	0.1082	-0.0182	0.0444	0.0020	0.0286	0.0763	0.0815
PD	0.0000	0.1055	0.0000	0.0442	0.0000	0.0000	0.0749	0.0749
AG	0.0000	0.1515	0.0000	0.0629	0.0000	0.0000	0.1072	0.1072
CD	0.0000	0.1875	0.0000	0.0770	0.0000	0.0000	0.1322	0.1322
IN	0.0000	0.2280	0.0000	0.0943	0.0000	0.0000	0.1612	0.1612
SN	-0.1407	0.2787	0.0299	0.1155	-0.0554	0.1206	0.1971	0.2311
SB	0.0081	0.6181	0.0581	0.2577	0.0331	0.0354	0.4379	0.4393
BA	0.0000	1.1791	0.0000	0.4873	0.0000	0.0000	0.8332	0.8332
LA	0.0000	2.0686	0.0000	0.8598	0.0000	0.0000	1.4642	1.4642
HG	-0.0032	0.0180	0.0022	0.0073	-0.0005	0.0038	0.0126	0.0132
PB	0.0000	0.0723	0.0000	0.0301	0.0000	0.0000	0.0512	0.0512
EC	43.1302	3.8482	37.9459	4.6783	40.5381	3.6658	4.2632	5.6226 *
OC	34.6152	3.8558	30.5139	3.9241	32.5646	2.9000	3.8900	4.8520 *
Backup filter OC	14.1768	2.8584	9.9788	1.7024	12.0778	2.9684	2.2804	3.7432 *
MG	-1.5264	0.0631	-0.0150	0.0203	-0.7707	1.0687	0.0417	1.0695
NA	0.2464	0.3334	0.0996	0.1393	0.1730	0.1038	0.2364	0.2581
CL	0.4031	0.4096	0.1629	0.1715	0.2830	0.1698	0.2905	0.3366
NO3	0.2986	0.4081	0.3561	0.1757	0.3273	0.0407	0.2919	0.2947 *
SO4	-0.0962	0.4110	0.5311	0.1816	0.2174	0.4436	0.2963	0.5334
NH4	0.0000	0.2569	0.1590	0.1105	0.0795	0.1124	0.1837	0.2154
Fine Mass Emission Rate (mg/km driven)	360.14	9.52	456.17	47.65	408.16	67.90	28.59	73.67

TABLE C.4. FIREPLACE TESTS

	PINE WOOD TEST 1 (% +- SD)		PINE WOOD TEST 2 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.0169	0.0034	0.0125	0.0035	0.0147	0.0031	0.0035	0.0046 *
SI	0.0286	0.0050	0.0392	0.0050	0.0339	0.0075	0.0050	0.0090 *
P	0.0204	0.0128	0.0224	0.0139	0.0214	0.0014	0.0133	0.0134 *
S	0.0920	0.0148	0.0701	0.0104	0.0811	0.0155	0.0126	0.0200 *
CL	0.5082	0.0715	0.5713	0.0313	0.5398	0.0446	0.0514	0.0681 *
K	0.4005	0.0562	0.5476	0.0288	0.4740	0.1040	0.0425	0.1124 *
CA	0.0169	0.0033	0.0166	0.0033	0.0168	0.0002	0.0033	0.0033 *
TI	0.0008	0.0004	0.0002	0.0006	0.0005	0.0004	0.0005	0.0007
V	-0.0002	0.0003	0.0000	0.0004	-0.0001	0.0001	0.0004	0.0004
CR	0.0007	0.0003	0.0011	0.0005	0.0009	0.0003	0.0004	0.0005 *
MN	0.0001	0.0003	-0.0002	0.0006	0.0000	0.0002	0.0005	0.0005
FE	0.0103	0.0018	0.0069	0.0014	0.0086	0.0024	0.0016	0.0029 *
NI	0.0014	0.0004	0.0040	0.0006	0.0027	0.0018	0.0005	0.0019 *
CU	0.0247	0.0035	0.0003	0.0007	0.0125	0.0173	0.0021	0.0174
ZN	0.0231	0.0033	0.0108	0.0009	0.0170	0.0087	0.0021	0.0089 *
GA	-0.0001	0.0003	-0.0001	0.0004	-0.0001	0.0000	0.0004	0.0004
AS	0.0011	0.0018	0.0016	0.0013	0.0014	0.0004	0.0016	0.0016
SE	0.0000	0.0003	0.0000	0.0004	0.0000	0.0000	0.0004	0.0004
BR	0.0017	0.0004	0.0013	0.0006	0.0015	0.0003	0.0005	0.0006 *
RB	0.0007	0.0005	0.0001	0.0007	0.0004	0.0004	0.0006	0.0007
SR	0.0000	0.0005	0.0002	0.0009	0.0001	0.0001	0.0007	0.0007
Y	0.0000	0.0007	0.0000	0.0011	0.0000	0.0000	0.0009	0.0009
ZR	0.0000	0.0028	0.0000	0.0045	0.0000	0.0000	0.0036	0.0036
MO	0.0000	0.0018	0.0000	0.0029	0.0000	0.0000	0.0023	0.0023
PD	0.0000	0.0018	-0.0002	0.0030	-0.0001	0.0001	0.0024	0.0024
AG	0.0000	0.0023	0.0070	0.0042	0.0035	0.0049	0.0033	0.0059
CD	-0.0012	0.0031	0.0000	0.0050	-0.0006	0.0008	0.0041	0.0041
IN	0.0000	0.0039	0.0000	0.0063	0.0000	0.0000	0.0051	0.0051
SN	-0.0036	0.0047	-0.0008	0.0076	-0.0022	0.0020	0.0062	0.0065
SB	-0.0030	0.0103	-0.0139	0.0172	-0.0084	0.0077	0.0138	0.0158
BA	-0.0104	0.0197	0.0000	0.0321	-0.0052	0.0074	0.0259	0.0269
LA	-0.0155	0.0349	0.0000	0.0575	-0.0077	0.0110	0.0462	0.0475
HG	0.0000	0.0003	0.0000	0.0006	0.0000	0.0000	0.0005	0.0005
PB	0.0287	0.0043	0.0091	0.0021	0.0189	0.0139	0.0032	0.0142 *
EC	7.2816	1.0294	3.1851	0.2343	5.2334	2.8967	0.6319	2.9648 *
OC	48.6419	6.8046	48.1992	2.5215	48.4206	0.3125	4.6631	4.6735 *
Backup filter OC	1.0914	0.1762	0.8202	0.1722	0.9558	0.1918	0.1742	0.2591 *
MG++	-0.0078	0.0016	0.0575	0.0022	0.0249	0.0462	0.0019	0.0462
NA+	0.1564	0.0220	0.0325	0.0150	0.0944	0.0876	0.0185	0.0895 *
CL-	1.0259	0.1350	0.7692	0.0246	0.8976	0.1815	0.0798	0.1983 *
NO3-	0.1172	0.0188	0.1517	0.0194	0.1345	0.0244	0.0191	0.0310 *
SO4=	0.1889	0.0272	0.1028	0.0190	0.1459	0.0609	0.0231	0.0651 *
NH4+	0.2096	0.0288	0.1700	0.0137	0.1898	0.0280	0.0213	0.0352 *
Fine Mass Emission Rate (g/kg wood)	15.809	2.060	10.140	0.045	12.975	4.009	1.053	4.144

TABLE C.4. FIREPLACE TESTS (CONT.)

	OAK WOOD TEST 3 (% +- SD)		ALMOND WOOD TEST 4 (% +- SD)		ALMOND WOOD TEST 6 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.0137	0.0048	0.0109	0.0068	0.0096	0.0046	0.0114	0.0021	0.0050	0.0055 *
SI	0.2393	0.0297	0.0991	0.0117	0.0402	0.0064	0.1262	0.1023	0.0159	0.1035 *
P	0.0231	0.0165	0.0312	0.0193	0.0213	0.0138	0.0252	0.0053	0.0162	0.0170 *
S	0.1294	0.0180	0.1242	0.0166	0.0521	0.0146	0.1019	0.0432	0.0164	0.0462 *
CL	0.4809	0.0378	0.7477	0.0413	0.3201	0.0200	0.5162	0.2160	0.0330	0.2185 *
K	0.7930	0.0596	1.2669	0.0665	0.5780	0.0310	0.8793	0.3525	0.0520	0.3563 *
CA	0.0035	0.0045	0.0092	0.0066	0.0186	0.0040	0.0104	0.0076	0.0050	0.0091 *
TI	0.0004	0.0008	0.0000	0.0008	0.0005	0.0009	0.0003	0.0003	0.0008	0.0009
V	-0.0003	0.0006	-0.0002	0.0006	0.0002	0.0007	-0.0001	0.0003	0.0006	0.0007
CR	0.0000	0.0007	-0.0004	0.0007	0.0053	0.0009	0.0016	0.0032	0.0008	0.0033
MN	0.0003	0.0008	0.0005	0.0008	0.0000	0.0009	0.0003	0.0003	0.0008	0.0009
FE	0.0048	0.0019	-0.0001	0.0019	0.0212	0.0027	0.0086	0.0112	0.0022	0.0114
NI	0.0021	0.0007	0.0000	0.0007	0.0033	0.0009	0.0018	0.0017	0.0008	0.0018
CU	0.0003	0.0009	0.0001	0.0010	-0.0007	0.0010	-0.0001	0.0005	0.0010	0.0011
ZN	0.0141	0.0014	0.0332	0.0021	0.0194	0.0015	0.0222	0.0099	0.0017	0.0100 *
GA	0.0000	0.0005	0.0000	0.0006	0.0000	0.0006	0.0000	0.0000	0.0006	0.0006
AS	0.0016	0.0022	0.0013	0.0018	-0.0005	0.0019	0.0008	0.0011	0.0020	0.0023
SE	0.0001	0.0005	-0.0003	0.0006	-0.0002	0.0006	-0.0001	0.0002	0.0006	0.0006
BR	0.0142	0.0014	0.0043	0.0009	0.0018	0.0009	0.0068	0.0066	0.0011	0.0066 *
RB	0.0005	0.0010	0.0013	0.0011	0.0007	0.0011	0.0008	0.0004	0.0011	0.0011
SR	0.0001	0.0012	0.0004	0.0013	0.0000	0.0013	0.0002	0.0002	0.0013	0.0013
Y	0.0007	0.0015	0.0000	0.0016	0.0000	0.0016	0.0002	0.0004	0.0016	0.0016
ZR	0.0000	0.0063	-0.0011	0.0069	-0.0037	0.0070	-0.0016	0.0019	0.0067	0.0070
MO	0.0000	0.0039	-0.0025	0.0044	-0.0046	0.0045	-0.0024	0.0023	0.0043	0.0048
PD	-0.0043	0.0042	-0.0011	0.0046	-0.0009	0.0044	-0.0021	0.0019	0.0044	0.0048
AG	0.0000	0.0057	0.0000	0.0060	-0.0026	0.0064	-0.0008	0.0014	0.0060	0.0062
CD	0.0000	0.0070	0.0001	0.0077	0.0000	0.0078	0.0000	0.0001	0.0075	0.0075
IN	0.0055	0.0087	0.0000	0.0093	0.0021	0.0096	0.0025	0.0028	0.0092	0.0096
SN	-0.0036	0.0105	-0.0097	0.0115	-0.0123	0.0118	-0.0085	0.0045	0.0113	0.0121
SB	0.0076	0.0231	0.0066	0.0256	0.0000	0.0253	0.0047	0.0041	0.0247	0.0260
BA	0.0000	0.0444	-0.0171	0.0497	0.0000	0.0497	-0.0057	0.0099	0.0479	0.0489
LA	-0.0298	0.0784	-0.0119	0.0875	-0.0765	0.0883	-0.0394	0.0334	0.0847	0.0911
HG	-0.0006	0.0007	0.0004	0.0008	0.0003	0.0008	0.0000	0.0006	0.0008	0.0009
PB	0.0231	0.0034	0.0046	0.0031	0.0057	0.0031	0.0111	0.0104	0.0032	0.0109 *
EC	2.9314	0.3070	3.4087	0.2971	2.2456	0.2277	2.8619	0.5847	0.2773	0.6471 *
OC	47.2881	3.5763	48.7538	2.5717	49.1487	2.5760	48.3969	0.9804	2.9080	3.0688 *
Backup filter OC	2.6866	0.3096	2.6835	0.2916	2.7667	0.2678	2.7123	0.0472	0.2896	0.2934 *
MG++	-0.0547	0.0047	-0.0173	0.0037	0.0273	0.0035	-0.0149	0.0411	0.0040	0.0412
NA+	0.0416	0.0252	0.0189	0.0253	0.0006	0.0243	0.0204	0.0205	0.0249	0.0323
CL-	0.6657	0.0505	0.8539	0.0374	0.4115	0.0327	0.6437	0.2220	0.0402	0.2256 *
NO3-	0.2300	0.0346	0.3205	0.0332	0.2099	0.0311	0.2535	0.0589	0.0330	0.0675 *
SO4=	0.3063	0.0367	0.2678	0.0327	0.1851	0.0309	0.2531	0.0619	0.0334	0.0704 *
NH4+	0.1536	0.0228	0.1371	0.0211	0.1460	0.0204	0.1452	0.0083	0.0214	0.0230 *
Fine Mass Emission Rate (g/kg wood)	6.157	0.330	4.664	0.009	5.018	0.021	5.276	0.784	0.120	0.793

TABLE C.6. NATURAL GAS HOME APPLIANCE TESTS

	NATURAL GAS TEST 1 (% +- SD)		NATURAL GAS TEST 2 (% +- SD)		NATURAL GAS TEST 3 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	-0.1362	0.2917	0.4358	0.9209	0.3730	0.2458	0.2242	0.3137	0.4861	0.5786
SI	-0.4732	0.2680	0.8153	0.6947	0.4979	0.1961	0.2800	0.6713	0.3863	0.7746
P	-0.0789	0.1531	0.0422	0.4747	0.1272	0.1201	0.0302	0.1036	0.2493	0.2700
S	-0.0968	1.0187	0.0000	3.1294	2.2988	0.8689	0.7340	1.3560	1.6723	2.1530
CL	-0.1685	0.4589	-0.0494	1.4024	-0.0592	0.3455	-0.0924	0.0661	0.7356	0.7386
K	0.0661	0.2026	0.3195	0.6380	0.1347	0.1750	0.1734	0.1311	0.3385	0.3630
CA	1.7425	0.7129	0.7117	0.6026	0.6713	0.1675	1.0418	0.6071	0.4943	0.7829 *
TI	0.0581	0.0769	0.1772	0.2444	0.0559	0.0556	0.0971	0.0694	0.1256	0.1435
V	0.0402	0.0582	-0.0213	0.1770	0.0339	0.0409	0.0176	0.0338	0.0920	0.0981
CR	-0.0215	0.0581	0.1001	0.1817	0.0567	0.0471	0.0451	0.0616	0.0956	0.1138
MN	0.0171	0.0738	0.0703	0.2248	-0.0315	0.0524	0.0186	0.0509	0.1170	0.1276
FE	-0.4302	0.2326	-0.0182	0.5118	0.7107	0.1842	0.0874	0.5777	0.3095	0.6554
NI	-0.0215	0.0581	0.1474	0.2050	0.1418	0.0586	0.0892	0.0959	0.1072	0.1439
CU	-0.1263	0.1127	-2.3321	1.0584	1.8233	0.2821	-0.2117	2.0790	0.4844	2.1347
ZN	0.0091	0.0684	-1.6249	0.7356	1.1349	0.1804	-0.1603	1.3877	0.3281	1.4259
GA	-0.0215	0.0409	0.0000	0.1208	0.0000	0.0319	-0.0072	0.0124	0.0645	0.0657
AS	0.0000	0.1471	0.0000	0.4645	0.0000	0.1103	0.0000	0.0000	0.2406	0.2406
SE	0.0741	0.0630	0.1687	0.1904	-0.0596	0.0415	0.0611	0.1147	0.0983	0.1511
BR	-0.0534	0.0764	0.1985	0.2472	-0.0389	0.0525	0.0354	0.1414	0.1254	0.1890
RB	0.1051	0.1112	-0.0582	0.3368	0.0030	0.0784	0.0166	0.0825	0.1751	0.1936
SR	0.1868	0.1378	-0.5953	0.4397	-0.0376	0.0843	-0.1487	0.4027	0.2206	0.4592
Y	0.0119	0.1421	0.2066	0.4541	-0.0468	0.1047	0.0672	0.1326	0.2336	0.2687
ZR	0.0000	0.5889	-0.6052	1.8871	0.0000	0.4436	-0.2017	0.3494	0.9732	1.0340
MO	0.7512	0.5031	-0.2485	1.2779	0.0297	0.2932	0.1775	0.5160	0.6914	0.8627
PD	-0.1470	0.4405	1.1949	1.4602	0.0806	0.3133	0.3762	0.7181	0.7380	1.0297
AG	-0.2474	0.5379	· 0.9158	1.8189	-0.1080	0.3951	0.1868	0.6362	0.9173	1.1167
CD	0.0000	0.6154	-0.3728	1.9858	0.6447	0.4747	0.0906	0.5148	1.0253	1.1473
IN	-0.4553	0.8485	-1.3585	2.6808	-0.8188	0.6518	-0.8775	0.4545	1.3937	1.4659
SN	-0.5700	1.0344	0.0000	3.1337	-0.0316	0.7576	-0.2005	0.3204	1.6419	1.6729
SB	-0.6668	2.1392	2.1648	6.7398	0.2299	1.6541	0.5760	1.4472	3.5110	3.7976
BA	-2.3339	4.1696	0.7872	12.8740	0.8699	3.0437	-0.2256	1.8263	6.6968	6.9404
LA	-2.9685	7.4680	0.0000	23.2957	0.1503	5.6304	-0.9394	1.7589	12.1314	12.2582
HG	0.0000	0.1259	0.2671	0.4266	0.0000	0.0957	0.0890	0.1542	0.2161	0.2655
PB	0.1872	0.2657	-0.1807	0.8029	-0.0011	0.1914	0.0018	0.1840	0.4200	0.4585
EC	-0.6511	10.2302	13.4194	36.5968	7.3890	12.2098	6.7191	7.0591	19.6789	20.9067
OC	72.3370	32.2129	89.5293	60.0495	92.8916	20.9725	84.9193	11.0255	37.7450	39.3223 *
Backup filter OC	52.2755	25.5560	74.1429	57.7532	58.6367	22.8616	61.6860	11.2479	35.3903	37.1347 *
MG	0.0455	0.2585	-9.9328	4.2487	5.3669	0.7674	-1.5068	7.7671	1.7582	7.9636
NA	0.8242	1.8014	4.4239	6.3580	1.1522	1.9331	2.1334	1.9904	3.3642	3.9089
CL	2.0996	2.3253	7.2383	8.0628	2.2873	2.3869	3.8751	2.9142	4.2583	5.1600
NO3	5.1326	2.9589	1.8763	7.4351	3.2193	2.4049	3.4094	1.6365	4.2663	4.5694
SO4	2.9551	2.4624	29.2228	14.4046	5.7609	2.5047	12.6463	14.4241	6.4572	15.8035
NH4	1.3289	1.4802	0.0000	4.6135	0.0000	1.4842	0.4430	0.7672	2.5260	2.6399
Fine Mass Emission Rate (ng/kJ burned)	71.51	27.76	22.46	9.40	43.50	5.79	45.82	24.61	14.32	28.47

TABLE C.6. MEAT COOKING TESTS

	KLEAN, CHARBR. TEST 1 (% +- SD)		REGULAR, CHARBR. TEST 2 (% +- SD)		MEAN	S.D. of MEAN	Avg.of S.D.s	Overall S.D.
AL	0.1000	0.0504	0.0592	0.0138	0.0796	0.0288	0.0321	0.0432 *
SI	0.1565	0.0422	0.0591	0.0127	0.1078	0.0689	0.0274	0.0741 *
P	0.0858	0.0371	0.1180	0.0276	0.1019	0.0228	0.0323	0.0396 *
S	0.0980	0.1604	0.0179	0.0392	0.0579	0.0566	0.0998	0.1148
CL	0.0937	0.0741	0.0816	0.0194	0.0877	0.0086	0.0468	0.0475 *
K	0.0620	0.0338	0.2676	0.0226	0.1648	0.1454	0.0281	0.1481 *
CA	0.0939	0.0307	0.0191	0.0087	0.0565	0.0529	0.0197	0.0564 *
TI	0.0197	0.0122	0.0011	0.0029	0.0104	0.0132	0.0075	0.0152
V	0.0042	0.0078	0.0014	0.0020	0.0028	0.0020	0.0049	0.0053
CR	-0.0014	0.0090	-0.0006	0.0021	-0.0010	0.0006	0.0055	0.0056
MN	-0.0009	0.0104	-0.0004	0.0023	-0.0007	0.0004	0.0063	0.0064
FE	0.1118	0.0347	0.0309	0.0082	0.0714	0.0572	0.0214	0.0611 *
NI	0.0070	0.0112	0.0076	0.0033	0.0073	0.0004	0.0072	0.0073 *
CU	0.5925	0.0872	0.0947	0.0161	0.3436	0.3520	0.0517	0.3558
ZN	0.3818	0.0563	0.0506	0.0100	0.2162	0.2342	0.0331	0.2365
GA	-0.0054	0.0070	-0.0008	0.0015	-0.0031	0.0033	0.0043	0.0054
AS	0.0000	0.0216	0.0040	0.0049	0.0020	0.0028	0.0133	0.0136
SE	0.0042	0.0084	-0.0028	0.0018	0.0007	0.0049	0.0051	0.0071
BR	0.0145	0.0113	0.0033	0.0023	0.0089	0.0079	0.0068	0.0104
RB	0.0038	0.0152	-0.0060	0.0033	-0.0011	0.0069	0.0093	0.0116
SR	0.0100	0.0167	-0.0015	0.0038	0.0042	0.0081	0.0103	0.0131
Y	0.0046	0.0208	0.0014	0.0046	0.0030	0.0023	0.0127	0.0129
ZR	0.0000	0.0902	0.0000	0.0200	0.0000	0.0000	0.0551	0.0551
MO	0.0547	0.0586	0.0000	0.0126	0.0273	0.0387	0.0356	0.0525
PD	-0.0184	0.0691	0.0000	0.0131	-0.0092	0.0130	0.0411	0.0431
AG	0.0481	0.0794	0.0056	0.0178	0.0269	0.0301	0.0486	0.0571
CD	-0.0046	0.0936	0.0143	0.0199	0.0049	0.0134	0.0567	0.0583
IN	0.0599	0.1204	-0.0020	0.0284	0.0290	0.0438	0.0744	0.0863
SN	0.0662	0.1616	0.0098	0.0329	0.0380	0.0399	0.0922	0.1005
SB	0.0084	0.3112	-0.0296	0.0687	-0.0106	0.0269	0.1900	0.1918
BA	0.3367	0.6091	0.0610	0.1366	0.1988	0.1949	0.3724	0.4203
LA	-0.6961	1.1357	0.1955	0.2469	-0.2503	0.6305	0.6913	0.9356
HG	-0.0009	0.0160	0.0001	0.0044	-0.0004	0.0007	0.0112	0.0112
PB	0.0565	0.0382	-0.0034	0.0082	0.0265	0.0424	0.0232	0.0483
EC	-0.8988	2.8686	0.1053	0.5968	-0.3968	0.7100	1.7327	1.8726
OC	60.6118	9.6166	56.9780	4.3568	58.7949	2.5694	6.9867	7.4442 *
Backup filter OC	8.1833	3.9121	2.6121	0.9488	5.3977	3.9394	2.4304	4.6288 *
MG	2.0574	0.2655	-0.2364	0.0161	0.9105	1.6220	0.1408	1.6281
NA	0.3847	0.5196	0.0732	0.0974	0.2290	0.2203	0.3085	0.3791
CL	0.6294	0.6404	0.1198	0.1196	0.3746	0.3603	0.3800	0.5237
NO3	0.1398	0.6306	-0.1016	0.1200	0.0191	0.1707	0.3753	0.4123
SO4	0.3031	0.6330	0.1081	0.1203	0.2056	0.1379	0.3767	0.4011
NH4	0.0000	0.3925	0.0000	0.0747	0.0000	0.0000	0.2336	0.2336
Fine Mass Emission Rate (g/kg meat)	7.143	0.884	39.807	1.293	23.475	23.097	1.089	23.123

TABLE C.6. MEAT COOKING TESTS (CONT.)

	XLEAN, FRIED TEST 3 (% +- SD)		REGULAR, FRIED TEST 4 (% +- SD)		MEAN	S.D. of MEAN	Avg. of S.D.s	Overall S.D.
AL	-0.2363	0.3200	0.1080	0.3801	-0.0642	0.2435	0.3501	0.4264
SI	-0.2603	0.2494	-0.2356	0.2482	-0.2480	0.0175	0.2488	0.2494
P	0.0025	0.1908	-0.1030	0.2014	-0.0503	0.0746	0.1961	0.2098
S	2.9884	1.4275	0.0879	1.2984	1.5381	2.0510	1.3630	2.4625
CL	1.1681	0.6058	-0.4605	0.5842	0.3538	1.1516	0.5950	1.2962
K	0.3601	0.2588	0.3650	0.2630	0.3626	0.0035	0.2609	0.2609 *
CA	0.2692	0.1977	0.0281	0.2009	0.1487	0.1705	0.1993	0.2623
TI	0.0794	0.0943	-0.1088	0.1009	-0.0147	0.1331	0.0976	0.1650
V	-0.0363	0.0602	0.0135	0.0687	-0.0114	0.0352	0.0645	0.0734
CR	0.0509	0.0663	0.2464	0.0946	0.1487	0.1382	0.0804	0.1599
MN	-0.0061	0.0684	0.0879	0.0929	0.0409	0.0665	0.0807	0.1045
FE	-0.0293	0.2000	0.5029	0.2478	0.2368	0.3763	0.2239	0.4379
NI	0.0555	0.0753	0.0432	0.0961	0.0494	0.0087	0.0857	0.0861
CU	0.6488	0.2621	-0.8310	0.2552	-0.0911	1.0464	0.2587	1.0779
ZN	0.3225	0.1598	-0.4693	0.1698	-0.0734	0.5599	0.1648	0.5836
GA	-0.0363	0.0463	-0.0040	0.0545	-0.0202	0.0228	0.0504	0.0553
AS	0.0000	0.1565	0.0000	0.1828	0.0000	0.0000	0.1697	0.1697
SE	0.0416	0.0604	-0.0289	0.0727	0.0064	0.0499	0.0666	0.0832
BR	0.1140	0.0801	0.0529	0.0962	0.0835	0.0432	0.0882	0.0982
RB	0.0254	0.1009	0.1555	0.1354	0.0904	0.0920	0.1182	0.1497
SR	-0.1634	0.1269	0.1758	0.1483	0.0062	0.2399	0.1376	0.2766
Y	-0.0484	0.1427	0.1888	0.1845	0.0702	0.1677	0.1636	0.2343
ZR	0.0000	0.6168	0.0000	0.7621	0.0000	0.0000	0.6895	0.6895
MO	0.0000	0.3959	0.4820	0.5212	0.2410	0.3408	0.4586	0.5713
PD	-0.2602	0.4379	0.0000	0.5589	-0.1301	0.1840	0.4984	0.5313
AG	0.4561	0.5573	0.0416	0.7039	0.2488	0.2931	0.6306	0.6954
CD	-0.0016	0.6513	0.0000	0.7831	-0.0008	0.0011	0.7172	0.7172
IN	-0.4299	0.8623	1.1559	1.1200	0.3630	1.1213	0.9912	1.4966
SN	0.3286	1.0593	-0.3933	1.3038	-0.0324	0.5105	1.1816	1.2871
SB	-1.3677	2.2085	0.2673	2.8624	-0.5502	1.1561	2.5354	2.7866
BA	0.4854	4.2187	0.4259	5.2693	0.4557	0.0421	4.7440	4.7442
LA	5.7882	7.9918	-1.1754	9.4901	2.3064	4.9240	8.7409	10.0325
HG	-0.1997	0.1456	0.0000	0.1609	-0.0998	0.1412	0.1533	0.2084
PB	0.4286	0.2877	-0.0263	0.3202	0.2017	0.3210	0.3040	0.4420
EC	-12.2821	17.9653	0.1460	16.9964	-6.0680	8.7880	17.4809	19.5655
OC	56.8546	26.9909	57.8640	23.5139	57.3593	0.7140	25.2524	25.2625 *
Backup filter OC	20.0348	21.3972	25.1468	21.2651	22.5908	3.6147	21.3312	21.6353 *
MG	0.1786	0.4210	-7.8175	1.1164	-3.8195	5.6541	0.7687	5.7061
NA	2.1473	2.9345	-1.2441	2.8692	0.4516	2.3981	2.9018	3.7645
CL	3.5134	3.6608	3.5185	3.5497	3.5160	0.0034	3.6053	3.6053
NO3	3.5134	3.6408	0.6520	3.4932	2.0827	2.0233	3.5670	4.1009
SO4	0.1302	3.4988	1.6944	3.5048	0.9123	1.1061	3.5018	3.6723
NH4	0.0000	2.2434	0.0000	2.1726	0.0000	0.0000	2.2080	2.2080
Fine Mass Emission Rate (g/kg meat)	1.406	0.386	1.176	0.156	1.291	0.163	0.271	0.316

TABLE C.7. CIGARETTES

	"LIGHT" TEST 1 (% +- SD)		REGULAR TEST 2 (% +- SD)		MENTHOL TEST 3 (% +- SD)		FILTERTIP TEST 4 (% +- SD)		MEAN	S.D. of MEAN	Avg. of S.D.s	Overall S.D.
AL	0.0044	0.0026	0.0118	0.0030	0.0096	0.0036	0.0029	0.0026	0.0072	0.0042	0.0029	0.0061 *
SI	0.0009	0.0016	0.0030	0.0018	-0.0044	0.0022	0.0009	0.0016	0.0001	0.0032	0.0018	0.0036
P	0.0066	0.0018	0.0033	0.0018	0.0110	0.0027	0.0068	0.0019	0.0064	0.0033	0.0021	0.0038 *
S	0.1343	0.0108	0.1501	0.0126	0.1387	0.0166	0.1282	0.0114	0.1378	0.0092	0.0126	0.0166 *
CL	0.2760	0.0168	0.1994	0.0126	0.2610	0.0167	0.1906	0.0119	0.2290	0.0407	0.0142	0.0431 *
K	0.4269	0.0223	0.4411	0.0233	0.3719	0.0207	0.4066	0.0214	0.4116	0.0300	0.0219	0.0372 *
CA	0.0026	0.0024	-0.0013	0.0026	-0.0012	0.0027	-0.0002	0.0023	-0.0001	0.0018	0.0026	0.0030
TI	-0.0003	0.0004	0.0002	0.0006	-0.0007	0.0006	0.0014	0.0006	0.0001	0.0009	0.0006	0.0010
V	-0.0002	0.0003	0.0000	0.0003	0.0000	0.0006	-0.0001	0.0003	-0.0001	0.0001	0.0004	0.0004
CR	-0.0002	0.0004	-0.0001	0.0004	-0.0001	0.0006	0.0004	0.0004	0.0000	0.0003	0.0004	0.0006
MN	-0.0004	0.0004	-0.0003	0.0006	-0.0003	0.0006	0.0003	0.0004	-0.0002	0.0003	0.0006	0.0006
FE	0.0003	0.0009	-0.0004	0.0011	-0.0006	0.0016	0.0006	0.0010	0.0000	0.0006	0.0011	0.0012
NI	0.0000	0.0004	0.0000	0.0004	-0.0002	0.0006	0.0000	0.0004	0.0000	0.0001	0.0004	0.0004
CU	0.0193	0.0018	0.0118	0.0012	-0.0026	0.0009	0.0060	0.0007	0.0084	0.0094	0.0012	0.0094
ZN	0.0134	0.0012	0.0076	0.0008	-0.0018	0.0006	0.0037	0.0006	0.0067	0.0064	0.0008	0.0066
GA	-0.0001	0.0002	0.0001	0.0003	0.0006	0.0004	0.0000	0.0002	0.0001	0.0003	0.0003	0.0004
AS	0.0000	0.0008	0.0000	0.0009	0.0000	0.0012	0.0002	0.0009	0.0000	0.0001	0.0010	0.0010
SE	0.0001	0.0003	0.0002	0.0004	0.0000	0.0006	0.0000	0.0003	0.0001	0.0001	0.0004	0.0004
BR	0.0028	0.0006	0.0017	0.0006	0.0030	0.0007	0.0026	0.0006	0.0026	0.0006	0.0006	0.0008 *
RB	-0.0002	0.0006	0.0007	0.0007	0.0007	0.0010	0.0001	0.0006	0.0003	0.0006	0.0007	0.0009
SR	-0.0006	0.0006	0.0006	0.0008	0.0002	0.0011	0.0001	0.0007	0.0001	0.0004	0.0008	0.0009
Y	-0.0007	0.0008	0.0002	0.0009	0.0016	0.0013	0.0006	0.0009	0.0004	0.0009	0.0010	0.0013
ZR	0.0010	0.0036	0.0060	0.0039	0.0000	0.0068	0.0010	0.0038	0.0020	0.0027	0.0043	0.0050
MO	0.0004	0.0026	0.0000	0.0027	-0.0019	0.0039	0.0004	0.0027	-0.0003	0.0011	0.0030	0.0031
PD	0.0000	0.0023	-0.0007	0.0028	-0.0036	0.0041	0.0021	0.0028	-0.0006	0.0023	0.0030	0.0038
AG	-0.0029	0.0029	-0.0001	0.0034	-0.0016	0.0048	0.0007	0.0033	-0.0010	0.0016	0.0036	0.0039
CD	-0.0004	0.0036	0.0036	0.0041	0.0068	0.0069	0.0000	0.0038	0.0022	0.0030	0.0043	0.0052
IN	-0.0032	0.0046	-0.0037	0.0052	0.0049	0.0076	-0.0002	0.0060	-0.0006	0.0039	0.0056	0.0069
SN	-0.0043	0.0068	0.0022	0.0066	0.0090	0.0092	-0.0041	0.0062	0.0007	0.0063	0.0069	0.0094
SB	-0.0027	0.0112	0.0000	0.0124	-0.0030	0.0180	-0.0034	0.0123	-0.0023	0.0016	0.0136	0.0136
BA	0.0000	0.0270	-0.0114	0.0304	-0.0097	0.0429	-0.0146	0.0293	-0.0089	0.0063	0.0324	0.0330
LA	0.0000	0.0384	-0.0077	0.0446	0.0413	0.0642	0.0000	0.0432	0.0084	0.0222	0.0476	0.0625
HG	0.0000	0.0007	0.0007	0.0009	0.0000	0.0011	0.0000	0.0008	0.0002	0.0003	0.0009	0.0009
PB	0.0020	0.0014	-0.0006	0.0017	-0.0018	0.0022	0.0002	0.0016	0.0000	0.0016	0.0017	0.0023
EC	0.6913	0.1349	0.3086	0.0862	0.6048	0.1907	0.3411	0.0888	0.4864	0.1904	0.1261	0.2278 *
OC	63.1748	3.2618	61.0223	3.1212	57.7938	3.2196	56.0128	2.8972	59.5009	3.2090	3.1260	4.4792 *
Backup filter OC	3.5247	0.2824	2.1653	0.1783	3.8838	0.2772	2.2589	0.1532	2.9682	0.8747	0.2228	0.9026 *
MG++	-.0447	0.0031	0.0320	0.0014	0.0064	0.0024	0.0308	0.0013	0.0061	0.0359	0.0021	0.0359
NA+	-.0193	0.0214	0.0068	0.0094	0.0302	0.0166	0.0200	0.0090	0.0094	0.0214	0.0141	0.0266
CL-	0.2869	0.0263	0.2693	0.0136	0.3126	0.0347	0.2687	0.0130	0.2844	0.0206	0.0219	0.0301 *
NO3-	0.0403	0.0263	0.0813	0.0121	0.0867	0.0236	0.0768	0.0116	0.0713	0.0210	0.0184	0.0280 *
SO4=	-.0066	0.0264	0.0699	0.0120	0.0921	0.0226	0.0778	0.0116	0.0686	0.0437	0.0181	0.0473 *
NH4+	0.0338	0.0062	0.0468	0.0084	0.0383	0.0146	0.0434	0.0029	0.0403	0.0064	0.0080	0.0096 *
Fine Mass Emission Rate (mg/cigarette)	14.10	0.20	21.84	0.20	23.11	0.20	22.37	0.20	20.36	4.20	0.20	4.20

TABLE C.8. VEGETATIVE DETRITUS

	GREEN VEGETATION TEST 1 (% +- SD)		GREEN VEGETATION TEST 2 (% +- SD)		DEAD VEGETATION TEST 3 (% +- SD)		DEAD VEGETATION TEST 4 (% +- SD)		MEAN	S.D. of MEAN	Avg. of S.D.s	Overall S.D.
AL	3.1366	0.2724	2.2211	0.2072	2.4920	0.2283	2.4267	0.2242	2.5691	0.3956	0.2330	0.4590 *
SI	8.7768	0.9493	5.8321	0.6321	9.7066	1.0496	9.0923	0.9844	8.3520	1.7237	0.9039	1.9463 *
P	0.3179	0.0342	0.3849	0.0374	0.2666	0.0292	0.2491	0.0294	0.3046	0.0610	0.0326	0.0691 *
S	0.6694	0.0503	0.5148	0.0903	0.6934	0.0446	0.5948	0.0617	0.6181	0.0807	0.0617	0.1016 *
CL	0.3621	0.0263	0.3934	0.0396	0.2789	0.0193	0.2773	0.0298	0.3279	0.0589	0.0287	0.0656 *
K	2.2806	0.1179	1.5814	0.0884	1.4781	0.0766	1.3555	0.0770	1.6739	0.4149	0.0900	0.4245 *
CA	2.1881	0.1137	2.0292	0.1091	2.5422	0.1302	2.3945	0.1273	2.2885	0.2258	0.1201	0.2557 *
TI	0.2889	0.0319	0.2475	0.0160	0.2884	0.0166	0.2426	0.0156	0.2668	0.0253	0.0198	0.0321 *
V	0.0084	0.0107	0.0226	0.0047	0.0237	0.0037	0.0153	0.0046	0.0175	0.0071	0.0069	0.0093 *
CR	0.0449	0.0036	0.1138	0.0082	0.0217	0.0019	0.0340	0.0040	0.0536	0.0412	0.0044	0.0415 *
MN	0.0751	0.0047	0.0607	0.0057	0.0526	0.0033	0.0546	0.0046	0.0608	0.0102	0.0046	0.0111 *
FE	3.6660	0.1861	2.3733	0.1239	2.7105	0.1374	2.3129	0.1206	2.7667	0.6252	0.1420	0.6411 *
NI	0.0375	0.0032	0.2063	0.0135	0.0104	0.0013	0.0371	0.0043	0.0728	0.0899	0.0056	0.0901
CU	0.2839	0.0154	8.4682	0.4302	0.0786	0.0047	0.1813	0.0117	2.2530	4.1443	0.1155	4.1459
ZN	0.1987	0.0111	4.8962	0.2519	0.1074	0.0061	0.1635	0.0104	1.3414	2.3701	0.0699	2.3712
GA	0.0001	0.0011	0.0000	0.0085	0.0000	0.0007	0.0000	0.0015	0.0000	0.0000	0.0030	0.0030
AS	0.0033	0.0063	0.0016	0.0302	0.0021	0.0034	0.0012	0.0055	0.0021	0.0009	0.0114	0.0114
SE	0.0022	0.0011	0.0038	0.0022	0.0014	0.0007	0.0046	0.0018	0.0030	0.0015	0.0015	0.0021 *
BR	0.0046	0.0013	0.0101	0.0028	0.0065	0.0010	0.0074	0.0025	0.0072	0.0023	0.0019	0.0030 *
RB	0.0100	0.0020	0.0082	0.0038	0.0056	0.0013	0.0071	0.0034	0.0077	0.0019	0.0026	0.0032 *
SR	0.0294	0.0028	0.0286	0.0047	0.0219	0.0019	0.0224	0.0040	0.0256	0.0040	0.0034	0.0052 *
Y	0.0000	0.0026	0.0000	0.0067	0.0000	0.0018	0.0089	0.0046	0.0022	0.0044	0.0037	0.0058
ZR	0.0000	0.0111	0.0000	0.0239	0.0000	0.0076	0.0000	0.0212	0.0000	0.0000	0.0159	0.0159
MO	0.0142	0.0075	0.0000	0.0151	0.0000	0.0061	0.0239	0.0132	0.0095	0.0117	0.0102	0.0155
PD	0.0124	0.0080	0.0000	0.0148	0.0086	0.0054	0.0291	0.0147	0.0125	0.0122	0.0107	0.0162
AG	0.0070	0.0091	0.8371	0.0588	0.0071	0.0064	0.1206	0.0224	0.2430	0.3997	0.0242	0.4004
CD	0.0086	0.0109	0.0195	0.0220	0.0126	0.0075	0.0377	0.0199	0.0196	0.0129	0.0151	0.0198
IN	0.0248	0.0145	0.0321	0.0286	0.0070	0.0097	0.0184	0.0248	0.0206	0.0106	0.0194	0.0221
SN	0.0033	0.0172	0.0447	0.0396	0.0183	0.0117	0.0206	0.0304	0.0217	0.0171	0.0247	0.0301
SB	0.0561	0.0360	0.0340	0.0695	0.0087	0.0231	0.0285	0.0613	0.0318	0.0196	0.0475	0.0513
BA	0.6204	0.1062	0.2119	0.1742	0.1469	0.0592	0.2715	0.1606	0.3127	0.2114	0.1226	0.2443 *
LA	0.1195	0.1218	0.2670	0.2431	0.0000	0.0786	0.1804	0.2135	0.1417	0.1122	0.1643	0.1989
HG	0.0022	0.0025	0.0060	0.0063	0.0024	0.0018	0.0000	0.0037	0.0027	0.0025	0.0033	0.0042
PB	0.0867	0.0078	0.5585	0.0327	0.0405	0.0045	0.0531	0.0089	0.1847	0.2500	0.0135	0.2503
EC	---	---	0.6777	0.3756	1.1820	0.3834	0.9743	0.7215	0.9447	0.2535	0.4935	0.5548 *
OC	---	---	29.5666	1.8266	31.4754	1.9010	36.0197	2.4736	32.3639	3.3150	2.0671	3.9067 *
Backup filter OC	---	---	2.9844	0.5388	2.6191	0.5076	3.2989	0.8474	2.9675	0.3402	0.6313	0.7171 *
MG++	---	---	0.4593	0.0105	0.1884	0.0154	0.8465	0.0211	0.4981	0.3308	0.0157	0.3311 *
NA+	---	---	0.0000	0.0725	0.1433	0.0683	0.0000	0.1447	0.0478	0.0827	0.0952	0.1261
CL-	---	---	0.1319	0.0892	0.1242	0.0841	0.0000	0.1778	0.0864	0.0740	0.1170	0.1385
NO3-	---	---	0.4198	0.1833	0.4679	0.0876	0.2456	0.1779	0.3778	0.1170	0.1496	0.1899 *
SO4=	---	---	0.4198	0.1503	0.5342	0.0882	0.2105	0.1775	0.3882	0.1642	0.1387	0.2149 *
NH4+	---	---	0.0671	0.0237	0.0000	0.0828	0.0000	0.0380	0.0190	0.0330	0.0482	0.0584

Appendix D

Organic Mass Distribution Characteristics for Ambient Samples

These tables contain the quantitative data obtained from high-resolution gas chromatographic analyses of the ambient samples. The total and resolved area counts obtained in each of the elution zones defined by adjacent n-alkanes are presented for both the neutral and acid+neutral fractions of the extract. In addition, the mass of organic material that eluted in each zone also is given, in units of $\mu g/m^3$.

The results for each monthly composite are given for Pasadena, downtown Los Angeles and West Los Angeles. The two composite samples extracted for San Nicholas Island are also included.

Pasadena - January

(filename = PAS01A)
(Size of sample = 72.910 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	34381.	18932.	28160.	6807.	0.019	0.011	0.013	0.003
C12 to C13	155287.	44106.	284111.	111992.	0.093	0.026	0.136	0.054
C13 to C14	170176.	32548.	201824.	36185.	0.103	0.020	0.098	0.018
C14 to C15	183133.	32015.	218574.	27736.	0.114	0.020	0.109	0.014
C15 to C16	340226.	153265.	365401.	182921.	0.212	0.095	0.182	0.091
C16 to C17	416615.	216924.	363591.	192508.	0.275	0.143	0.192	0.102
C17 to C18	478269.	231841.	302440.	84635.	0.305	0.148	0.155	0.043
C18 to C19	373403.	136993.	257682.	53395.	0.241	0.088	0.133	0.028
C19 to C20	486569.	226259.	390429.	159479.	0.324	0.151	0.208	0.085
C20 to C21	472152.	199173.	236818.	21945.	0.315	0.133	0.126	0.012
C21 to C22	291875.	42232.	235481.	26668.	0.211	0.031	0.136	0.015
C22 to C23	430453.	162265.	246515.	21057.	0.311	0.117	0.143	0.012
C23 to C24	345629.	52671.	298765.	36707.	0.259	0.040	0.180	0.022
C24 to C25	381424.	69523.	391131.	48855.	0.286	0.052	0.235	0.029
C25 to C26	525201.	132887.	437167.	50880.	0.444	0.112	0.296	0.034
C26 to C27	469017.	45996.	508872.	67095.	0.397	0.039	0.345	0.045
C27 to C28	482382.	23584.	583102.	54296.	0.430	0.021	0.416	0.039
C28 to C29	478199.	53765.	599137.	45831.	0.426	0.048	0.427	0.033
C29 to C30	459814.	26417.	687027.	41831.	0.448	0.026	0.536	0.033
C30 to C31	409974.	29733.	693031.	25682.	0.400	0.029	0.541	0.020
C31 to C32	382150.	31413.	869430.	72675.	0.454	0.037	0.827	0.069
C32 to C33	289972.	32053.	837227.	51469.	0.344	0.038	0.796	0.049
C33 to C34	235220.	25726.	926699.	36153.	0.292	0.032	0.923	0.036
C34 to C35	158972.	17684.	739277.	22258.	0.198	0.022	0.736	0.022
C35 to C36	124896.	7202.	829510.	24828.	0.192	0.011	1.023	0.031
C36 to 78 min	85165.	46311.	655371.	36001.	0.131	0.071	0.808	0.044
TOTAL	8660554.	2091518.	12186772.	1539889.	7.225	1.561	9.718	0.983

Pasadena - February

(filename = PAS02A)
(Size of sample = 74.130 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	60261.	30882.	35025.	11941.	0.022	0.011	0.017	0.006
C12 to C13	391591.	171272.	299494.	86207.	0.154	0.068	0.157	0.045
C13 to C14	354611.	82673.	264818.	79688.	0.141	0.033	0.140	0.042
C14 to C15	326743.	56293.	228499.	37758.	0.134	0.023	0.125	0.021
C15 to C16	447944.	155600.	306164.	126794.	0.183	0.064	0.167	0.069
C16 to C17	628840.	332299.	336488.	172434.	0.273	0.144	0.195	0.100
C17 to C18	669468.	287545.	249998.	62204.	0.281	0.121	0.140	0.035
C18 to C19	515468.	157578.	203993.	45418.	0.218	0.067	0.115	0.026
C19 to C20	556447.	167913.	211443.	20103.	0.244	0.074	0.124	0.012
C20 to C21	613221.	212097.	201420.	8006.	0.269	0.093	0.118	0.005
C21 to C22	429642.	54123.	187099.	15140.	0.204	0.026	0.119	0.010
C22 to C23	539782.	137357.	195854.	20820.	0.257	0.065	0.124	0.013
C23 to C24	403929.	17094.	215635.	16545.	0.199	0.008	0.142	0.011
C24 to C25	428341.	37544.	271849.	20052.	0.211	0.019	0.179	0.013
C25 to C26	530879.	48389.	299699.	35400.	0.295	0.027	0.222	0.026
C26 to C27	519409.	34308.	342455.	60540.	0.289	0.019	0.254	0.045
C27 to C28	550310.	37382.	376137.	54703.	0.322	0.022	0.294	0.043
C28 to C29	539749.	60182.	380151.	50383.	0.316	0.035	0.297	0.039
C29 to C30	522626.	21804.	374975.	19661.	0.335	0.014	0.320	0.017
C30 to C31	426986.	17101.	307560.	22174.	0.274	0.011	0.263	0.019
C31 to C32	416352.	35726.	293952.	27113.	0.325	0.028	0.306	0.028
C32 to C33	342710.	32593.	259185.	28976.	0.268	0.025	0.270	0.030
C33 to C34	283437.	22914.	200435.	20383.	0.232	0.019	0.219	0.022
C34 to C35	200068.	16881.	144762.	10185.	0.164	0.014	0.158	0.011
C35 to C36	170718.	9516.	109638.	8260.	0.173	0.010	0.148	0.011
C36 to 78 min	74596.	21102.	43204.	15046.	0.076	0.021	0.058	0.020
TOTAL	10944128.	2258168.	6339932.	1075934.	5.861	1.060	4.670	0.719

Pasadena - March

(filename = PAS03A)
(Size of sample = 76.990 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	37313.	22107.	9325.	4466.	0.013	0.008	0.004	0.002
C12 to C13	244691.	115773.	139615.	67766.	0.089	0.042	0.060	0.029
C13 to C14	265483.	70896.	184563.	67957.	0.098	0.026	0.080	0.029
C14 to C15	232994.	58848.	171653.	45983.	0.088	0.022	0.076	0.020
C15 to C16	362484.	164042.	370379.	227361.	0.137	0.062	0.164	0.101
C16 to C17	562227.	357778.	432855.	300511.	0.226	0.144	0.204	0.142
C17 to C18	455388.	260377.	262521.	111570.	0.177	0.101	0.120	0.051
C18 to C19	500944.	207944.	194947.	56680.	0.196	0.081	0.090	0.026
C19 to C20	423768.	169792.	296597.	109995.	0.172	0.069	0.141	0.052
C20 to C21	485622.	207584.	169483.	16440.	0.197	0.084	0.081	0.008
C21 to C22	294980.	40460.	176790.	18044.	0.130	0.018	0.091	0.009
C22 to C23	397642.	134455.	183849.	22693.	0.175	0.059	0.095	0.012
C23 to C24	338316.	33388.	219492.	31535.	0.154	0.015	0.118	0.017
C24 to C25	324073.	33729.	249048.	42789.	0.148	0.015	0.133	0.023
C25 to C26	427619.	54331.	323035.	56052.	0.220	0.028	0.195	0.034
C26 to C27	427532.	48402.	343492.	39965.	0.220	0.025	0.207	0.024
C27 to C28	440797.	47882.	346695.	35883.	0.239	0.026	0.221	0.023
C28 to C29	441205.	56029.	350867.	48512.	0.239	0.030	0.223	0.031
C29 to C30	414147.	27325.	330288.	25293.	0.245	0.016	0.230	0.018
C30 to C31	360613.	9851.	274265.	17176.	0.214	0.006	0.191	0.012
C31 to C32	342808.	33293.	270474.	32562.	0.247	0.024	0.229	0.028
C32 to C33	261803.	32994.	178760.	20116.	0.189	0.024	0.152	0.017
C33 to C34	241112.	21006.	151998.	19806.	0.182	0.016	0.135	0.018
C34 to C35	179507.	11659.	99151.	12424.	0.136	0.009	0.088	0.011
C35 to C36	128000.	3716.	60861.	6786.	0.120	0.003	0.067	0.007
C36 to 78 min	41932.	12482.	13304.	20626.	0.039	0.012	0.015	0.023
TOTAL	8633000.	2236143.	5804307.	1458991.	4.288	0.965	3.409	0.766

Pasadena - April

(filename = PAS04A)
(Size of sample = 76.960 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	38125.	18528.	18675.	4470.	0.018	0.009	0.009	0.002
C12 to C13	196204.	67450.	127639.	7168.	0.101	0.035	0.067	0.004
C13 to C14	235706.	59886.	187282.	46714.	0.122	0.031	0.099	0.025
C14 to C15	201697.	18612.	165862.	11449.	0.108	0.010	0.090	0.006
C15 to C16	291895.	65271.	292837.	105124.	0.156	0.035	0.160	0.057
C16 to C17	408647.	197888.	306647.	156905.	0.232	0.112	0.178	0.091
C17 to C18	382680.	104108.	212987.	38563.	0.210	0.057	0.119	0.022
C18 to C19	356516.	145134.	200675.	26915.	0.197	0.080	0.113	0.015
C19 to C20	358649.	108979.	170659.	33019.	0.205	0.062	0.100	0.019
C20 to C21	435512.	183758.	189173.	9484.	0.249	0.105	0.111	0.006
C21 to C22	285461.	40155.	167409.	9295.	0.177	0.025	0.106	0.006
C22 to C23	327129.	73159.	179369.	7944.	0.203	0.045	0.114	0.005
C23 to C24	298920.	12307.	192673.	14362.	0.192	0.008	0.127	0.009
C24 to C25	271359.	13325.	219769.	15066.	0.175	0.009	0.145	0.010
C25 to C26	325461.	32261.	230332.	10166.	0.236	0.023	0.171	0.008
C26 to C27	311390.	25003.	250525.	18386.	0.226	0.018	0.186	0.014
C27 to C28	318329.	19666.	281490.	25719.	0.243	0.015	0.220	0.020
C28 to C29	597491.	322690.	260240.	39485.	0.456	0.246	0.203	0.031
C29 to C30	292576.	8733.	234374.	10888.	0.245	0.007	0.200	0.009
C30 to C31	269199.	20969.	212311.	7278.	0.225	0.018	0.181	0.006
C31 to C32	255680.	31591.	215415.	26457.	0.260	0.032	0.224	0.028
C32 to C33	213805.	51939.	126377.	24989.	0.218	0.053	0.132	0.026
C33 to C34	191105.	53296.	107415.	10638.	0.204	0.057	0.117	0.012
C34 to C35	187209.	68420.	74016.	12585.	0.200	0.073	0.081	0.014
C35 to C36	106198.	25401.	31252.	6042.	0.140	0.034	0.042	0.008
C36 to 78 min	95010.	48059.	7946.	6151.	0.126	0.063	0.011	0.008
TOTAL	7251953.	1816588.	4663349.	685262.	5.122	1.263	3.304	0.460

Pasadena - May

(filename = PAS05A)
(Size of sample = 76.440 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	57940.	22453.	30509.	5395.	0.027	0.010	0.013	0.002
C12 to C13	283216.	67710.	211684.	19889.	0.140	0.034	0.100	0.009
C13 to C14	338147.	91719.	277401.	75635.	0.169	0.046	0.132	0.036
C14 to C15	272925.	4926.	237961.	18325.	0.140	0.003	0.116	0.009
C15 to C16	409331.	110804.	469431.	218625.	0.211	0.057	0.229	0.107
C16 to C17	538603.	269856.	442375.	224244.	0.295	0.148	0.230	0.116
C17 to C18	502376.	183018.	315870.	72394.	0.265	0.097	0.158	0.036
C18 to C19	416686.	116216.	255828.	52343.	0.222	0.062	0.129	0.026
C19 to C20	408528.	83717.	321604.	68103.	0.225	0.046	0.168	0.036
C20 to C21	475467.	156609.	234155.	18942.	0.262	0.086	0.123	0.010
C21 to C22	323832.	33238.	229032.	14257.	0.194	0.020	0.130	0.008
C22 to C23	375836.	77335.	236513.	23752.	0.225	0.046	0.134	0.013
C23 to C24	296524.	6569.	255513.	20442.	0.184	0.004	0.151	0.012
C24 to C25	282268.	5879.	268809.	11624.	0.175	0.004	0.158	0.007
C25 to C26	284966.	11836.	258742.	9077.	0.199	0.008	0.172	0.006
C26 to C27	303581.	4694.	287948.	19021.	0.212	0.003	0.191	0.013
C27 to C28	315172.	15376.	312392.	34965.	0.232	0.011	0.219	0.024
C28 to C29	300259.	27003.	295076.	50196.	0.221	0.020	0.206	0.035
C29 to C30	278253.	0.	273441.	14895.	0.224	0.000	0.209	0.011
C30 to C31	250082.	7076.	220281.	18345.	0.202	0.006	0.169	0.014
C31 to C32	227640.	14436.	211611.	29254.	0.224	0.014	0.197	0.027
C32 to C33	184023.	18092.	148219.	26954.	0.181	0.018	0.138	0.025
C33 to C34	130717.	8273.	95739.	13075.	0.134	0.009	0.094	0.013
C34 to C35	99019.	4517.	75948.	6796.	0.102	0.005	0.074	0.007
C35 to C36	78496.	9845.	9143.	4129.	0.100	0.013	0.011	0.005
C36 to 78 min	20532.	5474.	1405.	20455.	0.026	0.007	0.002	0.025
TOTAL	7454419.	1356671.	5976630.	1091132.	4.793	0.775	3.654	0.634

Pasadena - June

(filename = PAS06A)
(Size of sample = 76.350 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	53675.	19198.	40815.	8341.	0.030	0.011	0.016	0.003
C12 to C13	259547.	63302.	254267.	51888.	0.153	0.037	0.109	0.022
C13 to C14	269470.	70625.	300992.	82983.	0.161	0.042	0.131	0.036
C14 to C15	245885.	27176.	265853.	39912.	0.151	0.017	0.119	0.018
C15 to C16	325272.	86521.	472845.	194093.	0.199	0.053	0.211	0.087
C16 to C17	463139.	223406.	456208.	204900.	0.302	0.146	0.216	0.097
C17 to C18	412631.	128352.	372670.	73913.	0.260	0.081	0.171	0.034
C18 to C19	379208.	107007.	298552.	43229.	0.241	0.068	0.138	0.020
C19 to C20	370064.	66133.	339709.	58019.	0.243	0.043	0.163	0.028
C20 to C21	419884.	124228.	299214.	13570.	0.276	0.082	0.143	0.006
C21 to C22	291428.	28778.	307596.	23125.	0.208	0.021	0.160	0.012
C22 to C23	355022.	80835.	325511.	14299.	0.253	0.058	0.169	0.007
C23 to C24	257346.	7496.	295204.	15933.	0.191	0.006	0.159	0.009
C24 to C25	267152.	4298.	324669.	8104.	0.198	0.003	0.175	0.004
C25 to C26	252795.	4386.	312067.	6797.	0.211	0.004	0.189	0.004
C26 to C27	266514.	12950.	329056.	21640.	0.222	0.011	0.200	0.013
C27 to C28	267511.	14481.	343302.	35018.	0.235	0.013	0.219	0.022
C28 to C29	263304.	28220.	338960.	56088.	0.231	0.025	0.217	0.036
C29 to C30	233579.	2916.	288414.	15062.	0.225	0.003	0.202	0.011
C30 to C31	199348.	2295.	256114.	17590.	0.192	0.002	0.179	0.012
C31 to C32	197065.	17154.	251229.	26098.	0.231	0.020	0.214	0.022
C32 to C33	145098.	14343.	194610.	33494.	0.170	0.017	0.166	0.029
C33 to C34	100632.	6021.	154529.	17588.	0.123	0.007	0.138	0.016
C34 to C35	117777.	7229.	114147.	16870.	0.144	0.009	0.102	0.015
C35 to C36	42435.	1753.	71025.	12893.	0.064	0.003	0.079	0.014
C36 to 78 min	8791.	4394.	33979.	18014.	0.013	0.007	0.038	0.020
TOTAL	6464572.	1153497.	7041537.	1109461.	4.927	0.786	4.021	0.598

Pasadena - July

(filename = PAS07A)
(Size of sample = 75.850 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	32344.	5241.	19014.	2703.	0.029	0.005	0.016	0.002
C12 to C13	150423.	11273.	76554.	2483.	0.145	0.011	0.070	0.002
C13 to C14	141033.	8324.	89055.	10094.	0.138	0.008	0.082	0.009
C14 to C15	125441.	7369.	90822.	3073.	0.126	0.007	0.086	0.003
C15 to C16	171597.	23205.	167793.	52562.	0.172	0.023	0.160	0.050
C16 to C17	207096.	76483.	157892.	52999.	0.221	0.082	0.160	0.054
C17 to C18	215369.	57618.	145406.	16417.	0.222	0.059	0.142	0.016
C18 to C19	194070.	47566.	126255.	13042.	0.202	0.049	0.125	0.013
C19 to C20	199214.	36643.	134660.	13680.	0.214	0.039	0.137	0.014
C20 to C21	247407.	70924.	140209.	1111.	0.266	0.076	0.143	0.001
C21 to C22	178113.	14153.	137422.	3132.	0.208	0.016	0.152	0.003
C22 to C23	203575.	40773.	147075.	8608.	0.237	0.048	0.163	0.010
C23 to C24	181053.	9678.	153081.	5456.	0.219	0.012	0.176	0.006
C24 to C25	167275.	7870.	156134.	6856.	0.202	0.010	0.179	0.008
C25 to C26	167714.	2760.	179295.	4072.	0.229	0.004	0.232	0.005
C26 to C27	172961.	7758.	180045.	9904.	0.236	0.011	0.233	0.013
C27 to C28	188220.	14433.	222471.	20258.	0.270	0.021	0.303	0.028
C28 to C29	174492.	18347.	188891.	19131.	0.251	0.026	0.258	0.026
C29 to C30	167714.	5907.	185386.	11902.	0.264	0.009	0.277	0.018
C30 to C31	141952.	5134.	151477.	12948.	0.223	0.008	0.226	0.019
C31 to C32	143651.	11859.	155976.	21469.	0.275	0.023	0.284	0.039
C32 to C33	117464.	13040.	107622.	16081.	0.225	0.025	0.196	0.029
C33 to C34	95542.	6899.	85827.	9008.	0.192	0.014	0.163	0.017
C34 to C35	63768.	5702.	46301.	6121.	0.128	0.011	0.088	0.012
C35 to C36	32315.	5197.	26691.	5919.	0.080	0.013	0.063	0.014
C36 to 78 min	11430.	4224.	9024.	4063.	0.028	0.010	0.021	0.010
TOTAL	3891233.	518380.	3280378.	333092.	5.001	0.621	4.136	0.421

Pasadena - August

(filename = PAS08A)
(Size of sample = 76.120 cu meters)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total	AREA COUNTS Acid+Neutral Resolved	AREA COUNTS Neutral Total	AREA COUNTS Neutral Resolved	ug/cu meters Acid+Neutral Total	ug/cu meters Acid+Neutral Resolved	ug/cu meters Neutral Total	ug/cu meters Neutral Resolved
16 min to C12	40511.	6097.	30038.	8135.	0.021	0.003	0.014	0.004
C12 to C13	184458.	14062.	123698.	10558.	0.103	0.008	0.061	0.005
C13 to C14	166198.	11004.	131533.	18585.	0.093	0.006	0.066	0.009
C14 to C15	159971.	11080.	139122.	17399.	0.092	0.006	0.071	0.009
C15 to C16	230938.	30979.	239059.	88036.	0.133	0.018	0.122	0.045
C16 to C17	268126.	96709.	226098.	87462.	0.165	0.059	0.123	0.048
C17 to C18	288483.	95070.	225731.	38851.	0.171	0.056	0.119	0.020
C18 to C19	250473.	47501.	185360.	32699.	0.150	0.028	0.098	0.017
C19 to C20	276189.	58037.	209171.	30083.	0.171	0.036	0.115	0.017
C20 to C21	321599.	90396.	204160.	7950.	0.199	0.056	0.112	0.004
C21 to C22	237832.	20940.	202006.	12581.	0.160	0.014	0.120	0.007
C22 to C23	270441.	58515.	213560.	25184.	0.182	0.039	0.127	0.015
C23 to C24	249908.	20403.	229619.	24562.	0.174	0.014	0.142	0.015
C24 to C25	227419.	12491.	221615.	19723.	0.159	0.009	0.137	0.012
C25 to C26	224040.	3020.	243817.	20047.	0.176	0.002	0.170	0.014
C26 to C27	238682.	8390.	265343.	26201.	0.188	0.007	0.185	0.018
C27 to C28	267311.	31178.	300875.	66066.	0.221	0.026	0.221	0.048
C28 to C29	247663.	20277.	274120.	34062.	0.205	0.017	0.201	0.025
C29 to C30	235750.	7168.	261344.	19911.	0.214	0.006	0.210	0.016
C30 to C31	226283.	10821.	249254.	32481.	0.205	0.010	0.200	0.026
C31 to C32	211465.	18538.	234024.	31917.	0.233	0.020	0.229	0.031
C32 to C33	160380.	20275.	177769.	24310.	0.177	0.022	0.174	0.024
C33 to C34	133379.	9682.	130971.	13652.	0.154	0.011	0.134	0.014
C34 to C35	111992.	5143.	110570.	8035.	0.129	0.006	0.113	0.008
C35 to C36	79094.	5409.	68671.	10422.	0.113	0.008	0.087	0.013
C36 to 78 min	20807.	7572.	22455.	14212.	0.030	0.011	0.028	0.018
TOTAL	5329392.	720757.	4919983.	723124.	4.018	0.500	3.380	0.485

Pasadena - September

(filename = PAS09A)
(Size of sample = 61.000 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	37718.	6655.	23479.	4401.	0.018	0.003	0.011	0.002
C12 to C13	170140.	11622.	103508.	4301.	0.085	0.006	0.053	0.002
C13 to C14	156847.	10439.	108595.	11618.	0.079	0.005	0.056	0.006
C14 to C15	153791.	9399.	118445.	10382.	0.079	0.005	0.063	0.006
C15 to C16	236312.	39783.	217948.	67638.	0.122	0.021	0.116	0.036
C16 to C17	254680.	84914.	186824.	68456.	0.140	0.047	0.105	0.039
C17 to C18	278360.	94598.	167338.	28711.	0.148	0.050	0.091	0.016
C18 to C19	236554.	50190.	155740.	23976.	0.127	0.027	0.086	0.013
C19 to C20	250070.	48082.	128165.	20453.	0.139	0.027	0.073	0.012
C20 to C21	289773.	67583.	145175.	5043.	0.161	0.037	0.083	0.003
C21 to C22	219925.	17488.	132285.	6280.	0.132	0.011	0.082	0.004
C22 to C23	258378.	54556.	149452.	22073.	0.155	0.033	0.092	0.014
C23 to C24	238665.	18022.	167632.	18424.	0.149	0.011	0.107	0.012
C24 to C25	218690.	11166.	154296.	14942.	0.136	0.007	0.099	0.010
C25 to C26	221159.	7622.	190320.	14454.	0.155	0.005	0.137	0.010
C26 to C27	242647.	13306.	211836.	13713.	0.171	0.009	0.153	0.010
C27 to C28	278548.	36891.	261046.	52531.	0.206	0.027	0.199	0.040
C28 to C29	267653.	21796.	243932.	25747.	0.198	0.016	0.186	0.020
C29 to C30	252940.	8449.	234581.	28143.	0.205	0.007	0.195	0.023
C30 to C31	252845.	12341.	239527.	21254.	0.205	0.010	0.199	0.018
C31 to C32	225939.	18542.	219610.	27026.	0.223	0.018	0.223	0.027
C32 to C33	183303.	21128.	155739.	23887.	0.181	0.021	0.158	0.024
C33 to C34	123100.	9236.	126753.	16857.	0.127	0.010	0.135	0.018
C34 to C35	103466.	8249.	87644.	14253.	0.107	0.009	0.093	0.015
C35 to C36	59444.	5323.	33547.	8912.	0.076	0.007	0.044	0.012
C36 to 78 min	22618.	5392.	19991.	17547.	0.029	0.007	0.026	0.023
TOTAL	5233565.	692772.	3983408.	571022.	3.552	0.435	2.865	0.413

Pasadena - October

(filename = PAS10A)
(Size of sample = 76.380 cu meters)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total	Resolved	Neutral Total	Resolved	ug/cu meters Acid+Neutral Total	Resolved	Neutral Total	Resolved
16 min to C12	34153.	4696.	22016.	4426.	0.019	0.003	0.010	0.002
C12 to C13	154279.	7161.	101181.	4514.	0.092	0.004	0.052	0.002
C13 to C14	150036.	10849.	117230.	19935.	0.090	0.007	0.060	0.010
C14 to C15	148043.	12885.	135587.	16153.	0.091	0.008	0.072	0.009
C15 to C16	229106.	43474.	248516.	92016.	0.141	0.027	0.132	0.049
C16 to C17	234938.	79880.	214228.	81928.	0.154	0.052	0.121	0.046
C17 to C18	291344.	99097.	202767.	43526.	0.185	0.063	0.110	0.024
C18 to C19	213530.	53190.	196385.	45091.	0.137	0.034	0.108	0.025
C19 to C20	228467.	41647.	169144.	23464.	0.151	0.028	0.096	0.013
C20 to C21	279368.	80199.	169772.	5949.	0.185	0.053	0.096	0.003
C21 to C22	185592.	11021.	153745.	8858.	0.133	0.008	0.095	0.005
C22 to C23	224614.	50636.	170491.	19330.	0.161	0.036	0.105	0.012
C23 to C24	204709.	19414.	190132.	21713.	0.153	0.014	0.121	0.014
C24 to C25	195827.	14543.	196804.	16240.	0.146	0.011	0.126	0.010
C25 to C26	205645.	24517.	208569.	14818.	0.173	0.021	0.150	0.011
C26 to C27	224647.	13919.	248440.	25571.	0.189	0.012	0.179	0.018
C27 to C28	249083.	23050.	295584.	37372.	0.220	0.020	0.224	0.028
C28 to C29	241973.	16085.	274874.	25731.	0.214	0.014	0.208	0.020
C29 to C30	253147.	8925.	301785.	23550.	0.245	0.009	0.250	0.020
C30 to C31	214663.	5950.	268486.	16828.	0.208	0.006	0.223	0.014
C31 to C32	222872.	21690.	272319.	26667.	0.263	0.026	0.275	0.027
C32 to C33	190288.	28132.	190637.	19402.	0.224	0.033	0.193	0.020
C33 to C34	141248.	13989.	155389.	16308.	0.174	0.017	0.164	0.017
C34 to C35	109382.	11855.	119515.	9471.	0.135	0.015	0.126	0.010
C35 to C36	71965.	7980.	68430.	8817.	0.110	0.012	0.090	0.012
C36 to 78 min	18629.	13110.	13290.	14398.	0.028	0.020	0.017	0.019
TOTAL	4917548.	717894.	4705316.	642076.	4.020	0.552	3.403	0.439

Pasadena - November

(filename = PAS11A)
(Size of sample = 78.460 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	49183.	15767.	30827.	8192.	0.017	0.005	0.012	0.003
C12 to C13	203280.	17062.	126778.	8571.	0.073	0.006	0.054	0.004
C13 to C14	207016.	14902.	154548.	26529.	0.076	0.005	0.066	0.011
C14 to C15	217640.	19158.	161449.	12138.	0.082	0.007	0.071	0.005
C15 to C16	357459.	97861.	328847.	143240.	0.134	0.037	0.144	0.063
C16 to C17	351132.	97839.	223213.	72528.	0.140	0.039	0.104	0.034
C17 to C18	501643.	204109.	251095.	71933.	0.193	0.079	0.113	0.032
C18 to C19	386420.	113721.	208460.	51787.	0.150	0.044	0.095	0.024
C19 to C20	443439.	140756.	250045.	66777.	0.178	0.057	0.118	0.031
C20 to C21	480046.	155513.	205639.	13139.	0.193	0.063	0.097	0.006
C21 to C22	322168.	28756.	192771.	12688.	0.140	0.013	0.098	0.006
C22 to C23	437461.	130637.	215907.	19489.	0.191	0.057	0.110	0.010
C23 to C24	369350.	34265.	251750.	27617.	0.167	0.016	0.133	0.015
C24 to C25	392742.	29738.	276526.	33209.	0.178	0.013	0.146	0.018
C25 to C26	497960.	98172.	348003.	34582.	0.254	0.050	0.208	0.021
C26 to C27	481625.	59871.	377684.	32713.	0.246	0.031	0.225	0.020
C27 to C28	490955.	25650.	414525.	43491.	0.264	0.014	0.261	0.027
C28 to C29	504834.	65551.	411420.	50831.	0.271	0.035	0.259	0.032
C29 to C30	477927.	24700.	390050.	26907.	0.281	0.015	0.268	0.019
C30 to C31	436208.	35684.	353258.	19402.	0.256	0.021	0.243	0.013
C31 to C32	396334.	38188.	340393.	33988.	0.284	0.027	0.285	0.028
C32 to C33	339501.	37822.	282462.	39293.	0.243	0.027	0.237	0.033
C33 to C34	276484.	22267.	199106.	20768.	0.207	0.017	0.175	0.018
C34 to C35	221380.	13835.	169211.	11062.	0.166	0.010	0.149	0.010
C35 to C36	178423.	3440.	123678.	7605.	0.166	0.003	0.134	0.008
C36 to 78 min	95595.	13903.	46789.	30917.	0.089	0.013	0.051	0.034
TOTAL	9116205.	1539167.	6334434.	919396.	4.639	0.703	3.856	0.525

Pasadena - December

(filename = PAS12A)
(Size of sample = 77.100 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	·Resolved	Total	Resolved	Total	Resolved
16 min to C12	51162.	16701.	31726.	6823.	0.021	0.007	0.014	0.003
C12 to C13	224266.	23334.	143128.	5158.	0.099	0.010	0.069	0.002
C13 to C14	215000.	13997.	154452.	15746.	0.096	0.006	0.075	0.008
C14 to C15	226918.	11727.	195239.	5751.	0.104	0.005	0.097	0.003
C15 to C16	440640.	161008.	372814.	181730.	0.203	0.074	0.186	0.091
C16 to C17	372103.	109523.	234760.	63441.	0.182	0.054	0.124	0.034
C17 to C18	537450.	214220.	279796.	78365.	0.254	0.101	0.143	0.040
C18 to C19	404978.	115290.	239730.	52155.	0.193	0.055	0.124	0.027
C19 to C20	495625.	176038.	256591.	81179.	0.244	0.087	0.137	0.043
C20 to C21	493120.	139291.	215711.	10898.	0.243	0.069	0.115	0.006
C21 to C22	356270.	28928.	213010.	15439.	0.190	0.015	0.123	0.009
C22 to C23	488271.	131156.	242092.	22622.	0.261	0.070	0.140	0.013
C23 to C24	438372.	38822.	303375.	26268.	0.243	0.022	0.183	0.016
C24 to C25	488400.	36519.	323011.	31682.	0.271	0.020	0.195	0.019
C25 to C26	613442.	122999.	416352.	36451.	0.384	0.077	0.283	0.025
C26 to C27	557412.	41851.	434992.	26631.	0.349	0.026	0.295	0.018
C27 to C28	544248.	45044.	443585.	40180.	0.358	0.030	0.317	0.029
C28 to C29	565110.	62743.	438725.	26787.	0.372	0.041	0.313	0.019
C29 to C30	538020.	26275.	435735.	11565.	0.388	0.019	0.341	0.009
C30 to C31	472336.	24462.	371226.	14108.	0.340	0.018	0.290	0.011
C31 to C32	453829.	41280.	385522.	36149.	0.398	0.036	0.367	0.034
C32 to C33	373713.	46150.	302141.	35698.	0.328	0.041	0.288	0.034
C33 to C34	300969.	25932.	215383.	23088.	0.277	0.024	0.215	0.023
C34 to C35	233474.	17598.	169997.	7179.	0.215	0.016	0.170	0.007
C35 to C36	192406.	10858.	132247.	3584.	0.219	0.012	0.163	0.004
C36 to 78 min	106966.	18928.	63596.	7879.	0.122	0.022	0.079	0.010
TOTAL	10184500.	1700674.	7014936.	866556.	6.353	0.956	4.847	0.537

Downtown Los Angeles - January

(filename = DLA01A)
(Size of sample = 75.250 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	41104.	14360.	28048.	2984.	0.033	0.012	0.012	0.001
C12 to C13	257420.	37625.	278600.	16309.	0.224	0.033	0.129	0.008
C13 to C14	245920.	21687.	344732.	42349.	0.216	0.019	0.161	0.020
C14 to C15	225755.	16007.	276164.	15673.	0.203	0.014	0.133	0.008
C15 to C16	362987.	104947.	370501.	127963.	0.327	0.095	0.178	0.062
C16 to C17	433465.	184456.	392693.	174677.	0.415	0.177	0.201	0.089
C17 to C18	342096.	131759.	316270.	71118.	0.317	0.122	0.156	0.035
C18 to C19	310304.	87221.	242292.	42381.	0.290	0.081	0.121	0.021
C19 to C20	316386.	81608.	285305.	72688.	0.306	0.079	0.147	0.037
C20 to C21	392525.	149249.	279900.	60831.	0.379	0.144	0.144	0.031
C21 to C22	248435.	30527.	225367.	18360.	0.260	0.032	0.126	0.010
C22 to C23	335751.	98392.	264471.	26910.	0.352	0.103	0.148	0.015
C23 to C24	309987.	35733.	333714.	43039.	0.337	0.039	0.194	0.025
C24 to C25	357597.	48701.	436069.	63265.	0.389	0.053	0.253	0.037
C25 to C26	423859.	69942.	551813.	67321.	0.519	0.086	0.361	0.044
C26 to C27	431112.	38420.	620784.	59375.	0.528	0.047	0.406	0.039
C27 to C28	442401.	21017.	636449.	52896.	0.571	0.027	0.439	0.036
C28 to C29	461480.	24742.	653133.	34138.	0.596	0.032	0.450	0.024
C29 to C30	482027.	26240.	693024.	34391.	0.681	0.037	0.523	0.026
C30 to C31	408472.	20066.	591542.	40615.	0.577	0.028	0.446	0.031
C31 to C32	390780.	41052.	588825.	61797.	0.672	0.071	0.541	0.057
C32 to C33	338530.	38601.	496852.	54940.	0.582	0.066	0.456	0.050
C33 to C34	246938.	21631.	404827.	45404.	0.445	0.039	0.389	0.044
C34 to C35	185960.	10788.	269392.	37781.	0.335	0.019	0.259	0.036
C35 to C36	129031.	3531.	218051.	24456.	0.288	0.008	0.260	0.029
C36 to 78 min	61816.	2265.	178151.	34944.	0.138	0.005	0.212	0.042
TOTAL	8182138.	1360567.	9976969.	1326605.	9.979	1.468	6.847	0.857

Downtown Los Angeles - February

(filename = DLA02A)
(Size of sample = 76.800 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	60721.	25802.	26698.	2869.	0.024	0.010	0.011	0.001
C12 to C13	466943.	158009.	338675.	100405.	0.195	0.066	0.149	0.044
C13 to C14	445870.	91402.	376425.	58733.	0.188	0.038	0.167	0.026
C14 to C15	361063.	50672.	287722.	23530.	0.156	0.022	0.131	0.011
C15 to C16	480750.	122277.	327684.	79303.	0.208	0.053	0.149	0.036
C16 to C17	667934.	334545.	392754.	190624.	0.307	0.154	0.190	0.092
C17 to C18	627254.	247008.	279694.	38717.	0.279	0.110	0.131	0.018
C18 to C19	535090.	177253.	261024.	75844.	0.240	0.079	0.123	0.036
C19 to C20	493032.	119924.	242265.	43609.	0.229	0.056	0.118	0.021
C20 to C21	617499.	237489.	266694.	55714.	0.286	0.110	0.130	0.027
C21 to C22	401567.	46531.	205574.	10925.	0.202	0.023	0.109	0.006
C22 to C23	522331.	129774.	230548.	14722.	0.263	0.065	0.122	0.008
C23 to C24	392891.	47013.	259567.	22424.	0.205	0.025	0.143	0.012
C24 to C25	496073.	53733.	321194.	30667.	0.259	0.028	0.177	0.017
C25 to C26	526187.	79550.	424324.	47479.	0.310	0.047	0.263	0.029
C26 to C27	569584.	50821.	454667.	52352.	0.335	0.030	0.282	0.032
C27 to C28	590247.	49485.	489431.	44594.	0.366	0.031	0.320	0.029
C28 to C29	622580.	42701.	516870.	37467.	0.386	0.026	0.337	0.024
C29 to C30	610273.	35800.	517554.	33237.	0.414	0.024	0.370	0.024
C30 to C31	536688.	32692.	447255.	22782.	0.364	0.022	0.320	0.016
C31 to C32	526461.	54254.	454934.	49053.	0.435	0.045	0.396	0.043
C32 to C33	419085.	42976.	362506.	40448.	0.346	0.036	0.316	0.035
C33 to C34	359242.	44285.	321723.	36785.	0.311	0.038	0.293	0.034
C34 to C35	244503.	10609.	218531.	10383.	0.212	0.009	0.199	0.009
C35 to C36	189660.	5952.	173442.	7120.	0.203	0.006	0.196	0.008
C36 to 78 min	120557.	13982.	94032.	15842.	0.129	0.015	0.106	0.018
TOTAL	11884085.	2304539.	8291787.	1145628.	6.850	1.169	5.248	0.658

Downtown Los Angeles - March

(filename = DLA03A)
(Size of sample = 77.460 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	37595.	11756.	21560.	3029.	0.018	0.006	0.009	0.001
C12 to C13	276609.	59188.	219058.	28201.	0.139	0.030	0.096	0.011
C13 to C14	275129.	31321.	248536.	41375.	0.139	0.016	0.109	0.017
C14 to C15	258755.	22754.	217086.	13772.	0.135	0.012	0.098	0.006
C15 to C16	337981.	70661.	356037.	125427.	0.176	0.037	0.161	0.053
C16 to C17	494944.	249172.	445423.	236333.	0.274	0.138	0.214	0.106
C17 to C18	423347.	183794.	289116.	56945.	0.226	0.098	0.134	0.025
C18 to C19	358964.	118650.	239815.	55248.	0.193	0.064	0.112	0.024
C19 to C20	331017.	66546.	251588.	56523.	0.184	0.037	0.122	0.026
C20 to C21	422550.	159554.	255987.	64245.	0.235	0.089	0.124	0.029
C21 to C22	274869.	34799.	203119.	16062.	0.166	0.021	0.107	0.008
C22 to C23	352317.	97174.	233413.	20791.	0.213	0.059	0.123	0.010
C23 to C24	315958.	31141.	270091.	29366.	0.198	0.020	0.147	0.015
C24 to C25	352837.	44840.	365810.	54365.	0.221	0.028	0.200	0.028
C25 to C26	456102.	66391.	414941.	77294.	0.323	0.047	0.255	0.044
C26 to C27	459804.	26873.	498424.	47235.	0.325	0.019	0.307	0.027
C27 to C28	484811.	44873.	529290.	47488.	0.361	0.033	0.343	0.029
C28 to C29	533060.	46295.	569590.	44317.	0.397	0.034	0.369	0.027
C29 to C30	542283.	29406.	582788.	24738.	0.442	0.024	0.413	0.016
C30 to C31	470922.	20702.	515899.	25806.	0.384	0.017	0.366	0.017
C31 to C32	462910.	45383.	478364.	46498.	0.460	0.045	0.413	0.037
C32 to C33	389954.	40900.	404955.	59082.	0.387	0.041	0.350	0.048
C33 to C34	339345.	25729.	371876.	53142.	0.353	0.027	0.336	0.045
C34 to C35	239023.	4728.	220916.	19939.	0.248	0.005	0.200	0.017
C35 to C36	179657.	7859.	183623.	8871.	0.231	0.010	0.206	0.009
C36 to 78 min	117021.	13640.	88035.	7610.	0.151	0.018	0.099	0.008
TOTAL	9187764.	1554129.	8475340.	1263702.	6.578	0.972	5.413	0.683

Downtown Los Angeles - April

(filename = DLA04A)
(Size of sample = 77.220 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	41908.	13878.	19952.	4525.	0.022	0.007	0.010	0.002
C12 to C13	257453.	50555.	148001.	9297.	0.143	0.028	0.081	0.005
C13 to C14	276768.	52521.	185432.	33950.	0.155	0.029	0.102	0.019
C14 to C15	236479.	23444.	170659.	5936.	0.136	0.013	0.096	0.003
C15 to C16	313136.	59526.	248707.	77610.	0.180	0.034	0.141	0.044
C16 to C17	444626.	216190.	336781.	183559.	0.272	0.132	0.202	0.110
C17 to C18	393942.	133874.	208231.	37336.	0.233	0.079	0.121	0.022
C18 to C19	338461.	96737.	174250.	31657.	0.202	0.058	0.102	0.019
C19 to C20	317599.	61950.	185984.	33266.	0.196	0.038	0.113	0.020
C20 to C21	404562.	148622.	193550.	38150.	0.250	0.092	0.117	0.023
C21 to C22	272287.	25318.	170505.	10709.	0.182	0.017	0.112	0.007
C22 to C23	342295.	74901.	178082.	10289.	0.229	0.050	0.117	0.007
C23 to C24	273554.	23394.	181664.	17486.	0.190	0.016	0.124	0.012
C24 to C25	280625.	15695.	246389.	28196.	0.195	0.011	0.168	0.019
C25 to C26	350206.	38067.	276471.	25734.	0.274	0.030	0.213	0.020
C26 to C27	352831.	42937.	322637.	34258.	0.276	0.034	0.248	0.026
C27 to C28	360145.	34306.	333082.	31714.	0.297	0.028	0.270	0.026
C28 to C29	388875.	36537.	356468.	35028.	0.321	0.030	0.289	0.028
C29 to C30	384365.	15515.	351984.	22580.	0.347	0.014	0.312	0.020
C30 to C31	341395.	8268.	304451.	12843.	0.308	0.007	0.270	0.011
C31 to C32	326661.	32774.	282840.	34177.	0.359	0.036	0.305	0.037
C32 to C33	269590.	26339.	233065.	27085.	0.296	0.029	0.252	0.029
C33 to C34	236046.	20590.	206516.	26920.	0.272	0.024	0.233	0.030
C34 to C35	162810.	7403.	142995.	7520.	0.187	0.009	0.162	0.009
C35 to C36	118289.	2912.	93385.	5246.	0.169	0.004	0.131	0.007
C36 to 78 min	55020.	8962.	31402.	13273.	0.078	0.013	0.044	0.019
TOTAL	7539928.	1271215.	5583483.	798344.	5.771	0.863	4.333	0.575

Downtown Los Angeles - May

(filename = DLA05A)
(Size of sample = 76.810 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	52428.	15951.	24059.	3489.	0.021	0.007	0.010	0.001
C12 to C13	347383.	56192.	208960.	24884.	0.152	0.025	0.094	0.011
C13 to C14	397237.	77983.	270803.	68163.	0.176	0.035	0.122	0.031
C14 to C15	323752.	18424.	209060.	12683.	0.147	0.008	0.097	0.006
C15 to C16	425853.	70115.	367224.	134759.	0.194	0.032	0.171	0.063
C16 to C17	696991.	323825.	479386.	277040.	0.337	0.157	0.237	0.137
C17 to C18	509935.	169874.	302035.	71456.	0.238	0.079	0.144	0.034
C18 to C19	450820.	97110.	282207.	50154.	0.213	0.046	0.136	0.024
C19 to C20	421119.	71026.	239534.	38047.	0.205	0.035	0.119	0.019
C20 to C21	509082.	177113.	268316.	49629.	0.248	0.086	0.134	0.025
C21 to C22	369379.	45903.	238669.	16789.	0.195	0.024	0.129	0.009
C22 to C23	397568.	67808.	222801.	11151.	0.210	0.036	0.120	0.006
C23 to C24	376000.	17127.	256533.	21126.	0.207	0.009	0.144	0.012
C24 to C25	334162.	29433.	275417.	17212.	0.184	0.016	0.155	0.010
C25 to C26	401144.	29029.	329045.	25126.	0.248	0.018	0.208	0.016
C26 to C27	390239.	21286.	329333.	22352.	0.242	0.013	0.208	0.014
C27 to C28	418199.	27097.	378521.	23680.	0.273	0.018	0.252	0.016
C28 to C29	412716.	38114.	371470.	41368.	0.269	0.025	0.247	0.028
C29 to C30	393783.	4655.	360520.	24073.	0.281	0.003	0.263	0.018
C30 to C31	366043.	9030.	313770.	9334.	0.261	0.006	0.229	0.007
C31 to C32	330686.	16678.	297545.	29731.	0.287	0.014	0.264	0.026
C32 to C33	284765.	27337.	243655.	19721.	0.248	0.024	0.216	0.018
C33 to C34	234845.	21049.	197074.	18672.	0.214	0.019	0.183	0.017
C34 to C35	168911.	5078.	138066.	3237.	0.154	0.005	0.128	0.003
C35 to C36	117321.	2629.	98190.	5602.	0.132	0.003	0.113	0.006
C36 to 78 min	43121.	2152.	27511.	4118.	0.049	0.002	0.032	0.005
TOTAL	9173482.	1442018.	6729704.	1023596.	5.387	0.746	4.155	0.560

Downtown Los Angeles - June

(filename = DLA06A)
(Size of sample = 76.410 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	44064.	5743.	23290.	3348.	0.027	0.004	0.010	0.001
C12 to C13	295212.	39121.	203738.	16853.	0.195	0.026	0.097	0.008
C13 to C14	320211.	45023.	268173.	58941.	0.214	0.030	0.128	0.028
C14 to C15	263062.	6327.	207824.	8053.	0.181	0.004	0.102	0.004
C15 to C16	324278.	34304.	320895.	93707.	0.223	0.024	0.158	0.046
C16 to C17	474806.	211448.	438486.	233020.	0.347	0.154	0.229	0.122
C17 to C18	395677.	106529.	278946.	41864.	0.279	0.075	0.141	0.021
C18 to C19	348261.	80394.	272981.	41483.	0.248	0.057	0.139	0.021
C19 to C20	320683.	46201.	231915.	33995.	0.236	0.034	0.122	0.018
C20 to C21	373986.	107296.	255727.	41809.	0.275	0.079	0.135	0.022
C21 to C22	256448.	22576.	231260.	11408.	0.205	0.018	0.132	0.007
C22 to C23	278586.	43128.	215116.	7891.	0.222	0.034	0.123	0.005
C23 to C24	242099.	7815.	235669.	15986.	0.201	0.006	0.140	0.009
C24 to C25	240341.	5155.	269906.	10530.	0.199	0.004	0.160	0.006
C25 to C26	250469.	13075.	274546.	15974.	0.234	0.012	0.184	0.011
C26 to C27	261019.	14845.	314427.	24353.	0.244	0.014	0.210	0.016
C27 to C28	265135.	22026.	323144.	30692.	0.261	0.022	0.228	0.022
C28 to C29	277233.	26245.	345578.	37627.	0.273	0.026	0.243	0.027
C29 to C30	275262.	6311.	330400.	13407.	0.296	0.007	0.255	0.010
C30 to C31	226744.	2193.	279547.	10881.	0.244	0.002	0.216	0.008
C31 to C32	216745.	23546.	269259.	29553.	0.284	0.031	0.253	0.028
C32 to C33	182979.	17089.	221836.	28482.	0.240	0.022	0.208	0.027
C33 to C34	161228.	18972.	199218.	21663.	0.221	0.026	0.196	0.021
C34 to C35	102497.	8672.	127079.	10452.	0.141	0.012	0.125	0.010
C35 to C36	62133.	3218.	97345.	3795.	0.106	0.005	0.119	0.005
C36 to 78 min	17264.	6545.	34309.	13732.	0.029	0.011	0.042	0.017
TOTAL	6476422.	923797.	6270614.	859499.	5.623	0.741	4.095	0.520

Downtown Los Angeles - July

(filename = DLA07A)
(Size of sample = 76.350 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	32025.	3346.	17024.	1665.	0.034	0.004	0.018	0.002
C12 to C13	211421.	10537.	116796.	3437.	0.242	0.012	0.132	0.004
C13 to C14	181503.	5212.	101704.	6596.	0.210	0.006	0.116	0.008
C14 to C15	151898.	0.	105915.	4039.	0.181	0.000	0.125	0.005
C15 to C16	204519.	15783.	127784.	28336.	0.243	0.019	0.150	0.033
C16 to C17	232778.	69738.	142402.	57857.	0.294	0.088	0.178	0.072
C17 to C18	245103.	57195.	118882.	13824.	0.299	0.070	0.144	0.017
C18 to C19	199946.	40231.	98871.	15032.	0.246	0.050	0.121	0.018
C19 to C20	202871.	25080.	102476.	13112.	0.259	0.032	0.129	0.017
C20 to C21	248062.	62985.	113336.	18782.	0.316	0.080	0.143	0.024
C21 to C22	176179.	11695.	98674.	4351.	0.244	0.016	0.135	0.006
C22 to C23	205625.	38602.	104647.	9560.	0.284	0.053	0.143	0.013
C23 to C24	191971.	3876.	99447.	7691.	0.276	0.006	0.141	0.011
C24 to C25	172204.	8013.	122012.	9803.	0.247	0.012	0.173	0.014
C25 to C26	174210.	7373.	120466.	8139.	0.282	0.012	0.193	0.013
C26 to C27	188939.	12669.	140903.	19213.	0.306	0.021	0.226	0.031
C27 to C28	199895.	16495.	148040.	24688.	0.341	0.028	0.249	0.042
C28 to C29	219588.	18105.	171121.	23660.	0.374	0.031	0.288	0.040
C29 to C30	205909.	6044.	167399.	14291.	0.384	0.011	0.309	0.026
C30 to C31	187192.	6800.	152813.	10780.	0.349	0.013	0.282	0.020
C31 to C32	184449.	14222.	150775.	21324.	0.419	0.032	0.339	0.048
C32 to C33	156193.	11982.	127699.	14468.	0.355	0.027	0.287	0.033
C33 to C34	131092.	8401.	97375.	7582.	0.312	0.020	0.229	0.018
C34 to C35	77468.	0.	62170.	3422.	0.184	0.000	0.146	0.008
C35 to C36	45395.	3949.	32610.	3449.	0.134	0.012	0.095	0.010
C36 to 78 min	7042.	4449.	11786.	8187.	0.021	0.013	0.034	0.024
TOTAL	4433477.	462782.	2853127.	353288.	6.837	0.667	4.526	0.555

Downtown Los Angeles - August

(filename = DLA08A)
(Size of sample = 76.460 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	34760.	4357.	28730.	4221.	0.020	0.003	0.013	0.002
C12 to C13	230203.	9529.	163124.	5031.	0.143	0.006	0.077	0.002
C13 to C14	202681.	14848.	155209.	17672.	0.127	0.009	0.074	0.008
C14 to C15	188530.	6961.	167345.	3290.	0.122	0.004	0.082	0.002
C15 to C16	247701.	30871.	246548.	66244.	0.160	0.020	0.121	0.032
C16 to C17	296465.	99314.	248125.	94493.	0.204	0.068	0.129	0.049
C17 to C18	319574.	83897.	227875.	26504.	0.212	0.056	0.115	0.013
C18 to C19	263992.	55494.	216263.	27844.	0.177	0.037	0.110	0.014
C19 to C20	289176.	55040.	191770.	24237.	0.200	0.038	0.101	0.013
C20 to C21	331053.	85378.	217185.	26229.	0.229	0.059	0.114	0.014
C21 to C22	246562.	23963.	206392.	15872.	0.185	0.018	0.118	0.009
C22 to C23	282379.	54928.	196070.	15912.	0.212	0.041	0.112	0.009
C23 to C24	267526.	21026.	234502.	23325.	0.209	0.016	0.139	0.014
C24 to C25	259292.	14007.	252728.	18271.	0.202	0.011	0.150	0.011
C25 to C26	254722.	11067.	247876.	8511.	0.224	0.010	0.165	0.006
C26 to C27	278197.	15961.	299609.	17409.	0.245	0.014	0.200	0.012
C27 to C28	308838.	43608.	333547.	48135.	0.286	0.040	0.234	0.034
C28 to C29	325804.	10001.	366919.	29624.	0.302	0.009	0.258	0.021
C29 to C30	310669.	8363.	351970.	18028.	0.315	0.008	0.271	0.014
C30 to C31	306999.	16694.	343706.	23757.	0.311	0.017	0.264	0.018
C31 to C32	273791.	20963.	322819.	33377.	0.338	0.026	0.302	0.031
C32 to C33	243334.	22456.	287391.	30544.	0.300	0.028	0.269	0.029
C33 to C34	187453.	12592.	228847.	17909.	0.242	0.016	0.224	0.018
C34 to C35	133970.	7116.	154631.	6611.	0.173	0.009	0.152	0.006
C35 to C36	81436.	0.	126421.	2781.	0.130	0.000	0.154	0.003
C36 to 78 min	30440.	1143.	60486.	14587.	0.049	0.002	0.073	0.018
TOTAL	6195547.	729577.	5876088.	620418.	5.318	0.567	4.021	0.402

Downtown Los Angeles - September

(filename = DLA09A)
(Size of sample = 91.190 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	37132.	9260.	28947.	6666.	0.017	0.004	0.010	0.002
C12 to C13	227251.	10790.	162063.	3614.	0.109	0.005	0.059	0.001
C13 to C14	203396.	12707.	166447.	21942.	0.098	0.006	0.062	0.008
C14 to C15	204470.	15624.	158246.	3141.	0.101	0.008	0.060	0.001
C15 to C16	271323.	40907.	288475.	96769.	0.135	0.020	0.110	0.037
C16 to C17	368015.	131851.	283934.	101349.	0.194	0.070	0.115	0.041
C17 to C18	352010.	124912.	240885.	35157.	0.179	0.064	0.094	0.014
C18 to C19	309868.	70371.	223514.	24642.	0.159	0.036	0.088	0.010
C19 to C20	323381.	35623.	234745.	18723.	0.172	0.019	0.096	0.008
C20 to C21	375248.	87543.	245160.	27745.	0.200	0.047	0.100	0.011
C21 to C22	288283.	23441.	229505.	11918.	0.166	0.014	0.102	0.005
C22 to C23	365639.	79230.	233655.	1109.	0.211	0.046	0.103	0.000
C23 to C24	334159.	27753.	277072.	24345.	0.200	0.017	0.127	0.011
C24 to C25	321826.	29967.	339076.	20978.	0.193	0.018	0.156	0.010
C25 to C26	399793.	37581.	360146.	16094.	0.270	0.025	0.186	0.008
C26 to C27	432479.	35481.	453816.	46973.	0.292	0.024	0.235	0.024
C27 to C28	493458.	58454.	549163.	102770.	0.351	0.042	0.299	0.056
C28 to C29	533084.	46828.	592211.	52208.	0.379	0.033	0.323	0.028
C29 to C30	539901.	33870.	619062.	20592.	0.420	0.026	0.369	0.012
C30 to C31	528758.	24059.	600561.	64849.	0.411	0.019	0.358	0.039
C31 to C32	501466.	42535.	597992.	60092.	0.475	0.040	0.435	0.044
C32 to C33	455230.	39155.	486141.	33088.	0.432	0.037	0.353	0.024
C33 to C34	354809.	50822.	436285.	42576.	0.352	0.050	0.332	0.032
C34 to C35	254434.	10349.	291537.	14953.	0.253	0.010	0.222	0.011
C35 to C36	215243.	3864.	240837.	8873.	0.265	0.005	0.227	0.008
C36 to 78 min	116571.	2969.	148048.	19602.	0.143	0.004	0.140	0.018
TOTAL	8807227.	1085946.	8487523.	880768.	6.178	0.688	4.762	0.466

Downtown Los Angeles - October

(filename = DLA10A)
(Size of sample = 76.230 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	32512.	5648.	24126.	4502.	0.017	0.003	0.011	0.002
C12 to C13	205372.	4831.	143858.	0.	0.116	0.003	0.068	0.000
C13 to C14	191949.	11051.	135206.	11561.	0.110	0.006	0.065	0.006
C14 to C15	200676.	16626.	164806.	11148.	0.118	0.010	0.081	0.005
C15 to C16	277175.	38613.	267865.	89545.	0.163	0.023	0.132	0.044
C16 to C17	366669.	123666.	258710.	93300.	0.229	0.077	0.136	0.049
C17 to C18	374424.	149584.	219128.	29193.	0.226	0.090	0.111	0.015
C18 to C19	310137.	66602.	202676.	28007.	0.188	0.040	0.104	0.014
C19 to C20	320176.	33886.	207026.	24132.	0.201	0.021	0.109	0.013
C20 to C21	385128.	106138.	219402.	32073.	0.242	0.067	0.116	0.017
C21 to C22	271335.	16927.	190182.	12578.	0.185	0.012	0.109	0.007
C22 to C23	369245.	73046.	187502.	13311.	0.252	0.050	0.107	0.008
C23 to C24	312114.	28897.	229548.	16435.	0.221	0.020	0.137	0.010
C24 to C25	367828.	21123.	285659.	20787.	0.260	0.015	0.170	0.012
C25 to C26	404013.	44285.	325144.	21317.	0.322	0.035	0.218	0.014
C26 to C27	499578.	46465.	421001.	49346.	0.399	0.037	0.282	0.033
C27 to C28	570330.	62320.	489083.	70978.	0.479	0.052	0.346	0.050
C28 to C29	600405.	31044.	550179.	47703.	0.504	0.026	0.389	0.034
C29 to C30	628105.	38908.	549578.	23698.	0.577	0.036	0.425	0.018
C30 to C31	594971.	40328.	513010.	36733.	0.547	0.037	0.397	0.028
C31 to C32	590409.	34988.	514842.	47096.	0.661	0.039	0.485	0.044
C32 to C33	427975.	48934.	396429.	58873.	0.479	0.055	0.373	0.055
C33 to C34	451621.	56144.	385904.	54559.	0.530	0.066	0.381	0.054
C34 to C35	283284.	9569.	226480.	13671.	0.332	0.011	0.223	0.013
C35 to C36	230911.	8257.	181608.	11325.	0.335	0.012	0.222	0.014
C36 to 78 min	125770.	1637.	96153.	19914.	0.183	0.002	0.117	0.024
TOTAL	9392112.	1119517.	7385105.	841785.	7.877	0.846	5.315	0.585

Downtown Los Angeles - November

(filename = DLA11A)
(Size of sample = 75.570 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	40520.	9195.	29205.	5531.	0.028	0.006	0.012	0.002
C12 to C13	235075.	10218.	181286.	0.	0.172	0.007	0.082	0.000
C13 to C14	208535.	9964.	183871.	13098.	0.154	0.007	0.084	0.006
C14 to C15	202765.	7361.	183190.	3246.	0.154	0.006	0.086	0.002
C15 to C16	285345.	37100.	306033.	98262.	0.217	0.028	0.144	0.046
C16 to C17	301218.	91327.	270009.	84536.	0.244	0.074	0.135	0.042
C17 to C18	396971.	154604.	229420.	33313.	0.310	0.121	0.111	0.016
C18 to C19	299336.	76642.	235067.	27842.	0.236	0.060	0.115	0.014
C19 to C20	297390.	56914.	219706.	21929.	0.243	0.046	0.111	0.011
C20 to C21	355252.	100125.	247445.	36847.	0.290	0.082	0.125	0.019
C21 to C22	251489.	25848.	229030.	16096.	0.222	0.023	0.125	0.009
C22 to C23	344742.	89787.	230892.	6528.	0.305	0.079	0.126	0.004
C23 to C24	322699.	26522.	318612.	30412.	0.296	0.024	0.181	0.017
C24 to C25	347942.	19879.	401725.	34202.	0.320	0.018	0.228	0.019
C25 to C26	464980.	68189.	473878.	20389.	0.481	0.071	0.304	0.013
C26 to C27	468000.	41778.	565287.	57179.	0.484	0.043	0.362	0.037
C27 to C28	498347.	22402.	615339.	39168.	0.543	0.024	0.415	0.026
C28 to C29	533338.	52014.	650910.	39166.	0.581	0.057	0.439	0.026
C29 to C30	541644.	38949.	694244.	26306.	0.646	0.046	0.512	0.019
C30 to C31	478687.	27745.	576050.	32638.	0.571	0.033	0.425	0.024
C31 to C32	469303.	38076.	594297.	54250.	0.682	0.055	0.534	0.049
C32 to C33	357430.	29636.	453860.	46667.	0.519	0.043	0.408	0.042
C33 to C34	350374.	28229.	429258.	63094.	0.533	0.043	0.404	0.059
C34 to C35	212232.	19690.	281376.	24188.	0.323	0.030	0.265	0.023
C35 to C36	175035.	5640.	209768.	13300.	0.330	0.011	0.245	0.016
C36 to 78 min	104916.	9438.	139901.	21238.	0.198	0.018	0.163	0.025
TOTAL	8543565.	1097272.	8949659.	849425.	9.083	1.057	6.144	0.566

Downtown Los Angeles - December

(filename = DLA12A)
(Size of sample = 90.940 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	44562.	5453.	24524.	4898.	0.026	0.003	0.010	0.002
C12 to C13	240714.	11583.	165381.	0.	0.148	0.007	0.072	0.000
C13 to C14	229293.	0.	185592.	19413.	0.142	0.000	0.081	0.008
C14 to C15	230470.	0.	174982.	0.	0.147	0.000	0.079	0.000
C15 to C16	354545.	53330.	323721.	101582.	0.226	0.034	0.145	0.046
C16 to C17	375389.	109767.	270697.	87922.	0.254	0.074	0.129	0.042
C17 to C18	459138.	129510.	258439.	50488.	0.300	0.085	0.119	0.023
C18 to C19	363723.	47367.	232932.	25931.	0.240	0.031	0.108	0.012
C19 to C20	467626.	69566.	298429.	42498.	0.319	0.048	0.144	0.020
C20 to C21	490232.	136681.	271814.	33395.	0.335	0.093	0.131	0.016
C21 to C22	365316.	32858.	253744.	9722.	0.271	0.024	0.132	0.005
C22 to C23	557627.	133227.	352207.	23039.	0.413	0.099	0.184	0.012
C23 to C24	561211.	33626.	426169.	58770.	0.432	0.026	0.231	0.032
C24 to C25	619804.	37971.	626229.	86331.	0.477	0.029	0.340	0.047
C25 to C26	849689.	104167.	698140.	82178.	0.737	0.090	0.427	0.050
C26 to C27	851463.	74591.	819080.	62766.	0.738	0.065	0.501	0.038
C27 to C28	856118.	18167.	831315.	51897.	0.781	0.017	0.535	0.033
C28 to C29	892335.	44434.	884547.	53055.	0.814	0.041	0.569	0.034
C29 to C30	905562.	23672.	886756.	20170.	0.904	0.024	0.624	0.014
C30 to C31	817874.	35330.	830733.	29530.	0.817	0.035	0.585	0.021
C31 to C32	782308.	51418.	783126.	74623.	0.952	0.063	0.672	0.064
C32 to C33	601338.	62998.	614979.	75136.	0.732	0.077	0.528	0.064
C33 to C34	575305.	54443.	577320.	79012.	0.733	0.069	0.519	0.071
C34 to C35	352545.	18205.	360764.	34132.	0.449	0.023	0.324	0.031
C35 to C36	294820.	17307.	294829.	14649.	0.465	0.027	0.328	0.016
C36 to 78 min	201843.	18070.	245572.	45534.	0.319	0.029	0.273	0.051
TOTAL	13340850.	1323741.	11692021.	1166671.	12.171	1.112	7.790	0.754

West Los Angeles - January

(filename = WLA01A)
(Size of sample = 30.420 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	8609.	0.	853.	0.	0.004	0.000	0.001	0.000
C12 to C13	279426.	54349.	10180.	3655.	0.136	0.026	0.007	0.002
C13 to C14	233282.	64025.	20448.	12913.	0.115	0.031	0.013	0.008
C14 to C15	191965.	8472.	8905.	6841.	0.097	0.004	0.006	0.005
C15 to C16	314326.	64384.	110983.	67150.	0.159	0.033	0.075	0.045
C16 to C17	560651.	229147.	194681.	29879.	0.301	0.123	0.139	0.021
C17 to C18	589153.	271312.	226141.	53459.	0.306	0.141	0.156	0.037
C18 to C19	337812.	54116.	118288.	21934.	0.177	0.028	0.083	0.015
C19 to C20	241240.	10025.	113387.	9888.	0.131	0.005	0.082	0.007
C20 to C21	426737.	197525.	89551.	15408.	0.231	0.107	0.065	0.011
C21 to C22	334511.	90655.	104764.	15918.	0.196	0.053	0.082	0.012
C22 to C23	372253.	110747.	116537.	18558.	0.218	0.065	0.091	0.015
C23 to C24	341365.	39802.	145146.	20445.	0.208	0.024	0.118	0.017
C24 to C25	450824.	59486.	206063.	36316.	0.275	0.036	0.168	0.030
C25 to C26	524567.	99578.	275361.	43752.	0.360	0.068	0.252	0.040
C26 to C27	524433.	80135.	318998.	48880.	0.360	0.055	0.292	0.045
C27 to C28	494101.	37194.	313785.	22309.	0.357	0.027	0.303	0.022
C28 to C29	529296.	36816.	352497.	25674.	0.383	0.027	0.340	0.025
C29 to C30	560102.	52598.	375147.	41140.	0.443	0.042	0.396	0.043
C30 to C31	442331.	10764.	324064.	8473.	0.350	0.009	0.342	0.009
C31 to C32	441387.	48242.	322040.	30047.	0.426	0.047	0.414	0.039
C32 to C33	355766.	46452.	284671.	31192.	0.343	0.045	0.366	0.040
C33 to C34	317375.	40705.	306077.	16271.	0.321	0.041	0.412	0.022
C34 to C35	259423.	38985.	271593.	22538.	0.262	0.039	0.366	0.030
C35 to C36	198031.	25775.	222615.	13398.	0.248	0.032	0.372	0.022
C36 to 78 min	145123.	32443.	148322.	18585.	0.182	0.041	0.248	0.031
TOTAL	9474089.	1803732.	4981097.	634623.	6.588	1.150	5.189	0.594

West Los Angeles - February

(filename = WLA02A)
(Size of sample = 76.410 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	0.	0.	903.	0.	0.000	0.000	0.001	0.000
C12 to C13	234825.	63275.	57839.	0.	0.116	0.031	0.040	0.000
C13 to C14	209258.	34112.	42189.	12649.	0.104	0.017	0.030	0.009
C14 to C15	208916.	10922.	45191.	0.	0.107	0.006	0.033	0.000
C15 to C16	329813.	97852.	158587.	63037.	0.169	0.050	0.114	0.045
C16 to C17	585621.	272415.	201669.	37720.	0.318	0.148	0.154	0.029
C17 to C18	582319.	255346.	165761.	22821.	0.306	0.134	0.123	0.017
C18 to C19	373801.	76866.	174484.	34703.	0.198	0.041	0.130	0.026
C19 to C20	383577.	67399.	129654.	17079.	0.210	0.037	0.100	0.013
C20 to C21	488968.	170180.	75747.	13836.	0.268	0.093	0.059	0.011
C21 to C22	406830.	62117.	138430.	0.	0.242	0.037	0.116	0.000
C22 to C23	418534.	105927.	112425.	14782.	0.249	0.063	0.094	0.012
C23 to C24	305581.	9513.	118151.	7266.	0.189	0.006	0.103	0.006
C24 to C25	390426.	23866.	147554.	15530.	0.241	0.015	0.128	0.014
C25 to C26	405257.	64802.	177700.	27527.	0.282	0.045	0.174	0.027
C26 to C27	451153.	32911.	215537.	22025.	0.314	0.023	0.211	0.022
C27 to C28	484949.	50107.	229293.	19029.	0.355	0.037	0.237	0.020
C28 to C29	434210.	34112.	240837.	30830.	0.318	0.025	0.249	0.032
C29 to C30	442927.	11242.	230393.	11038.	0.355	0.009	0.260	0.012
C30 to C31	407306.	9919.	210420.	6998.	0.326	0.008	0.238	0.008
C31 to C32	385019.	48978.	212484.	28561.	0.376	0.048	0.292	0.039
C32 to C33	300299.	35053.	175548.	29636.	0.293	0.034	0.242	0.041
C33 to C34	260724.	28662.	124260.	7088.	0.267	0.029	0.179	0.010
C34 to C35	209534.	25108.	93939.	3187.	0.214	0.026	0.135	0.005
C35 to C36	158360.	7578.	52932.	1109.	0.201	0.010	0.094	0.002
C36 to 78 min	104813.	10793.	11628.	10199.	0.133	0.014	0.021	0.018
TOTAL	8963020.	1609055.	3543555.	436650.	6.149	0.984	3.556	0.418

West Los Angeles - March

(filename = WLA03A)
(Size of sample = 76.950 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	0.	0.	716.	0.	0.000	0.000	0.001	0.000
C12 to C13	184653.	19180.	2149.	0.	0.082	0.009	0.002	0.000
C13 to C14	165815.	27894.	7186.	7869.	0.074	0.013	0.006	0.007
C14 to C15	194180.	21428.	4385.	1521.	0.090	0.010	0.004	0.001
C15 to C16	307410.	75152.	82171.	39167.	0.142	0.035	0.073	0.035
C16 to C17	497987.	235025.	145713.	37648.	0.244	0.115	0.138	0.036
C17 to C18	562685.	281936.	105167.	17069.	0.267	0.134	0.096	0.016
C18 to C19	332386.	87801.	119665.	41169.	0.159	0.042	0.110	0.038
C19 to C20	333001.	74386.	83170.	16714.	0.165	0.037	0.079	0.016
C20 to C21	460234.	196484.	65466.	9948.	0.228	0.097	0.062	0.009
C21 to C22	365314.	90338.	65857.	9386.	0.196	0.048	0.068	0.010
C22 to C23	361546.	107926.	70376.	12685.	0.194	0.058	0.073	0.013
C23 to C24	279744.	14710.	77555.	7638.	0.156	0.008	0.083	0.008
C24 to C25	338948.	22008.	97546.	14734.	0.189	0.012	0.105	0.016
C25 to C26	379647.	66891.	131072.	17382.	0.238	0.042	0.158	0.021
C26 to C27	419377.	42950.	165789.	22308.	0.263	0.027	0.200	0.027
C27 to C28	470272.	53174.	164966.	16400.	0.311	0.035	0.210	0.021
C28 to C29	424203.	34530.	179079.	20011.	0.281	0.023	0.228	0.025
C29 to C30	424122.	7834.	171620.	14572.	0.307	0.006	0.239	0.020
C30 to C31	392353.	8423.	161751.	3374.	0.284	0.006	0.225	0.005
C31 to C32	369948.	34058.	156878.	17593.	0.326	0.030	0.266	0.030
C32 to C33	284535.	30946.	142710.	22380.	0.251	0.027	0.242	0.038
C33 to C34	266462.	30836.	123324.	7128.	0.246	0.028	0.219	0.013
C34 to C35	239621.	24165.	121054.	3551.	0.221	0.022	0.215	0.006
C35 to C36	185701.	1162.	85554.	0.	0.212	0.001	0.188	0.000
C36 to 78 min	166275.	16826.	41515.	9191.	0.190	0.019	0.091	0.020
TOTAL	8406419.	1606063.	2572434.	369438.	5.318	0.885	3.383	0.431

West Los Angeles - April

(filename = WLA04A)
(Size of sample = 76.980 cu meters)

	AREA COUNTS				ug/cu meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	2135.	0.	0.	0.	0.001	0.000	0.000	0.000
C12 to C13	274934.	53510.	132726.	0.	0.137	0.027	0.056	0.000
C13 to C14	284295.	51518.	126815.	32581.	0.143	0.026	0.054	0.014
C14 to C15	258267.	10084.	87592.	6187.	0.133	0.005	0.038	0.003
C15 to C16	431633.	145409.	251048.	103600.	0.222	0.075	0.110	0.045
C16 to C17	670546.	316397.	439512.	233673.	0.367	0.173	0.205	0.109
C17 to C18	537254.	221451.	235071.	45065.	0.284	0.117	0.106	0.020
C18 to C19	363335.	71595.	274386.	61068.	0.194	0.038	0.125	0.028
C19 to C20	371820.	66981.	189559.	22863.	0.205	0.037	0.089	0.011
C20 to C21	460390.	161966.	158149.	15426.	0.254	0.089	0.074	0.007
C21 to C22	362148.	58184.	159924.	11452.	0.217	0.035	0.081	0.006
C22 to C23	367548.	85288.	168957.	19884.	0.220	0.051	0.086	0.010
C23 to C24	299410.	8822.	171930.	15760.	0.186	0.005	0.091	0.008
C24 to C25	321308.	28443.	184281.	19500.	0.200	0.018	0.097	0.010
C25 to C26	341177.	45602.	258661.	27376.	0.239	0.032	0.154	0.016
C26 to C27	351964.	27543.	271188.	31090.	0.247	0.019	0.162	0.019
C27 to C28	387056.	43553.	277144.	28039.	0.286	0.032	0.174	0.018
C28 to C29	343469.	34245.	312456.	48610.	0.253	0.025	0.196	0.031
C29 to C30	345629.	22456.	279523.	12772.	0.279	0.018	0.192	0.009
C30 to C31	305724.	10996.	262374.	6101.	0.247	0.009	0.180	0.004
C31 to C32	299452.	37357.	240551.	22478.	0.295	0.037	0.201	0.019
C32 to C33	200367.	30205.	210823.	23187.	0.197	0.030	0.176	0.019
C33 to C34	192239.	10401.	175709.	10971.	0.198	0.011	0.154	0.010
C34 to C35	153490.	11868.	157343.	5812.	0.158	0.012	0.138	0.005
C35 to C36	107630.	0.	119095.	0.	0.137	0.000	0.129	0.000
C36 to 78 min	50918.	2709.	69791.	2272.	0.065	0.003	0.076	0.002
TOTAL	8084138.	1556583.	5214608.	805767.	5.365	0.925	3.145	0.423

West Los Angeles - May

(filename = WLA05A)
(Size of sample = 76.340 cu meters)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total	AREA COUNTS Acid+Neutral Resolved	AREA COUNTS Neutral Total	AREA COUNTS Neutral Resolved	ug/cu meters Acid+Neutral Total	ug/cu meters Acid+Neutral Resolved	ug/cu meters Neutral Total	ug/cu meters Neutral Resolved
16 min to C12	7626.	0.	2682.	0.	0.003	0.000	0.003	0.000
C12 to C13	410748.	68978.	91527.	7387.	0.177	0.030	0.115	0.009
C13 to C14	445213.	73516.	78242.	13561.	0.193	0.032	0.099	0.017
C14 to C15	350141.	21891.	58128.	701.	0.156	0.010	0.076	0.001
C15 to C16	686173.	219921.	131777.	38640.	0.306	0.098	0.172	0.050
C16 to C17	928048.	473019.	206305.	97868.	0.441	0.225	0.286	0.136
C17 to C18	681580.	247865.	132892.	28933.	0.313	0.114	0.178	0.039
C18 to C19	543411.	142052.	144577.	43966.	0.251	0.066	0.195	0.059
C19 to C20	386709.	46054.	84743.	6914.	0.185	0.022	0.118	0.010
C20 to C21	548881.	144744.	65673.	4057.	0.263	0.069	0.092	0.006
C21 to C22	370158.	51624.	63244.	4635.	0.192	0.027	0.096	0.007
C22 to C23	433115.	85953.	59127.	3559.	0.225	0.045	0.090	0.005
C23 to C24	324930.	0.	60200.	0.	0.175	0.000	0.095	0.000
C24 to C25	323378.	13102.	66261.	0.	0.174	0.007	0.104	0.000
C25 to C26	326176.	5363.	71222.	3041.	0.198	0.003	0.126	0.005
C26 to C27	321634.	16534.	80234.	4449.	0.195	0.010	0.142	0.008
C27 to C28	311322.	24140.	73685.	8789.	0.199	0.015	0.138	0.016
C28 to C29	336481.	28033.	75990.	8099.	0.215	0.018	0.142	0.015
C29 to C30	292043.	3915.	72899.	0.	0.204	0.003	0.149	0.000
C30 to C31	253390.	1858.	52098.	958.	0.177	0.001	0.106	0.002
C31 to C32	238706.	8793.	55814.	9546.	0.204	0.007	0.139	0.024
C32 to C33	188780.	9241.	33007.	6963.	0.161	0.008	0.082	0.017
C33 to C34	144007.	4586.	14124.	0.	0.129	0.004	0.037	0.000
C34 to C35	124387.	6181.	15422.	4429.	0.111	0.006	0.040	0.012
C35 to C36	73301.	1371.	1017.	0.	0.081	0.002	0.003	0.000
C36 to 78 min	19388.	0.	0.	1283.	0.021	0.000	0.000	0.004
TOTAL	9069726.	1698734.	1790890.	297778.	4.951	0.821	2.824	0.443

West Los Angeles - June

(filename = WLA06A)
(Size of sample = 76.470 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	7324.	0.	6424.	0.	0.002	0.000	0.003	0.000
C12 to C13	521139.	118763.	178810.	22163.	0.157	0.036	0.075	0.009
C13 to C14	562762.	106774.	162434.	40864.	0.172	0.033	0.069	0.017
C14 to C15	434375.	9206.	174317.	1918.	0.136	0.003	0.076	0.001
C15 to C16	765890.	185475.	293853.	93750.	0.240	0.058	0.128	0.041
C16 to C17	1055195.	536460.	469747.	242217.	0.352	0.179	0.217	0.112
C17 to C18	841932.	302927.	253664.	60090.	0.271	0.097	0.113	0.027
C18 to C19	622476.	138785.	311300.	106847.	0.202	0.045	0.140	0.048
C19 to C20	516207.	60832.	181702.	5757.	0.173	0.020	0.085	0.003
C20 to C21	643689.	187121.	143727.	5645.	0.216	0.063	0.067	0.003
C21 to C22	489528.	78679.	152551.	12010.	0.178	0.029	0.077	0.006
C22 to C23	489892.	94877.	149272.	13594.	0.178	0.035	0.075	0.007
C23 to C24	380667.	2077.	154495.	6213.	0.144	0.001	0.081	0.003
C24 to C25	403128.	19296.	157799.	14645.	0.153	0.007	0.083	0.008
C25 to C26	388682.	0.	162470.	4406.	0.166	0.000	0.096	0.003
C26 to C27	371589.	17511.	170557.	11626.	0.158	0.007	0.101	0.007
C27 to C28	368579.	24701.	181045.	19465.	0.165	0.011	0.113	0.012
C28 to C29	384481.	21792.	190628.	30441.	0.173	0.010	0.119	0.019
C29 to C30	343223.	0.	164718.	5459.	0.169	0.000	0.112	0.004
C30 to C31	299234.	1420.	135452.	1026.	0.147	0.001	0.092	0.001
C31 to C32	285668.	28705.	126908.	14168.	0.171	0.017	0.105	0.012
C32 to C33	223952.	17583.	93595.	12086.	0.134	0.011	0.078	0.010
C33 to C34	182298.	9076.	72253.	2345.	0.114	0.006	0.063	0.002
C34 to C35	156821.	6067.	51221.	12354.	0.098	0.004	0.045	0.011
C35 to C36	106611.	0.	28577.	0.	0.083	0.000	0.031	0.000
C36 to 78 min	53860.	0.	13580.	6045.	0.042	0.000	0.015	0.007
TOTAL	10899202.	1968127.	4181099.	745134.	4.195	0.672	2.256	0.370

West Los Angeles - July

(filename = WLA07A)
(Size of sample = 75.750 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	0.	0.	3558.	0.	0.000	0.000	0.001	0.000
C12 to C13	540271.	62750.	300164.	985.	0.185	0.021	0.116	0.000
C13 to C14	453282.	34679.	319069.	10761.	0.156	0.012	0.125	0.004
C14 to C15	392492.	6780.	248957.	0.	0.139	0.002	0.100	0.000
C15 to C16	635602.	98442.	413179.	68564.	0.225	0.035	0.166	0.028
C16 to C17	868861.	332529.	518760.	185306.	0.327	0.125	0.222	0.079
C17 to C18	719051.	250190.	366493.	45943.	0.262	0.091	0.152	0.019
C18 to C19	535851.	72109.	271813.	23896.	0.197	0.026	0.113	0.010
C19 to C20	677233.	215917.	271757.	14235.	0.257	0.082	0.117	0.006
C20 to C21	421412.	15265.	208805.	6507.	0.160	0.006	0.090	0.003
C21 to C22	475645.	35316.	225378.	10216.	0.196	0.015	0.105	0.005
C22 to C23	491479.	115851.	204035.	13782.	0.202	0.048	0.095	0.006
C23 to C24	392782.	19072.	198023.	17783.	0.168	0.008	0.096	0.009
C24 to C25	381732.	16437.	195203.	9141.	0.163	0.007	0.095	0.004
C25 to C26	355517.	6484.	194835.	6326.	0.171	0.003	0.107	0.003
C26 to C27	424996.	24225.	226264.	13810.	0.205	0.012	0.124	0.008
C27 to C28	406245.	39465.	211188.	31806.	0.206	0.020	0.122	0.018
C28 to C29	419172.	17705.	246401.	19124.	0.213	0.009	0.142	0.011
C29 to C30	362218.	3733.	220028.	9760.	0.201	0.002	0.139	0.006
C30 to C31	356804.	973.	195374.	6167.	0.198	0.001	0.123	0.004
C31 to C32	296960.	12718.	174769.	9409.	0.201	0.009	0.134	0.007
C32 to C33	230181.	12837.	132720.	3328.	0.156	0.009	0.102	0.003
C33 to C34	196138.	12027.	110481.	4839.	0.139	0.009	0.089	0.004
C34 to C35	158719.	3186.	81256.	0.	0.113	0.002	0.065	0.000
C35 to C36	105749.	0.	21897.	0.	0.093	0.000	0.022	0.000
C36 to 78 min	47666.	0.	6775.	0.	0.042	0.000	0.007	0.000
TOTAL	10346058.	1408690.	5567182.	511688.	4.577	0.553	2.772	0.238

West Los Angeles - August

(filename = WLA08A)
(Size of sample = 76.720 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	5422.	0.	0.	0.	0.002	0.000	0.000	0.000
C12 to C13	427908.	10949.	189510.	2007.	0.164	0.004	0.077	0.001
C13 to C14	334347.	21561.	175021.	14160.	0.129	0.008	0.072	0.006
C14 to C15	299404.	4726.	173397.	3229.	0.119	0.002	0.073	0.001
C15 to C16	456285.	63317.	257379.	43407.	0.181	0.025	0.109	0.018
C16 to C17	630521.	212809.	312895.	99021.	0.266	0.090	0.141	0.044
C17 to C18	522122.	145052.	213869.	23234.	0.213	0.059	0.093	0.010
C18 to C19	388415.	29995.	230769.	32256.	0.160	0.012	0.101	0.014
C19 to C20	523020.	169623.	161625.	18240.	0.222	0.072	0.073	0.008
C20 to C21	296056.	16046.	151875.	4385.	0.126	0.007	0.069	0.002
C21 to C22	360952.	41005.	146785.	11775.	0.166	0.019	0.072	0.006
C22 to C23	370887.	78953.	132716.	6131.	0.171	0.036	0.065	0.003
C23 to C24	288431.	13896.	130222.	9230.	0.138	0.007	0.066	0.005
C24 to C25	281855.	15502.	132365.	9572.	0.135	0.007	0.068	0.005
C25 to C26	266453.	4194.	131386.	4114.	0.144	0.002	0.076	0.002
C26 to C27	306290.	20703.	156276.	14944.	0.165	0.011	0.090	0.009
C27 to C28	309719.	38647.	194759.	36387.	0.176	0.022	0.118	0.022
C28 to C29	338661.	27203.	166303.	16874.	0.192	0.015	0.101	0.010
C29 to C30	279733.	4633.	167877.	7960.	0.174	0.003	0.111	0.005
C30 to C31	297913.	42474.	147566.	13899.	0.185	0.026	0.098	0.009
C31 to C32	239011.	17131.	127169.	10042.	0.181	0.013	0.103	0.008
C32 to C33	197622.	16824.	97739.	7578.	0.150	0.013	0.079	0.006
C33 to C34	152044.	3671.	88619.	9815.	0.121	0.003	0.075	0.008
C34 to C35	125825.	1367.	72384.	12347.	0.100	0.001	0.061	0.010
C35 to C36	78103.	0.	27948.	0.	0.077	0.000	0.029	0.000
C36 to 78 min	38018.	0.	17904.	3981.	0.037	0.000	0.019	0.004
TOTAL	7815017.	1000281.	3804358.	414588.	3.891	0.459	2.038	0.219

West Los Angeles - September

(filename = WLA09A)
(Size of sample = 76.590 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	0.	0.	2524.	0.	0.000	0.000	0.002	0.000
C12 to C13	324894.	11227.	123133.	0.	0.134	0.005	0.091	0.000
C13 to C14	269638.	14863.	86766.	5796.	0.112	0.006	0.065	0.004
C14 to C15	261833.	7811.	75117.	4023.	0.112	0.003	0.058	0.003
C15 to C16	368183.	53982.	126133.	19370.	0.158	0.023	0.097	0.015
C16 to C17	508030.	160759.	174425.	56370.	0.231	0.073	0.143	0.046
C17 to C18	483277.	165169.	138394.	17275.	0.212	0.073	0.109	0.014
C18 to C19	365376.	49836.	135137.	23407.	0.162	0.022	0.108	0.019
C19 to C20	280899.	29681.	95065.	7511.	0.129	0.014	0.078	0.006
C20 to C21	431328.	118750.	84164.	918.	0.198	0.054	0.069	0.001
C21 to C22	332141.	23463.	87130.	5933.	0.165	0.012	0.078	0.005
C22 to C23	365902.	74904.	84935.	2891.	0.182	0.037	0.076	0.003
C23 to C24	303898.	11336.	89078.	5781.	0.157	0.006	0.083	0.005
C24 to C25	311390.	12463.	97254.	6948.	0.161	0.006	0.090	0.006
C25 to C26	327833.	16287.	103317.	3311.	0.191	0.009	0.108	0.003
C26 to C27	383988.	29999.	129448.	12598.	0.224	0.017	0.136	0.013
C27 to C28	448079.	56395.	158268.	22110.	0.275	0.035	0.175	0.024
C28 to C29	418837.	37806.	145391.	5462.	0.257	0.023	0.160	0.006
C29 to C30	431136.	23868.	167332.	4594.	0.289	0.016	0.202	0.006
C30 to C31	426311.	26650.	140905.	5384.	0.286	0.018	0.170	0.006
C31 to C32	377737.	30866.	142164.	15709.	0.309	0.025	0.209	0.023
C32 to C33	325293.	21950.	108684.	7266.	0.266	0.018	0.160	0.011
C33 to C34	266788.	16192.	85461.	5601.	0.228	0.014	0.132	0.009
C34 to C35	205968.	7565.	64185.	4437.	0.176	0.006	0.099	0.007
C35 to C36	145055.	3620.	23495.	0.	0.154	0.004	0.045	0.000
C36 to 78 min	94025.	0.	5659.	3129.	0.100	0.000	0.011	0.006
TOTAL	8457839.	1005442.	2673564.	245824.	4.866	0.520	2.754	0.242

West Los Angeles - October

(filename = WLA10A)
(Size of sample = 76.530 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	1517.	0.	2330.	0.	0.000	0.000	0.002	0.000
C12 to C13	283712.	13503.	109945.	0.	0.098	0.005	0.100	0.000
C13 to C14	232626.	17035.	76834.	3638.	0.081	0.006	0.070	0.003
C14 to C15	265027.	29455.	68294.	4981.	0.095	0.011	0.064	0.005
C15 to C16	442354.	75790.	142203.	24944.	0.158	0.027	0.134	0.024
C16 to C17	557039.	178971.	162675.	15185.	0.212	0.068	0.163	0.015
C17 to C18	595125.	230415.	138598.	13771.	0.219	0.085	0.134	0.013
C18 to C19	431178.	78189.	144153.	19683.	0.160	0.029	0.141	0.019
C19 to C20	543659.	203443.	101937.	8441.	0.209	0.078	0.103	0.009
C20 to C21	351143.	35555.	97074.	4268.	0.135	0.014	0.098	0.004
C21 to C22	419244.	66951.	93682.	4894.	0.174	0.028	0.103	0.005
C22 to C23	451656.	123370.	94923.	3766.	0.188	0.051	0.104	0.004
C23 to C24	363844.	28786.	97637.	7515.	0.157	0.012	0.111	0.009
C24 to C25	369542.	33710.	112652.	5190.	0.160	0.015	0.128	0.006
C25 to C26	462850.	53040.	134790.	7492.	0.225	0.026	0.173	0.010
C26 to C27	565687.	65239.	176795.	20144.	0.275	0.032	0.227	0.026
C27 to C28	605542.	82300.	201959.	24866.	0.310	0.042	0.273	0.034
C28 to C29	627284.	68730.	203710.	18283.	0.322	0.035	0.275	0.025
C29 to C30	638450.	60090.	218388.	5251.	0.358	0.034	0.323	0.008
C30 to C31	600286.	32016.	192842.	4077.	0.337	0.018	0.285	0.006
C31 to C32	565231.	46081.	197186.	15388.	0.386	0.031	0.355	0.028
C32 to C33	477070.	50916.	153546.	16197.	0.326	0.035	0.277	0.029
C33 to C34	395290.	36095.	123633.	14834.	0.283	0.026	0.233	0.028
C34 to C35	322532.	28553.	96559.	4743.	0.231	0.020	0.182	0.009
C35 to C36	221118.	2593.	48474.	0.	0.196	0.002	0.113	0.000
C36 to 78 min	189811.	14585.	26316.	4383.	0.168	0.013	0.061	0.010
TOTAL	10978817.	1655411.	3217135.	251934.	5.463	0.742	4.234	0.328

West Los Angeles - November

(filename = WLA11A)
(Size of sample = 75.840 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	5451.	0.	5421.	0.	0.002	0.000	0.002	0.000
C12 to C13	296507.	0.	222842.	0.	0.110	0.000	0.110	0.000
C13 to C14	267173.	4290.	192612.	6473.	0.100	0.002	0.096	0.003
C14 to C15	274678.	12031.	144448.	0.	0.106	0.005	0.074	0.000
C15 to C16	403890.	37462.	275172.	63121.	0.155	0.014	0.141	0.032
C16 to C17	536299.	150655.	311637.	19871.	0.219	0.062	0.169	0.011
C17 to C18	616295.	244948.	248562.	20184.	0.243	0.097	0.130	0.011
C18 to C19	438087.	44686.	266496.	29530.	0.175	0.018	0.141	0.016
C19 to C20	387377.	20811.	195875.	0.	0.160	0.009	0.107	0.000
C20 to C21	528189.	162793.	188691.	10740.	0.218	0.067	0.103	0.006
C21 to C22	471557.	94093.	189250.	13514.	0.211	0.042	0.112	0.008
C22 to C23	506280.	139532.	192451.	6953.	0.226	0.062	0.114	0.004
C23 to C24	446852.	48395.	214139.	19852.	0.208	0.022	0.132	0.012
C24 to C25	572774.	105958.	269883.	41958.	0.266	0.049	0.166	0.026
C25 to C26	674858.	157312.	378152.	46016.	0.353	0.082	0.263	0.032
C26 to C27	731188.	82741.	434668.	42789.	0.383	0.043	0.302	0.030
C27 to C28	747589.	48618.	472776.	34206.	0.412	0.027	0.346	0.025
C28 to C29	749781.	54557.	449429.	14937.	0.413	0.030	0.329	0.011
C29 to C30	770275.	54768.	466982.	26689.	0.464	0.033	0.374	0.021
C30 to C31	679956.	30821.	412242.	14445.	0.410	0.019	0.330	0.012
C31 to C32	632319.	68588.	390206.	42431.	0.465	0.050	0.381	0.041
C32 to C33	524618.	52413.	311968.	33616.	0.385	0.039	0.304	0.033
C33 to C34	419080.	36894.	250026.	29486.	0.322	0.028	0.255	0.030
C34 to C35	270039.	19008.	189030.	26351.	0.208	0.015	0.193	0.027
C35 to C36	276762.	5273.	121850.	2131.	0.264	0.005	0.154	0.003
C36 to 78 min	177153.	10159.	47863.	22031.	0.169	0.010	0.061	0.028
TOTAL	12405027.	1686806.	6842671.	567324.	6.647	0.829	4.890	0.421

West Los Angeles - December

(filename = WLA12A)
(Size of sample = 91.240 cu meters)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total		AREA COUNTS Neutral Total		ug/cu meters Acid+Neutral Total		ug/cu meters Neutral Total	
	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	0.	0.	0.	0.	0.000	0.000	0.000	0.000
C12 to C13	219887.	0.	182303.	0.	0.084	0.000	0.092	0.000
C13 to C14	130159.	0.	106853.	0.	0.050	0.000	0.054	0.000
C14 to C15	242268.	0.	97391.	0.	0.096	0.000	0.051	0.000
C15 to C16	521510.	32559.	268937.	42276.	0.206	0.013	0.140	0.022
C16 to C17	635362.	170976.	335502.	21900.	0.266	0.072	0.186	0.012
C17 to C18	651299.	182899.	276693.	40703.	0.264	0.074	0.148	0.022
C18 to C19	539070.	40689.	264039.	42244.	0.220	0.017	0.142	0.023
C19 to C20	638471.	203137.	207524.	3926.	0.270	0.086	0.116	0.002
C20 to C21	378751.	21392.	172652.	6014.	0.160	0.009	0.096	0.003
C21 to C22	514144.	81605.	179768.	8880.	0.236	0.037	0.109	0.005
C22 to C23	543352.	116567.	197026.	5660.	0.249	0.053	0.119	0.003
C23 to C24	552332.	65199.	240830.	31056.	0.263	0.031	0.151	0.020
C24 to C25	722752.	103879.	310340.	55167.	0.344	0.049	0.195	0.035
C25 to C26	846225.	221081.	435823.	51803.	0.454	0.119	0.309	0.037
C26 to C27	858497.	74747.	463033.	46289.	0.461	0.040	0.328	0.033
C27 to C28	846810.	62462.	394065.	26628.	0.479	0.035	0.294	0.020
C28 to C29	878508.	75908.	552948.	12241.	0.496	0.043	0.413	0.009
C29 to C30	858696.	52921.	466104.	13553.	0.531	0.033	0.381	0.011
C30 to C31	787883.	33072.	429932.	0.	0.487	0.020	0.351	0.000
C31 to C32	693230.	55369.	387138.	45366.	0.522	0.042	0.385	0.045
C32 to C33	605559.	47369.	307755.	21465.	0.456	0.036	0.306	0.021
C33 to C34	477060.	40108.	241015.	25308.	0.376	0.032	0.251	0.026
C34 to C35	381731.	30555.	179090.	5738.	0.301	0.024	0.187	0.006
C35 to C36	259339.	16523.	107568.	11450.	0.253	0.016	0.139	0.015
C36 to 78 min	221149.	24142.	20092.	7326.	0.216	0.024	0.026	0.009
TOTAL	14004044.	1753159.	6824421.	524993.	7.742	0.905	4.968	0.380

San Nicholas Island - July, August, September

(filename = SNISUMA)
(Size of sample = 199.390 cu meters)

Elution Zone	AREA COUNTS				ug/cu meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	31951.	14042.	23432.	9042.	0.004	0.002	0.002	0.001
C12 to C13	126938.	35364.	140557.	42109.	0.018	0.005	0.013	0.004
C13 to C14	118262.	36497.	130620.	37582.	0.017	0.005	0.013	0.004
C14 to C15	124091.	16685.	130738.	23360.	0.019	0.003	0.013	0.002
C15 to C16	415188.	309075.	589768.	488705.	0.062	0.047	0.059	0.049
C16 to C17	336831.	204104.	456486.	309214.	0.054	0.033	0.048	0.033
C17 to C18	397892.	273460.	309659.	178044.	0.061	0.042	0.032	0.018
C18 to C19	265996.	95608.	307053.	162972.	0.041	0.015	0.032	0.017
C19 to C20	222142.	97007.	289632.	165679.	0.036	0.016	0.031	0.018
C20 to C21	240359.	83611.	190846.	33123.	0.039	0.013	0.020	0.004
C21 to C22	143034.	15084.	177729.	32790.	0.025	0.003	0.021	0.004
C22 to C23	188080.	51542.	179374.	22551.	0.033	0.009	0.021	0.003
C23 to C24	135175.	5594.	162895.	5922.	0.025	0.001	0.020	0.001
C24 to C25	155009.	5363.	186639.	8762.	0.028	0.001	0.022	0.001
C25 to C26	139369.	0.	166887.	7139.	0.029	0.000	0.023	0.001
C26 to C27	206997.	26227.	261490.	36390.	0.042	0.005	0.035	0.005
C27 to C28	191444.	26247.	223274.	30457.	0.041	0.006	0.032	0.004
C28 to C29	175077.	10979.	197927.	17477.	0.038	0.002	0.028	0.002
C29 to C30	175747.	7242.	209983.	19802.	0.041	0.002	0.033	0.003
C30 to C31	137071.	14322.	152050.	19098.	0.032	0.003	0.024	0.003
C31 to C32	114143.	5401.	130630.	3596.	0.033	0.002	0.025	0.001
C32 to C33	132330.	3912.	178802.	17936.	0.038	0.001	0.034	0.003
C33 to C34	80292.	0.	107562.	0.	0.024	0.000	0.021	0.000
C34 to C35	101680.	4050.	119647.	2366.	0.031	0.001	0.024	0.000
C35 to C36	56585.	4493.	66246.	0.	0.021	0.002	0.016	0.000
C36 to 78 min	23849.	1687.	25938.	0.	0.009	0.001	0.006	0.000
TOTAL	4435532.	1347596.	5115864.	1674116.	0.843	0.219	0.646	0.179

San Nicholas Island - October, November, December

(filename = SNIFALLA)
(Size of sample = 247.990 cu meters)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total	AREA COUNTS Acid+Neutral Resolved	AREA COUNTS Neutral Total	AREA COUNTS Neutral Resolved	ug/cu meters Acid+Neutral Total	ug/cu meters Acid+Neutral Resolved	ug/cu meters Neutral Total	ug/cu meters Neutral Resolved
16 min to C12	21876.	3273.	24974.	9621.	0.003	0.000	0.002	0.001
C12 to C13	137149.	26844.	133524.	32767.	0.021	0.004	0.012	0.003
C13 to C14	126761.	31135.	124347.	27482.	0.020	0.005	0.011	0.003
C14 to C15	149327.	16680.	146762.	33846.	0.024	0.003	0.014	0.003
C15 to C16	565977.	443453.	789968.	674656.	0.091	0.071	0.074	0.063
C16 to C17	451719.	279310.	631100.	455905.	0.077	0.048	0.063	0.046
C17 to C18	509390.	280861.	435567.	241110.	0.084	0.046	0.042	0.023
C18 to C19	334288.	138277.	418712.	218875.	0.056	0.023	0.041	0.021
C19 to C20	240436.	44998.	289348.	131575.	0.041	0.008	0.029	0.013
C20 to C21	251449.	59844.	224258.	39625.	0.043	0.010	0.023	0.004
C21 to C22	187472.	27645.	220334.	52658.	0.035	0.005	0.024	0.006
C22 to C23	199917.	38566.	213745.	27318.	0.037	0.007	0.023	0.003
C23 to C24	173053.	14482.	180231.	21619.	0.034	0.003	0.020	0.002
C24 to C25	200158.	33442.	248084.	53109.	0.039	0.006	0.028	0.006
C25 to C26	186821.	18518.	238242.	28733.	0.041	0.004	0.030	0.004
C26 to C27	217979.	22401.	286450.	40462.	0.048	0.005	0.037	0.005
C27 to C28	211237.	12049.	245368.	25630.	0.049	0.003	0.033	0.003
C28 to C29	196228.	0.	243154.	18312.	0.045	0.000	0.033	0.002
C29 to C30	195111.	7195.	248401.	20183.	0.049	0.002	0.037	0.003
C30 to C31	160282.	11915.	190975.	22450.	0.040	0.003	0.028	0.003
C31 to C32	143177.	4514.	171684.	8042.	0.044	0.001	0.031	0.001
C32 to C33	161390.	6413.	207573.	16288.	0.049	0.002	0.037	0.003
C33 to C34	92140.	0.	154234.	1511.	0.030	0.000	0.029	0.000
C34 to C35	135104.	4463.	162479.	5601.	0.043	0.001	0.031	0.001
C35 to C36	81248.	4194.	106607.	5000.	0.032	0.002	0.025	0.001
C36 to 78 min	48945.	1395.	54971.	1816.	0.019	0.001	0.013	0.000
TOTAL	5378634.	1531867.	6391092.	2214194.	1.094	0.263	0.771	0.226

Appendix E

Organic Mass Distribution Characteristics for Source Samples

These tables contain the quantitative data obtained from high-resolution gas chromatographic analyses of the source samples. The total and resolved area counts obtained in each of the elution zones defined by adjacent n-alkanes are presented for both the neutral and acid+neutral fractions of the extract. In addition, the mass of organic material that eluted in each zone is also given, using units appropriate to the source sampled.

The order of the tables, which corresponds to the discussion of the results contained in Chapter 4, is as follows:

Blank Filters: 16 47-mm

(filename = BLANK16150A)
(Size of sample = 278.000 sq cm)

Elution Zone	AREA COUNTS				ug/sq cm			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	15889.	7462.	16620.	4078.	0.006	0.003	0.004	0.001
C12 to C13	59298.	1346.	42616.	2331.	0.023	0.001	0.011	0.001
C13 to C14	50434.	5082.	30631.	8143.	0.020	0.002	0.008	0.002
C14 to C15	43320.	5690.	19392.	2435.	0.018	0.002	0.005	0.001
C15 to C16	55477.	2567.	39314.	4619.	0.023	0.001	0.011	0.001
C16 to C17	35593.	1467.	18196.	1652.	0.015	0.001	0.005	0.000
C17 to C18	39133.	5989.	21535.	3745.	0.016	0.003	0.006	0.001
C18 to C19	26048.	1228.	19053.	2947.	0.011	0.001	0.005	0.001
C19 to C20	37998.	3941.	9002.	2216.	0.017	0.002	0.003	0.001
C20 to C21	31199.	8935.	17061.	4518.	0.014	0.004	0.005	0.001
C21 to C22	27781.	6037.	16320.	4929.	0.013	0.003	0.005	0.002
C22 to C23	25395.	4003.	16270.	5371.	0.012	0.002	0.005	0.002
C23 to C24	16724.	0.	11413.	0.	0.008	0.000	0.004	0.000
C24 to C25	16728.	0.	10804.	0.	0.008	0.000	0.004	0.000
C25 to C26	20742.	1032.	7381.	1274.	0.012	0.001	0.003	0.000
C26 to C27	18461.	1787.	8846.	0.	0.010	0.001	0.003	0.000
C27 to C28	10027.	0.	11291.	937.	0.006	0.000	0.004	0.000
C28 to C29	10770.	0.	5447.	0.	0.006	0.000	0.002	0.000
C29 to C30	12681.	0.	3837.	0.	0.008	0.000	0.002	0.000
C30 to C31	11820.	0.	5899.	1134.	0.008	0.000	0.002	0.000
C31 to C32	23269.	1314.	13676.	3216.	0.018	0.001	0.007	0.002
C32 to C33	28341.	6927.	2325.	2213.	0.022	0.005	0.001	0.001
C33 to C34	15393.	2464.	3538.	2092.	0.013	0.002	0.002	0.001
C34 to C35	3324.	0.	1149.	0.	0.003	0.000	0.001	0.000
C35 to C36	5096.	1667.	3509.	0.	0.005	0.002	0.002	0.000
C36 to 80 min	9957.	0.	1646.	0.	0.010	0.000	0.001	0.000
TOTAL	650898.	68938.	356771.	57850.	0.326	0.035	0.111	0.018

Industrial Boiler, No. 2 Fuel Oil, Experiment 2

(filename = BOILERFO2A)
(Size of sample = 2.453 kkJoules)

Elution Zone	AREA COUNTS				ug/kkJoules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	76609.	57759.	12671.	1554.	2.012	1.517	0.344	0.042
C12 to C13	104746.	12149.	116263.	7317.	2.943	0.341	3.374	0.212
C13 to C14	131764.	54110.	142236.	23252.	3.737	1.535	4.166	0.681
C14 to C15	103700.	9339.	121930.	6176.	3.023	0.272	3.671	0.186
C15 to C16	137951.	37942.	155837.	24504.	4.021	1.106	4.691	0.738
C16 to C17	182952.	52563.	224535.	62442.	5.669	1.629	7.186	1.998
C17 to C18	395909.	227643.	520200.	316073.	11.852	6.814	16.083	9.772
C18 to C19	222171.	38075.	365934.	165009.	6.709	1.150	11.413	5.146
C19 to C20	266870.	63898.	296157.	56814.	8.339	1.997	9.558	1.834
C20 to C21	380435.	122294.	393081.	118018.	11.888	3.821	12.686	3.809
C21 to C22	511066.	224679.	566344.	235997.	17.312	7.611	19.814	8.256
C22 to C23	397633.	80090.	479188.	139044.	13.469	2.713	16.765	4.865
C23 to C24	293475.	22320.	356032.	22008.	10.326	0.785	12.939	0.800
C24 to C25	288019.	17413.	305646.	14183.	10.134	0.613	11.108	0.515
C25 to C26	271403.	56333.	305926.	45704.	10.761	2.234	12.528	1.872
C26 to C27	202582.	2855.	239652.	3160.	8.033	0.113	9.814	0.129
C27 to C28	273034.	91522.	314657.	92220.	11.400	3.821	13.569	3.977
C28 to C29	172838.	0.	211465.	0.	7.216	0.000	9.119	0.000
C29 to C30	224886.	10976.	249261.	20011.	10.275	0.501	11.763	0.944
C30 to C31	193269.	3627.	245608.	14195.	8.831	0.166	11.590	0.670
C31 to C32	127863.	6274.	152597.	12698.	7.118	0.349	8.774	0.730
C32 to C33	98858.	3630.	120724.	9354.	5.503	0.202	6.941	0.538
C33 to C34	82330.	1595.	89161.	3060.	4.799	0.093	5.368	0.184
C34 to C35	29031.	0.	56980.	0.	1.692	0.000	3.431	0.000
C35 to C36	16027.	0.	13755.	2331.	1.157	0.000	1.026	0.174
C36 to 80 min	12906.	0.	8171.	0.	0.932	0.000	0.609	0.000
TOTAL	5198327.	1197086.	6064011.	1395124.	189.151	39.383	228.328	48.073

Industrial Boiler, No. 2 Fuel Oil, Exp. 5, Res.Ch.

(filename = BOILERFO5RESA)
(Size of sample = 1.864 kkJoules)

Elution Zone	AREA COUNTS				ug/ kkJoules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	66138.	48488.	85578.	1451.	1.511	1.108	1.331	0.023
C12 to C13	190739.	63098.	388172.	29041.	4.662	1.542	6.462	0.483
C13 to C14	139053.	22229.	462483.	133772.	3.431	0.548	7.771	2.248
C14 to C15	152707.	23427.	339723.	48721.	3.872	0.594	5.867	0.841
C15 to C16	185300.	56724.	504618.	81475.	4.699	1.438	8.715	1.407
C16 to C17	250510.	110950.	592583.	118259.	6.753	2.991	10.879	2.171
C17 to C18	285294.	103260.	650624.	237096.	7.430	2.689	11.540	4.205
C18 to C19	242456.	64403.	425828.	54120.	6.370	1.692	7.619	0.968
C19 to C20	219770.	27168.	480731.	135309.	5.975	0.739	8.901	2.505
C20 to C21	341638.	117202.	738561.	402200.	9.288	3.186	13.674	7.447
C21 to C22	392984.	190285.	591638.	268320.	11.581	5.608	11.874	5.385
C22 to C23	327250.	105918.	539056.	222539.	9.644	3.121	10.819	4.466
C23 to C24	258191.	33763.	400902.	51692.	7.904	1.034	8.358	1.078
C24 to C25	288862.	15416.	384921.	34609.	8.843	0.472	8.025	0.722
C25 to C26	257301.	25094.	363720.	42063.	8.876	0.866	8.545	0.988
C26 to C27	222514.	4260.	310607.	4668.	7.676	0.147	7.297	0.110
C27 to C28	247174.	54413.	359305.	84233.	8.978	1.976	8.888	2.084
C28 to C29	177800.	0.	244718.	0.	6.458	0.000	6.054	0.000
C29 to C30	229201.	7516.	282967.	7509.	9.111	0.299	7.660	0.203
C30 to C31	166128.	1939.	256687.	22090.	6.604	0.077	6.949	0.598
C31 to C32	145132.	8488.	170743.	22187.	7.029	0.411	5.632	0.732
C32 to C33	103221.	3812.	153750.	76369.	4.999	0.185	5.071	2.519
C33 to C34	78820.	3907.	84693.	46116.	3.997	0.198	2.925	1.593
C34 to C35	65831.	0.	44916.	29894.	3.339	0.000	1.551	1.033
C35 to C36	39568.	3468.	7754.	9275.	2.486	0.218	0.332	0.397
C36 to 80 min	17123.	0.	0.	0.	1.076	0.000	0.000	0.000
TOTAL	5090705.	1095228.	8865278.	2163008.	162.590	31.139	182.741	44.206

Industrial Boiler, No. 2 Fuel Oil, Exp. 5, Tunnel

(filename = BOILERFO5TUNA)
(Size of sample = 1.852 kkJoules)

Elution Zone	AREA COUNTS				ug/ kkJoules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	61198.	38492.	22999.	1898.	1.741	1.095	1.050	0.087
C12 to C13	165901.	32902.	141762.	15263.	5.051	1.002	6.924	0.745
C13 to C14	158031.	28469.	168283.	53449.	4.857	0.875	8.296	2.635
C14 to C15	151695.	27659.	98587.	16527.	4.791	0.874	4.995	0.837
C15 to C16	187350.	42096.	125448.	31652.	5.918	1.330	6.356	1.604
C16 to C17	294851.	122777.	175821.	57989.	9.901	4.123	9.470	3.123
C17 to C18	288677.	97037.	254952.	102726.	9.365	3.148	13.266	5.345
C18 to C19	236638.	69915.	253888.	130089.	7.744	2.288	13.327	6.829
C19 to C20	211999.	50662.	197509.	61153.	7.179	1.716	10.728	3.322
C20 to C21	323201.	126234.	304875.	161441.	10.944	4.275	16.560	8.769
C21 to C22	324493.	150713.	239414.	94822.	11.912	5.532	14.097	5.583
C22 to C23	262502.	80518.	213682.	74047.	9.636	2.956	12.582	4.360
C23 to C24	206310.	21763.	167201.	16967.	7.867	0.830	10.227	1.038
C24 to C25	217091.	9253.	152420.	10370.	8.278	0.353	9.323	0.634
C25 to C26	192420.	21564.	143800.	13124.	8.268	0.927	9.911	0.905
C26 to C27	160414.	2438.	131296.	921.	6.893	0.105	9.049	0.063
C27 to C28	180053.	46459.	146980.	25668.	8.147	2.102	10.667	1.863
C28 to C29	119836.	0.	110440.	0.	5.422	0.000	8.015	0.000
C29 to C30	132729.	5913.	127556.	10578.	6.572	0.293	10.131	0.840
C30 to C31	113380.	1695.	133374.	12194.	5.614	0.084	10.593	0.968
C31 to C32	59079.	6431.	89413.	6598.	3.564	0.388	8.652	0.638
C32 to C33	20741.	5368.	84580.	30225.	1.251	0.324	8.185	2.925
C33 to C34	6965.	2597.	45841.	12454.	0.440	0.164	4.645	1.262
C34 to C35	1066.	0.	52318.	5668.	0.067	0.000	5.301	0.574
C35 to C36	2071.	0.	24337.	0.	0.162	0.000	3.055	0.000
C36 to 80 min	1437.	0.	14756.	0.	0.112	0.000	1.852	0.000
TOTAL	4080128.	990955.	3621532.	945823.	151.695	34.781	227.257	54.950

Automobiles, Catalyst-Equipped

(filename = CARCATA)
(Size of sample = 75.922 meters)

	AREA COUNTS				ug/meters			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	100208.	48454.	34588.	2351.	0.052	0.025	0.019	0.001
C12 to C13	391169.	110316.	230237.	43394.	0.217	0.061	0.138	0.026
C13 to C14	348923.	59798.	268552.	30069.	0.195	0.033	0.162	0.018
C14 to C15	439609.	68084.	398978.	115183.	0.252	0.039	0.247	0.071
C15 to C16	442132.	70840.	445425.	136344.	0.254	0.041	0.276	0.084
C16 to C17	450585.	29042.	495088.	113739.	0.275	0.018	0.326	0.075
C17 to C18	590148.	79332.	528481.	141685.	0.348	0.047	0.336	0.090
C18 to C19	672280.	130644.	589282.	123774.	0.400	0.078	0.378	0.079
C19 to C20	688389.	47425.	613736.	73422.	0.424	0.029	0.408	0.049
C20 to C21	961651.	132401.	750331.	44696.	0.592	0.082	0.498	0.030
C21 to C22	1013213.	175893.	926229.	147932.	0.676	0.117	0.667	0.107
C22 to C23	979848.	64702.	884973.	58076.	0.654	0.043	0.637	0.042
C23 to C24	1098385.	45680.	1006749.	41221.	0.762	0.032	0.753	0.031
C24 to C25	1278534.	40740.	1163784.	28441.	0.886	0.028	0.871	0.021
C25 to C26	1241449.	15540.	1143087.	3544.	0.970	0.012	0.964	0.003
C26 to C27	1345583.	8771.	1302931.	14101.	1.051	0.007	1.098	0.012
C27 to C28	1498668.	60635.	1411693.	68070.	1.233	0.050	1.253	0.060
C28 to C29	1341850.	0.	1274907.	7907.	1.104	0.000	1.132	0.007
C29 to C30	1311636.	0.	1241347.	0.	1.181	0.000	1.206	0.000
C30 to C31	1116620.	45604.	1062078.	49543.	1.005	0.041	1.032	0.048
C31 to C32	946587.	47761.	904627.	48152.	1.038	0.052	1.071	0.057
C32 to C33	745331.	40320.	683049.	38219.	0.818	0.044	0.808	0.045
C33 to C34	550857.	17273.	524951.	28844.	0.633	0.020	0.651	0.036
C34 to C35	414225.	5143.	385089.	12140.	0.476	0.006	0.477	0.015
C35 to C36	283848.	13545.	261231.	14956.	0.404	0.019	0.401	0.023
C36 to 80 min	207160.	0.	135175.	3093.	0.295	0.000	0.208	0.005
TOTAL	20458892.	1357943.	18666602.	1388896.	16.194	0.924	16.017	1.036

Automobiles, NonCatalyst

(filename = CARNONCATA)
(Size of sample = 62.986 meters)

Elution Zone	AREA COUNTS				ug/meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	32560.	11530.	30571.	4398.	0.038	0.013	0.025	0.004
C12 to C13	229777.	19346.	277348.	24286.	0.287	0.024	0.240	0.021
C13 to C14	244629.	20213.	356520.	43556.	0.309	0.026	0.311	0.038
C14 to C15	387483.	28036.	646340.	105274.	0.503	0.036	0.580	0.095
C15 to C16	489531.	75961.	856122.	248429.	0.635	0.099	0.769	0.223
C16 to C17	549294.	94432.	870581.	163399.	0.758	0.130	0.831	0.156
C17 to C18	788607.	146684.	1219086.	307591.	1.051	0.195	1.124	0.284
C18 to C19	965889.	166629.	1389798.	311677.	1.298	0.224	1.293	0.290
C19 to C20	1232499.	208685.	1863650.	409784.	1.715	0.290	1.794	0.394
C20 to C21	1686468.	210429.	2307750.	329224.	2.346	0.293	2.221	0.317
C21 to C22	2309425.	402472.	2717754.	449092.	3.483	0.607	2.836	0.469
C22 to C23	2530004.	407213.	3726517.	542730.	3.815	0.614	3.888	0.566
C23 to C24	2980591.	269079.	4144146.	372267.	4.669	0.422	4.492	0.403
C24 to C25	3071998.	373284.	4329174.	386950.	4.812	0.585	4.692	0.419
C25 to C26	2643227.	290397.	3721425.	386518.	4.666	0.513	4.545	0.472
C26 to C27	2894788.	274402.	4136582.	509485.	5.110	0.484	5.052	0.622
C27 to C28	2355134.	208117.	3316413.	477195.	4.378	0.387	4.265	0.614
C28 to C29	2136503.	16750.	3035197.	85700.	3.971	0.031	3.904	0.110
C29 to C30	1919061.	74755.	2689974.	138691.	3.903	0.152	3.786	0.195
C30 to C31	1665957.	54986.	2335899.	83843.	3.389	0.112	3.288	0.118
C31 to C32	1266004.	92333.	1788292.	140192.	3.138	0.229	3.067	0.240
C32 to C33	1172336.	114334.	1603137.	170622.	2.905	0.283	2.749	0.293
C33 to C34	832984.	54295.	1135476.	76073.	2.162	0.141	2.039	0.137
C34 to C35	598674.	14474.	823131.	23222.	1.554	0.038	1.478	0.042
C35 to C36	537636.	123917.	728218.	177210.	1.728	0.398	1.620	0.394
C36 to 80 min	324973.	20220.	437001.	27678.	1.045	0.065	0.972	0.062
TOTAL	35846040.	3772973.	50486108.	5995086.	63.667	6.391	61.861	6.977

Trucks, Heavy-Duty Diesel

(filename = DIESELA)
(Size of sample = 10.110 meters)

Elution Zone	AREA COUNTS				ug/meters			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	24117.	5549.	5050.	0.	0.103	0.024	0.017	0.000
C12 to C13	122794.	0.	37522.	0.	0.560	0.000	0.135	0.000
C13 to C14	129693.	0.	96100.	7739.	0.597	0.000	0.349	0.028
C14 to C15	233017.	32530.	239378.	57557.	1.102	0.154	0.893	0.215
C15 to C16	294514.	0.	366589.	0.	1.393	0.000	1.367	0.000
C16 to C17	460852.	67840.	623112.	77966.	2.317	0.341	2.470	0.309
C17 to C18	739777.	118158.	978444.	144554.	3.594	0.574	3.748	0.554
C18 to C19	1075249.	216128.	1387052.	252967.	5.269	1.059	5.359	0.977
C19 to C20	1398370.	239574.	1650802.	225507.	7.091	1.215	6.600	0.902
C20 to C21	1833665.	471234.	2225688.	585144.	9.298	2.390	8.899	2.340
C21 to C22	1675142.	210771.	2263964.	331133.	9.208	1.159	9.812	1.435
C22 to C23	1766478.	284027.	2129988.	256693.	9.710	1.561	9.232	1.113
C23 to C24	1395687.	95881.	1712582.	174513.	7.969	0.547	7.710	0.786
C24 to C25	1337539.	152191.	1620038.	132685.	7.637	0.869	7.294	0.597
C25 to C26	1217031.	108102.	1471157.	120695.	7.831	0.696	7.464	0.612
C26 to C27	1140345.	77137.	1490816.	78446.	7.337	0.496	7.563	0.398
C27 to C28	1472530.	273536.	1815989.	361885.	9.977	1.853	9.701	1.933
C28 to C29	1164241.	15722.	1511968.	13618.	7.888	0.107	8.077	0.073
C29 to C30	1141333.	65184.	1469969.	93863.	8.462	0.483	8.594	0.549
C30 to C31	1173432.	88780.	1522248.	124285.	8.700	0.658	8.899	0.727
C31 to C32	838701.	58439.	1102283.	118896.	7.577	0.528	7.851	0.847
C32 to C33	694154.	48614.	890125.	73703.	6.271	0.439	6.340	0.525
C33 to C34	547152.	30220.	704268.	47338.	5.176	0.286	5.253	0.353
C34 to C35	405095.	11059.	520786.	21247.	3.832	0.105	3.884	0.158
C35 to C36	289566.	3291.	333448.	5869.	3.393	0.039	3.081	0.054
C36 to 80 min	178962.	0.	162357.	1208.	2.097	0.000	1.500	0.011
TOTAL	22749440.	2673967.	28331728.	3307511.	144.392	15.582	142.092	15.495

Roofing Tar Pot

(filename = TARPOTA)
(Size of sample = 39.370 mg emissio)

Elution Zone	AREA COUNTS				ug/mg emissio			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	11825.	0.	0.	0.	0.413	0.000	0.000	0.000
C12 to C13	24424.	0.	14723.	0.	0.913	0.000	0.545	0.000
C13 to C14	121305.	0.	95266.	51379.	4.579	0.000	3.557	1.919
C14 to C15	386122.	116650.	395214.	144134.	14.979	4.525	15.168	5.532
C15 to C16	658701.	117493.	779902.	163122.	25.553	4.558	29.932	6.260
C16 to C17	1286977.	266599.	1366814.	390585.	53.073	10.994	55.764	15.935
C17 to C18	1439879.	284304.	1741292.	452555.	57.366	11.327	68.634	17.838
C18 to C19	1827776.	315780.	1991916.	377637.	73.459	12.691	79.202	15.015
C19 to C20	1685003.	222550.	1959646.	244896.	70.077	9.255	80.629	10.076
C20 to C21	1916908.	303779.	2195174.	279252.	79.721	12.634	90.320	11.490
C21 to C22	2260731.	386321.	2583686.	371602.	101.921	17.417	115.238	16.574
C22 to C23	2311900.	344231.	2735482.	349513.	104.228	15.519	122.008	15.589
C23 to C24	2004581.	165678.	2368302.	184790.	93.876	7.759	109.725	8.561
C24 to C25	1949987.	146363.	2171737.	147000.	91.319	6.854	100.618	6.811
C25 to C26	1359705.	51288.	1788712.	65937.	71.754	2.707	93.386	3.442
C26 to C27	1070772.	13340.	1266292.	20470.	56.507	0.704	66.111	1.069
C27 to C28	743424.	0.	885470.	0.	41.310	0.000	48.678	0.000
C28 to C29	496565.	0.	583222.	0.	27.593	0.000	32.062	0.000
C29 to C30	370599.	0.	430703.	0.	22.536	0.000	25.912	0.000
C30 to C31	249409.	11973.	279788.	5984.	15.167	0.728	16.832	0.360
C31 to C32	243716.	32743.	311182.	51030.	18.057	2.426	22.810	3.740
C32 to C33	195341.	21048.	186810.	21662.	14.473	1.559	13.693	1.588
C33 to C34	143473.	20306.	165504.	11420.	11.131	1.575	12.704	0.877
C34 to C35	137018.	1313.	124611.	0.	10.631	0.102	9.565	0.000
C35 to C36	129020.	4681.	121056.	2304.	12.400	0.450	11.510	0.219
C36 to 80 min	188871.	12591.	186518.	18106.	18.152	1.210	17.735	1.722
TOTAL	23214040.	2839031.	26729026.	3353378.	1091.186	124.995	1242.339	144.617

Roofing Tar Pot - Replicate Sample

(filename = PTARPOTA)
(Size of sample = 21.091 mg emissio)

Elution Zone	AREA COUNTS				ug/mg emissio			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	23641.	12343.	2544.	0.	0.667	0.348	0.088	0.000
C12 to C13	29252.	0.	12058.	0.	0.884	0.000	0.447	0.000
C13 to C14	128057.	51234.	81860.	36159.	3.904	1.562	3.063	1.353
C14 to C15	461592.	151470.	398746.	140945.	14.463	4.746	15.336	5.421
C15 to C16	794309.	200068.	824955.	192208.	24.888	6.269	31.727	7.392
C16 to C17	1691428.	514995.	1496030.	501921.	56.339	17.154	61.165	20.521
C17 to C18	1996713.	573077.	1996715.	574664.	64.253	18.441	78.868	22.699
C18 to C19	2422828.	466295.	2230727.	429734.	78.649	15.137	88.885	17.123
C19 to C20	2099659.	279954.	2022257.	279249.	70.529	9.404	83.381	11.514
C20 to C21	2722545.	343965.	2572987.	326026.	91.452	11.554	106.088	13.443
C21 to C22	2647771.	332491.	2490218.	399338.	96.414	12.107	111.304	17.849
C22 to C23	2665566.	298350.	2623688.	308304.	97.062	10.864	117.269	13.780
C23 to C24	2137720.	180908.	2099343.	160030.	80.859	6.843	97.470	7.430
C24 to C25	1961671.	87414.	1901588.	107125.	74.200	3.306	88.288	4.974
C25 to C26	1246368.	21063.	1238479.	21500.	53.125	0.898	64.796	1.125
C26 to C27	922608.	0.	887029.	10848.	39.325	0.000	46.408	0.568
C27 to C28	624384.	0.	596812.	0.	28.023	0.000	32.879	0.000
C28 to C29	410685.	0.	387032.	0.	18.432	0.000	21.322	0.000
C29 to C30	334602.	0.	312840.	0.	16.434	0.000	18.861	0.000
C30 to C31	186936.	5373.	181377.	8713.	9.182	0.264	10.935	0.525
C31 to C32	220676.	33261.	148244.	2329.	13.206	1.990	10.889	0.171
C32 to C33	170444.	8466.	126957.	4158.	10.200	0.507	9.326	0.305
C33 to C34	118425.	0.	88502.	5134.	7.421	0.000	6.808	0.395
C34 to C35	124574.	0.	78809.	0.	7.806	0.000	6.062	0.000
C35 to C36	90259.	0.	37439.	4833.	7.006	0.000	3.567	0.461
C36 to 80 min	119384.	0.	31106.	2219.	9.267	0.000	2.964	0.211
TOTAL	26352102.	3560727.	24868348.	3515437.	973.990	121.393	1118.196	147.259

Radial Tire Wear

(filename = PTIREDUSTA)
(Size of sample = 9.164 mg tire du)

	AREA COUNTS				ug/mg tire du			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	7937.	4192.	7946.	2878.	0.053	0.028	0.038	0.014
C12 to C13	23554.	2204.	18731.	0.	0.167	0.016	0.096	0.000
C13 to C14	18410.	5226.	13075.	3657.	0.132	0.037	0.067	0.019
C14 to C15	10944.	0.	10572.	0.	0.080	0.000	0.056	0.000
C15 to C16	30829.	9146.	18014.	0.	0.227	0.067	0.095	0.000
C16 to C17	14556.	0.	14272.	0.	0.114	0.000	0.080	0.000
C17 to C18	37203.	7422.	45548.	7358.	0.281	0.056	0.248	0.040
C18 to C19	112584.	37461.	109904.	19340.	0.858	0.285	0.603	0.106
C19 to C20	160552.	11987.	216073.	24034.	1.266	0.095	1.227	0.137
C20 to C21	402956.	213848.	321066.	43895.	3.177	1.686	1.824	0.249
C21 to C22	499180.	239999.	345485.	43280.	4.266	2.051	2.127	0.266
C22 to C23	517614.	230529.	468154.	47202.	4.424	1.970	2.882	0.291
C23 to C24	348620.	58587.	456198.	67069.	3.095	0.520	2.918	0.429
C24 to C25	492738.	187392.	515752.	43520.	4.374	1.664	3.299	0.278
C25 to C26	763068.	418962.	457441.	11131.	7.634	4.191	3.297	0.080
C26 to C27	426333.	36062.	570171.	40456.	4.265	0.361	4.109	0.292
C27 to C28	477112.	44353.	712031.	66426.	5.026	0.467	5.403	0.504
C28 to C29	512511.	25862.	663503.	31813.	5.399	0.272	5.035	0.241
C29 to C30	579431.	18042.	806237.	32984.	6.680	0.208	6.696	0.274
C30 to C31	688154.	69272.	1050711.	97855.	7.933	0.799	8.726	0.813
C31 to C32	883082.	102635.	1176281.	141952.	12.403	1.442	11.902	1.436
C32 to C33	898787.	106103.	1238066.	132428.	12.624	1.490	12.527	1.340
C33 to C34	1041002.	120802.	1553369.	175627.	15.311	1.777	16.459	1.861
C34 to C35	1008726.	108330.	1466031.	121741.	14.836	1.593	15.534	1.290
C35 to C36	952488.	97627.	1336939.	115530.	17.354	1.779	17.548	1.516
C36 to 120 min	1083603.	287638.	1513996.	224103.	60.000	5.241	45.000	2.941
TOTAL	11991974.	2443681.	15105566.	1494279.	191.722	28.095	167.667	14.418

Radial Tire Wear - Replicate Sample

(filename = TIREDUSTA)
(Size of sample = 9.631 mg tire du)

Elution Zone (incl. lower bound)	AREA COUNTS: Acid+Neutral Total	AREA COUNTS: Acid+Neutral Resolved	AREA COUNTS: Neutral Total	AREA COUNTS: Neutral Resolved	ug/mg tire du: Acid+Neutral Total	ug/mg tire du: Acid+Neutral Resolved	ug/mg tire du: Neutral Total	ug/mg tire du: Neutral Resolved
16 min to C12	8309.	1077.	8762.	4129.	0.049	0.006	0.035	0.016
C12 to C13	26895.	2510.	34915.	4485.	0.170	0.016	0.148	0.019
C13 to C14	18773.	6684.	23117.	7990.	0.120	0.043	0.099	0.034
C14 to C15	16988.	0.	11791.	0.	0.112	0.000	0.052	0.000
C15 to C16	50946.	4210.	29108.	1341.	0.334	0.028	0.128	0.006
C16 to C17	6216.	0.	15963.	0.	0.043	0.000	0.075	0.000
C17 to C18	43385.	31797.	14090.	9780.	0.292	0.214	0.064	0.044
C18 to C19	51105.	11940.	89413.	21604.	0.348	0.081	0.407	0.098
C19 to C20	164148.	16796.	208032.	34848.	1.155	0.118	0.980	0.164
C20 to C21	491130.	221737.	387859.	49730.	3.456	1.560	1.827	0.234
C21 to C22	585991.	270949.	610070.	203748.	4.470	2.067	3.116	1.041
C22 to C23	618554.	261979.	570056.	61571.	4.719	1.998	2.912	0.314
C23 to C24	462504.	102642.	729179.	202354.	3.665	0.813	3.869	1.074
C24 to C25	619399.	242532.	657359.	64078.	4.908	1.922	3.488	0.340
C25 to C26	958082.	539324.	552781.	24838.	8.555	4.816	3.305	0.148
C26 to C27	501095.	30556.	659817.	51079.	4.474	0.273	3.945	0.305
C27 to C28	617565.	53369.	813043.	68909.	5.807	0.502	5.118	0.434
C28 to C29	611274.	21068.	749809.	28664.	5.747	0.198	4.720	0.180
C29 to C30	713594.	19046.	909350.	32594.	7.342	0.196	6.265	0.225
C30 to C31	809410.	70895.	1036676.	113948.	8.328	0.729	7.142	0.785
C31 to C32	1162564.	104884.	1476220.	138589.	14.575	1.315	12.391	1.163
C32 to C33	1125899.	92653.	1409599.	128713.	14.115	1.162	11.832	1.080
C33 to C34	1400963.	130316.	1639099.	175702.	18.392	1.711	14.407	1.544
C34 to C35	1396318.	104501.	1753934.	147847.	18.331	1.372	15.416	1.300
C35 to C36	1336319.	102044.	1790875.	155172.	21.731	1.659	19.499	1.690
C36 to 120 min	3798455.	288605.	4197185.	255786.	61.771	4.693	45.699	2.785
TOTAL	17595882.	2732114.	20378102.	1987499.	213.010	27.493	166.936	15.025

Dilution Air for Fireplace - Oak Wood

(filename = 03BLANK3A)
(Size of sample = 23.515 g wood)

Elution Zone	AREA COUNTS				ug/g wood			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	26401.	11751.	17836.	7847.	0.032	0.014	0.015	0.007
C12 to C13	113932.	46808.	111784.	38280.	0.150	0.062	0.099	0.034
C13 to C14	105315.	55272.	132603.	69080.	0.140	0.073	0.119	0.062
C14 to C15	69528.	16196.	76463.	16925.	0.095	0.022	0.070	0.016
C15 to C16	80200.	17110.	96300.	26328.	0.109	0.023	0.089	0.024
C16 to C17	116411.	45142.	142668.	53785.	0.169	0.065	0.140	0.053
C17 to C18	132934.	55843.	162319.	68022.	0.186	0.078	0.153	0.064
C18 to C19	105808.	36024.	133151.	40525.	0.149	0.051	0.127	0.039
C19 to C20	104830.	22773.	129974.	20812.	0.153	0.033	0.128	0.021
C20 to C21	108537.	22601.	146323.	32679.	0.159	0.033	0.144	0.032
C21 to C22	196648.	70814.	233617.	86560.	0.312	0.112	0.250	0.093
C22 to C23	142325.	13834.	180324.	18780.	0.226	0.022	0.193	0.020
C23 to C24	197038.	7832.	236466.	11168.	0.324	0.013	0.263	0.012
C24 to C25	165295.	920.	201313.	0.	0.272	0.002	0.224	0.000
C25 to C26	152398.	7293.	176488.	7558.	0.283	0.014	0.221	0.009
C26 to C27	118611.	2964.	136028.	3513.	0.220	0.005	0.170	0.004
C27 to C28	127004.	19024.	137354.	23895.	0.248	0.037	0.181	0.031
C28 to C29	84251.	0.	92493.	0.	0.165	0.000	0.122	0.000
C29 to C30	73702.	0.	71999.	0.	0.158	0.000	0.104	0.000
C30 to C31	56705.	0.	58758.	1105.	0.121	0.000	0.085	0.002
C31 to C32	57995.	3513.	56503.	3655.	0.151	0.009	0.099	0.006
C32 to C33	86133.	5667.	83467.	5566.	0.224	0.015	0.147	0.010
C33 to C34	69556.	2968.	67741.	5015.	0.190	0.008	0.125	0.009
C34 to C35	40348.	0.	38122.	0.	0.110	0.000	0.070	0.000
C35 to C36	19555.	2890.	17702.	4878.	0.066	0.010	0.040	0.011
C36 to 80 min	15897.	1122.	11447.	1904.	0.054	0.004	0.026	0.004
TOTAL	2567357.	468361.	2949243.	547880.	4.465	0.706	3.402	0.563

Fireplace - Oak Wood

(filename = FIREOAKA)
(Size of sample = 4.249 g wood)

	AREA COUNTS				ug/ g wood			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	4588.	0.	0.	0.	0.199	0.000	0.000	0.000
C12 to C13	144766.	105141.	650.	0.	6.732	4.889	0.015	0.000
C13 to C14	115584.	43702.	11663.	0.	5.425	2.051	0.268	0.000
C14 to C15	507954.	132689.	87724.	0.	24.505	6.401	2.072	0.000
C15 to C16	577483.	14656.	305194.	33889.	27.859	0.707	7.210	0.801
C16 to C17	1085716.	578986.	713226.	192607.	55.680	29.693	17.912	4.837
C17 to C18	1271446.	545342.	1296923.	486227.	62.995	27.019	31.467	11.797
C18 to C19	1679461.	900186.	1331176.	438096.	83.940	44.992	32.581	10.723
C19 to C20	2156902.	1255611.	2387725.	1311148.	111.552	64.939	60.473	33.207
C20 to C21	1870813.	694372.	2632857.	1497093.	96.756	35.912	66.682	37.917
C21 to C22	1647164.	414529.	1782464.	414259.	92.348	23.241	48.938	11.374
C22 to C23	1594658.	387477.	1631551.	356427.	89.404	21.724	44.794	9.786
C23 to C24	1288422.	127642.	1315322.	107156.	75.035	7.434	37.512	3.056
C24 to C25	1201792.	123930.	1367494.	142944.	69.990	7.217	39.000	4.077
C25 to C26	1331814.	139996.	1259734.	208308.	87.402	9.187	40.485	6.694
C26 to C27	1159730.	149112.	1091549.	77834.	76.109	9.786	35.080	2.501
C27 to C28	1312259.	342697.	1383673.	341045.	90.681	23.681	46.824	11.541
C28 to C29	1041098.	116843.	1009873.	28288.	71.943	8.074	34.174	0.957
C29 to C30	929916.	77573.	945963.	99068.	70.322	5.866	35.031	3.669
C30 to C31	946069.	156363.	869828.	125341.	71.544	11.825	32.212	4.642
C31 to C32	828032.	159318.	868159.	174918.	76.293	14.679	39.171	7.892
C32 to C33	703011.	139056.	746657.	148883.	64.774	12.812	33.689	6.718
C33 to C34	450488.	60663.	499724.	57726.	43.465	5.853	23.611	2.727
C34 to C35	401149.	25818.	356144.	22254.	38.704	2.491	16.827	1.051
C35 to C36	341155.	36217.	357294.	52488.	40.774	4.329	20.912	3.072
C36 to 80 min	319512.	44836.	295005.	70900.	38.187	5.359	17.266	4.150
TOTAL	24910988.	6772755.	24547578.	6386899.	1572.620	390.161	764.207	183.188

Dilution Air for Fireplace - Pine Wood

(filename = 03BLANK2A)
(Size of sample = 25.140 g wood)

Elution Zone	AREA COUNTS				ug/g wood			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	26401.	11751.	17836.	7847.	0.030	0.014	0.014	0.006
C12 to C13	113932.	46808.	111784.	38280.	0.140	0.058	0.093	0.032
C13 to C14	105315.	55272.	132603.	69080.	0.131	0.069	0.111	0.058
C14 to C15	69528.	16196.	76463.	16925.	0.089	0.021	0.066	0.015
C15 to C16	80200.	17110.	96300.	26328.	0.102	0.022	0.083	0.023
C16 to C17	116411.	45142.	142668.	53785.	0.158	0.061	0.130	0.049
C17 to C18	132934.	55843.	162319.	68022.	0.174	0.073	0.143	0.060
C18 to C19	105808.	36024.	133151.	40525.	0.140	0.048	0.119	0.036
C19 to C20	104830.	22773.	129974.	20812.	0.143	0.031	0.120	0.019
C20 to C21	108537.	22601.	146323.	32679.	0.148	0.031	0.135	0.030
C21 to C22	196648.	70814.	233617.	86560.	0.292	0.105	0.234	0.087
C22 to C23	142325.	13834.	180324.	18780.	0.211	0.021	0.180	0.019
C23 to C24	197038.	7832.	236466.	11168.	0.303	0.012	0.246	0.012
C24 to C25	165295.	920.	201313.	0.	0.255	0.001	0.209	0.000
C25 to C26	152398.	7293.	176488.	7558.	0.264	0.013	0.207	0.009
C26 to C27	118611.	2964.	136028.	3513.	0.206	0.005	0.159	0.004
C27 to C28	127004.	19024.	137354.	23895.	0.232	0.035	0.169	0.029
C28 to C29	84251.	0.	92493.	0.	0.154	0.000	0.114	0.000
C29 to C30	73702.	0.	71999.	0.	0.147	0.000	0.097	0.000
C30 to C31	56705.	0.	58758.	1105.	0.113	0.000	0.079	0.001
C31 to C32	57995.	3513.	56503.	3655.	0.141	0.009	0.093	0.006
C32 to C33	86133.	5667.	83467.	5566.	0.210	0.014	0.137	0.009
C33 to C34	69556.	2968.	67741.	5015.	0.177	0.008	0.117	0.009
C34 to C35	40348.	0.	38122.	0.	0.103	0.000	0.066	0.000
C35 to C36	19555.	2890.	17702.	4878.	0.062	0.009	0.038	0.010
C36 to 80 min	15897.	1122.	11447.	1904.	0.050	0.004	0.024	0.004
TOTAL	2567357.	468361.	2949243.	547880.	4.177	0.660	3.182	0.527

Fireplace - Pine Wood

(filename = FIREPINEA)
(Size of sample = 4.212 g wood)

	AREA COUNTS				ug/ g wood			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	5657.	0.	3004.	0.	0.357	0.000	0.204	0.000
C12 to C13	235259.	186332.	4621.	0.	15.864	12.565	0.336	0.000
C13 to C14	254037.	158442.	48362.	0.	17.291	10.784	3.554	0.000
C14 to C15	603244.	317741.	142573.	9563.	42.200	22.227	10.769	0.722
C15 to C16	551872.	31513.	453194.	72851.	38.606	2.204	34.232	5.503
C16 to C17	967828.	359709.	924935.	235611.	71.974	26.750	74.270	18.919
C17 to C18	1366167.	538295.	1427353.	645637.	98.153	38.674	110.728	50.086
C18 to C19	1407620.	376183.	1307688.	477741.	102.018	27.264	102.335	37.386
C19 to C20	1756061.	615777.	2020196.	906755.	131.698	46.181	163.592	73.428
C20 to C21	1935612.	440341.	2521852.	1173532.	145.164	33.024	204.215	95.031
C21 to C22	1961460.	525557.	1627018.	160620.	159.464	42.727	142.825	14.100
C22 to C23	1425582.	152145.	1567787.	86761.	115.898	12.369	137.625	7.616
C23 to C24	1817369.	173638.	1612066.	169291.	153.476	14.664	146.997	15.437
C24 to C25	2132778.	641990.	1563741.	139539.	180.113	54.216	142.591	12.724
C25 to C26	3596441.	1847089.	2760897.	992089.	342.250	175.776	283.693	101.941
C26 to C27	1658054.	151697.	1436292.	94002.	157.786	14.436	147.585	9.659
C27 to C28	1705498.	251706.	1727451.	283028.	170.900	25.222	186.907	30.623
C28 to C29	1584523.	19921.	1434178.	40404.	158.778	1.996	155.175	4.372
C29 to C30	1271139.	0.	1210709.	0.	139.391	0.000	143.354	0.000
C30 to C31	1696042.	429670.	1579851.	383968.	185.986	47.117	187.063	45.464
C31 to C32	1162950.	186728.	1154071.	188687.	155.378	24.948	166.491	27.221
C32 to C33	914475.	125856.	917537.	142350.	122.180	16.815	132.368	20.536
C33 to C34	771641.	120527.	697421.	124556.	107.960	16.863	105.359	18.817
C34 to C35	537799.	45873.	488492.	22794.	75.243	6.418	73.796	3.443
C35 to C36	424743.	60432.	401169.	62001.	73.613	10.474	75.073	11.603
C36 to 80 min	293827.	27114.	274152.	30721.	50.923	4.699	51.303	5.749
TOTAL	32037686.	7784276.	29306618.	6442501.	3012.665	688.415	2982.442	610.378

Dilution Air for Fireplace - Synthetic Log

(filename = 03BLANK6A)
(Size of sample = 2.839 g wood)

Elution Zone	AREA COUNTS				ug/g wood			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	26401.	11751.	17836.	7847.	0.269	0.120	0.122	0.054
C12 to C13	113932.	46808.	111784.	38280.	1.240	0.510	0.821	0.281
C13 to C14	105315.	55272.	132603.	69080.	1.157	0.607	0.983	0.512
C14 to C15	69528.	16196.	76463.	16925.	0.785	0.183	0.583	0.129
C15 to C16	80200.	17110.	96300.	26328.	0.906	0.193	0.734	0.201
C16 to C17	116411.	45142.	142668.	53785.	1.398	0.542	1.156	0.436
C17 to C18	132934.	55843.	162319.	68022.	1.542	0.648	1.270	0.532
C18 to C19	105808.	36024.	133151.	40525.	1.238	0.422	1.051	0.320
C19 to C20	104830.	22773.	129974.	20812.	1.269	0.276	1.062	0.170
C20 to C21	108537.	22601.	146323.	32679.	1.314	0.274	1.195	0.267
C21 to C22	196648.	70814.	233617.	86560.	2.581	0.930	2.069	0.766
C22 to C23	142325.	13834.	180324.	18780.	1.868	0.182	1.597	0.166
C23 to C24	197038.	7832.	236466.	11168.	2.687	0.107	2.175	0.103
C24 to C25	165295.	920.	201313.	0.	2.254	0.013	1.852	0.000
C25 to C26	152398.	7293.	176488.	7558.	2.342	0.112	1.829	0.078
C26 to C27	118611.	2964.	136028.	3513.	1.822	0.046	1.410	0.036
C27 to C28	127004.	19024.	137354.	23895.	2.055	0.308	1.499	0.261
C28 to C29	84251.	0.	92493.	0.	1.363	0.000	1.009	0.000
C29 to C30	73702.	0.	71999.	0.	1.305	0.000	0.860	0.000
C30 to C31	56705.	0.	58758.	1105.	1.004	0.000	0.702	0.013
C31 to C32	57995.	3513.	56503.	3655.	1.251	0.076	0.822	0.053
C32 to C33	86133.	5667.	83467.	5566.	1.858	0.122	1.215	0.081
C33 to C34	69556.	2968.	67741.	5015.	1.571	0.067	1.032	0.076
C34 to C35	40348.	0.	38122.	0.	0.911	0.000	0.581	0.000
C35 to C36	19555.	2890.	17702.	4878.	0.547	0.081	0.334	0.092
C36 to 80 min	15897.	1122.	11447.	1904.	0.445	0.031	0.216	0.036
TOTAL	2567357.	468361.	2949243.	547880.	36.984	5.847	28.177	4.664

Fireplace - Synthetic Log

(filename = FIRESYNTHA)
(Size of sample = 0.592 g wood)

Elution Zone (incl. lower bound)	AREA COUNTS Acid+Neutral Total	AREA COUNTS Acid+Neutral Resolved	AREA COUNTS Neutral Total	AREA COUNTS Neutral Resolved	ug/g wood Acid+Neutral Total	ug/g wood Acid+Neutral Resolved	ug/g wood Neutral Total	ug/g wood Neutral Resolved
16 min to C12	25145.	16360.	18129.	5470.	5.173	3.366	3.905	1.178
C12 to C13	64275.	13176.	34256.	0.	14.150	2.901	7.894	0.000
C13 to C14	45870.	23565.	36969.	7681.	10.193	5.236	8.599	1.787
C14 to C15	9259.	0.	24957.	0.	2.115	0.000	5.966	0.000
C15 to C16	44835.	0.	2047.	0.	10.239	0.000	0.489	0.000
C16 to C17	104918.	0.	94094.	0.	25.472	0.000	23.914	0.000
C17 to C18	313142.	53649.	291418.	49833.	73.448	12.583	71.552	12.236
C18 to C19	664152.	204173.	689764.	176771.	157.144	48.309	170.844	43.783
C19 to C20	1316092.	384613.	1424062.	467270.	322.229	94.168	364.987	119.761
C20 to C21	1883730.	635589.	1995975.	684156.	461.209	155.616	511.568	175.349
C21 to C22	1791606.	515642.	1988706.	638283.	475.515	136.858	552.537	177.339
C22 to C23	2104456.	551680.	2087056.	554062.	558.549	146.423	579.862	153.939
C23 to C24	1938680.	418302.	2049404.	463528.	534.494	115.326	591.471	133.777
C24 to C25	2184267.	529219.	2429241.	559344.	602.202	145.906	701.094	161.430
C25 to C26	2271597.	531037.	2148022.	530613.	705.733	164.981	698.581	172.566
C26 to C27	1917728.	314196.	2031867.	373122.	595.794	97.613	660.805	121.347
C27 to C28	2028185.	403513.	2437207.	327353.	663.493	132.004	834.624	112.102
C28 to C29	1977206.	240230.	1730874.	252643.	646.816	78.588	592.739	86.518
C29 to C30	2037049.	144127.	1978518.	162929.	729.260	51.597	741.465	61.059
C30 to C31	1574917.	153097.	1767765.	172687.	563.818	54.808	662.483	64.716
C31 to C32	1587543.	229979.	1637427.	298851.	692.458	100.313	747.651	136.456
C32 to C33	1510387.	248995.	1551191.	257430.	658.804	108.607	708.276	117.543
C33 to C34	1377214.	254830.	1436006.	257180.	629.052	116.395	686.610	122.968
C34 to C35	1377554.	212952.	1401758.	313468.	629.207	97.267	670.235	149.881
C35 to C36	1168711.	256369.	1196832.	293550.	661.259	145.054	708.871	173.867
C36 to 120 min	2474556.	871262.	2409815.	978184.	1400.109	492.962	1427.307	579.368
TOTAL	33793080.	7206555.	34893364.	7824408.	11827.938	2506.883	12734.332	2878.969

Cigarette Smoke

(filename = PCIGARETTESA)
(Size of sample = 0.460 cigarettes)

Elution Zone (incl. lower bound)	AREA COUNTS				ug/cigarettes			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	46449.	25835.	6889.	0.	13.627	7.579	1.942	0.000
C12 to C13	279081.	132166.	53446.	0.	87.608	41.489	16.120	0.000
C13 to C14	198806.	0.	165149.	25551.	62.991	0.000	50.278	7.779
C14 to C15	1477507.	1101119.	1487862.	1302043.	481.150	358.579	465.544	407.403
C15 to C16	360500.	0.	519680.	40531.	117.397	0.000	162.605	12.682
C16 to C17	860365.	195784.	956341.	326242.	297.846	67.778	318.105	108.517
C17 to C18	1084481.	176751.	1055921.	276666.	362.706	59.115	339.322	88.907
C18 to C19	1461950.	547372.	1610808.	565642.	493.240	184.675	522.176	183.364
C19 to C20	1038481.	115564.	1293589.	233694.	362.554	40.346	433.929	78.392
C20 to C21	2089991.	906700.	1767771.	371845.	729.658	316.547	592.992	124.734
C21 to C22	2066243.	704005.	1758688.	313187.	781.986	266.436	639.520	113.886
C22 to C23	1707652.	684868.	1546426.	331150.	646.274	259.194	562.334	120.418
C23 to C24	1428783.	154450.	1642845.	142878.	561.693	60.718	620.550	53.969
C24 to C25	1525472.	142258.	1606044.	169881.	599.704	55.925	606.649	64.169
C25 to C26	1085662.	66604.	1198590.	80343.	480.949	29.506	510.180	34.198
C26 to C27	1060426.	78532.	1119561.	50530.	469.770	34.790	476.541	21.508
C27 to C28	1311380.	295964.	1440971.	346584.	611.721	138.059	645.844	155.339
C28 to C29	914692.	56437.	993290.	46114.	426.677	26.326	445.193	20.668
C29 to C30	1047537.	286630.	1143022.	310140.	534.745	146.318	560.634	152.119
C30 to C31	1101414.	327814.	1245264.	417588.	562.247	167.342	610.782	204.820
C31 to C32	1618221.	958259.	1808693.	1088235.	1006.471	596.000	1080.877	650.330
C32 to C33	936670.	357917.	1009906.	399487.	582.573	222.611	603.521	238.734
C33 to C34	893411.	361175.	1005510.	467023.	581.878	235.233	629.238	292.258
C34 to C35	521806.	136328.	543603.	147727.	339.852	88.790	340.181	92.446
C35 to C36	338381.	51180.	356098.	56345.	273.002	41.292	276.044	43.678
C36 to 120 min	328852.	53465.	396636.	52096.	265.314	43.135	307.468	40.384
TOTAL	26784218.	7917177.	27732606.	7561522.	11733.633	3487.782	11818.572	3310.702

Cigarette Smoke - Replicate Sample

(filename = CIGARETTESA)
(Size of sample = 0.456 cigarettes

Elution Zone	AREA COUNTS				ug/cigarettes			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	59767.	37318.	13577.	0.	15.211	9.498	3.114	0.000
C12 to C13	526303.	327604.	371148.	0.	143.327	89.216	91.085	0.000
C13 to C14	347176.	44865.	383431.	0.	95.429	12.332	94.979	0.000
C14 to C15	2185838.	1739922.	2155962.	1688876.	617.518	491.543	548.886	429.971
C15 to C16	515895.	52710.	726785.	42831.	145.745	14.891	185.032	10.904
C16 to C17	1251979.	448239.	1540686.	504563.	376.000	134.617	416.979	136.557
C17 to C18	1388105.	355237.	1347774.	322467.	402.750	103.070	352.403	84.316
C18 to C19	1734279.	592207.	1894034.	637017.	507.604	173.332	499.579	168.022
C19 to C20	1515194.	161773.	1800563.	302386.	458.906	48.996	491.443	82.533
C20 to C21	2568248.	963468.	2185801.	386999.	777.844	291.805	596.590	105.627
C21 to C22	2520887.	887635.	2191302.	393801.	827.659	291.429	648.351	116.516
C22 to C23	2055698.	784447.	1846774.	347141.	674.928	257.550	546.414	102.710
C23 to C24	1674309.	166527.	1986328.	140946.	571.017	56.793	610.484	43.319
C24 to C25	1945394.	186836.	1932905.	200308.	663.469	63.720	594.064	61.563
C25 to C26	1322816.	84551.	1420857.	78180.	508.376	32.494	492.091	27.076
C26 to C27	1323188.	93627.	1329954.	71220.	508.519	35.982	460.608	24.666
C27 to C28	1470403.	281461.	1536189.	275999.	595.034	113.900	560.222	100.652
C28 to C29	1195131.	142581.	1258699.	132604.	483.639	57.699	459.026	48.358
C29 to C30	1320377.	363140.	1315887.	312238.	584.730	160.817	525.153	124.610
C30 to C31	1219772.	402378.	1374543.	397509.	540.177	178.194	548.562	158.641
C31 to C32	1860900.	1052343.	1984201.	1145214.	1004.078	567.808	964.805	556.853
C32 to C33	1083321.	388957.	1138477.	415388.	584.523	209.868	553.577	201.980
C33 to C34	1123290.	469071.	1212283.	473642.	634.678	265.033	617.270	241.169
C34 to C35	680516.	212573.	667259.	168291.	384.503	120.107	339.755	85.690
C35 to C36	392788.	78043.	399145.	70552.	274.916	54.623	251.757	44.500
C36 to 120 min	408975.	63965.	430637.	56084.	286.245	44.770	271.620	35.374
TOTAL	33690552.	10381478.	34445208.	8564256.	12666.825	3880.086	11723.851	2991.609

Hamburger Meat, Extra-Lean, Charbroiled

(filename = BURGCHXLEANA)
(Size of sample = 142.200 mg meat)

Elution Zone	AREA COUNTS				ug/mg meat			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	80643.	62992.	84720.	66973.	0.026	0.020	0.017	0.014
C12 to C13	217879.	70980.	149749.	85201.	0.076	0.025	0.033	0.019
C13 to C14	211822.	58647.	186743.	37515.	0.074	0.021	0.041	0.008
C14 to C15	225920.	26174.	212442.	40865.	0.081	0.009	0.048	0.009
C15 to C16	222494.	26913.	296274.	56512.	0.080	0.010	0.068	0.013
C16 to C17	296030.	70515.	414372.	176522.	0.113	0.027	0.100	0.043
C17 to C18	360199.	162888.	421885.	177191.	0.133	0.060	0.099	0.042
C18 to C19	272628.	41309.	368031.	94278.	0.102	0.015	0.087	0.022
C19 to C20	240011.	26912.	266483.	26619.	0.093	0.010	0.065	0.007
C20 to C21	396113.	169920.	306854.	37195.	0.153	0.066	0.075	0.009
C21 to C22	474364.	207481.	325080.	79016.	0.198	0.087	0.086	0.021
C22 to C23	332319.	87353.	349161.	27374.	0.139	0.037	0.093	0.007
C23 to C24	242217.	15286.	254597.	6124.	0.105	0.007	0.070	0.002
C24 to C25	239780.	34043.	297338.	61045.	0.104	0.015	0.082	0.017
C25 to C26	191189.	5535.	258305.	18435.	0.094	0.003	0.080	0.006
C26 to C27	195674.	5230.	310834.	83936.	0.096	0.003	0.096	0.026
C27 to C28	157418.	7422.	251399.	10359.	0.081	0.004	0.082	0.003
C28 to C29	136789.	0.	244405.	0.	0.071	0.000	0.080	0.000
C29 to C30	108357.	0.	207015.	0.	0.061	0.000	0.074	0.000
C30 to C31	121367.	1048.	175077.	10463.	0.068	0.001	0.063	0.004
C31 to C32	95685.	7101.	164835.	9517.	0.066	0.005	0.072	0.004
C32 to C33	86411.	4135.	140555.	3949.	0.059	0.003	0.061	0.002
C33 to C34	83566.	4714.	165852.	25153.	0.060	0.003	0.076	0.011
C34 to C35	52544.	0.	137435.	1680.	0.038	0.000	0.063	0.001
C35 to C36	35953.	4665.	106824.	1028.	0.032	0.004	0.060	0.001
C36 to 80 min	24662.	1815.	43262.	0.	0.022	0.002	0.024	0.000
TOTAL	5102034.	1103078.	6139527.	1136950.	2.226	0.435	1.796	0.290

Hamburger Meat, Regular, Charbroiled

(filename = BURGCHREGA)
(Size of sample = 143.800 mg meat)

Elution Zone	AREA COUNTS				ug/mg meat			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	83832.	78835.	3518.	0.	0.033	0.031	0.001	0.000
C12 to C13	143204.	80148.	171374.	137572.	0.060	0.034	0.055	0.045
C13 to C14	137899.	35801.	127979.	33188.	0.058	0.015	0.042	0.011
C14 to C15	176929.	37762.	208249.	40233.	0.077	0.016	0.070	0.014
C15 to C16	246109.	23491.	228334.	4200.	0.107	0.010	0.077	0.001
C16 to C17	321647.	28852.	318182.	16311.	0.148	0.013	0.114	0.006
C17 to C18	439389.	114100.	409600.	35792.	0.196	0.051	0.141	0.012
C18 to C19	419592.	27361.	482930.	53236.	0.189	0.012	0.168	0.019
C19 to C20	424003.	89195.	429619.	36251.	0.197	0.042	0.155	0.013
C20 to C21	1171237.	641852.	601940.	40103.	0.545	0.299	0.217	0.014
C21 to C22	1425797.	861946.	890277.	405425.	0.719	0.435	0.348	0.158
C22 to C23	917778.	353184.	729471.	111112.	0.463	0.178	0.285	0.043
C23 to C24	666799.	70659.	930055.	219676.	0.349	0.037	0.377	0.089
C24 to C25	943634.	196788.	832516.	97079.	0.494	0.103	0.338	0.039
C25 to C26	578691.	29938.	730000.	38728.	0.342	0.018	0.334	0.018
C26 to C27	742444.	151251.	767103.	128739.	0.438	0.089	0.351	0.059
C27 to C28	594370.	13702.	665116.	15801.	0.370	0.009	0.320	0.008
C28 to C29	574172.	10432.	647803.	12968.	0.357	0.006	0.312	0.006
C29 to C30	501374.	0.	615285.	0.	0.341	0.000	0.324	0.000
C30 to C31	444994.	24717.	491997.	8806.	0.303	0.017	0.259	0.005
C31 to C32	386781.	29921.	435116.	49162.	0.321	0.025	0.279	0.032
C32 to C33	354859.	27783.	409260.	29066.	0.294	0.023	0.263	0.019
C33 to C34	343724.	51123.	380441.	66727.	0.298	0.044	0.256	0.045
C34 to C35	273110.	12709.	305741.	21313.	0.237	0.011	0.205	0.014
C35 to C36	237738.	6478.	245082.	9357.	0.256	0.007	0.204	0.008
C36 to 80 min	187616.	0.	195189.	0.	0.202	0.000	0.162	0.000
TOTAL	12737722.	2998028.	12252177.	1610845.	7.395	1.525	5.654	0.677

Hamburger Meat, Fried

(filename = BURGFRA)
(Size of sample = 293.200 mg meat)

Elution Zone	AREA COUNTS				ug/mg meat			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	63936.	40521.	72388.	48742.	0.008	0.005	0.007	0.005
C12 to C13	202901.	67843.	195414.	64247.	0.027	0.009	0.019	0.006
C13 to C14	169165.	32774.	191802.	41678.	0.022	0.004	0.019	0.004
C14 to C15	157949.	6350.	228895.	97179.	0.022	0.001	0.023	0.010
C15 to C16	155533.	16279.	235707.	53798.	0.021	0.002	0.024	0.006
C16 to C17	179965.	13911.	216629.	62379.	0.026	0.002	0.024	0.007
C17 to C18	172877.	23641.	213450.	37008.	0.024	0.003	0.022	0.004
C18 to C19	222167.	63378.	256780.	80013.	0.031	0.009	0.027	0.009
C19 to C20	174523.	31775.	212804.	41865.	0.026	0.005	0.023	0.005
C20 to C21	284702.	79248.	285837.	47534.	0.042	0.012	0.031	0.005
C21 to C22	270884.	73201.	270162.	42763.	0.043	0.012	0.032	0.005
C22 to C23	215621.	35456.	222402.	3337.	0.034	0.006	0.027	0.000
C23 to C24	160579.	8703.	192012.	13683.	0.026	0.001	0.024	0.002
C24 to C25	157218.	17100.	171132.	18645.	0.026	0.003	0.021	0.002
C25 to C26	113459.	5653.	148891.	10039.	0.021	0.001	0.021	0.001
C26 to C27	114166.	12687.	142798.	20306.	0.021	0.002	0.020	0.003
C27 to C28	106703.	13674.	127242.	19287.	0.021	0.003	0.019	0.003
C28 to C29	75029.	0.	101254.	0.	0.015	0.000	0.015	0.000
C29 to C30	70791.	0.	89992.	0.	0.015	0.000	0.014	0.000
C30 to C31	57899.	977.	67360.	4662.	0.012	0.000	0.011	0.001
C31 to C32	60442.	5137.	65892.	5517.	0.016	0.001	0.013	0.001
C32 to C33	48716.	1470.	41999.	3692.	0.013	0.000	0.008	0.001
C33 to C34	25768.	1849.	54269.	11418.	0.007	0.001	0.011	0.002
C34 to C35	14287.	0.	13517.	0.	0.004	0.000	0.003	0.000
C35 to C36	11821.	1382.	14666.	0.	0.004	0.000	0.004	0.000
C36 to 80 min	8821.	0.	2924.	0.	0.003	0.000	0.001	0.000
TOTAL	3295922.	553009.	3836218.	727792.	0.531	0.082	0.464	0.081

Brake Lining Wear

(filename = BRAKEDUSTA)
(Size of sample = 32.298 mg brake d)

Elution Zone	AREA COUNTS				ug/mg brake d			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	29158.	20445.	11921.	1947.	0.041	0.029	0.020	0.003
C12 to C13	80526.	39263.	64080.	8453.	0.121	0.059	0.114	0.015
C13 to C14	87350.	38730.	69409.	18049.	0.132	0.059	0.124	0.032
C14 to C15	92174.	31755.	93254.	28909.	0.143	0.049	0.172	0.053
C15 to C16	95278.	19267.	72345.	4128.	0.148	0.030	0.133	0.008
C16 to C17	91089.	19919.	80200.	26798.	0.150	0.033	0.157	0.052
C17 to C18	101466.	44736.	82317.	20666.	0.162	0.071	0.156	0.039
C18 to C19	78555.	20552.	74622.	19063.	0.126	0.033	0.142	0.036
C19 to C20	80799.	9922.	68705.	4730.	0.135	0.017	0.136	0.009
C20 to C21	128567.	40815.	83300.	11035.	0.214	0.068	0.164	0.022
C21 to C22	155653.	53918.	109346.	29584.	0.281	0.097	0.234	0.063
C22 to C23	154416.	36145.	103309.	11116.	0.279	0.065	0.221	0.024
C23 to C24	128399.	12335.	91687.	2590.	0.241	0.023	0.204	0.006
C24 to C25	135008.	11854.	100921.	3782.	0.253	0.022	0.224	0.008
C25 to C26	126223.	8787.	88000.	4582.	0.267	0.019	0.220	0.011
C26 to C27	128340.	5315.	91907.	8552.	0.271	0.011	0.230	0.021
C27 to C28	109457.	5715.	87205.	6503.	0.244	0.013	0.230	0.017
C28 to C29	99202.	1894.	67131.	1701.	0.221	0.004	0.177	0.004
C29 to C30	85813.	1086.	65563.	2767.	0.209	0.003	0.189	0.008
C30 to C31	75890.	7332.	48291.	0.	0.185	0.018	0.139	0.000
C31 to C32	66438.	7831.	35576.	2465.	0.197	0.023	0.125	0.009
C32 to C33	56920.	3667.	37981.	3609.	0.169	0.011	0.134	0.013
C33 to C34	28287.	2592.	16414.	2525.	0.088	0.008	0.060	0.009
C34 to C35	11231.	0.	8801.	0.	0.035	0.000	0.032	0.000
C35 to C36	6490.	2998.	6502.	2233.	0.025	0.012	0.030	0.010
C36 to 80 min	2535.	0.	5819.	0.	0.010	0.000	0.027	0.000
TOTAL	2235264.	446873.	1664606.	225787.	4.347	0.776	3.796	0.475

Dilution Air for Natural Gas Home Appliances

(filename = 06BLANK123A)
(Size of sample = 15.344 kkJoules)

Elution Zone	AREA COUNTS				ug/kkJoules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	48378.	19420.	25806.	12197.	0.073	0.029	0.038	0.018
C12 to C13	176883.	44176.	116112.	32488.	0.284	0.071	0.181	0.051
C13 to C14	149395.	45119.	123072.	46829.	0.242	0.073	0.194	0.074
C14 to C15	158644.	28503.	117984.	28440.	0.264	0.047	0.191	0.046
C15 to C16	185122.	71338.	160818.	74941.	0.308	0.119	0.261	0.121
C16 to C17	214051.	65533.	168868.	78309.	0.379	0.116	0.291	0.135
C17 to C18	270040.	127890.	214649.	106972.	0.462	0.219	0.357	0.178
C18 to C19	173103.	59713.	151190.	54216.	0.298	0.103	0.254	0.091
C19 to C20	183961.	25618.	137407.	33280.	0.328	0.046	0.239	0.058
C20 to C21	176390.	31137.	169380.	31800.	0.315	0.056	0.294	0.055
C21 to C22	286326.	82839.	211130.	77309.	0.554	0.160	0.398	0.146
C22 to C23	196813.	47681.	203073.	52316.	0.381	0.092	0.382	0.098
C23 to C24	201545.	6974.	128126.	6284.	0.405	0.014	0.251	0.012
C24 to C25	129749.	5005.	108723.	4565.	0.261	0.010	0.213	0.009
C25 to C26	113294.	4974.	99494.	6009.	0.257	0.011	0.219	0.013
C26 to C27	118754.	8561.	92366.	8680.	0.269	0.019	0.204	0.019
C27 to C28	96816.	11339.	78667.	9878.	0.231	0.027	0.183	0.023
C28 to C29	80150.	0.	71954.	0.	0.191	0.000	0.167	0.000
C29 to C30	59405.	0.	61181.	0.	0.155	0.000	0.155	0.000
C30 to C31	61692.	0.	56161.	0.	0.161	0.000	0.143	0.000
C31 to C32	69012.	2777.	58943.	4887.	0.219	0.009	0.182	0.015
C32 to C33	102257.	4233.	93148.	15056.	0.325	0.013	0.288	0.047
C33 to C34	61961.	3798.	77720.	7484.	0.206	0.013	0.252	0.024
C34 to C35	25428.	0.	49450.	0.	0.085	0.000	0.160	0.000
C35 to C36	13094.	2446.	27018.	8118.	0.054	0.010	0.108	0.033
C36 to 80 min	18665.	0.	34027.	18775.	0.077	0.000	0.137	0.075
TOTAL	3370928.	699074.	2836467.	718833.	6.782	1.257	5.740	1.341

Natural Gas Home Appliances, Backup Filters

(filename = HOMEAPPLGASPHA)
(Size of sample = 4.618 kk Joules)

Elution Zone	AREA COUNTS				ug/kk Joules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	26810.	16369.	3844.	3551.	0.142	0.087	0.018	0.016
C12 to C13	103339.	40861.	18708.	10920.	0.588	0.232	0.093	0.054
C13 to C14	66112.	18715.	11298.	5405.	0.379	0.107	0.057	0.027
C14 to C15	73078.	17953.	28571.	15167.	0.431	0.106	0.147	0.078
C15 to C16	124899.	64684.	80913.	52950.	0.737	0.382	0.416	0.272
C16 to C17	81426.	32828.	34728.	17297.	0.511	0.206	0.190	0.095
C17 to C18	66498.	18791.	43537.	20326.	0.403	0.114	0.230	0.107
C18 to C19	74179.	28452.	44673.	19868.	0.453	0.174	0.238	0.106
C19 to C20	54341.	16584.	37924.	15977.	0.344	0.105	0.209	0.088
C20 to C21	67252.	13546.	45703.	9673.	0.425	0.086	0.252	0.053
C21 to C22	95522.	38738.	84256.	42054.	0.655	0.266	0.504	0.251
C22 to C23	80873.	24555.	70494.	21771.	0.554	0.168	0.421	0.130
C23 to C24	188354.	121262.	218077.	161595.	1.341	0.863	1.354	1.003
C24 to C25	69154.	15603.	67084.	13189.	0.492	0.111	0.417	0.082
C25 to C26	62084.	7408.	66844.	5564.	0.498	0.059	0.468	0.039
C26 to C27	73746.	28983.	86701.	24244.	0.592	0.233	0.607	0.170
C27 to C28	196974.	151068.	197051.	133053.	1.664	1.276	1.452	0.980
C28 to C29	47848.	0.	65144.	0.	0.404	0.000	0.480	0.000
C29 to C30	48142.	3292.	62537.	4534.	0.445	0.030	0.504	0.037
C30 to C31	32155.	0.	50660.	709.	0.297	0.000	0.408	0.006
C31 to C32	35405.	5648.	52024.	5248.	0.399	0.064	0.511	0.052
C32 to C33	49967.	4866.	84496.	4456.	0.563	0.055	0.830	0.044
C33 to C34	37949.	4400.	68323.	2627.	0.448	0.052	0.703	0.027
C34 to C35	21614.	0.	50845.	0.	0.255	0.000	0.523	0.000
C35 to C36	17853.	4779.	37234.	2716.	0.261	0.070	0.475	0.035
C36 to 80 min	14980.	4292.	14070.	1044.	0.219	0.063	0.179	0.013
TOTAL	1810554.	683677.	1625739.	593938.	13.501	4.908	11.685	3.766

Natural Gas Home Appliances

(filename = HOMEAPPLA)
(Size of sample = 14.352 kk Joules)

Elution Zone	AREA COUNTS				ug/kk Joules			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	47343.	18571.	29158.	0.	0.119	0.047	0.068	0.000
C12 to C13	188496.	22692.	129200.	7492.	0.509	0.061	0.323	0.019
C13 to C14	154092.	0.	123336.	0.	0.420	0.000	0.312	0.000
C14 to C15	194576.	0.	249437.	81661.	0.545	0.000	0.648	0.212
C15 to C16	201557.	20925.	183477.	0.	0.564	0.059	0.476	0.000
C16 to C17	260411.	29882.	272866.	27922.	0.775	0.089	0.753	0.077
C17 to C18	304273.	52568.	375994.	111320.	0.875	0.151	1.003	0.297
C18 to C19	316562.	53259.	387649.	52253.	0.918	0.154	1.043	0.141
C19 to C20	276220.	0.	380986.	45249.	0.829	0.000	1.060	0.126
C20 to C21	415265.	75607.	477402.	38562.	1.246	0.227	1.329	0.107
C21 to C22	489329.	127381.	696576.	237189.	1.592	0.414	2.102	0.716
C22 to C23	1158546.	800251.	2273646.	1711987.	3.769	2.603	6.861	5.166
C23 to C24	1145380.	704968.	2055231.	1229327.	3.871	2.382	6.442	3.853
C24 to C25	625630.	122597.	877614.	266566.	2.114	0.414	2.751	0.836
C25 to C26	437510.	23432.	514066.	70668.	1.666	0.089	1.816	0.250
C26 to C27	485854.	163220.	555362.	200838.	1.850	0.622	1.962	0.709
C27 to C28	1920120.	1600971.	2297890.	1968859.	7.699	6.420	8.546	7.322
C28 to C29	223153.	0.	254360.	36300.	0.895	0.000	0.946	0.135
C29 to C30	238301.	0.	283703.	0.	1.046	0.000	1.155	0.000
C30 to C31	277674.	96596.	187057.	13278.	1.218	0.424	0.761	0.054
C31 to C32	236513.	157657.	338935.	226712.	1.265	0.843	1.681	1.124
C32 to C33	146218.	58356.	166784.	80446.	0.782	0.312	0.827	0.399
C33 to C34	67064.	3964.	75994.	7260.	0.375	0.022	0.395	0.038
C34 to C35	47180.	0.	55943.	0.	0.264	0.000	0.290	0.000
C35 to C36	30924.	2332.	38590.	3713.	0.214	0.016	0.248	0.024
C36 to 80 min	22776.	0.	18597.	0.	0.158	0.000	0.120	0.000
TOTAL	9910967.	4135229.	13299853.	6417602.	35.578	15.350	43.916	21.604

Vegetative Detritus, Green Leaves

(filename = VEGGREENA)
(Size of sample = 2.379 mg veg.det)

Elution Zone	AREA COUNTS				ug/mg veg.det			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	21614.	9711.	17222.	4293.	0.608	0.273	0.497	0.124
C12 to C13	165404.	106399.	199240.	119576.	4.980	3.203	6.150	3.691
C13 to C14	101574.	44961.	117465.	31933.	3.087	1.366	3.660	0.995
C14 to C15	73661.	14168.	93862.	32308.	2.301	0.443	3.006	1.035
C15 to C16	92244.	21145.	101666.	30019.	2.881	0.660	3.255	0.961
C16 to C17	71001.	11878.	75560.	15957.	2.357	0.394	2.572	0.543
C17 to C18	92482.	42529.	76663.	30957.	2.967	1.364	2.521	1.018
C18 to C19	64171.	19572.	75434.	33873.	2.076	0.633	2.503	1.124
C19 to C20	41915.	10684.	48416.	1528.	1.403	0.358	1.662	0.052
C20 to C21	70818.	29436.	60783.	10569.	2.371	0.986	2.087	0.363
C21 to C22	52313.	14100.	50295.	9175.	1.899	0.512	1.872	0.341
C22 to C23	40011.	11149.	48448.	7786.	1.452	0.405	1.803	0.290
C23 to C24	39544.	1818.	57771.	2949.	1.491	0.069	2.233	0.114
C24 to C25	35030.	3361.	49508.	2524.	1.321	0.127	1.914	0.098
C25 to C26	45484.	10202.	56968.	6765.	1.933	0.433	2.482	0.295
C26 to C27	44853.	10913.	62178.	13964.	1.906	0.464	2.708	0.608
C27 to C28	63400.	29024.	88115.	28191.	2.836	1.298	4.042	1.293
C28 to C29	45231.	12069.	72788.	17617.	2.024	0.540	3.339	0.808
C29 to C30	154286.	119258.	167363.	109943.	7.554	5.839	8.401	5.519
C30 to C31	68730.	17195.	77920.	19283.	3.365	0.842	3.911	0.968
C31 to C32	235231.	193348.	241818.	174639.	14.032	11.533	14.789	10.680
C32 to C33	77944.	36181.	93317.	36779.	4.649	2.158	5.707	2.249
C33 to C34	130010.	87075.	127267.	73233.	8.121	5.439	8.150	4.690
C34 to C35	49161.	10915.	33151.	3758.	3.071	0.682	2.123	0.241
C35 to C36	47584.	14019.	33015.	10575.	3.682	1.085	2.619	0.839
C36 to 80 min	46353.	3099.	22268.	2084.	3.587	0.240	1.767	0.165
TOTAL	1970049.	884209.	2148501.	830278.	87.953	41.346	95.771	39.104

Vegetative Det., Green Leaves - Replicate Sample

(filename = PVEGGREENA)
(Size of sample = 1.438 mg veg.det)

Elution Zone	AREA COUNTS				ug/mg veg.det			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	25223.	1962.	24865.	10429.	0.814	0.063	0.861	0.361
C12 to C13	327377.	262426.	376659.	282131.	11.307	9.064	13.952	10.451
C13 to C14	118863.	59143.	135822.	62896.	4.144	2.062	5.078	2.352
C14 to C15	86977.	24399.	106863.	38079.	3.116	0.874	4.106	1.463
C15 to C16	116927.	42554.	109083.	37247.	4.189	1.525	4.192	1.431
C16 to C17	91945.	33431.	95857.	28855.	3.502	1.273	3.916	1.179
C17 to C18	126166.	73757.	135301.	76540.	4.643	2.714	5.340	3.021
C18 to C19	100686.	46479.	97542.	39010.	3.738	1.725	3.883	1.553
C19 to C20	53783.	9289.	61859.	6581.	2.066	0.357	2.548	0.271
C20 to C21	77795.	32060.	54108.	3218.	2.988	1.231	2.229	0.133
C21 to C22	55880.	13049.	46911.	6347.	2.327	0.543	2.095	0.283
C22 to C23	38424.	6592.	36066.	776.	1.600	0.274	1.611	0.035
C23 to C24	38684.	2637.	35567.	1310.	1.673	0.114	1.650	0.061
C24 to C25	39473.	2230.	34034.	2352.	1.707	0.096	1.579	0.109
C25 to C26	37921.	5934.	33673.	5534.	1.848	0.289	1.760	0.289
C26 to C27	38645.	8655.	37417.	9547.	1.884	0.422	1.956	0.499
C27 to C28	45800.	16729.	49928.	23918.	2.351	0.859	2.748	1.317
C28 to C29	50836.	13102.	39738.	7970.	2.609	0.672	2.187	0.439
C29 to C30	122699.	84202.	150703.	122254.	6.891	4.729	9.078	7.364
C30 to C31	86065.	37962.	64661.	23142.	4.834	2.132	3.895	1.394
C31 to C32	182326.	148107.	225626.	191980.	12.477	10.135	16.559	14.090
C32 to C33	95457.	51535.	81077.	35438.	6.532	3.527	5.950	2.601
C33 to C34	110026.	73881.	114867.	83637.	7.884	5.294	8.828	6.428
C34 to C35	41594.	13835.	23457.	3669.	2.981	0.991	1.803	0.282
C35 to C36	49836.	18587.	52696.	20035.	4.424	1.650	5.017	1.907
C36 to 80 min	53758.	13109.	24646.	3887.	4.772	1.164	2.346	0.370
TOTAL	2213166.	1095646.	2249026.	1126782.	107.300	53.781	115.168	59.682

Vegetative Detritus, Dead Leaves

(filename = VEGDEADA)
(Size of sample = 4.152 mg veg.det)

	AREA COUNTS				ug/mg veg.det			
Elution Zone	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	12444.	8165.	3250.	1686.	0.321	0.211	0.092	0.048
C12 to C13	80552.	55531.	72898.	43803.	2.226	1.535	2.215	1.331
C13 to C14	39598.	15217.	41113.	14898.	1.105	0.424	1.261	0.457
C14 to C15	22103.	0.	20766.	2339.	0.634	0.000	0.654	0.074
C15 to C16	30240.	1699.	30090.	1671.	0.867	0.049	0.948	0.053
C16 to C17	27606.	0.	21752.	1775.	0.841	0.000	0.729	0.059
C17 to C18	44433.	20221.	27745.	10243.	1.308	0.595	0.898	0.332
C18 to C19	33768.	9329.	28994.	14660.	1.003	0.277	0.947	0.479
C19 to C20	28161.	5425.	19088.	747.	0.866	0.167	0.645	0.025
C20 to C21	38290.	12044.	25805.	3488.	1.177	0.370	0.872	0.118
C21 to C22	36284.	10476.	24239.	4006.	1.209	0.349	0.888	0.147
C22 to C23	29889.	5008.	24733.	1515.	0.996	0.167	0.906	0.055
C23 to C24	25230.	1290.	29534.	2298.	0.873	0.045	1.124	0.087
C24 to C25	30743.	6141.	30106.	2412.	1.064	0.213	1.145	0.092
C25 to C26	33371.	6908.	35774.	4341.	1.301	0.269	1.534	0.186
C26 to C27	40508.	10641.	42893.	8719.	1.580	0.415	1.839	0.374
C27 to C28	54020.	21975.	53876.	20412.	2.218	0.902	2.432	0.921
C28 to C29	43293.	15501.	51902.	14183.	1.778	0.637	2.343	0.640
C29 to C30	162059.	134286.	153375.	118507.	7.283	6.035	7.577	5.855
C30 to C31	62014.	27274.	49638.	15053.	2.787	1.226	2.452	0.744
C31 to C32	227839.	191495.	199642.	162648.	12.475	10.485	12.017	9.790
C32 to C33	94231.	54876.	57647.	25444.	5.159	3.005	3.470	1.532
C33 to C34	154002.	116756.	116999.	87690.	8.830	6.694	7.375	5.527
C34 to C35	60698.	27380.	14559.	1067.	3.480	1.570	0.918	0.067
C35 to C36	75024.	36491.	25784.	21822.	5.329	2.592	2.013	1.704
C36 to 80 min	65860.	29369.	3321.	0.	4.678	2.086	0.259	0.000
TOTAL	1552260.	823498.	1205523.	585427.	71.387	40.316	57.553	30.696

Vegetative Det., Dead Leaves - Replicate Sample

(filename = PVEGDEADA)
(Size of sample = 1.505 mg veg.det)

Elution Zone	AREA COUNTS				ug/mg veg.det			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	17544.	7860.	15845.	8599.	0.578	0.259	0.392	0.213
C12 to C13	144256.	95921.	181116.	140063.	5.085	3.381	4.799	3.711
C13 to C14	92553.	48578.	107966.	80640.	3.293	1.728	2.887	2.157
C14 to C15	44526.	3307.	44618.	6417.	1.628	0.121	1.226	0.176
C15 to C16	52149.	3745.	53672.	21841.	1.907	0.137	1.475	0.600
C16 to C17	42753.	2528.	55561.	22289.	1.662	0.098	1.623	0.651
C17 to C18	61922.	23081.	85252.	53534.	2.326	0.867	2.407	1.511
C18 to C19	58156.	25480.	72990.	39592.	2.203	0.965	2.079	1.127
C19 to C20	31901.	4562.	41590.	5819.	1.251	0.179	1.226	0.171
C20 to C21	47726.	21439.	44037.	9626.	1.871	0.840	1.298	0.284
C21 to C22	39981.	14092.	40691.	10310.	1.699	0.599	1.300	0.329
C22 to C23	26516.	3242.	33648.	3276.	1.127	0.138	1.075	0.105
C23 to C24	30372.	1622.	43069.	8421.	1.341	0.072	1.429	0.279
C24 to C25	25932.	2451.	31764.	2156.	1.145	0.108	1.054	0.072
C25 to C26	28390.	5048.	40560.	7154.	1.412	0.251	1.517	0.267
C26 to C27	32633.	9043.	53706.	16923.	1.623	0.450	2.008	0.633
C27 to C28	43368.	17767.	78891.	34060.	2.272	0.931	3.106	1.341
C28 to C29	36396.	7512.	67423.	13866.	1.906	0.393	2.655	0.546
C29 to C30	140029.	108199.	258535.	205012.	8.027	6.202	11.139	8.833
C30 to C31	52447.	17939.	94968.	25307.	3.006	1.028	4.092	1.090
C31 to C32	196998.	169963.	373364.	315556.	13.758	11.870	19.600	16.565
C32 to C33	82827.	40420.	134792.	69919.	5.785	2.823	7.076	3.670
C33 to C34	138054.	96446.	279066.	196984.	10.097	7.054	15.341	10.829
C34 to C35	47562.	16124.	76109.	8937.	3.478	1.179	4.184	0.491
C35 to C36	55582.	19060.	144072.	68132.	5.035	1.727	9.811	4.640
C36 to 80 min	55890.	7857.	62774.	23225.	5.063	0.712	4.275	1.582
TOTAL	1626463.	773286.	2516079.	1397658.	88.578	44.113	109.072	61.875

Pasadena-Area Paved Road Dust

(filename = ROADDUSTA)
(Size of sample = 13.402 mg road du)

Elution Zone	AREA COUNTS				ug/mg road du			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	11735.	9433.	9512.	3613.	0.059	0.047	0.057	0.022
C12 to C13	231208.	205904.	251668.	201687.	1.240	1.105	1.603	1.285
C13 to C14	32005.	7354.	48237.	6164.	0.173	0.040	0.310	0.040
C14 to C15	46028.	5126.	53590.	7556.	0.256	0.029	0.354	0.050
C15 to C16	53172.	5524.	79086.	0.	0.296	0.031	0.523	0.000
C16 to C17	54393.	2156.	52414.	4387.	0.322	0.013	0.368	0.031
C17 to C18	93344.	32410.	67951.	11109.	0.533	0.185	0.461	0.075
C18 to C19	48256.	5886.	64518.	11075.	0.278	0.034	0.442	0.076
C19 to C20	60729.	11179.	62438.	1758.	0.362	0.067	0.442	0.012
C20 to C21	167313.	94602.	80850.	4404.	0.998	0.564	0.573	0.031
C21 to C22	192092.	87207.	112136.	6574.	1.242	0.564	0.861	0.050
C22 to C23	187382.	50287.	138644.	8003.	1.212	0.325	1.065	0.061
C23 to C24	180726.	14226.	197220.	6802.	1.214	0.096	1.573	0.054
C24 to C25	248184.	17507.	227030.	9613.	1.667	0.118	1.811	0.077
C25 to C26	238181.	23753.	266845.	8609.	1.803	0.180	2.399	0.077
C26 to C27	260579.	14177.	281476.	7228.	1.973	0.107	2.530	0.065
C27 to C28	301265.	19006.	292712.	17877.	2.401	0.152	2.771	0.169
C28 to C29	247679.	10375.	294792.	3880.	1.974	0.083	2.790	0.037
C29 to C30	301085.	17092.	318474.	17561.	2.626	0.149	3.299	0.182
C30 to C31	262762.	15236.	291789.	14342.	2.292	0.133	3.022	0.149
C31 to C32	277363.	34080.	330230.	25852.	2.948	0.362	4.168	0.326
C32 to C33	210723.	27477.	264771.	20868.	2.240	0.292	3.342	0.263
C33 to C34	201872.	33769.	293374.	27315.	2.247	0.376	3.877	0.361
C34 to C35	115281.	3416.	228500.	1895.	1.283	0.038	3.020	0.025
C35 to C36	63936.	9777.	220621.	4911.	0.881	0.135	3.612	0.080
C36 to 80 min	7342.	0.	244032.	0.	0.101	0.000	3.995	0.000
TOTAL	4094635.	756959.	4772910.	433083.	32.624	5.223	49.267	3.599

Pasadena-Area Paved Road Dust - Replicate Sample

(filename = PROADDUSTA)
(Size of sample = 15.457 mg road du)

Elution Zone	AREA COUNTS				ug/mg road du			
	Acid+Neutral		Neutral		Acid+Neutral		Neutral	
(incl. lower bound)	Total	Resolved	Total	Resolved	Total	Resolved	Total	Resolved
16 min to C12	30793.	28992.	13437.	6530.	0.085	0.080	0.043	0.021
C12 to C13	255036.	239416.	247461.	209104.	0.749	0.704	0.852	0.720
C13 to C14	45376.	13542.	22759.	0.	0.135	0.040	0.079	0.000
C14 to C15	37925.	9654.	16650.	0.	0.116	0.029	0.059	0.000
C15 to C16	53055.	12289.	21986.	0.	0.162	0.037	0.079	0.000
C16 to C17	61721.	26237.	13852.	7242.	0.200	0.085	0.053	0.028
C17 to C18	114279.	58062.	33862.	18185.	0.358	0.182	0.124	0.067
C18 to C19	79792.	21202.	46814.	17414.	0.252	0.067	0.173	0.064
C19 to C20	50404.	2435.	49626.	2237.	0.165	0.008	0.190	0.009
C20 to C21	298698.	174833.	85755.	9869.	0.976	0.571	0.328	0.038
C21 to C22	351782.	194003.	146159.	24670.	1.246	0.687	0.607	0.102
C22 to C23	322565.	111652.	180363.	13587.	1.143	0.396	0.749	0.056
C23 to C24	312632.	23716.	299635.	20008.	1.150	0.087	1.292	0.086
C24 to C25	389273.	42681.	312612.	19850.	1.432	0.157	1.348	0.086
C25 to C26	444359.	38492.	385975.	13179.	1.843	0.160	1.876	0.064
C26 to C27	452435.	44000.	411847.	22491.	1.876	0.182	2.001	0.109
C27 to C28	509965.	37733.	458648.	31896.	2.227	0.165	2.347	0.163
C28 to C29	481988.	22371.	418859.	7416.	2.105	0.098	2.143	0.038
C29 to C30	514142.	49078.	486539.	33646.	2.457	0.235	2.725	0.188
C30 to C31	458449.	35051.	442449.	29546.	2.191	0.167	2.478	0.165
C31 to C32	478144.	49032.	478597.	61837.	2.784	0.285	3.265	0.422
C32 to C33	475562.	64530.	384895.	38659.	2.769	0.376	2.626	0.264
C33 to C34	414206.	58378.	418000.	70515.	2.525	0.356	2.986	0.504
C34 to C35	313231.	21956.	312762.	14135.	1.910	0.134	2.235	0.101
C35 to C36	250617.	8909.	246862.	14993.	1.893	0.067	2.185	0.133
C36 to 80 min	182220.	10077.	148771.	7840.	1.376	0.076	1.317	0.069
TOTAL	7378649.	1398321.	6085175.	694849.	34.122	5.431	34.161	3.498