Determination of Particle Size Distribution and Chemical Composition of Particulate Matter from Selected Sources in California

Volume I
(Final Report)

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Abstract

Source sampling was conducted on forty particulate sources in the Great Basin Valleys, San Joaquin Valley, and Southeast Desert Air Basins. Chemical source profiles were developed for each of the sources in seven size categories. The seven size categories were $<1\mu$, 1μ to 2.5μ, $<2.5\mu$, 2.5μ to 10μ, $<10\mu$, $>10\mu$, and TSP. Chemical analyses were conducted for forty-three chemical species and mass. The chemical profile data have been reported in hard copy and on floppy disks in formats compatible with standard receptor and dispersion model input requirements.

The source sampling was conducted using several specialized sampling approaches and instruments. These included: (1) a ground-based parallel impactor sampling device (PISD); (2) an industrial dilution source sampler (DSS); (3) paved road dust sample collection with a high-volume road dust sampler or hand broom followed by laboratory resuspension in a custom resuspension system; (4) soil, unpaved road, and bulk material dust grab sampling followed by laboratory resuspension in the custom resuspension system; and (5) a modified Method 5G-type dilution tunnel for residential wood combustion (RWC) sampling. The RWC sampling was conducted in the laboratory under simulated burning conditions characteristic of the geographical area of interest. Impactors with cut-points of 1μ, 2.5μ, and 10μ were used for size characterization in the PISD, DSS, resuspension chamber, and modified Method 5G-type sampler. One channel in each device had no impactor in place, in order to collect the total suspended particle fraction (TSP).

Analyses were conducted for forty-three chemical species and mass on each of 593 filters. X-ray fluorescence spectrometric analysis was conducted on the Teflon filters for thirty-six elements. The particulate deposit mass was also determined from the Teflon filters with an electrobalance. Sections were removed from the quartz filters for ion chromatographic analysis, thermal/optical analysis, and automated colorimetric analysis. Water-soluble sodium and potassium were determined by atomic absorption spectrophotometry. Elemental carbon, carbonate carbon, and organic carbon were determined by the thermal/optical reflectance technique. Sulfate and nitrate were determined by ion chromatography. Ammonium was determined by automated colorimetry. The chemical data from each of the analytical procedures were merged to produce a single tabulation or profile with associated uncertainties for each size category for each source.

The sources for which source profiles have been determined include: agricultural soils, unpaved road dust, sand and cinder storage dust, alkaline desert soils, alkaline playa dust, unpaved urban area dust, paved road dust, diesel truck emissions, ski tour bus emissions (Mammoth Lakes), oil field crude oil combustion emissions, agricultural field burning emissions, dairy/feedlot emissions, and residential wood combustion emissions. The profiles that have been developed for these sources provide properly formatted state-of-the-art data for air quality modeling by receptor and dispersion models in the Great Basin Valleys, San Joaquin Valley, and Southeast Desert Air Basins.

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1.0 Introduction

1.1 Background

In December 1982, the California Air Resources Board (ARB) adopted a state ambient air quality standard for suspended particulate matter less than ten microns ($<10\mu$) in diameter. In July 1987, the U.S. Environmental Protection Agency (EPA) promulgated a national ambient air quality standard for fine particulate matter (PM_{10}) (U.S. Environmental Protection Agency, 1987b). Significant portions of the Great Basin Valleys, the San Joaquin Valley, and the Southeast Desert Air Basins are not in compliance with the state and federal PM_{10} standards. Thus, state implementation plans (SIPs) will need to be prepared, revised, or have their success evaluated for those areas (Ipps, 1987).

Receptor modeling is an extremely useful tool for determining the sources of ambient particulate material. The ARB plans to utilize receptor modeling techniques to generate valuable information for the preparation, revision, or evaluation of the SIPs.

In order to conduct chemical mass balance (CMB) receptor modeling (one of the most useful receptor models), detailed chemical analyses need to be conducted on both ambient and source samples. Ambient monitoring and subsequent filter analysis are relatively simple and routine, and are in progress or are completed at a number of monitoring locations. Source sampling and analysis, on the other hand, frequently require custom instrumentation and procedures.

Recognizing the need for source data, the ARB issued a request for proposal (RFP) on December 12, 1986 entitled "Determination of Particle Size Distributions and Chemical Composition of Particulate Matter from Selected Sources in California." OMNI Environmental Services, Inc. (OMNI), with the Desert Research Institute (DRI) as a major subcontractor, responded and was awarded the contract on June 3, 1987. This report presents the results of the work conducted under the contract.

The characterization of four size ranges of particles was specified in the RFP. The size ranges were: (1) less than one micron; (2) one micron to two and one-half microns; (3) two and one-half microns to ten microns; and (4) greater than ten microns.

As well as providing 10μ data directly related to PM_{10} ambient values, the size-resolved data sets permit the reconciling of sources with ambient particulate measurements and provide general insight into the environmental and human health impacts of specific sources. In addition, ARB's emission inventory contains size-resolved data (Taback et al., 1979) which will be supplemented by the data generated in this study.

The source categories of primary emphasis for this study were identified by the ARB prior to the start of the program. They were:

- Agricultural tillage;
- Paved roads;
- Unpaved roads;
- Construction and demolition;
- Livestock operations;
- Wind-blown agricultural land;
- Wind-blown desert land;
- Wind-blown urban unpaved areas;
- Vehicular diesel combustion;
- Forest fires;
- Agricultural burning;
- Woodstoves and fireplaces;
- Oil-field internal combustion engines; and
- Heavy crude combustion.

Upon review of updated emission inventory data and discussions with oil-field industry officials and local air pollution control engineers and scientists, it was jointly decided by ARB and OMNI personnel not to conduct source sampling on oil-field internal combustion engines and forest fires. Additional emphasis was, however, placed on vehicular diesel combustion and woodstove/fireplace sources as they appear more significant in the geographical area of interest. At ARB's request, less emphasis was also placed on collecting source samples from livestock operations.

Specialized source sampling instruments for the collection of particulate samples in a form compatible with the detailed chemical analysis needed for CMB modeling have been developed and their performance has been well documented (Core and Houck, 1987). The ARB's requirements that the particle size distribution and chemical composition be determined for four size ranges ($<1\mu$, 1μ - 2.5μ, 2.5μ - 10μ, $>10\mu$) for each source necessitated the development of new equipment specifically for use in this project. Following the fundamental design factors for previously used equipment of this type, parallel impactor sampling devices (PISDs) were developed for ground-based sampling of area sources, two dilution source samplers were developed for the sampling of high-temperature sources, and PISDs were interfaced with a resuspension chamber to sample size-resolved fractions of soil and road dust in the laboratory. Soil and road dust samples were collected in the field using standard protocols for grab sampling and by using a high-volume road dust sampler (Core and Houck, 1987).

General protocols for the gravimetric and chemical analyses of particulate source samples have been well-established (Core and Houck, 1987; Watson et al., 1988), albeit custom processing of samples is often required due to the wide range of chemical compositions and filter loadings which can be encountered in some source samples. X-ray fluorescence spectrometry, atomic absorption spectrophotometry, ion chromatography, automated colorimetry, and thermal/optical reflectance carbon analysis were used to quantify the forty-three chemical species measured on 593 filters. Benzene soluble organic (BSO) analysis was originally specified by the RFP. However, ARB and OMNI personnel agreed that deleting the BSO analysis and replacing it with ammonium (NH_4^+) analysis and an interlaboratory comparison program for organic and elemental carbon would be more appropriate. The interlaboratory comparison of organic and elemental carbon data was done because it has been demonstrated that reported organic carbon and elemental carbon values can vary significantly from laboratory to laboratory (Groblicki et al., 1983; Countess, 1987). A subset of twenty filters were analyzed by two additional independent laboratories (making a total of three laboratories) for the carbon comparison study.

Three appropriate data base formats have been developed for the use of source data and are being used to report the results of the study. These are: (1) a dBase III format compatible with the U.S. EPA source composition library (Core et al., 1984); (2) an ASCII file compatible with the U.S. EPA Chemical Element Receptor Model Version 7.0 (Watson, 1989) as well as ARB's Principal Components Analysis (PCA) and Chemical Mass Balance (CMB) Level I PM_{10} Assessment Package (Freeman et al., 1987; Watson et al., 1987); and (3) a data file with the data for the various size ranges of particles listed (Taback et al., 1979) for use in ARB's RAMIS emission inventory program.

1.2 Project Objectives and Tasks

The objectives of the study can be summarized as follows:

- To identify particulate sources which would represent the major sources that would be received at important PM_{10} receptors.

- To obtain representative samples of these particulate sources in four particle size ranges and to chemically characterize them for species which will allow their identification in PM_{10} receptor samples.

- To document the source characterization methods, the source operating parameters, and the accuracy, precision, and validity of source composition data.

- To create a data base incorporating this information that is compatible with existing source libraries, emissions inventories, and PM_{10} assessment models.

To realize these objectives, OMNI and DRI conducted four tasks.

Task 1: A source sampling and analysis plan was developed for identifying representative sampling locations, obtaining representative samples from those locations, analyzing those samples for specified chemical species, and assuring the quality of those measurements. This plan included a review of available PM_{10} data and emissions inventories, original site surveys of key receptor and source areas, and arrangements with source operating personnel for access to emission points. The plan was reviewed and approved by ARB personnel before the remaining three tasks were started.

Task 2: Source samples were collected in four specified size fractions on Teflon membrane and quartz fiber filter media. Samples were collected by diluted exhaust sampling, grab sampling or road vacuuming followed by laboratory resuspension, and ground-based plume sampling. The method selected depended on which was most appropriate for the specified source type. The samplers underwent calibrations and routine performance evaluations before deployment. Sampling sites and operating parameters were documented.

Task 3: Chemical and gravimetric analyses were conducted on approximately 150 separate source samples in the four specified size fractions. These analyses generated the desired source composition information on mass elements, ions, and other chemical species using the methods of gravimetric analysis, atomic absorption spectrophotometry, automated colorimetry, thermal/optical reflectance carbon analysis, ion chromatography, and x-ray fluorescence spectrometry. Replicate analyses and interlaboratory comparisons were performed. Minimum detectable concentrations were also quantified.

Task 4: Task 4 was the preparation of the final report and of a data base for the desired size fractions of the source emissions. The source compositions (percent of total mass emissions in a given size range which individual elements, ions, or other chemical species comprise) and their uncertainties were compiled in formats compatible with: (1) EPA's dBase III version of the source composition library; (2) EPA's Chemical Element Balance Receptor Model version 7.0

and ARB's PCA and CMB Level I PM_{10} Assessment Package; and (3) ARB's RAMIS emission inventory system.

Each of the four tasks was completed and is described in this report.

2.0 Source Sampling

2.1 Source Testing Alternatives

The receptor modeling scientific community is in agreement that the largest impediment to receptor modeling today is the dearth of accurate, precise, and comparable chemical profiles for major particulate emitters. These source profiles are needed quantitatively as input data for the Chemical Mass Balance receptor model, and they are needed qualitatively by the principal components and multiple linear regression receptor models.

Javitz et al. (1988), in summarizing a feasibility study of receptor models for the Electric Power Research Institute, concluded that the major weaknesses of all receptor models are caused by inadequate source composition data. Currently available source profiles exhibit the following limitations: (1) the species measured are more often those which are convenient rather than those which differentiate among sources; (2) the types of species and size fractions measured are not the same for different source types and are not equivalent to the types of measurements made at receptors; (3) measurement methods are non-standard and do not generate equivalent results for the same species; (4) source characteristics, fuels, and operating parameters are inadequately documented; (5) data are of poor or unknown quality; (6) source profile uncertainties are not reported; (7) source samples are not representative of source profiles as they appear at the receptor; and (8) data are not available in formats which can be conveniently interfaced to modeling software.

Javitz et al. (1988) recommend the development of a standardized approach to the sampling and analysis of particulate and gaseous emissions which would minimize these concerns with respect to future source profiles. Core and Houck (1987) present the beginnings of such a protocol assembled by a team of experts for the Oregon Department of Environmental Quality.

As illustrated in Figure 2.1-1, over the past decade a number of methods have evolved to extract samples from sources which will have chemical and physical properties similar to those found at a receptor. Several of these methods are described in detail by Chow et al. (1988), Core and Houck (1987), Gordon et al. (1984), Pan (1986), and Watson et al. (1987). In each of these methods, emitted particulate matter is collected on substrates which are then submitted to chemical analyses.

The ideal source sampling method would allow for chemical and physical transformations of source emissions to occur prior to sample collection. Methods which have been used to sample source emissions in receptor model studies include: (1) hot exhaust sampling; (2) diluted exhaust sampling; (3) plume sampling from

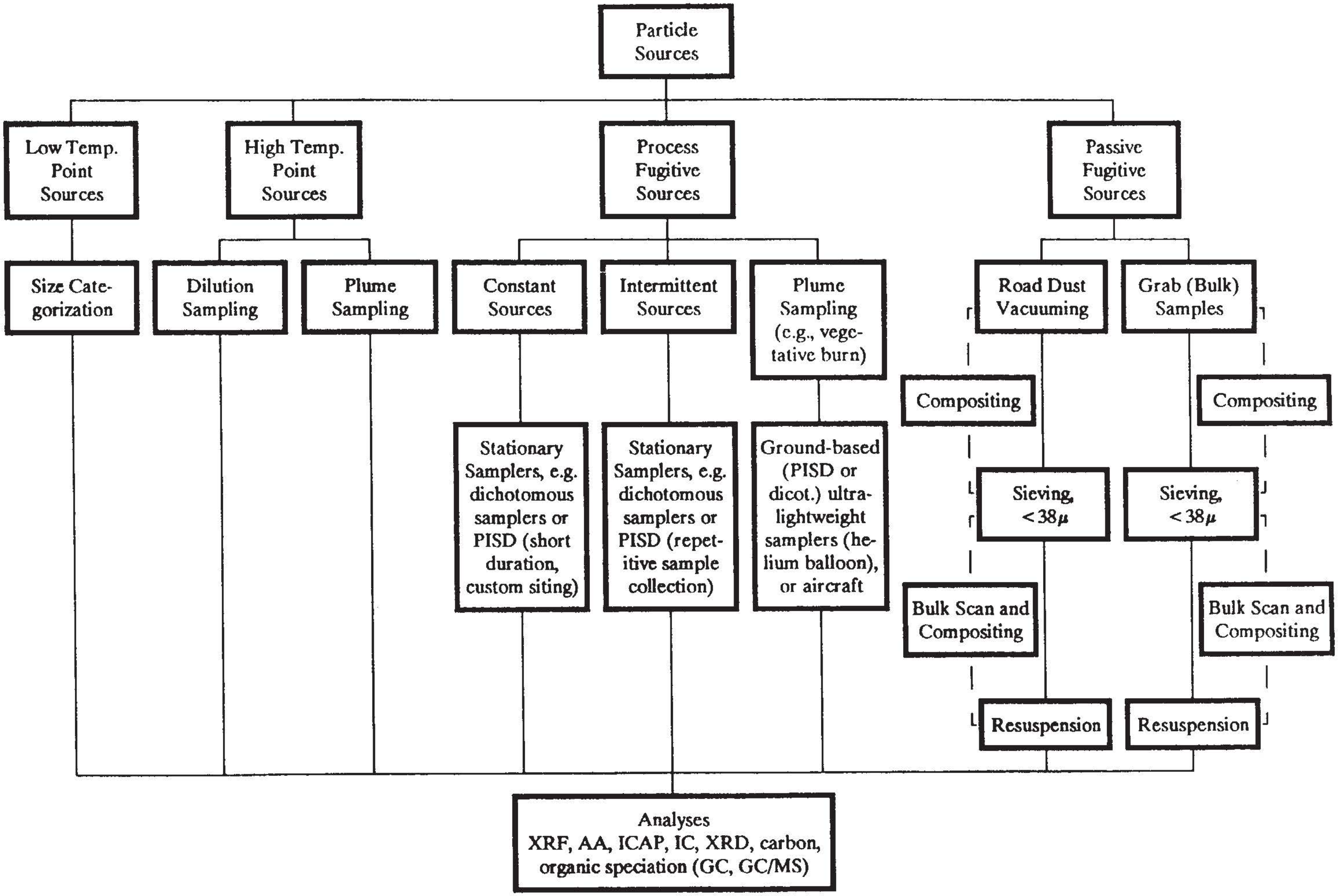

Figure 2.1-1. Flow Diagram of Aerosol Source Sampling Techniques.

airborne platforms; (4) ground-based sampling of single-source dominated air; and (5) grab sampling and resuspension.

Hot Exhaust Sampling

Hot exhaust sampling is well established for determining the emission rates of criteria pollutants, including primary particulate matter. These samples are not taken on substrates amenable to extensive analysis, nor are they generally size-specific. Components of these compliance-oriented methods have been incorporated into other exhaust sampling procedures. Hot exhaust sampling does not necessarily provide a chemical speciation representative of the source profile as it would appear at the receptor because it does not account for transformations which take place when the emissions cool. Hot exhaust sampling is not appropriate for receptor modeling studies.

Hot Exhaust Dilution Sampling

Dilution samples draw hot exhaust gases into a chamber where they are mixed with filtered ambient air. After an aging period, the particles are drawn through a size-selective inlet and onto the substrates. Multiple substrates for different chemical analyses are obtained simultaneously or via sequential sampling of the same gas stream. Houck et al. (1982) have developed such a system which draws the diluted sample through a virtual impactor to provide particle size fractionation. McCain and Williamson (1984) performed tests on this sampler which showed losses of large particles owing to inertial impaction and electrostatic charging. They recommended design changes to minimize these losses, and these changes have been implemented in current designs. Harris (1986), Huynh et al. (1984), Heinsohn et al. (1980), Stiles (1983), and Cooke et al. (1984) offer variations of the same principle.

Diluted exhaust sampling lends itself to laboratory simulations of emissions from individual sources. Dynamometer simulations of motor vehicle driving with exhaust sampled from a dilution tunnel can provide examples of aggregate emissions for a large number of separate vehicles. Similarly, wood stoves and fireplaces can be operated under different burning conditions with emissions sampled from a dilution tunnel.

Airborne Sampling

Source sampling from airborne platforms to characterize the chemical and physical properties of emissions has been performed from airplanes (Small et al., 1981; Richards et al., 1981, 1985), tethered balloons (Armstrong et al., 1981; Shah et al., 1988), and helicopters. It has also been proposed that model airplanes be used to carry ultra-light sampling payloads. Sampling components of appropriate weight and packaging are elevated above the emissions, usually on the order of 100 to 500 meters, to draw samples of the effluent.

The major advantage of airborne sampling for source characterization is that source profile fractionation might be determined if the sample can be taken at a time after emission (i.e., distance) sufficient to have allowed transformations to take place. The drawbacks of airborne plume sampling are: (1) it is difficult is know when the sampler is in the plume and when it is in ambient air; (2) it is difficult to stay in the plume long enough to obtain a sample; and (3) ambient air mixes with the plume, so the source profile is really a combination of emissions and ambient air.

Ground-based Source Sampling

Ground-based source sampling is identical to ambient sampling, but it is applied in situations for which the air being sampled is known to be dominated by emissions from a given source. The requirements of this method are: (1) meteorological conditions and sampling times conducive to domination by a particular source; (2) samples short enough to take advantage of those conditions; and (3) a minimum of other interfering source contributions. Pierson and Brachaczek (1983) and Hering et al. (1979) have characterized motor vehicles in tunnels. Rheingrover and Gordon (1980) characterized several point sources using ambient virtual impactor measurements when the sampling was downwind of the source.

Chow (1985) examined the effects of an elevated coal-fired power plant emission on ground-based samples in a rural environment. She could identify the presence of the plume from corresponding SO_2 and wind direction measurements, but she could not discern other chemical concentrations contributed by the power plant owing to an overwhelming abundance of geological material in her 24-hour sample. This method may be much better for fugitive and area sources, however, because their influence is more constant over time.

The advantages of ground-based sampling are: (1) it is representative of fractionated (presuming transformations are complete) and composite (for area sources such as home heating, motor vehicles, and resuspended dust) source profiles; (2) it is relatively economical; and (3) it is compatible with other receptor samples. The disadvantages are: (1) sampling times may be too short to obtain an adequate deposit; and (2) contributions from other source types interfere with the source profile.

Grab Sampling

Grab sampling involves removal of a bulk sample of material, resuspension and sampling onto substrates through size-selective inlets, and analysis for the selected species. A simple sample swept, shoveled, or vacuumed from a storage pile, transfer system, or roadbed can be taken to represent these source types. A number of different samples from the same source are generally averaged to obtain a representative source profile. The advantage of grab sampling and resuspension is that they are inexpensive and can be completed under controlled laboratory conditions. The disadvantage is that they are only applicable to fugitive dust sources from which large quantities of sample may be easily obtained.

2.2 Size Resolution with Impactors

The size resolution of particulate samples in the ground-based sampler, in the hot exhaust dilution samplers, and in the resuspension chamber system was achieved with impactors.

Impactors have a long history of use for aerosol sampling (Marple, 1970; Rau, 1986) and commercial units are available (Tuchman et al., 1986; Marple et al., 1987). To meet the four size categories required in this study and to produce particulate filters with uniform loadings desirable for multi-component chemical analyses, a custom impactor system was developed. For an ideal single-stage impactor, all particles with aerodynamic diameters larger than some design value (the cut-point) are captured by the impactor and all particles with aerodynamic diameters less than the cut-point diameter remain in the flowstream, passing the impactor. The term *Aerodynamic diameter* relates to the diameter of a spherical particle with a density of one gram per cubic centimeter that will have the same Stokes settling velocity as the actual particle being considered. As with any size-segregating technique, real impactors pass some particles which have aerodynamic diameters greater than the cut-point and capture some which have aerodynamic diameters smaller than the cut-point. However, sharp cut-points can be obtained with appropriate and relatively simple impactor design (Figure 2.2-1). Impactors segregate particles by interaction of viscous and inertial forces. Figure 2.2-1 shows a schematic drawing of an impactor. The jet increases the velocity of the flow stream and the particles within it so that particles which are acted upon by larger inertial forces than viscous drag forces, i.e., particles whose aerodynamic diameters are larger than the impactor cut-point, will impact on the impaction plate. Particles for which viscous drag forces are higher than inertial forces will remain in the flow stream. The impactor cut-point is defined as that particle diameter for which 50 percent of the particles are caught by the impactor and 50 percent are passed. In a well-designed impactor, particles which are not very much larger than the cut-point will be 100 percent captured by the impaction plate and particles which are not very much smaller than the cut-point will be 100 percent passed.

Impactor performance can be described in terms of Stokes' number (Marple et al., 1974) as shown by Equation 2.2-1:

$$\mathrm{Stk}_{50} = \frac{CV(D_{P50})^2}{9\mu W} \qquad \text{(Equation 2.2-1)}$$

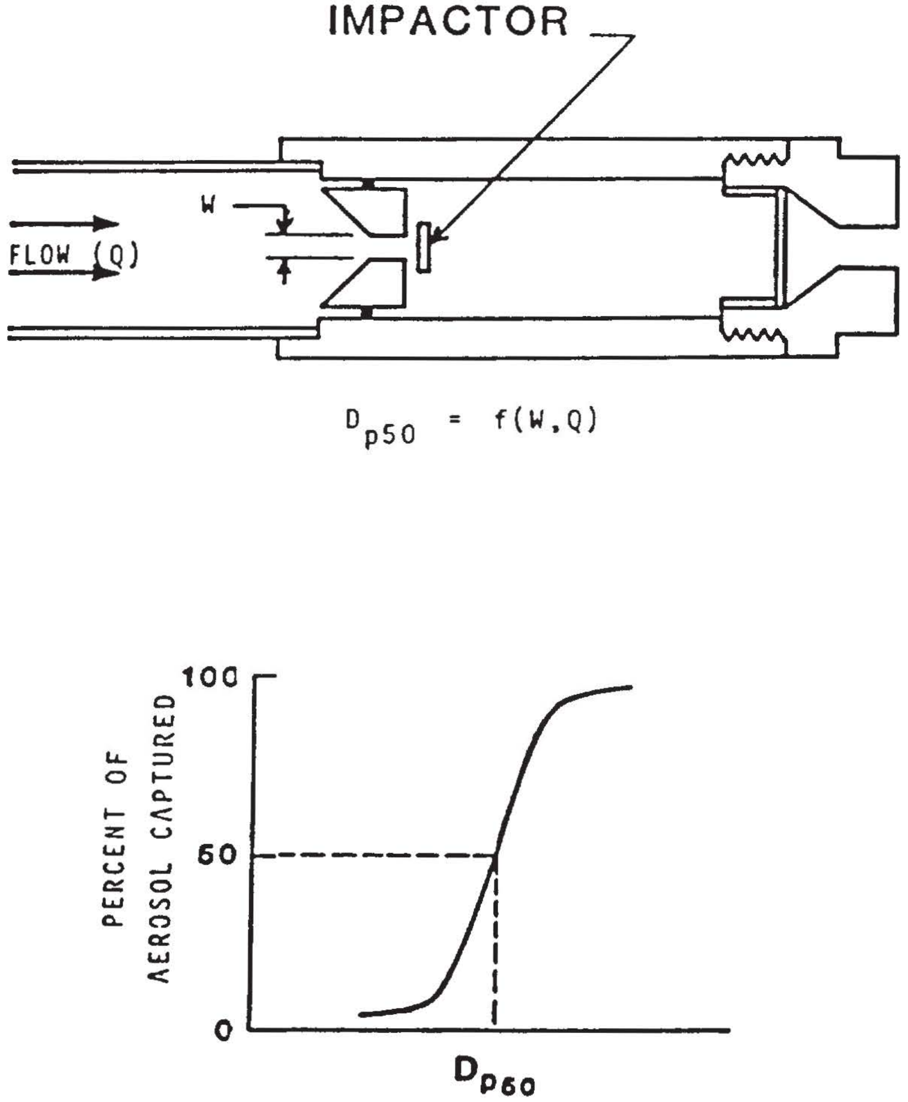

Figure 2.2-1. Impactor assembly schematic drawing (a) and generalized impactor performance curve (b).

Where $D_{p,50}$ = particle aerodynamic diameter (at 50% capture or cut-point);
V = jet velocity;
W = jet diameter;
C = Cunningham slip correction factor; and
μ = absolute viscosity of air.

Table 2.2-1 gives a summary of example impactor design parameters.

For very small impactor cut-points (such as the 0.3 and 0.6μ data in Table 2.2-1), other modifications need to be applied to Equation 2.2-1. For the cut-points of interest in this project (1, 2.5 and 10μ), direct calculations with Equation 2.2-1 provide a very accurate prediction of actual cut-points.

Table 2.2-2 gives the impactor design parameters used in the impactor developed for the sampling equipment deployed in this study. Figure 2.2-2 shows the impactor design details.

A series of tests were run to evaluate the performance of the impactors. Mono-dispersed latex aerosol particles were added to a filtered airstream for the evaluation. Figure 2.2-3 shows the test setup. The test aerosol was added to the airstream using a nebulizer. The test aerosol in a liquid suspension was added to deionized water in the nebulizer fluid reservoir. A clean airstream entering the nebulizer caused the test aerosol to be suspended in water droplets in the airstream leaving the nebulizer. The airstream leaving the nebulizer was then passed through a chamber containing a radioactive source, which removes static charge from the particles. It then went to a large glass flask where the aerosol aged and remaining water on the test aerosol particles evaporated. The stream containing the test aerosol was discharged to the atmosphere through a bell jar. The impactor to be tested was inserted into the bell jar where it sampled the test aerosol. Since the volumetric flow of the test aerosol was always greater than the sampling rate of the impactor, ambient air did not enter the bell jar. This allowed sampling of the test aerosol at atmospheric pressure. The impactor support assembly was first run without the impactor inserted through the flow range to be used in the test. Particle concentration leaving the impactor support assembly was determined as a function of flow through the impactor support assembly using a Royco (model 3050) optical particle counter. The impactor was then placed in the support assembly and the flow range was again traversed. Impaction plates were greased with Apiezon grease by troweling the grease with a razor blade. The ratio of the particle concentration measured with the impactor in to the particle concentration measured with the impactor out was the fraction of particles passed by the impactor. One minus this value expressed as a percent is the percent captured. Impactor performance was graphed by plotting the square root of the Stokes number versus the percent captured. Theory predicts that the 50% capture point should occur at the square root of the Stokes number value of 0.47.

Table 2.2-1
Example Impactor Design Parameters

Cut-point (μ)	W (mm)	n	V (cm/sec)	P_2/P_1	Re	Q_T (lpm)
2.5	3.15	1	1755	1.00	7250	8.3
1.2	1.97	1	4500	0.99	11618	8.3
0.6	1.30	1	10430	0.94	17782	8.3
0.3	0.60	4	15700	0.89	12354	10.7
0.1	0.15	20	19300	0.78	3796	4.1

W = jet diameter
n = number of jets
V = velocity through jet
P_1 = pressure upstream of the jet
P_2 = pressure downstream of the jet
Re = Reynolds number
Q_T = total flow through all the impactor jets

Table 2.2-2
California Study Impactor Design Parameters

Cut-point (μ)	W (mm)	T (mm)	S (mm)	n	Inlet Cone (°)	V (cm/sec)	P_2/P_1	Re	Q_T (lpm)
10	8.45	8.45	8.45	1	60	296	1.00	1668	10
2.5	3.40	3.40	6.81	1	60	1828	1.00	4131	10
1	1.91	1.91	3.81	1	60	5804	0.99	7381	10

W = jet diameter
T = throat length
S = jet-to-plate distance
n = number of jets
V = velocity through jet
P_1 = pressure upstream of jet
P_2 = pressure downstream of jet
Re = Reynolds number
Q_T = flow through impactor jet

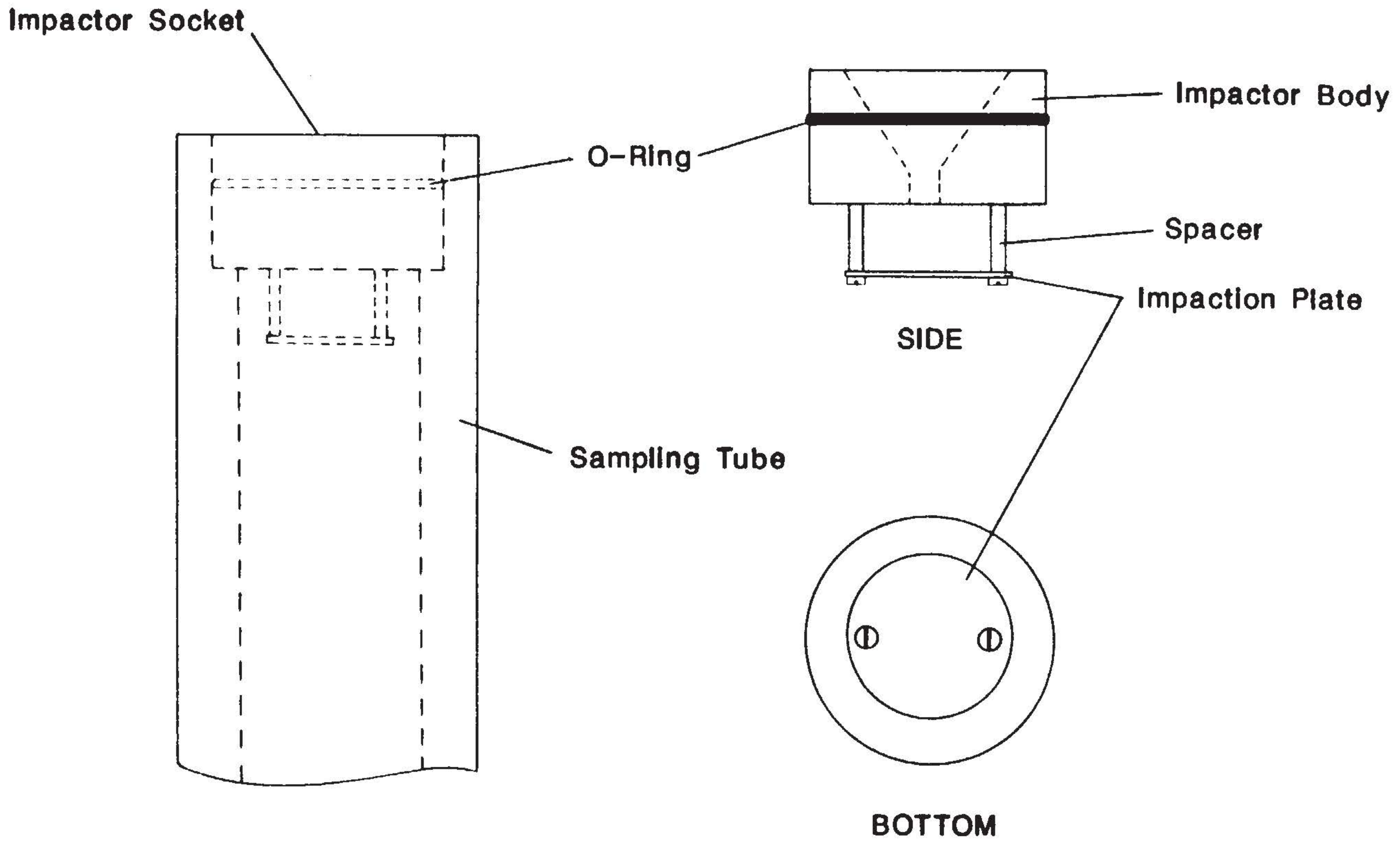

Figure 2.2-2. Impactor design.

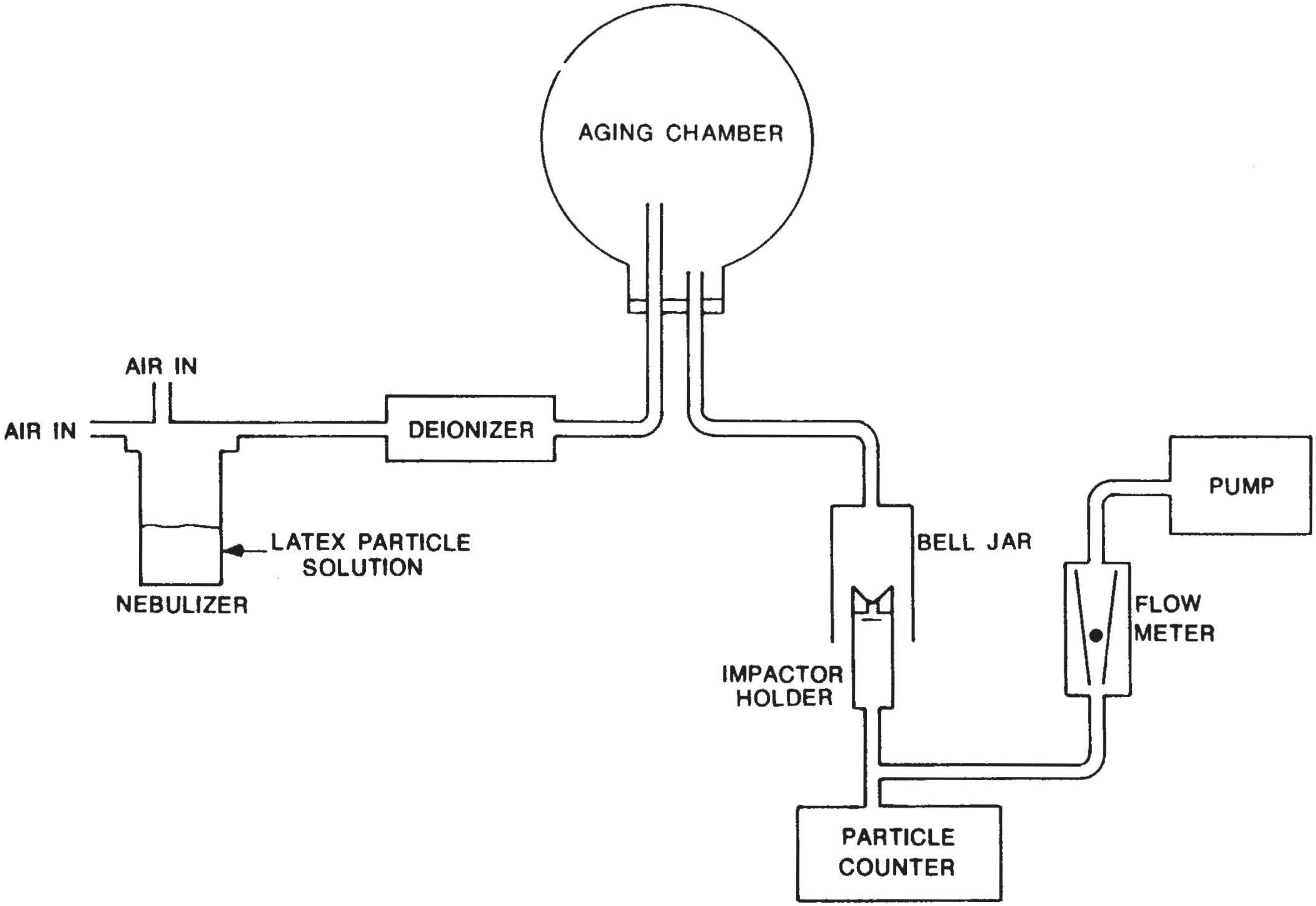

Figure 2.2-3. Schematic of impactor test system.

Performance of the 1.0μ impactor runs with 1.1μ latex particles is shown in Figure 2.2-4. This figure shows that the impactor performs as predicted by theory. Figure 2.2-5 shows the performance of the 2.5μ impactor run with 2.06μ particles. Again, the impactor performed as expected.

Performance evaluation of the 10μ impactor with the test system illustrated in Figure 2.2-3 was not possible because the particle concentrations were too low at that size, due to loss within the system. The theoretical performance of the 10μ impactor was confirmed by the near-simultaneous operation of three 10μ impactors along with a commercially available PM_{10} medium-volume sampler in a relatively clean ambient setting. The medium-volume sampler used in the comparison met the criteria for the PM_{10} federal reference method (U.S. EPA, 1987). Table 2.2-3 summarizes the comparison data for the 10μ impactor design and the commercial PM_{10} sampler.

To reduce particle bounce problems often associated with impactors, two steps were taken. These were: (1) all impaction stages were coated with Apiezon grease; and (2) cyclones were placed on front of the 1μ and 2.5μ impactors. Cheng and Yeh (1979) and Esmen et al. (1978) have demonstrated that greasing impaction plates significantly reduces particle bounce. Either Apiezon type M or Apiezon type T grease was used, depending on the sampling temperature expected. Due to the preponderance of particles larger than 2.5μ in many sampling environments, a pre-separator cyclone was placed in front of the 1μ and 2.5μ impactors to prevent the impaction plates from overloading. A single cyclone mounted on a manifold was installed in front of the 1μ and 2.5μ impactors. The flow through the cyclone was subsequently 20 lpm, which produces a cut-point of approximately 4μ (Chan and Lippman, 1974). Figure 2.2-6 illustrates the performance of the cyclone. While cyclones do not become "overloaded" as do impactors, their cut-points are less sharp. The combination of a cyclone pre-separator followed by an impactor for the final size cut provides the ideal solution for the overloading problem, as well as providing a particulate sample with a sharp cut-point.

Samples which were collected for this study consisted of particles which remained in the flowstream after passing the impactors and were collected on filters after the flow was collimated. Total aerosol mass and the chemical composition between two impactor cut-point values were determined by subtracting the mass and mass-weighed chemical composition collected behind the impactor from those of the next largest cut-point. By using data from a series of impactors in this way, the size distribution of particulate mass or the distribution of any other particulate property such as chemistry could be determined. Similarly, by subtracting the mass collected behind the 10μm impactor from the mass collected by the "total" sampler (no impactor) a measure of the aerosol mass above 10μm was obtained. The size categories are summarized in Table 2.2-4.

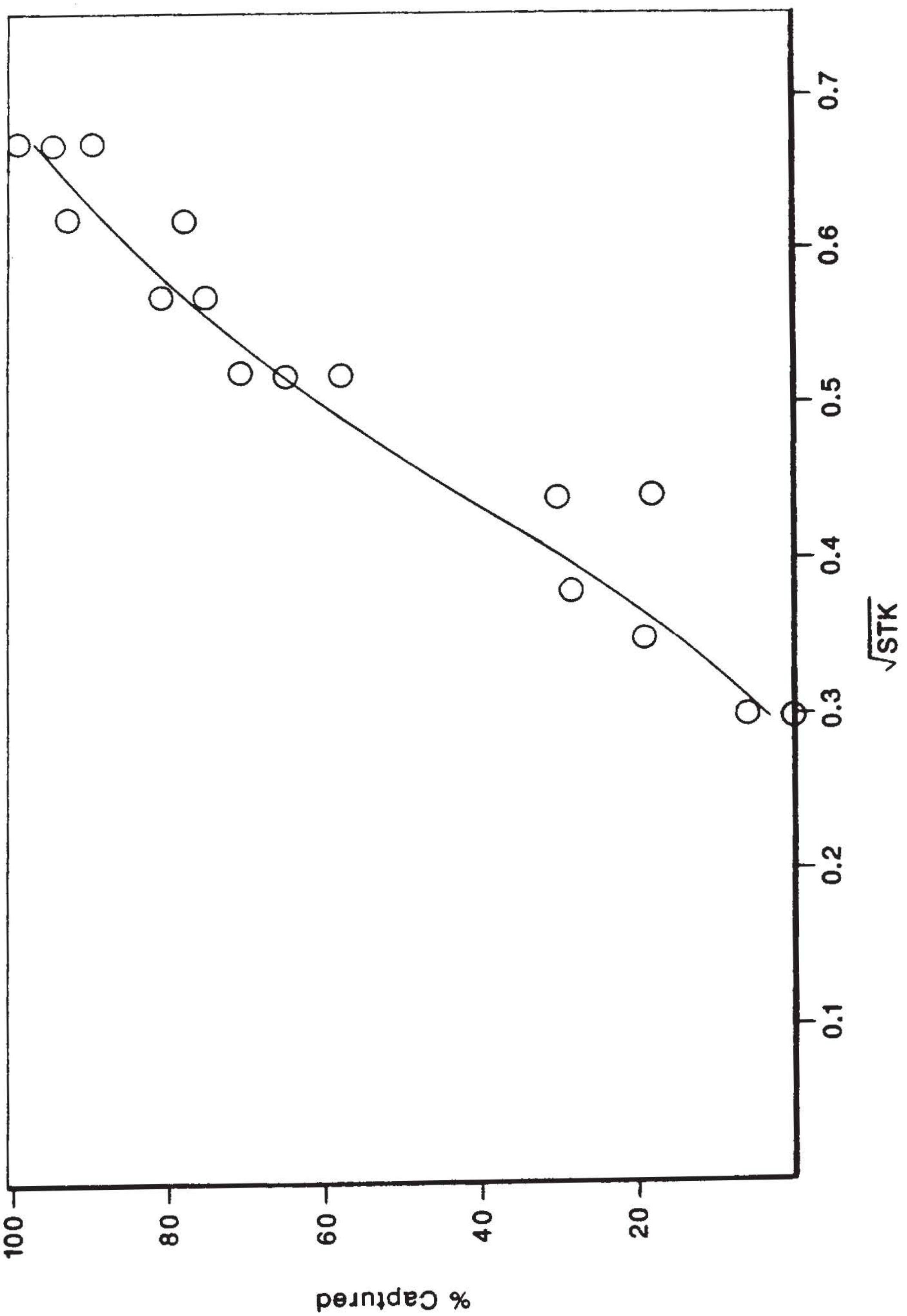

Figure 2.2-4. Impactor performance, 1.0μ impactor, 1.1μ test aerosol.

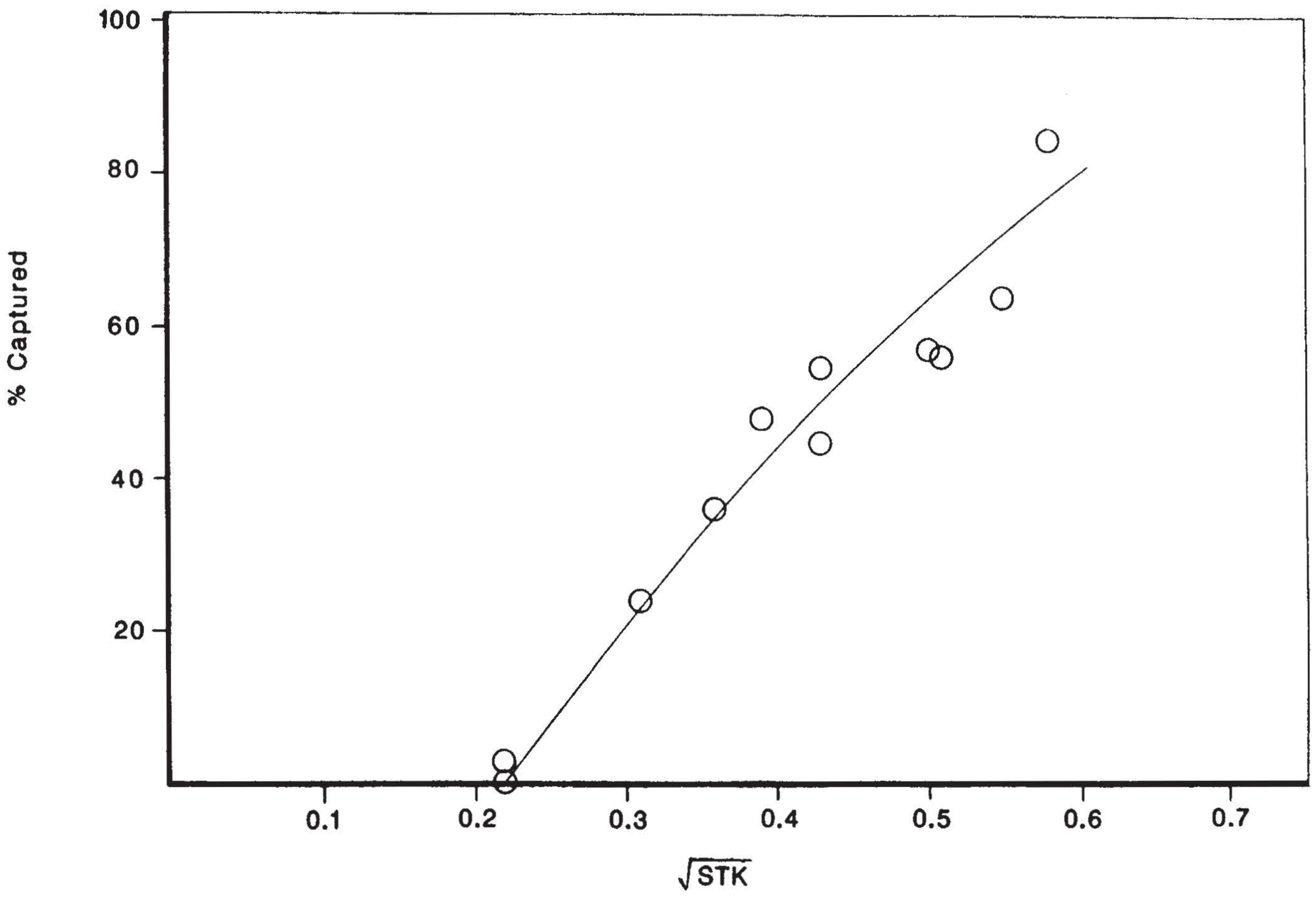

Figure 2.2-5. Impactor performance, 2.5μ impactor, 2.06μ test aerosol.

Table 2.2-3
Comparison of 10μ Impactor Performance with Commercial PM_{10} Sampler

Sampler	Calculated Mass Concentration ($\mu g/m^3$)
10μ impactor #1	27.8
10μ impactor #2	27.2
10μ impactor #3	25.2
Medium-volume PM_{10} sampler	29.8

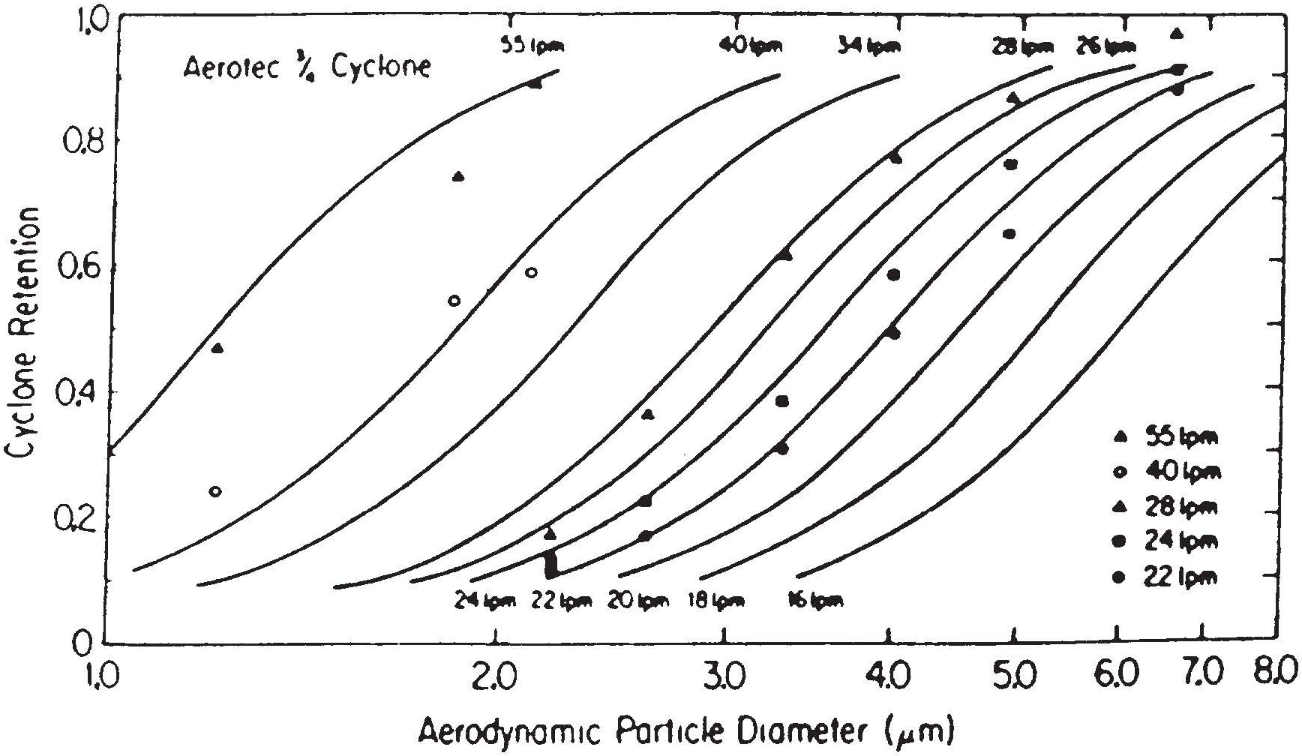

Figure 2.2-6. Collection efficiency of Aerotec $^3/_4$-in. cyclone (data from Chan and Lippmann [1974]).

Table 2.2-4
Size Categories

Size Range[a]	Method of Determination	Comments
$< 1.0\mu$	impactor cut-point	
1.0μ-2.5μ	subtraction of $< 1.0\mu$ data from $< 2.5\mu$ data	
$< 2.5\mu$	impactor cut-point	Often referred to as respirable fraction or $PM_{2.5}$.
2.5μ-10μ	subtraction of $< 2.5\mu$ data from $< 10\mu$ data	
$< 10\mu$	impactor cut-point	Often referred to as inhalable fraction or PM_{10}.
10μ-30μ ($> 10\mu$)	subtraction of $< 10\mu$ data from $< 30\mu$ data	Particles greater than approximately 30μ are not generally collected with most ambient or source sampling equipment and their half-life in the atmosphere is short. The 10μ-30μ size category can be referred to in essence as $> 10\mu$ and the $< 30\mu$ size category as total suspended particles (TSP).
$< 30\mu$ (TSP)	no impactor in sampler	

a. Effecive Aerodynamic Diameter (spherical, $\rho = 1 g/cm^3$)

2.3 PISD Ground-Based Sampler

A parallel impactor sampling device (PISD) was used for ground-based sampling. The PISD used the impactors and the cyclone described in Section 2.2. Figure 2.3-1 is a schematic diagram of the PISD. Figure 2.3-2 is a sketch of the system and Figure 2.3-3 is a detail drawing of the PISD sampling tubes. The sampler consists of two basic parts: the sampling module and the control module. The sampling module consists of a tripod-supported platform to which are attached four sample inlet tubes, the pre-separator cyclone, vacuum gauges, a manifold containing four critical orifices for flow control, and a flexible hose connecting the manifold to the control module. The control module contains a rotary vane pump, a cooling fan, an on/off switch, a non-resettable elapsed time meter, and a master vacuum gauge.

The PISD system is reasonably portable and rugged for field deployment. The tripod legs, sampling tubes, and rain caps are held in place with set bolts for rapid attachment and removal. The vacuum hose is attached to both the control module and sampling module by quick disconnects. The cyclone manifold is held in place with an air-tight gasket collar. The complete standard operating procedure (SOP) for the parallel impactor sampling device is provided in Appendix B.

2.4 Hot Exhaust Dilution Sampler for Industrial Sources

Point source and combustion emissions represent a special problem for source sampling and subsequent receptor modeling. The alteration in particulate chemistry and size distribution which occurs when combustion emissions cool and mix with ambient air requires that a dilution/cooling tunnel be utilized prior to aerosol sample collection. Condensation, agglomeration, volatilization, and secondary chemical reactions can all modify the character of source particles.

Figure 2.4-1 is a general schematic of the dilution source sampling system (DSS) which was used in the study. Figure 2.4-2 is a sketch of the system. Several different dilution chamber and inlet geometries were necessary to pragmatically position the sampler adjacent to each specific source, since it is desirable to minimize the inlet probe length as it has been found the principal point of particle loss is within the sampling probe and inlet line (McCain and Williamson, 1984). The dilution systems were designed to be "broken down" to be easily transported and cleaned in the field. The system has interchangeable dilution chamber lengths and bends, as well as various diameters and lengths of inlet probes. The dilution chamber components are constructed of light gauge 316 stainless steel to minimize sample contamination.

Characteristic temperatures, flow rates, particulate loading, and water vapor content (condensed water is deleterious to sample collection) vary dramatically with source type; consequently, the dilution ratio is

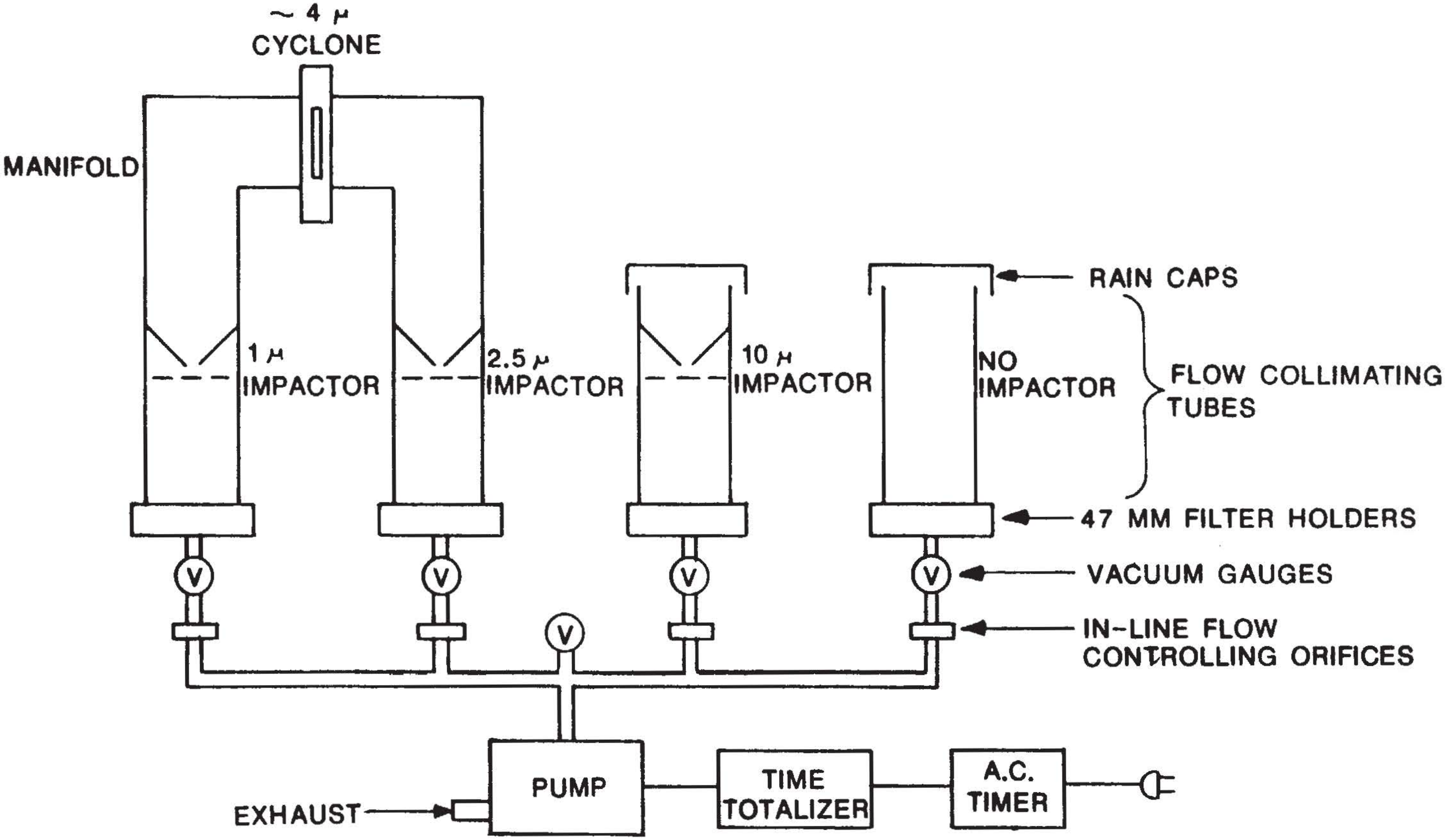

Figure 2.3-1. Schematic diagram of parallel impactor sampling device (PISD).

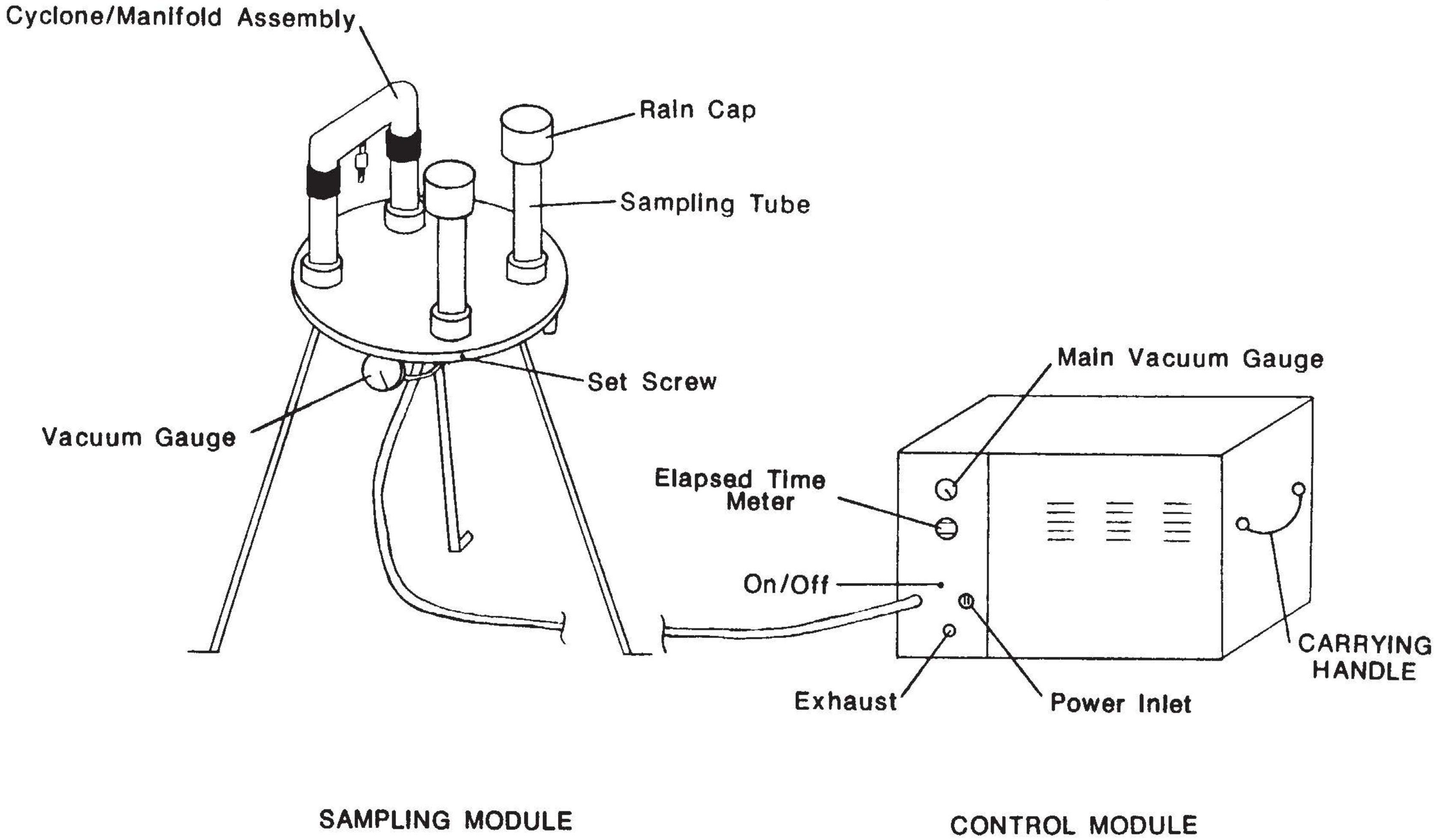

Figure 2.3-2. Sketch of the parallel impactor sampling device (PISD).

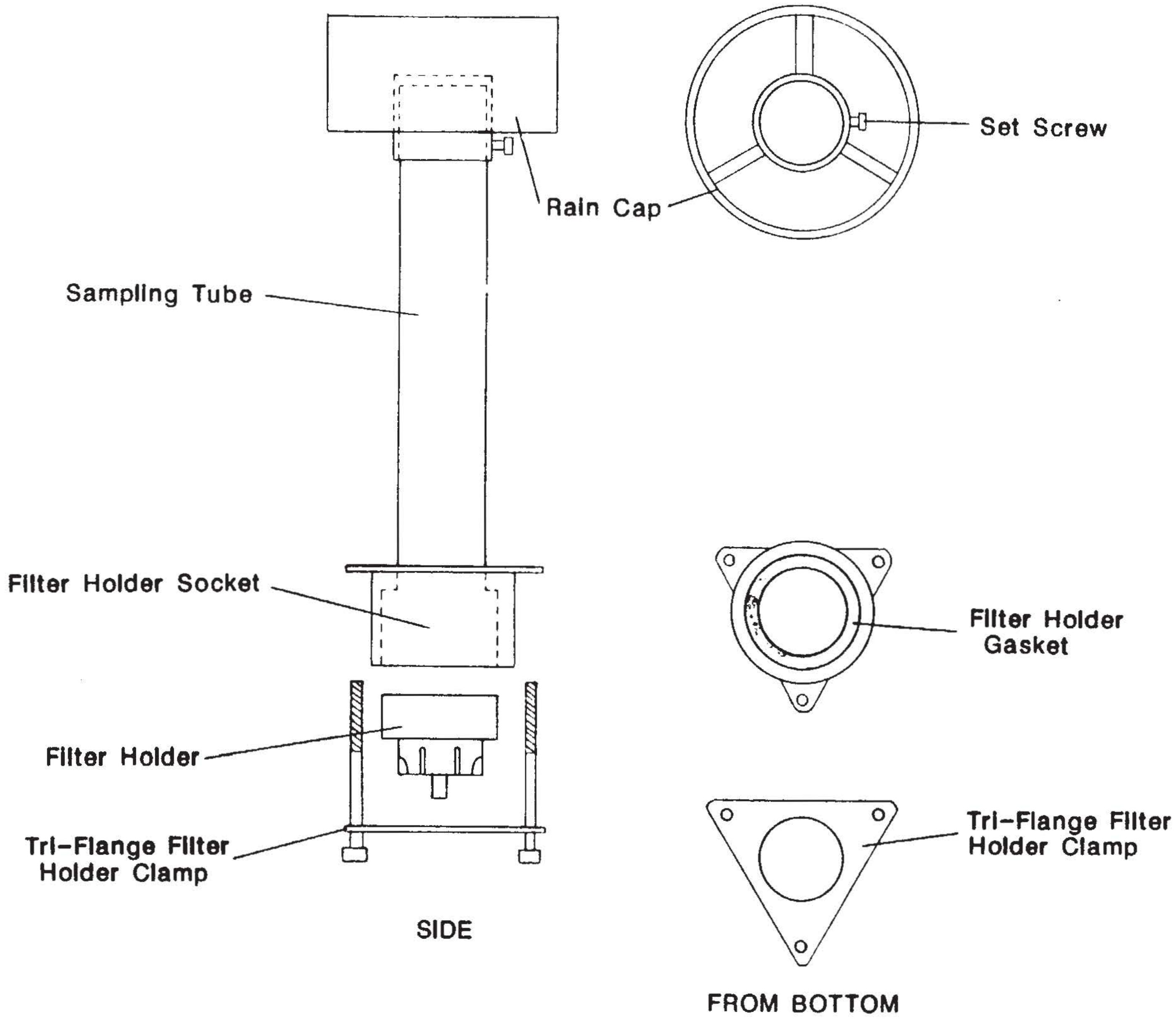

Figure 2.3-3. PISD sampling tube detail.

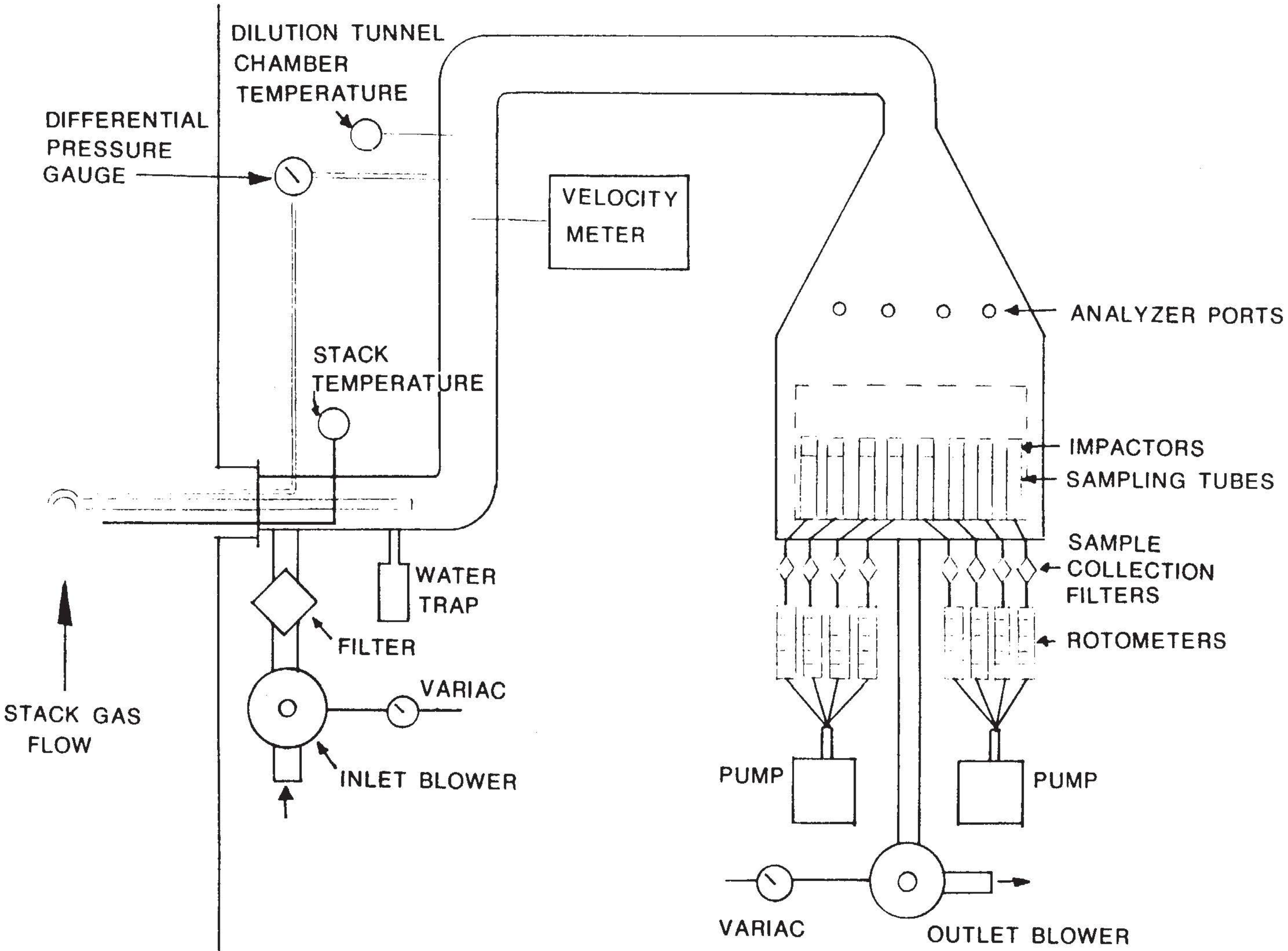

Figure 2.4-1. Schematic of the dilution sampling system.

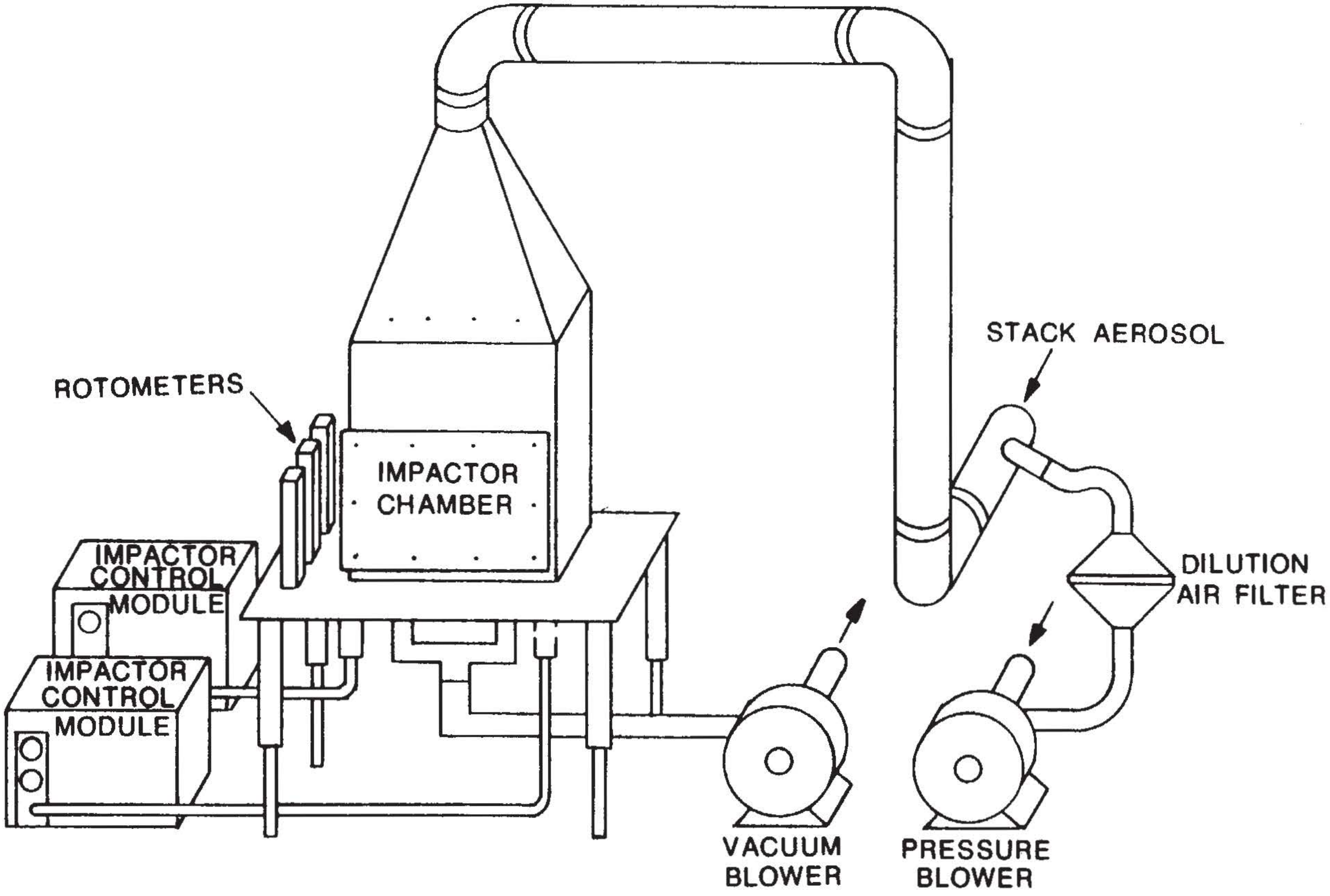

Figure 2.4-2. Sketch of the dilution sampling system.

adjustable (approximately 10:1 to 100:1) for general application. Additionally, because the sampler is often inherently in an area of high ambient particulate concentration, and because of the high ambient air/sample ratio, the dilution air is well filtered to prevent sample contamination. The dilution ratio is adjustable at any reasonable inlet flow by the combined control of an inlet blower and outlet vacuum pump. Both are controlled by variable transformers (Variacs). Inlet air is filtered with a standard high-volume 8 by 10 inch filter. The dilution ratio can be set at any predetermined value, since the inlet airflow rate is monitored with a thermal anemometer and the pressure difference between the interior of the dilution chamber and the source is monitored with a pressure gauge or manometer. The flow-versus-pressure difference is determined in the laboratory prior to field deployment. Dilution chamber temperature is monitored to ensure that the chamber temperature is a few degrees within ambient, and for documentation of the aerosol sampling environment. Two impactor systems (one for Teflon filters and one for quartz filters) withdraw samples from the dilution chamber. As with the PISD systems (Section 2.3), a flow collimating tube is placed in front of the impactors. While the diameter of the inlets of the collimating tubes could be restricted to achieve isokinetic sampling conditions, this is not essential since the majority of particles originating from combustion sources are significantly less than 5μ in aerodynamic diameter. Similarly, the flow in the inlet to the dilution chamber can be adjusted to remove the aerosol from the source isokinetically although, as mentioned, it is not critical.

The transfer of particulate-bearing stack gases via the heated probe to the dilution chamber is accomplished by maintaining a pressure differential between the dilution chamber and the interior of the stack. From Bernoulli's equation of continuity, it can be shown that the linear velocity of gas entering the inlet is dependent only on the pressure drop (ΔP) and density of the source gas (ρ), i.e.,

$$V = \sqrt{\Delta\rho/0.5\rho} \qquad \text{(Equation 2.4-1)}$$

Bernoulli's equation is only strictly applicable to idealized fluids but is illustrative for design consideration. Since the inlet will collect gas parallel with the direction of flow, the pressure value used to calculate ΔP in Equation 2.4-1 must take into account the effect of velocity pressure, i.e.,

$$\Delta P = [P_{S,S} + 0.5\, \rho_S V_S^2] - P_{d,S} \qquad \text{(Equation 2.4-2)}$$

where $P_{S,S}$ is the static pressure within the source;
ρ_S is the density of gas within the source;
V_S is the linear velocity of gas within the source; and
$P_{d,S}$ is the static pressure within the dilution chamber.

Measurement of ΔP can be accomplished by the use of commercially available tips connected to a manometer or Magnehelic gauge.

Reduced pressure and flow within the dilution chamber is produced by a vacuum pump. If the blower (Figures 2.4-1 and 2.4-2) is removed, each flow rate across the high-volume filter has a corresponding pressure drop associated with it which is determined by the filter medium. The addition of a Variac-controlled blower reduces the pressure drop and permits a wide range of combinations of dilution chamber pressure and flow rate. For example, if a high dilution flow rate (i.e., high dilution ratio) and a low pressure drop (low linear velocity in the sampling inlet) are desired, the vacuum pump would be operated at near-maximum power and the blower would be adjusted until the pressure drop across the high-volume filter was lowered to the point where low inlet velocities were obtained.

Some limited source data are generally collected prior to sample collection. Stack (or ducted exhaust) flow rate, temperature, water vapor content, and particulate concentration are helpful in estimating appropriate dilution ratios for selection on inlets and in estimating the duration of sample collection periods. Adequate data are frequently obtained from records of previous tests or characteristics of the source. Typical sampling periods are between 15 minutes and 2 hours. Sampling periods as short as five minutes have been encountered (a coal-fired power plant operating without emission controls) and as long as 14 hours (at efficient baghouses) have also been necessary with systems similar to the one developed for this study. Generally, the proper mass loading on the collection filter (approximately 0.5 to 2 mg) dictates the length of the sampling period required. In some cases during previous studies, long sampling durations have been required because a very high dilution ratio was needed to prevent water condensation from occurring. The standard operating procedure for the DSS system is included as Appendix C.

2.5 Hot Exhaust Dilution Sampler for Residential Wood Combustion

Residential wood combustion (RWC) appliances present special problems for dilution sampling, and producing representative source profiles is a complex task due to the inherent number of variables associated with them. Notable among these are: (1) appliance types and installation factors; (2) fuels; (3) fueling practices; and (4) burn conditions. Table 2.4-1 presents these variables in detail.

To further complicate the development of representative source profiles, woodburning appliances are difficult to sample because: (1) the emissions are tar-like; (2) the average stack gas velocity is low; (3) the average concentration of particulate material in the stack gas is high; (4) there is a high water vapor content in the stack gas; and (5) emission rates and gas velocities are very variable. In addition, the difference between particulate (solid and liquid) emissions and gaseous emissions is a matter of definition, since many of the

Table 2.4-1
Woodburning Appliance Variables

Source Type	Key Variables
Appliance Types and Installation Factors	Woodstove versus fireplace Woodstove firebox size Model (fundamental design) Woodstove technology type (catalyst versus noncatalyst) Damper (draft) control (excess air) Airtight versus non-airtight woodstove (excess air) Chimney system (draft)
Fuels	Species Moisture content Seasoned versus non-seasoned Size of fuel pieces Density Extent of decomposition
Fueling Practices	Burn rate Burn duration (all day versus evenings only) Fuel load amount Frequency of fueling Kindling (start-up) procedure Household trash
Burn Conditions	Kindling phase Main burn (dampered-down cool burn versus hot burn with excess air) Charcoal phase (end of burn) Damper (draft) settings

chemical compounds contained in wood smoke are semi-volatile. Woodburning appliances are also pragmatically difficult to sample as their stacks obviously have no sampling ports and in-field sampling requires the positioning of heavy, cumbersome, and noisy sampling equipment on private residences.

Due to the inherent variability among woodburning appliances and the difficulty of obtaining samples in the field from a meaningful number of appliances, a laboratory sampling methodology has been developed (Watson et al., 1988). The approach entails: (1) determination of the most abundant cordwood type(s), burn rates, appliance types, and burn cycles for a given geological area from existing literature, surveys, or from other studies; and (2) long-term, in-laboratory sampling of emissions from the most representative woodburning appliance types, operating under the mean burn rate and most common cycles, and using the most abundant wood type(s).

Since particulate emission rates, stack velocities, and apparently the chemical character of particles, vary dramatically over the course of a normal burn cycle (Burnet et al., 1986; Shelton and Gay, 1986), the DDS system used for industrial sampling is not appropriate for residential woodburning appliance application. Rapid changes in velocity and particulate loading levels over short time periods would be nearly impossible to follow in a proportionate manner with the DSS. In addition, the very high particulate concentration characteristic of residential wood combustion as compared to most controlled industrial sources makes the direct use of the DSS less than ideal.

To rectify these problems, a modified U.S. EPA reference Method 5G dilution tunnel system (U.S. EPA, 1987a) was used to dilute the entire appliance emissions with ambient air. From the diluted stream a fixed-flow aliquot was removed and passed through the parallel impactor system described in Section 2.2. Figure 2.4-3 is a schematic of the system. The most significant modification made in the Method 5G protocol was the increase in flow rates when fireplaces were tested to compensate for increased stack gas volumes characteristic of residential fireplaces as compared to woodstoves (Shelton and Gay, 1987). Since unfiltered ambient air was used for dilution/cooling, particulate samples of the dilution air were taken simultaneously with the source tests so that the contribution of the dilution air could be accounted for in the chemical composition of the samples collected. The ground-based PISD samplers were used to sample the dilution air.

The moisture content of the cordwood was measured with a Delmhorst Instrument Company model RC-IC moisture meter. A spring scale was used to pre-weigh appropriate amounts of each species of wood prior to the beginning of each test. Wood addition (target and actual), wood moisture content, fuel wood species, and draft control/door positions were recorded on prepared data sheets for each test.

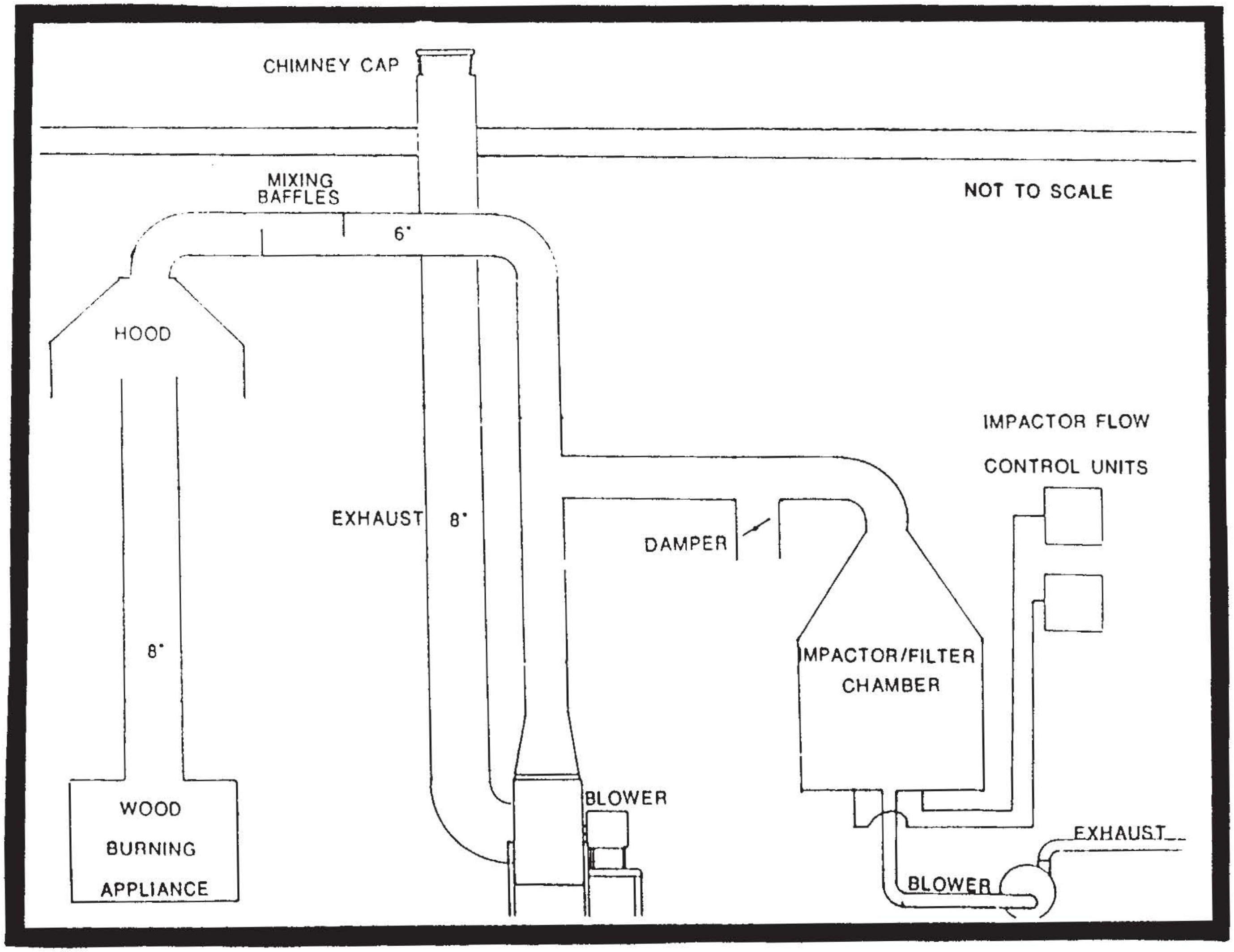

Figure 2.4-3. Sketch of modififed Method 5G dilution tunnel interfaced with impactor system.

2.6 Soil, Road Dust, and Bulk Sampling Procedures

Dust from roadways, from agricultural tillage, and from suspension by wind is recognized as being a major source of particles in most airsheds. Standard protocols have been developed for the sampling and analysis of dust (Core and Houck, 1987). Sampling protocols include procedures for sampling: (1) paved roads; (2) unpaved areas which have a surface layer with a distinct chemical character due to anthropogenic impact (e.g., unpaved roads and parking lots); and (3) dust sources with a relatively homogeneous near-surface chemical composition (e.g., tilled agricultural soils, native soils, and bulk material storage piles). Samples from paved roads were collected with a high-volume vacuum cleaner-like device, or with a small broom and dust pan. The high-volume road dust sampler is simply a modified high-volume ambient air sampler and has been deployed in numerous studies (e.g., Houck et al., 1981 and 1982). Samples from unpaved roads and parking lots were obtained by removing approximately the top centimeter of material with a masonry trowel. Samples of agricultural soils, native soils, and bulk materials were simply collected with a small shovel, although care was taken not to exceed approximately ten centimeters in sampling depth. While the actual physical collection of the dust samples is relatively simple, ensuring representative samples is not. Factors which need to be taken into consideration include: (1) proximity to receptor (ambient) monitoring sites; (2) traffic counts for roads; (3) industrial or agricultural track-out on roads; (4) soil wind erodibility; (5) soil types; (6) dust-producing agricultural activities; (7) predominant wind velocities; and (8) agricultural and industrial impacts on soil chemical composition. Compositing samples is a useful technique to ensure that representative chemical source profiles are produced. Collection of sub-samples at regular intervals along a roadway or at various points in an agricultural field or fields is a reasonable approach to compositing. Once bulk samples were collected, laboratory drying at low temperatures to avoid loss of volatile compounds, sieving to less than 38μ (400 mesh), resuspension, particulate collection with the PISD size-segregating samplers, and analysis by routine analytical techniques were conducted. Dust sampling procedures are given in Appendix D. Pre-analysis laboratory treatment and resuspension of samples are discussed in Section 3.3 and Appendix D.

2.7 Source Sampling Summary

Five types of source sampling procedures were performed in this study. They were: (1) ground-based sampling with a PISD sampler; (2) paved road dust sampling with a high-volume road dust sampler or hand broom; (3) grab sampling of soil, bulk material or unpaved road dust; (4) hot exhaust dilution sampling with an industrial dilution source sampler (DSS); and (5) hot exhaust dilution sampling of residential wood combustion with a modified Method 5G-type dilution sampler. A total of forty sources were sampled. Three to six replicates were collected for each source. The air quality at a number of the sources during sampling was such that background air sampling needed to be conducted simultaneously with the source sampling so that the source profile could be corrected for background air contamination. Appropriate field blanks were also collected in all cases. Table 2.7-1 summarizes the sources and source sampling procedures. Figure 2.7-1 illustrates the approximate locations of the dust sampling areas. Figure 2.7-2 illustrates the approximate location of other area and point sources which were sampled.

The source sampling was conducted during five periods: (1) All dust samples and cordwood for the Mammoth Lakes area were collected during September of 1987. (2) The diesel trucks at the Wheeler Ridge Weigh Station and a crude oil combustion unit in the west Kern County Oilfield (Santa Fe Energy Company) were sampled during November of 1987. Cordwood from the Bakersfield area was also collected during November of 1987. (3) Samples of fireplace emissions burning both Mammoth Lakes cordwood and Bakersfield cordwood, as well as emissions from a woodstove burning Mammoth Lakes cordwood, were collected at OMNI's Beaverton facilities in February of 1988. (4) Exhaust from diesel ski tour buses was sampled in Mammoth Lakes in February of 1988. (5) A Visalia area dairy, construction activities in the Fresno area, a crude oil combustion unit in the Kern River Oilfield (Chevron), and agricultural burning in the San Joaquin and Imperial River Valleys were sampled in June and July of 1988. Upon collection, all samples were delivered to the Desert Research Institute located in Reno, Nevada for analyses.

Three replicates were collected for each of the twenty-seven dust samples in the San Joaquin Valley, Great Basin Valleys, and Southeast Desert Air Basins. A detailed description of the samples is given in Table 2.7-2. The source types of the dust samples can be categorized into five sub-groupings: (1) agricultural soil; (2) paved roads; (3) unpaved roads and urban areas; (4) alkaline playa sediments and desert soils; and (5) sand and cinder storage areas. All sampling locations were selected based on their potential impact to ARB ambient monitoring sites from which data may eventually be used for CMB modeling and where future PM_{10} violations are anticipated based on historical ARB data.

Agricultural Soils

Nine agricultural soils were collected in the San Joaquin and Imperial Valleys. All samples were composite samples with the sub-samples that make up the composites representing the major soil series categories as well as areas of major agricultural crop types upwind (under predominant wind conditions) of a relevant ARB monitoring site. Soil Conservation Service surveys provided detailed aerial photographs on which soil series boundaries are superimposed. (U.S. Dept. Agr. Soil Conservation Service, undated; U.S. Dept. Agr. Soil Conservation Service, 1980; Perrier et al., 1974). Agricultural land use data, agricultural activities most likely to produce dust, and soil amendment information were obtained from the University of California Extension Service and California County Agricultural Commissioners publications (Watkins, 1987; Kunkel, 1987; Wilbur, 1987; Finnel, 1987; Karlik, undated; Gonzalez, 1985), and interviews with staff members.

Table 2.7-1
Source Sampling Summary

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Stockton Area ag. soil (peat)	SOIL 01	1	GS/RS	3	NA	Composite of peat soils from delta area NW of Stockton
Stockton Area ag. soil (mineral)	SOIL 02	2	GS/RS	3	NA	Composite of mineral soils in the predominantly upwind (NW) direction of Stockton
Fresno paved road (city street)	SOIL 03	3	PRD/RS	3	NA	Collected along Olive Street near monitoring site
Visalia Area ag. soil (cotton/walnut)	SOIL 04	4	GS/RS	3	NA	Composite of sandy loam soils in predominantly upwind (NW) direction of Visalia, cotton fields & walnut grass
Visalia Area ag. soil (raisin)	SOIL 05	5	GS/RS	3	NA	Composite of sandy loam soils in Dinuba area, raisin vineyards
Visalia Sand and Gravel storage	SOIL 06	6	GS/RS	3	NA	Commercial sand and gravel operation 3 blocks east of monitoring site
Visalia urban unpaved (parking lots)	SOIL 07	7	GS/RS	3	NA	Composite of 3 unpaved lots in vicinity of monitoring site
Visalia paved road (city street)	SOIL 08	8	PRD/RS	3	NA	Composite from 4 streets around monitoring site
Bakersfield Area ag. soil (alkaline)	SOIL 09	9	GS/RS	3	NA	Composite of alkaline soils in Wasco area
Bakersfield Area ag. soil (sandy)	SOIL 10	10	GS/RS	3	NA	Composite of sandy loam soils, 11 km NW of Bakersfield

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Bakersfield Area unpaved roads (Oildale)	SOIL 11	11	GS/RS	3	NA	Composite of unpaved roads in Kern River Oilfield north of Oildale monitoring site
Bakersfield paved road (city street)	SOIL 12	12	PRD/RS	3	NA	Chester Street near monitoring site
Bakersfield urban unpaved (parking lots and alleys)	SOIL 13	13	GS/RS	3	NA	Composite of 3 unpaved areas near monitoring site
Bakersfield Area ag. soil (sandy loam)	SOIL 14	14	GS/RS	3	NA	Composite of Wasco Series sandy loam soils west of Bakersfield
Bakersfield Area ag. soil (cajon)	SOIL 15	15	GS/RS	3	NA	Composite of Cajon Series sandy loam soils west of Bakersfield
Bakersfield Area unpaved roads (residential)	SOIL 16	16	GS/RS	3	NA	Unpaved residential roads west of Bakersfield
Taft unpaved roads	SOIL 17	17	GS/RS	3	NA	Road leading to monitoring site
Brawley urban unpaved (parking lots)	SOIL 18	18	GS/RS	3	NA	Composite of 3 unpaved parking lots near monitoring site
Brawley paved roads (city streets)	SOIL 19	19	PRD/RS	3	NA	Composite of Main Street, and post office and police station paved parking lots

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
El Centro paved roads (city streets)	SOIL 20	20	PRD/RS	3	NA	Composite of streets around monitoring site
El Centro Area ag. soil	SOIL 21	21	GS/RS	3	NA	Composite of silty clay, silty clay loam, and clay loam soils found in El Centro and Brawley areas
Trona Area desert soil	SOIL 22	22	GS/RS	3	NA	Composite of 5 Searles Lake lake bed sediments
Lone Pine Area desert soil (lake bed)	SOIL 23	23	GS/RS	3	NA	Composite of Owens Lake lake bed sediments
Lone Pine Area desert soil (alkaline)	SOIL 24	24	GS/RS	3	NA	Composite of Owens Lake lake bed alkaline sediments
Lone Pine Area desert soil (sandy)	SOIL 25	25	GS/RS	3	NA	Composite of sandy soils between Lone Pine and Independence
Mammoth Lakes road cinder	SOIL 26	26	GS/RS	3	NA	Volcanic cinders from McGee Creek Storage Area
Mammoth Lakes paved road (city streets)	SOIL 27	27	PRD/RS	3	NA	Main Street and Laurel Mt. Road
Diesel Truck Emissions	WHDIEC	DE	PISD	6	2	174 diesel trucks sampled; engines "revved up" and idled; Wheeler Ridge Weight Station

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Oil Field Crude Oil Boiler Emissions (west-side Kern County oilfield)	SFCRUC	SF	DSS	4	NA	Santa Fe Energy Unit 118
Oil Field Crude Oil Boiler Emissions (Kern River oilfield)	CHCRUC	CH	DSS	3	NA	Chevron Racetrack Steam Plant
Bakersfield Area ag. burning (wheat & barley)	BAAGBC	BB	PISD	3	NA	Composite of 3 wheat and barley stubble burns
El Centro Area ag. burning (wheat)	ELAGBC	BE	PISD	3	NA	Composite of 3 wheat stubble burns
Stockton Area ag. burning (wheat)	STAGBC	BS	PISD	3	NA	Composite of 3 wheat stubble burns
Visalia Area ag. burning (wheat)	VIAGBC	BV	PISD	4	NA	Composite of 3 wheat stubble burns
Visalia Area dairy/feedlot dust	DIDAIC	DR	PISD	3	NA	Dairy north of Visalia
Fresno Area construction emissions (freeway)	FRCONC	CS	PISD	3	NA	Construction, Highway 40

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Mammoth Lakes diesel ski tour buses	MADIEC	TB	PISD	3	NA	Composite of 3 parking lots (idling)
Bakersfield fireplace	BAMAJC	FB	MM 5G	3	3	Bakersfield cordwood, Majestic fireplace
Mammoth Lakes fireplace	MAMAJC	FM	MM 5G	3	3	Mammoth Lakes cordwood, Majestic fireplace
Mammoth Lakes woodstove[c]	MAFISC	WM	MM 5G	3	3	Bakersfield cordwood, Fisher Mama Bear stove

a. Figures 2.7-1 and 2.7-2.

b. GS/RS = grab sampling/resuspension
PRD/RS = paved road dust sampling/resuspension
PISD = Parallel Impactor Sampling Device (ground-based)
DSS = Dilution Source Sampler
MM 5G = Modified U.S. EPA Method 5G dilution tunnel

c. Two sequential filter sets made up one of the three runs with the woodstove burning Mammoth Lakes cordwood.

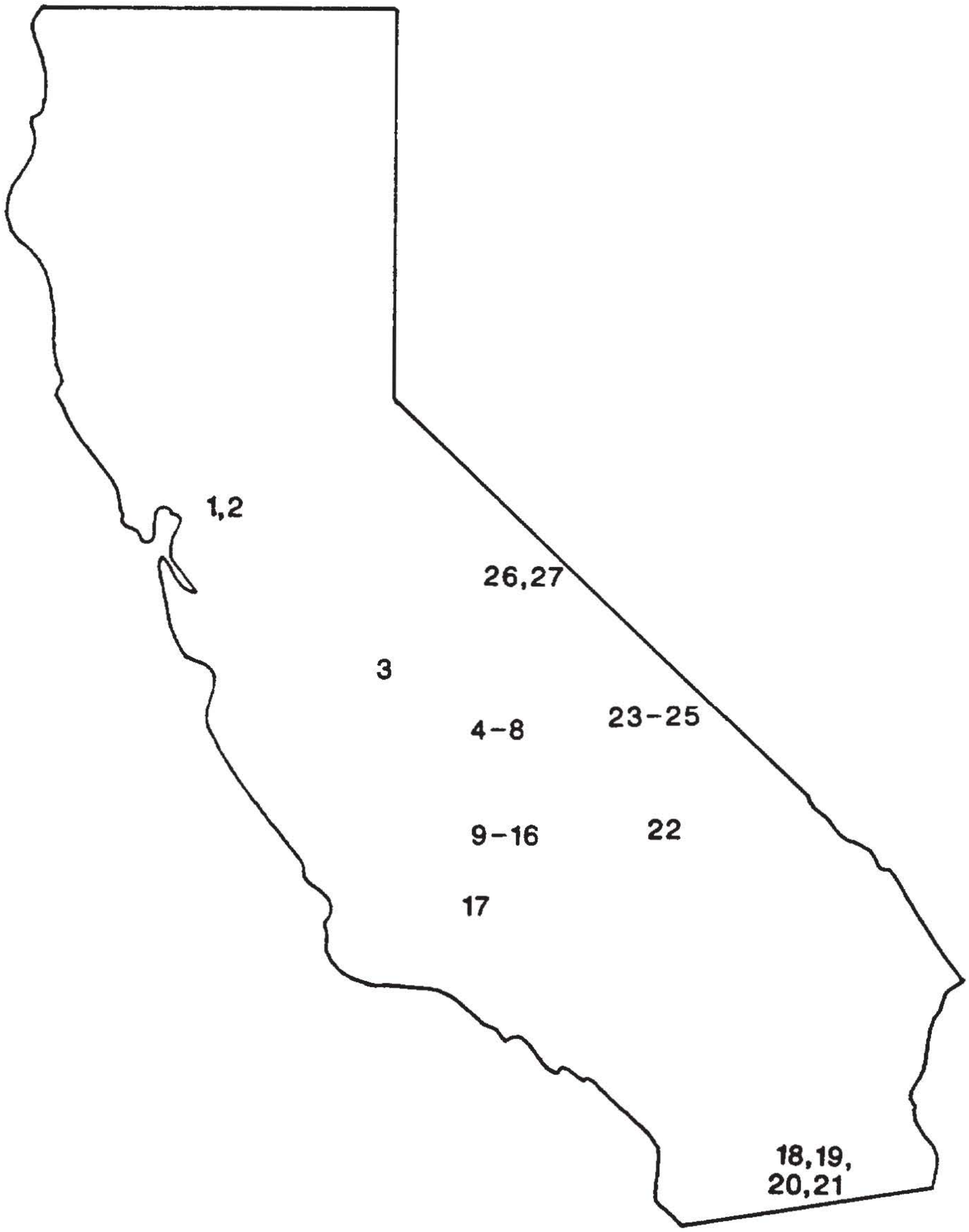

Figure 2.7-1. Approximate location of dust sampling areas. Sample identification numbers are listed in Table 2.7-1.

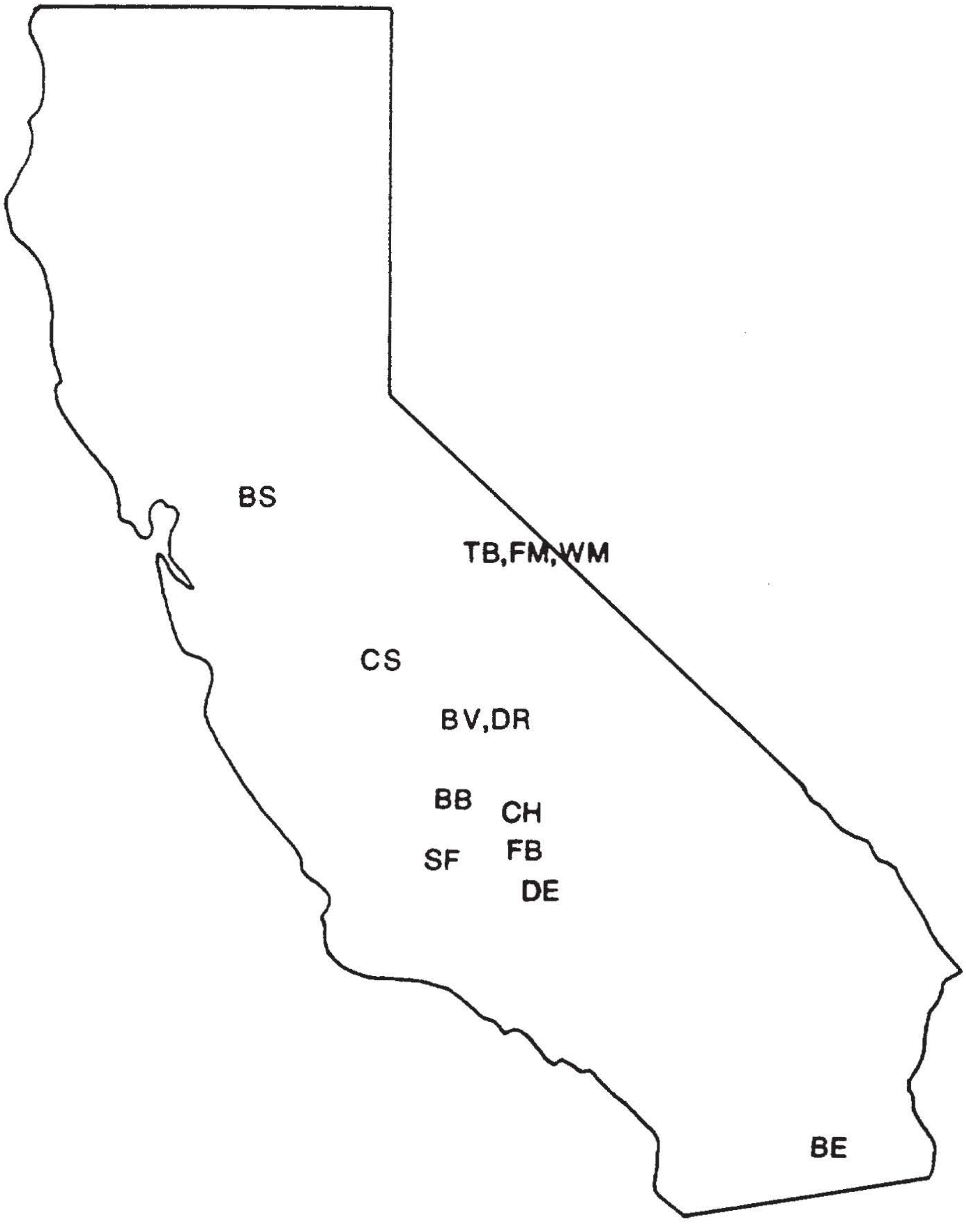

Figure 2.7-2. Approximate location of point and area sources. Sample identification codes are listed in Table 2.7-1.

Table 2.7-2
Detailed Dust Sample Description

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 01	1	9/15/87	Agricultural Soil	Stockton, Hazelton St.	Peat Soil collected along Eight Mile Rd. Four soil types (KL, Kl, Rl, and RN of Kingile and Rindge series) used for soil composite. This soil is suspected to be the source of "the black cloud" seen in Stockton. Soil collected from the Empire Tract and King Island "Delta" areas.
SOIL 02	2	9/15/87	Agricultural Soil	Stockton, Hazelton St.	"Mineral" soil, collected along Mueller Rd. Three soil types (EF, EA, and ME of Egbert and Merritt series) used for soil composite. These are common mineral soils upwind of Stockton (to the NW).
SOIL 03	3	9/16/87	Paved Road	Fresno, Olive St.	Composite sample collected along Olive St. on north and south sides of street from corner of Fisher St. to 75 meters to the west.
SOIL 04	4	9/16/87	Agricultural Soil	Visalia, Church St.	Composite of 4 samples from cotton and walnut fields NW of Visalia. Four samples: (1) cotton field near intersection of Demurre Rd. and Goshen Ave.; (2) walnut field near intersection of Demurre Rd. and Goshen Ave.; (3) cotton field south of Ave. 328 (Co. Rd. J34) along Demurre Rd.; and (4) cotton field near intersection of J34 and J19. All soils collected are recent alluvium soils and are of the Foster series sandy loam.
SOIL 05	5	9/16/87	Agricultural Soil	Visalia, Church St.	Composite of three soil samples from raisin vineyards in the Dinuba area. Three samples collected: (1) near interesection of Nebraska and J19; (2) along J19 appx. 2 km south of Dinuba; and (3) near intersection of Nebraska and J19. All soils are from raised ancient alluvium of the Greenfield sandy loam series.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 06	6	9/16/87	Sand & Gravel Storage	Visalia, Church St.	Sand and gravel from sand and gravel mixing operation three blocks east of Church St. monitoring stations. Collected from storage pile and from under conveyor belt. The sand and gravel operation is potentially a major fugitive source impacting the sampling site.
SOIL 07	7	9/16/87	Unpaved Urban Area	Visalia, Church St.	Material from three unpaved parking lots near ambient monitoring site were composited. These were from: (1) parking lot 30 meters west of monitoring site; (2) dirt from between two railroad tracks near intersection of Gordon and Oak Sts. which is approximately 100 meters west of monitoring site.
SOIL 08	8	9/16/87	Paved Road	Visalia, Church St.	Numerous samples were collected from the four streets that surround the monitoring site.
SOIL 09	9	9/17/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Garces alkaline soil series samples collected from cotton fields, north of Hwy. 46 along Gun Club Rd. in the Wasco area. Several soil samples were collected and composited.
SOIL 10	10	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Kimberlina sandy loam soils collected from cotton fields approximately 11 km NW of Bakersfield along 7th Standard Rd. near intersection of Calloway Dr. Several samples collected and composited.
SOIL 11	11	9/18/87	Unpaved Road	Bakersfield, Chester St.; Oildale, Manor St.	Numerous unpaved road soil samples were collected and composited in the Kern River Oilfield north of the Oildale monitoring site.
SOIL 12	12	9/18/87	Paved Road	Bakersfield, Chester St.	Samples collected along Chester St. on both sides of street near ambient monitoring site.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 13	13	9/18/87	Unpaved Urban Area	Bakersfield, Chester St.	Sample is a composite of three samples collected from unpaved parking lots near the ambient monitoring site.
SOIL 14	14	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Several Wasco series sandy loam soils were collected and composited from tilled fields near intersection of Stockdale Hwy. and Old River Rd. west of Bakersfield.
SOIL 15	15	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Several Cajon series sandy loam soils were collected and composited from alfalfa field along Stockdale Hwy. 1.3 km west of Hwy. 43.
SOIL 16	16	9/18/87	Unpaved Road	Bakersfield, Chester St.; Oildale, Manor St.	Three dirt roads adjacent to residential land use, intersecting Rosedale Hwy. (Hwy. 58) approximately 9 miles west of Bakersfield were sampled and composited.
SOIL 17	17	9/18/87	Unpaved Road	Taft, 10th St.	Several soil samples were collected and composited from unpaved road leading to Moose Lodge 143 behind fire station. It appears that the unpaved road has a heavy impact on the ambient monitoring instruments due to proximity, dusty conditions, and the fact that the ambient monitors were only approximately 0.7 meters above the ground.
SOIL 18	18	9/20/87	Unpaved Urban Area	Brawley, Main St. (Hwy. 78 & 111)	Three unpaved parking lots near monitoring sites were sampled and samples were composited.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 19	19	9/20/87	Paved Road	Brawley, Main St. (Hwy. 78 & 111)	Composite sample consists of roughly 70% of material collected on both sides of Main St. (Hwy. 78 & 111) in front of ambient monitoring site and 30% from Post Office delivery vehicles and police paved parking lots immediately adjacent to monitoring site.
SOIL 20	20	9/21/87	Paved Road	El Centro (corner of Ninth and State Sts.)	Several paved road dust samples were collected on both sides of the streets around the block on which the ambient monitoring site is located. The samples collected were composited.
SOIL 21	21	9/21/87	Agricultural Soil	El Centro (corner of Ninth and State Sts.); Brawley, Main St. (Hwy. 78 & 111)	Imperial-Holtville-Glenbar silty clay, silty clay loam, and clay loam series were collected. Four samples were collected along Forrester Rd. between Worthington Rd. (S28) and Aten Rd. in Bermuda grass fields. The four soil samples were composited. This soil series is very common in the Imperial River Valley and, according to the Soil Conservation Service, is highly wind-erodible. It is believed that this soil type impacts both the Brawley and El Centro sites.
SOIL 22	22	9/22/87	Alkaline Playa Sediments and Desert Soil	Trona, Market St.	A composite of five samples was taken from Searles lakebed east of Trona. The samples were from: (1) 4.8 km east of Trona Rd. and 1.6 km north of monitoring site; (2) 10 km east of Trona Rd. and 0.8 km north of South Trona; (3) approximately 4 km east of Trona monitoring site near roadside rest area; (4) approximately 200 meters east of Trona and 0.8 km south of Westend; (5) 6 km east and 2 km north of the Trona Pinnacles.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 23	23	9/23/87	Alkaline Playa Sediments and Desert Soil	Lone Pine, Locust St.	Desert sand collected from Owens lake. A composite was made from numerous samples collected at two locations. Location #1 was 1.6 km ESE of Swansea and Location #2 was near the Phase 2 sand fence site.
SOIL 24	24	9/23/87	Alkaline Playa Sediments	Lone Pine, Locust St.	A composite of four Owens Lake alkaline sediments was made from numerous samples collected east of the DRI test site (southern section of lake).
SOIL 25	25	9/23/87	Desert Soil	Lone Pine, Locust St.	Composite was made of soils collected at five locations in Owens Valley between Lone Pine and Independence. Location #1 consisted of Winnedumah-Mazourka-Cajon-Eclipse series. These were sands, loamy sands, loams, and silty loams 0.8 km north of Lone Pine monitor along Lone Pine Station Rd.; Location #2, common undescribed river silt 200 meters west of Owens River on Lone Pine Station Rd.; Location #3, Mazourka-Cajon-Eclipse series, sands and sandy loams, 1.4 km south of Mazourka Canyon Rd., 8 km west of Independence; Location #4, same soils series as Location #3, soils collected on a "slick," 1.0 km north of Mazourka Canyon Rd., 8 km west of Independence; and Location #5, Winnedumah soil on dirt road, .8 km north of Mazourka Canyon Rd., 4 km west of Independence.
SOIL 26	26	9/24/87	Cinder Storage	Mammoth Lakes, Gateway	Sample collected from the CALTRANS McGee Creek Storage Area. Material is from the Black Point Cinder Pit, near Mono Lake.
SOIL 27	27	9/24/87	Paved Road Dust	Mammoth Lakes, Gateway	Composite of samples collected along Main St. (Hwy. 203) and Laural Mountain Rd. around Mammoth Lakes Gateway monitoring site.

a. Map ID: Figure 2.7-1.

The agricultural soil samples collected were:

- Peat soils from the Delta region northwest of Stockton (source of Stockton "black cloud") (Schultz and Carlton, 1959);
- Mineral soils collected northwest of Stockton;
- Soils collected in cotton and walnut growing areas northwest of Visalia;
- Soils collected in raisin vineyards northwest of Visalia;
- Four composite soil samples representing the major soil types and agricultural crop areas west and northwest of Bakersfield; and
- A composite of predominant Imperial Valley agricultural soils.

Paved Roads

Six paved road dust samples were collected adjacent to ARB PM_{10} monitoring sites. The paved road samples were collected at the following locations:

- Fresno - Along Olive Street from the corner of Fisher Street to 75 meters west of monitors;
- Visalia - Sample collected from all four streets making up block where monitors were located (Church Street);
- Bakersfield - Along Chester Street, approximately 100 meters on either side of monitors;
- Brawley - Highways 78 and 11, and post office and police parking lots adjacent to the city block were monitors are located;
- El Centro - Ninth and State Streets near monitors; and
- Mammoth Lakes - Main Street (Highway 203) and Laurel Mountain Road near monitors.

Unpaved Roads and Urban Areas

Six samples were collected from unpaved roads and urban areas. As with the paved road dust samples, locations were selected near ARB PM_{10} monitoring sites. The unpaved road and urban samples were collected at the following locations:

- Visalia - Three unpaved parking lots near the Church Street monitoring site;
- Oildale - Unpaved roads in Kern River Oilfields north of Manor Street monitoring site;
- Bakersfield - Unpaved parking lots near Chester Street monitoring site;
- Bakersfield - Unpaved roads in residential areas west of Bakersfield;

- Taft - Unpaved road adjacent to monitors; and
- Brawley - Three unpaved parking lots near monitoring site.

Alkaline Playa Sediment and Desert Soils

Material was collected on and around Searles Lake (dry), around Owens Lake (dry), and in the desert range land between Lone Pine and Independence in the Owens Valley. The alkaline material of the Searles and Owens Lakes has been well quantified, as have the dust storms originating in their playas (Kerr-McGee Chemical Corporation, undated; Barone et al., 1979; Kusko et al., 1981; Kusko and Cahill, 1984; Saint-Armand, 1986).

Due to the lowering of the water table in the Owens Valley by the withdrawal of water by the Department of Water and Power of the City of Los Angeles (LADWP), vegetation has died, producing a number of barren areas in the Owens Valley which are sources of wind-blown dust. The four samples of alkaline playa material and desert soils were:

- Searles Lake - Five locations on and around Searles Lake East of Trona
- Owens Lake - Desert Sands.
- Owens Lake - Alkaline Crusts.
- Desert Soil, Owens Valley - Five locations between Lone Pine and Independence.

Sand and Cinder Storage Areas

Two samples were collected in this category. Sand was collected from a commercial sand and gravel mixing operation three blocks east of the Visalia Church Street monitoring site. While the storage and mixing operation is clearly not an important area-wide dust source, it was sampled due to its proximity to the ambient monitoring site. A road cinder sample was collected from Caltrans' McKee Creek cinder storage area outside Mammoth Lake. The cinder has been recognized as a wintertime particulate source after it is applied to roads in the area (Kemp, 1986). It is a volcanic cinder material, and it is suspected that crushing by vehicular traffic increases the fine fraction percentage. This sample was ground with a ceramic ball mill before laboratory sieving and resuspension procedures (Appendix D). This was conducted to simulate crushing by vehicular traffic.

In addition to the twenty-seven dust sample categories, thirteen other area and point source categories were sampled. These samples were collected with the ground-based PISD sampler, the industrial dilution source sampler (DSS), or the modified Method 5G-type dilution tunnel. Appendix E is a summary of point and area source filter samples.

Crude-Oil-Fueled Steam Generators

Emission samples were collected from two crude-oil-fueled steam generating units with the industrial dilution source sampler (DSS). Four replicate samples were collected from a unit operated by the Santa Fe Energy Company in the West Kern County Oilfield. Three replicate samples were collected from a unit operated by Chevron USA in the Kern River Oilfield. A unit from the West Kern County Oilfield and another from the Kern River Oilfield were sampled due to the possibility that differences in the crude oil chemical makeup between the two oilfields might influence the chemical composition of the particulate emissions. Tables 2.7-3 and 2.7-4 list the stack and sampler operation parameters during sampling at the two sites.

Diesel Truck Emissions

Integrated samples of commercial diesel truck traffic emissions were collected at the Wheeler Ridge Weigh Station located south of the intersection of Interstate Highway 5 and Highway 99 south of Bakersfield. The weigh station was operated by the California Highway Patrol (CHP). Six replicate runs were conducted with the PISD samplers. The PISD samplers were placed on a catwalk above inspection bay 3 of the inspection building. A CHP officer periodically directed trucks through the building specifically for the sampling effort. After deceleration, drivers were asked to maintain engine speeds of 1200 RPM. Consequently, emissions during deceleration, during a constant operating speed, and during acceleration as they were leaving were sampled. Emissions from a total of 174 trucks were sampled over the course of the six replicate runs (Table 2.7-5). Two upwind ambient background PISD samplers were situated approximately 100 meters northwest of the weigh station.

Diesel Ski Tour Bus Emissions

The emissions from ski tour buses operating in the Mammoth Lakes area were sampled with the PISD samplers situated in their exhaust plumes. Three replicate runs were conducted (these were not true replicates since different buses were sampled during each run). The ski tour buses, which are tuned for lower elevations and warmer temperatures than encountered at Mammoth Lakes, require long warm-up idling periods. Frequently, when temperatures are very low, they are idled all night. The long idling periods represent an air quality problem in the Mammoth Lakes area during the ski season. Most of the sampling was conducted in the Sierra Nevada Inn parking lot during the morning and in the Mammoth Mountain Ski Area parking lot in

Table 2.7-3
Stack and Sampler Operation Parameters, Oil-Fired Steam Generator: Chevron Racetrack Steam Plant

Company:	Chevron
Plant:	Racetrack Steam Plant, Sec. 27 29S/29E
City:	Bakersfield, California
Fuel:	Crude oil
No. of Generators:	Seven
No. of Stacks:	One
Port:	Female, east side of stack, $1^1/_2$ meters below top of stack and approximately $1^1/_2$ meters above platform
Platform:	Approximately 20 meters from ground
Scrubber Technology:	
Manufacturer:	Neptune Airpol, Inc.; Serial #4041
Date of Manufacture:	9/30/82
Description:	Two levels of water spray. Water level maintained approximately 1 meter at bottom of scrubber. Soda ash added to control pH; kept at pH 6.8 (gauge shows 6.85). Density and level of solution in bottom of scrubber maintained automatically. Includes set of anti-mist screens to prevent liquid fall-out.
Meaurements:	
Date:	6/14/88
Time:	1430
Ambient Temperature:	85° F (29° C)
Stack Temperature:	134° F (57° C)
Stack Velocity Pressure:	0.05 inch H_2O
Stack Static Pressure:	0 to +0.05 inch H_2O
Calculated Stack Velocity:	4.1 meters per second
Sampling Parameters:	
Nozzle Size:	$^1/_2$ inch
Dilution Ratio:	1 : 15
Distance of Nozzle from Stack Wall:	48 inches

Table 2.7-4
Stack and Sampler Operation Parameters, Oil-Fired Steam Generator: Santa Fe Energy Unit 118

Company: Santa Fe Energy Company

Plant: Santa Fe Energy Unit 118

City: Fellows, California

Stack: #118 steam generator emissions, after scrubber

Fuel: Crude oil

Port: 4 inch female NPT, north side of stack, approximately 1 meter from top of stack

Platform: Approximately 10 meters from ground

Scrubber Technology:

- Manufacturer: Air Pol
- Description: Two levels of water sprays
  - Water level maintained to approximately 1 meter at bottom of scrubber
  - Soda ash solution added for control of pH within 7.0 to 7.2
  - Density and level of solution in bottom of scrubber maintained automatically
  - Includes set of anti-mist screens to prevent liquid fall-out

Plume: Heavily loaded with water vapor; appearance of plume after water dissipated was blue and carried horizontally, with little vertical climb

Meaurements:

- Date: 11/19/87
- Time: 0900
- Ambient Temperature: 65° F (18° C)
- Stack Temperature: 147° F (64° C)
- Stack Velocity Pressure: 0.05 inch H_2O
- Stack Static Pressure: 0 to +0.05 inch H_2O
- Calculated Stack Velocity: 4.1 meters per second

Sampling Parameters:

- Nozzle Size: $^3/_8$ inch
- Dilution Ratio: 1 : 30
- Distance of Nozzle from Stack Wall: 48 inches

Table 2.7-5
Truck Count, Diesel Emissions;
Wheeler Ridge Weigh Station

Run #	Number of Trucks Counted					
	Freightliner	Peterbilt	Kenworth	International	Other*	Total
1	13	7	13	6	5	44
2	12	6	7	8	7	40
3	10	4	4	2	1	21
4	7	5	5	2	1	20
5	8	2	5	4	1	20
6	10	5	5	7	2	29
Totals	60	29	39	29	17	174

* *Other* includes GMC, Ford, and Mack.

the afternoon. No background air samples were collected due to the relatively good surrounding air quality during the sampling program and the short-duration, high-impact source samples which were collected.

Agricultural Burning

Three or four replicate runs of agricultural burning emissions were collected using the PISD samplers in each of four areas. It should be noted that the multiple runs were not true replicates as each sample was from a different agricultural burning event. No background air samples were collected due to the short-duration, high-impact source samples which were collected. The four agricultural burning sample sets that were collected are as follows:

- Two wheat stubble fires and a barley stubble fire were sampled in the Bakersfield area. All three locations were in Kern County, 20 kilometers south of Bakersfield, 10 kilometers west of Bakersfield, and 5 kilometers south of Shafter, respectively.

- Three wheat stubble fires were sampled in the El Centro area. They were collected in Imperial County fields, 7 kilometers northwest of El Centro, 10 kilometers southwest of El Centro, and 8 kilometers south of El Centro.

- Three wheat stubble fires were sampled in the Visalia area. They were collected in Tulare county in fields 20 kilometers east of Tipton, 5 kilometers west of Tulare, and 3 kilometers east of Tulare.

- Three wheat stubble fires were sampled in the Stockton area. They were in San Joaquin County. One was 25 kilometers northwest of Stockton and two sets were 10 kilometers north of Tracy.

It should be noted that the burning of other agricultural crop residues also occurs, but that wheat stubble is one of the major crop residues burned in the study areas.

Dairy/Feedlot Dust

Dairies and feedlots have been recognized as significant potential sources of particles in California (Azevedo, 1974; California Cattle Feeders Assoc., 1971; Miller, 1962; Miller et al., 1974). Three replicates of emissions generated at a dairy in the Visalia area were sampled with PISD samplers. No background samples were collected, as the emissions from the dairy dominated the samples.

Construction Emissions

Three replicate samples were collected of dust and emissions generated by Highway 40 construction in Fresno (Figure 2.7-3). The samples were collected using the PISD samplers situated downwind of the construction activity. No background samples were collected, as the dust and emissions from the construction dominated the samples.

Residential Wood Combustion

Residential Wood Combustion (RWC) has been demonstrated as being a significant source of particulate material in California High Sierra communities (Ipps, 1987) and in San Joaquin Valley communities (Engineering Science, 1982; Inouye, 1985). In High Sierra resort communities such as Mammoth Lakes, both fireplaces and woodstoves are significant. In the San Joaquin communities with milder climates, fireplaces are much more predominant than woodstoves. It has been estimated, for example, that the total number of woodstoves (including fireplace inserts, which function like woodstoves) in the Fresno area in 1984 was 7,556 as compared to 51,339 fireplaces (Inouye, 1985). The corresponding estimated ratio of inhalable particulate emissions between fireplaces and woodstoves was 12:1. Since Bakersfield has a slightly milder climate than Fresno (2128 versus 2601 heating degree days), it was assumed that fireplaces represent even a larger fraction of the total residential wood combustion emissions in Bakersfield as compared to Fresno.

As discussed in Section 2.5, laboratory sampling of woodburning appliances with a modified Method 5G-type sampler appears to be the most appropriate approach to obtain RWC source profiles. Three replicate runs each simulating fireplace use in Bakersfield, fireplace use in Mammoth Lakes, and woodstove use in Mammoth Lakes were conducted at OMNI's testing facility in Beaverton, Oregon. Since unfiltered laboratory air was used for dilution, background PISD samplers were run simultaneously with the modified Method 5G-type sampler.

Fuel wood and woodstove dealers were surveyed in both the Bakersfield and Mammoth Lakes areas to determine the principal wood types burned. An official with the Inyo National Forest was also interviewed regarding wood types cut for use in Mammoth Lakes. Table 2.7-6 lists the consensus of opinions as to the major wood types used in both communities with an estimated relative percent usage. Of course, many miscellaneous wood types are burned in both communities but apparently none at more than a few percent level each. Interestingly, almond is a major wood type burned in the Bakersfield area due to the abundance of almond orchard trimmings. During the tests the wood types were burned in the same proportion as the estimated usage for the Mammoth Lakes and Bakersfield sampling runs. The percent moisture on a dry basis of the cordwood which was obtained is also given in Table 2.7-6.

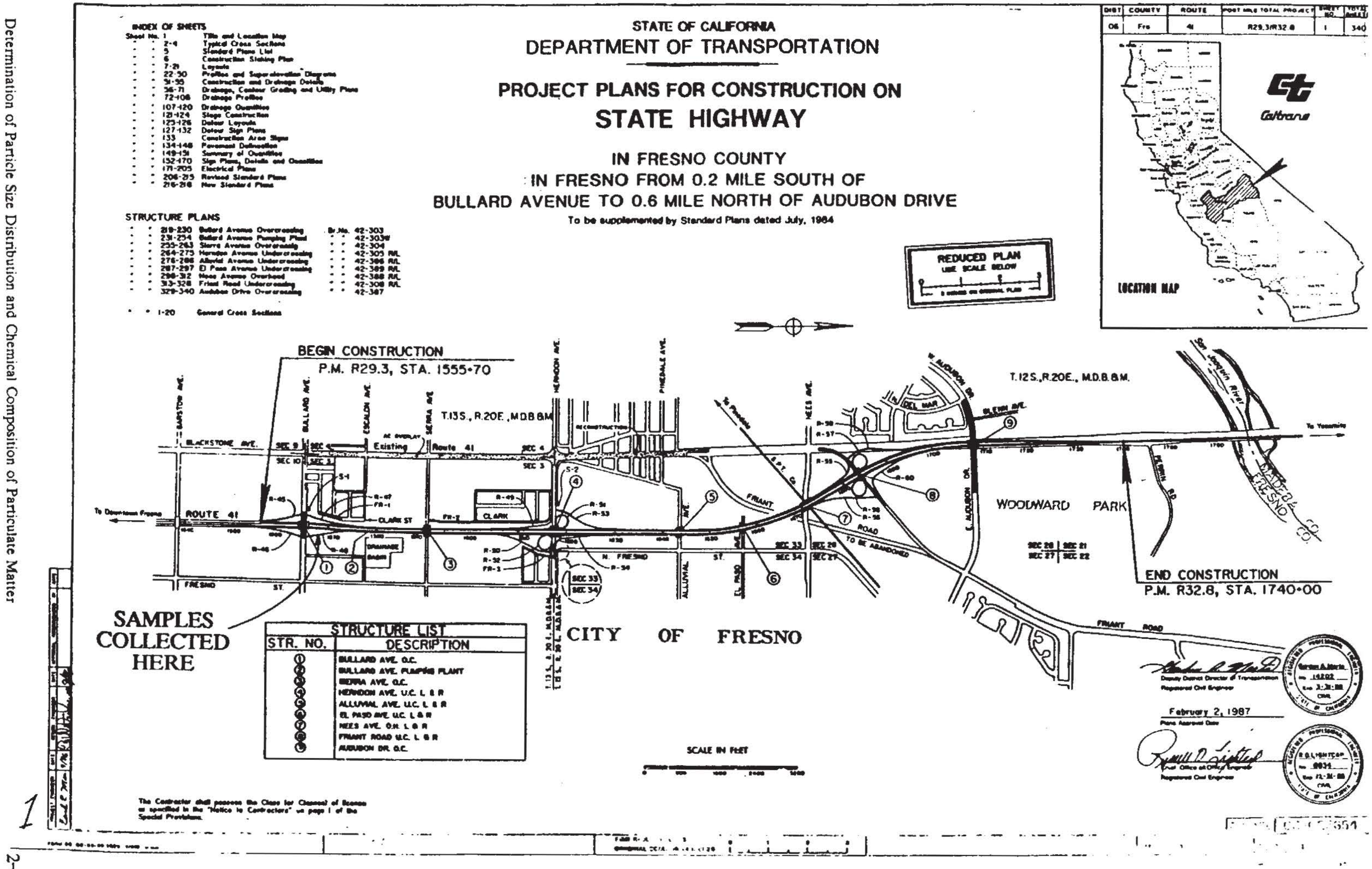

Figure 2.7-3. Location of construction sampling.

Table 2.7-6
Mammoth Lakes and Bakersfield Cordwood

Area/Species	Estimated Usage (percent)	Moisture Content (percent dry basis)
Mammoth Lakes		
Lodgepole Pine	20	14
Jeffrey Pine	60	15
Red Fir	20	13
Bakersfield		
Almond	60	13
White Oak	40	13

A more-or-less typical fireplace and airtight woodstove (non-catalytic) were used for the tests. These appliances were well broken in before use. (New appliances may give erroneous particulate source profiles due to the burning of paint and oil.) The target burn rate for the woodstove tests was approximately 1.5 kg(dry)/hr. The target burn rate for the fireplace tests was between approximately 3 to 4 kg(dry)/hr. The wood addition period for all tests was 5 hours, which represents a typical evening burn period for fireplaces and woodstoves in communities such as Mammoth Lakes and Bakersfield. Sampling was continued until the flue temperature (30 cm above the appliance) was less than 100°F (38°C). The dilution ratio was lower for the fireplace tests than for the woodstove tests since flue gas flows are much higher for fireplaces than for airtight woodstoves. Tables 2.7-7 through 2.7-9 give the woodstove and sampler operation parameters for the simulated Mammoth Lakes woodstove runs. Tables 2.7-10 through 2.7-12 give the fireplace and sampler operation parameters for the simulated Mammoth Lakes fireplace runs. Tables 2.7-13 through 2.7-15 give the fireplace and sampler operation parameters for the simulated Bakersfield fireplace runs. Two sequential filter sets were used on one of the three Mammoth Lakes woodstove runs. A weighted averaged (based on volume sampled) was calculated for that overall run profile.

Table 2.7-7
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 1

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in doors

Operation

Date:	February 10, 1988
Wood Addition Period:	5 hours
Burn Period:	10.52 hours
Burn Rate:	1.53 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
1146	Jeffrey Pine	0.43 (kindling)	Door open
1146	Jeffrey Pine	0.87 (starter logs)	Door closed
1150	Jeffrey Pine	1.30	Both dampers open
1212	—	—	One spin draft open; other closed
1222	Jeffrey Pine	1.74	One spin draft open; other closed
1244	—	—	Both spin drafts open one-half turn
1420	Lodgepole Pine	1.93	Both spin drafts open one-half turn
1524	Jeffrey Pine	4.00	Both spin drafts open 2 $^1/_2$ turns
1550	—	—	Both spin drafts open two turns
1646	Red Fir	3.89	One spin draft $^1/_2$ open; other $^3/_4$ open
1646	Lodgepole Pine	1.05	One spin draft $^1/_2$ open; other $^3/_4$ open
1646	Jeffrey Pine	0.87	One spin draft $^1/_2$ open; other $^3/_4$ open
2217	Test terminated		

Sampler:

Total Sampling Time:	10.52 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	297° F/147.2° C
Typical Chamber Temperature:	76° F/24.4° C
Typical Ambient Temperature:	61° F/15.9° C

Table 2.7-8
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 2

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in door

Operation

Date:	February 11, 1988
Wood Addition Period:	5 hours
Burn Period:	10.32 hours
Burn Rate:	1.60 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0914	Jeffrey Pine	0.43 (kindling)	Door open
0914	Jeffrey Pine	0.87 (starter logs)	Door open
0919	Jeffrey Pine	1.30	Dampers open/door closed
1000	Lodgepole Pine	1.23	Drafts open two turns
1047	Jeffrey Pine	2.26	Drafts open two turns
1154	Lodgepole Pine	2.11	Drafts open two turns
1308	Jeffrey Pine	1.65	Drafts open two turns
1341	Jeffrey Pine	1.22	Drafts open two turns
1414	Red Fir	3.63	Dampers open three-quarter turn
1414	Jeffrey Pine	1.83	Dampers open three-quarter turn
1932	Test terminated		

Sampler:

Total Sampling Time:	10.32 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	289° F/142.8° C
Typical Chamber Temperature:	75° F/23.6° C
Typical Ambient Temperature:	62° F/18.3° C

Table 2.7-9
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 3

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in door

Operation

Date:	February 12, 1988
Wood Addition Period:	5 hours
Burn Period:	9.47 hours
Burn Rate:	1.72 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0918	Jeffrey Pine	0.43 (kindling)	Door open
0918	Jeffrey Pine	0.87 (starter logs)	Door open
0925	Jeffrey Pine	1.65	Drafts open/door closed
0956	Red Fir	1.59	Drafts open two turns
1103	Jeffrey Pine	1.74	Drafts open two turns
1217	Red Fir	1.86	Drafts open two turns
1307	Red Fir	0.53	Drafts open two turns
1329	Lodgepole Pine	1.84	Drafts open two turns
1349	Jeffrey Pine	0.78	Drafts open two turns
1425	Jeffrey Pine	3.91	Drafts open three-quarter turn
1425	Lodgepole Pine	1.05	Drafts open three-quarter turn
1846	Test terminated		

Sampler:

Total Sampling Time:	9.47 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	316° F/157.8° C
Typical Chamber Temperature:	78° F/25.6° C
Typical Ambient Temperature:	66° F/18.9° C

Table 2.7-10
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 1

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 5, 1988
Wood Addition Period:	5 hours
Burn Period:	6.9 hours
Burn Rate:	3.67 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0930	Jeffrey Pine	0.43 (kindling)	Open
0930	Jeffrey Pine	0.87 (starter logs)	Open
0934	Lodgepole Pine	1.84	Open
1047	Jeffrey Pine	2.09	Open
1104	Jeffrey Pine	3.04	Open
1145	Jeffrey Pine	2.52	Open
1255	Lodgepole Pine	1.84	Open
1321	Jeffrey Pine	3.48	Open
1356	Jeffrey Pine	2.70	Open
1356	Lodgepole Pine	1.32	Open
1430	Red Fir	5.22	Open
1624	Test terminated		

Sampler:

Total Sampling Time:	6.9 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	291° F/144.0° C
Typical Chamber Temperature:	121° F/49.6° C
Typical Ambient Temperature:	55° F/12.5° C

Table 2.7-11
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 2

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 8, 1988
Wood Addition Period:	5 hours
Burn Period:	6.34 hours
Burn Rate:	4.15 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0945	Jeffrey Pine	0.43 (kindling)	Open
0945	Jeffrey Pine	0.87 (starter logs)	Open
0948	Jeffrey Pine	2.26	Open
1008	Jeffrey Pine	1.48	Open
1048	Jeffrey Pine	3.39	Open
1141	Jeffrey Pine	3.65	Open
1218	Lodgepole Pine	2.46	Open
1305	Jeffrey Pinee	1.83	Open
1327	Red Fir	4.96	Open
1445	Red Fir	0.71	Open
1445	Jeffrey Pine	1.91	Open
1445	Lodgepole Pine	2.37	Open
1605	Test terminated		

Sampler:

Total Sampling Time:	6.34 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	369° F/187.2° C
Typical Chamber Temperature:	105° F/40.6° C
Typical Ambient Temperature:	60° F/15.6° C

Table 2.7-12
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 3

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 9, 1988
Wood Addition Period:	5 hours
Burn Period:	6.12 hours
Burn Rate:	4.10 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0810	Jeffrey Pine	0.43 (kindling)	Open
0810	Jeffrey Pine	0.87 (starter logs)	Open
0815	Jeffrey Pine	1.83	Open
0830	Lodgepole Pine	2.02	Open
0856	Jeffrey Pine	0.96	Open
0927	Jeffrey Pine	1.91	Open
0947	Lodgepole Pine	3.07	Open
1025	Red Fir	2.21	Open
1046	Jeffrey Pine	2.00	Open
1107	Jeffrey Pine	3.04	Open
1153	Jeffrey Pine	2.78	Open
1231	Jeffrey Pine	1.04	Open
1310	Red Fir	2.92	Open
1417	Test terminated		

Sampler:

Total Sampling Time:	6.12 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	261° F/127.2° C
Typical Chamber Temperature:	107° F/41.5° C
Typical Ambient Temperature:	56° F/13.3° C

Table 2.7-13
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 1

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 2, 1988
Wood Addition Period:	5 hours
Burn Period:	6.68 hours
Burn Rate:	3.75 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0844	Almond	0.44 (kindling)	Open
0844	Almond	0.88 (starter logs)	Open
0855	Almond	1.42	Open
0909	Oak	1.24	Open
0922	Oak	3.36	Open
0949	Almond	3.36	Open
1040	Oak	3.98	Open
1142	Almond	1.68	Open
1210	Almond	3.45	Open
1313	Almond	1.77	Open
1344	Almond	2.30	Open
1344	Oak	1.15	Open
1525	Test terminated		

Sampler:

Total Sampling Time:	6.68 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	240° F/115.6° C
Typical Chamber Temperature:	94° F/34.4° C
Typical Ambient Temperature:	51° F/10.6° C

Table 2.7-14
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 2

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 3, 1988
Wood Addition Period:	5 hours
Burn Period:	6.54 hours
Burn Rate:	3.83 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0821	Almond	0.44 (kindling)	Open
0821	Almond	0.88 (starter logs)	Open
0828	Almond	1.86	Open
0835	Almond	2.65	Open
0922	Oak	3.45	Open
1001	Almond	4.07	Open
1043	Oak	3.81	Open
1129	Oak	2.92	Open
1158	Almond	1.42	Open
1258	Almond	1.06	Open
1321	Almond	2.48	Open
1453	Test terminated		

Sampler:

Total Sampling Time:	6.54 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	288° F/142.2° C
Typical Chamber Temperature:	107° F/41.7° C
Typical Ambient Temperature:	59° F/15.0° C

Table 2.7-15
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 3

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 4, 1988
Wood Addition Period:	5 hours
Burn Period:	6.44 hours
Burn Rate:	3.90 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
1201	Almond	0.44 (kindling)	Open
1201	Almond	0.88 (starter logs)	Open
1213	Almond	1.95	Open
1227	Almond	2.65	Open
1317	Oak	3.54	Open
1412	Oak	3.89	Open
1551	Almond	6.19	Open
1646	Oak	2.48	Open
1701	Almond	3.10	Open
1828	Test terminated		

Sampler:

Total Sampling Time:	6.44 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	268° F/131.1° C
Typical Chamber Temperature:	90° F/32.2° C
Typical Ambient Temperature:	58° F/14.4° C

Determination of Particle Size Distribution and Chemical Composition of Particulate Matter from Selected Sources in California

Volume I
(Final Report)

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1.0 Introduction

1.1 Background

In December 1982, the California Air Resources Board (ARB) adopted a state ambient air quality standard for suspended particulate matter less than ten microns ($<10\mu$) in diameter. In July 1987, the U.S. Environmental Protection Agency (EPA) promulgated a national ambient air quality standard for fine particulate matter (PM_{10}) (U.S. Environmental Protection Agency, 1987b). Significant portions of the Great Basin Valleys, the San Joaquin Valley, and the Southeast Desert Air Basins are not in compliance with the state and federal PM_{10} standards. Thus, state implementation plans (SIPs) will need to be prepared, revised, or have their success evaluated for those areas (Ipps, 1987).

Receptor modeling is an extremely useful tool for determining the sources of ambient particulate material. The ARB plans to utilize receptor modeling techniques to generate valuable information for the preparation, revision, or evaluation of the SIPs.

In order to conduct chemical mass balance (CMB) receptor modeling (one of the most useful receptor models), detailed chemical analyses need to be conducted on both ambient and source samples. Ambient monitoring and subsequent filter analysis are relatively simple and routine, and are in progress or are completed at a number of monitoring locations. Source sampling and analysis, on the other hand, frequently require custom instrumentation and procedures.

Recognizing the need for source data, the ARB issued a request for proposal (RFP) on December 12, 1986 entitled "Determination of Particle Size Distributions and Chemical Composition of Particulate Matter from Selected Sources in California." OMNI Environmental Services, Inc. (OMNI), with the Desert Research Institute (DRI) as a major subcontractor, responded and was awarded the contract on June 3, 1987. This report presents the results of the work conducted under the contract.

The characterization of four size ranges of particles was specified in the RFP. The size ranges were: (1) less than one micron; (2) one micron to two and one-half microns; (3) two and one-half microns to ten microns; and (4) greater than ten microns.

As well as providing 10μ data directly related to PM_{10} ambient values, the size-resolved data sets permit the reconciling of sources with ambient particulate measurements and provide general insight into the environmental and human health impacts of specific sources. In addition, ARB's emission inventory contains size-resolved data (Taback et al., 1979) which will be supplemented by the data generated in this study.

The source categories of primary emphasis for this study were identified by the ARB prior to the start of the program. They were:

- Agricultural tillage;
- Paved roads;
- Unpaved roads;
- Construction and demolition;
- Livestock operations;
- Wind-blown agricultural land;
- Wind-blown desert land;
- Wind-blown urban unpaved areas;
- Vehicular diesel combustion;
- Forest fires;
- Agricultural burning;
- Woodstoves and fireplaces;
- Oil-field internal combustion engines; and
- Heavy crude combustion.

Upon review of updated emission inventory data and discussions with oil-field industry officials and local air pollution control engineers and scientists, it was jointly decided by ARB and OMNI personnel not to conduct source sampling on oil-field internal combustion engines and forest fires. Additional emphasis was, however, placed on vehicular diesel combustion and woodstove/fireplace sources as they appear more significant in the geographical area of interest. At ARB's request, less emphasis was also placed on collecting source samples from livestock operations.

Specialized source sampling instruments for the collection of particulate samples in a form compatible with the detailed chemical analysis needed for CMB modeling have been developed and their performance has been well documented (Core and Houck, 1987). The ARB's requirements that the particle size distribution and chemical composition be determined for four size ranges ($<1\mu$, 1μ - 2.5μ, 2.5μ - 10μ, $>10\mu$) for each source necessitated the development of new equipment specifically for use in this project. Following the fundamental design factors for previously used equipment of this type, parallel impactor sampling devices (PISDs) were developed for ground-based sampling of area sources, two dilution source samplers were developed for the sampling of high-temperature sources, and PISDs were interfaced with a resuspension chamber to sample size-resolved fractions of soil and road dust in the laboratory. Soil and road dust samples were collected in the field using standard protocols for grab sampling and by using a high-volume road dust sampler (Core and Houck, 1987).

General protocols for the gravimetric and chemical analyses of particulate source samples have been well-established (Core and Houck, 1987; Watson et al., 1988), albeit custom processing of samples is often required due to the wide range of chemical compositions and filter loadings which can be encountered in some source samples. X-ray fluorescence spectrometry, atomic absorption spectrophotometry, ion chromatography, automated colorimetry, and thermal/optical reflectance carbon analysis were used to quantify the forty-three chemical species measured on 593 filters. Benzene soluble organic (BSO) analysis was originally specified by the RFP. However, ARB and OMNI personnel agreed that deleting the BSO analysis and replacing it with ammonium (NH_4^+) analysis and an interlaboratory comparison program for organic and elemental carbon would be more appropriate. The interlaboratory comparison of organic and elemental carbon data was done because it has been demonstrated that reported organic carbon and elemental carbon values can vary significantly from laboratory to laboratory (Groblicki et al., 1983; Countess, 1987). A subset of twenty filters were analyzed by two additional independent laboratories (making a total of three laboratories) for the carbon comparison study.

Three appropriate data base formats have been developed for the use of source data and are being used to report the results of the study. These are: (1) a dBase III format compatible with the U.S. EPA source composition library (Core et al., 1984); (2) an ASCII file compatible with the U.S. EPA Chemical Element Receptor Model Version 7.0 (Watson, 1989) as well as ARB's Principal Components Analysis (PCA) and Chemical Mass Balance (CMB) Level I PM_{10} Assessment Package (Freeman et al., 1987; Watson et al., 1987); and (3) a data file with the data for the various size ranges of particles listed (Taback et al., 1979) for use in ARB's RAMIS emission inventory program.

1.2 Project Objectives and Tasks

The objectives of the study can be summarized as follows:

- To identify particulate sources which would represent the major sources that would be received at important PM_{10} receptors.

- To obtain representative samples of these particulate sources in four particle size ranges and to chemically characterize them for species which will allow their identification in PM_{10} receptor samples.

- To document the source characterization methods, the source operating parameters, and the accuracy, precision, and validity of source composition data.
- To create a data base incorporating this information that is compatible with existing source libraries, emissions inventories, and PM_{10} assessment models.

To realize these objectives, OMNI and DRI conducted four tasks.

Task 1: A source sampling and analysis plan was developed for identifying representative sampling locations, obtaining representative samples from those locations, analyzing those samples for specified chemical species, and assuring the quality of those measurements. This plan included a review of available PM_{10} data and emissions inventories, original site surveys of key receptor and source areas, and arrangements with source operating personnel for access to emission points. The plan was reviewed and approved by ARB personnel before the remaining three tasks were started.

Task 2: Source samples were collected in four specified size fractions on Teflon membrane and quartz fiber filter media. Samples were collected by diluted exhaust sampling, grab sampling or road vacuuming followed by laboratory resuspension, and ground-based plume sampling. The method selected depended on which was most appropriate for the specified source type. The samplers underwent calibrations and routine performance evaluations before deployment. Sampling sites and operating parameters were documented.

Task 3: Chemical and gravimetric analyses were conducted on approximately 150 separate source samples in the four specified size fractions. These analyses generated the desired source composition information on mass elements, ions, and other chemical species using the methods of gravimetric analysis, atomic absorption spectrophotometry, automated colorimetry, thermal/optical reflectance carbon analysis, ion chromatography, and x-ray fluorescence spectrometry. Replicate analyses and interlaboratory comparisons were performed. Minimum detectable concentrations were also quantified.

Task 4: Task 4 was the preparation of the final report and of a data base for the desired size fractions of the source emissions. The source compositions (percent of total mass emissions in a given size range which individual elements, ions, or other chemical species comprise) and their uncertainties were compiled in formats compatible with: (1) EPA's dBase III version of the source composition library; (2) EPA's Chemical Element Balance Receptor Model version 7.0

and ARB's PCA and CMB Level I PM_{10} Assessment Package; and (3) ARB's RAMIS emission inventory system.

Each of the four tasks was completed and is described in this report.

2.0 Source Sampling

2.1 Source Testing Alternatives

The receptor modeling scientific community is in agreement that the largest impediment to receptor modeling today is the dearth of accurate, precise, and comparable chemical profiles for major particulate emitters. These source profiles are needed quantitatively as input data for the Chemical Mass Balance receptor model, and they are needed qualitatively by the principal components and multiple linear regression receptor models.

Javitz et al. (1988), in summarizing a feasibility study of receptor models for the Electric Power Research Institute, concluded that the major weaknesses of all receptor models are caused by inadequate source composition data. Currently available source profiles exhibit the following limitations: (1) the species measured are more often those which are convenient rather than those which differentiate among sources; (2) the types of species and size fractions measured are not the same for different source types and are not equivalent to the types of measurements made at receptors; (3) measurement methods are non-standard and do not generate equivalent results for the same species; (4) source characteristics, fuels, and operating parameters are inadequately documented; (5) data are of poor or unknown quality; (6) source profile uncertainties are not reported; (7) source samples are not representative of source profiles as they appear at the receptor; and (8) data are not available in formats which can be conveniently interfaced to modeling software.

Javitz et al. (1988) recommend the development of a standardized approach to the sampling and analysis of particulate and gaseous emissions which would minimize these concerns with respect to future source profiles. Core and Houck (1987) present the beginnings of such a protocol assembled by a team of experts for the Oregon Department of Environmental Quality.

As illustrated in Figure 2.1-1, over the past decade a number of methods have evolved to extract samples from sources which will have chemical and physical properties similar to those found at a receptor. Several of these methods are described in detail by Chow et al. (1988), Core and Houck (1987), Gordon et al. (1984), Pan (1986), and Watson et al. (1987). In each of these methods, emitted particulate matter is collected on substrates which are then submitted to chemical analyses.

The ideal source sampling method would allow for chemical and physical transformations of source emissions to occur prior to sample collection. Methods which have been used to sample source emissions in receptor model studies include: (1) hot exhaust sampling; (2) diluted exhaust sampling; (3) plume sampling from

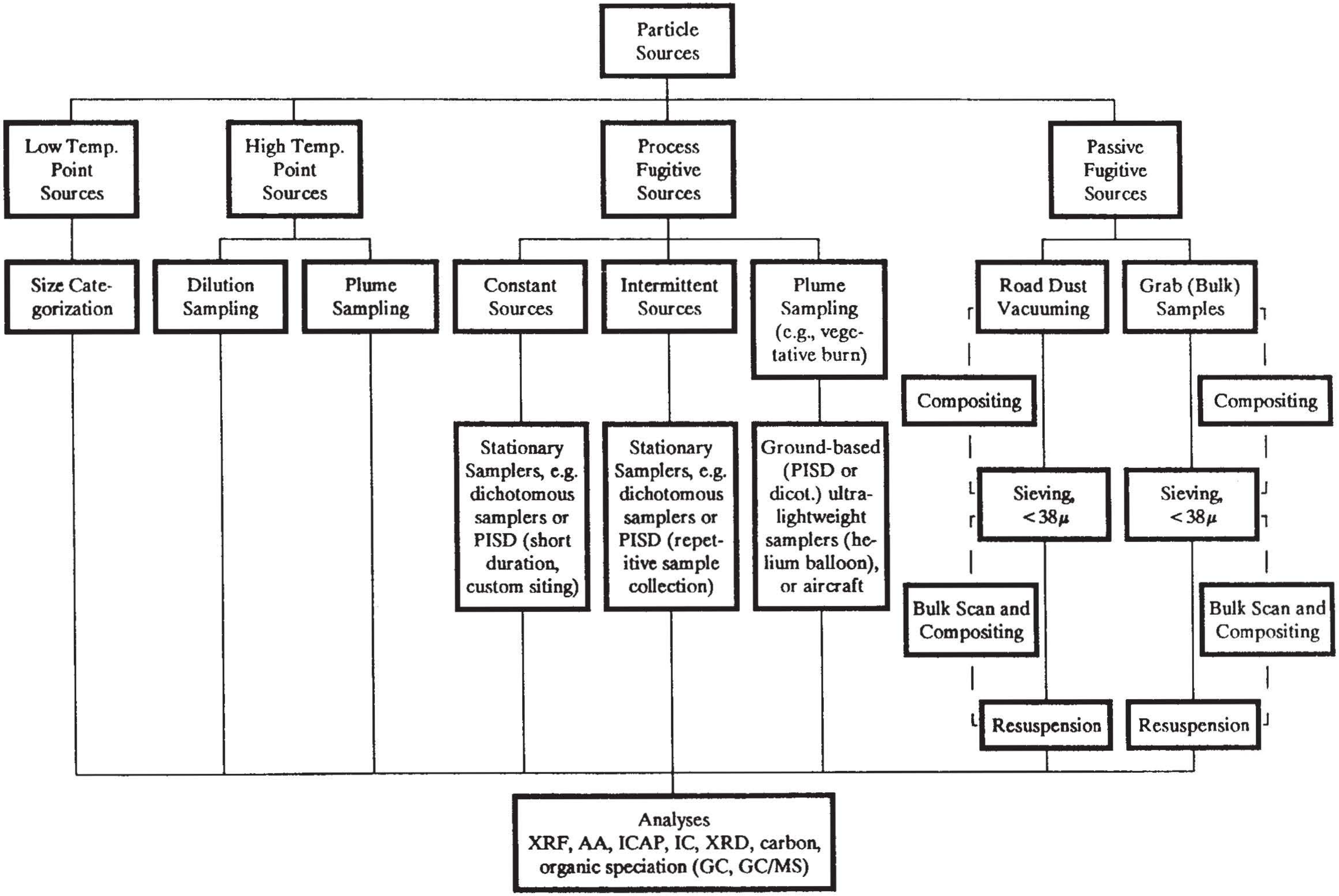


Figure 2.1-1. Flow Diagram of Aerosol Source Sampling Techniques.

airborne platforms; (4) ground-based sampling of single-source dominated air; and (5) grab sampling and resuspension.

Hot Exhaust Sampling

Hot exhaust sampling is well established for determining the emission rates of criteria pollutants, including primary particulate matter. These samples are not taken on substrates amenable to extensive analysis, nor are they generally size-specific. Components of these compliance-oriented methods have been incorporated into other exhaust sampling procedures. Hot exhaust sampling does not necessarily provide a chemical speciation representative of the source profile as it would appear at the receptor because it does not account for transformations which take place when the emissions cool. Hot exhaust sampling is not appropriate for receptor modeling studies.

Hot Exhaust Dilution Sampling

Dilution samples draw hot exhaust gases into a chamber where they are mixed with filtered ambient air. After an aging period, the particles are drawn through a size-selective inlet and onto the substrates. Multiple substrates for different chemical analyses are obtained simultaneously or via sequential sampling of the same gas stream. Houck et al. (1982) have developed such a system which draws the diluted sample through a virtual impactor to provide particle size fractionation. McCain and Williamson (1984) performed tests on this sampler which showed losses of large particles owing to inertial impaction and electrostatic charging. They recommended design changes to minimize these losses, and these changes have been implemented in current designs. Harris (1986), Huynh et al. (1984), Heinsohn et al. (1980), Stiles (1983), and Cooke et al. (1984) offer variations of the same principle.

Diluted exhaust sampling lends itself to laboratory simulations of emissions from individual sources. Dynamometer simulations of motor vehicle driving with exhaust sampled from a dilution tunnel can provide examples of aggregate emissions for a large number of separate vehicles. Similarly, wood stoves and fireplaces can be operated under different burning conditions with emissions sampled from a dilution tunnel.

Airborne Sampling

Source sampling from airborne platforms to characterize the chemical and physical properties of emissions has been performed from airplanes (Small et al., 1981; Richards et al., 1981, 1985), tethered balloons (Armstrong et al., 1981; Shah et al., 1988), and helicopters. It has also been proposed that model airplanes be used to carry ultra-light sampling payloads. Sampling components of appropriate weight and packaging are elevated above the emissions, usually on the order of 100 to 500 meters, to draw samples of the effluent.

The major advantage of airborne sampling for source characterization is that source profile fractionation might be determined if the sample can be taken at a time after emission (i.e., distance) sufficient to have allowed transformations to take place. The drawbacks of airborne plume sampling are: (1) it is difficult is know when the sampler is in the plume and when it is in ambient air; (2) it is difficult to stay in the plume long enough to obtain a sample; and (3) ambient air mixes with the plume, so the source profile is really a combination of emissions and ambient air.

Ground-based Source Sampling

Ground-based source sampling is identical to ambient sampling, but it is applied in situations for which the air being sampled is known to be dominated by emissions from a given source. The requirements of this method are: (1) meteorological conditions and sampling times conducive to domination by a particular source; (2) samples short enough to take advantage of those conditions; and (3) a minimum of other interfering source contributions. Pierson and Brachaczek (1983) and Hering et al. (1979) have characterized motor vehicles in tunnels. Rheingrover and Gordon (1980) characterized several point sources using ambient virtual impactor measurements when the sampling was downwind of the source.

Chow (1985) examined the effects of an elevated coal-fired power plant emission on ground-based samples in a rural environment. She could identify the presence of the plume from corresponding SO_2 and wind direction measurements, but she could not discern other chemical concentrations contributed by the power plant owing to an overwhelming abundance of geological material in her 24-hour sample. This method may be much better for fugitive and area sources, however, because their influence is more constant over time.

The advantages of ground-based sampling are: (1) it is representative of fractionated (presuming transformations are complete) and composite (for area sources such as home heating, motor vehicles, and resuspended dust) source profiles; (2) it is relatively economical; and (3) it is compatible with other receptor samples. The disadvantages are: (1) sampling times may be too short to obtain an adequate deposit; and (2) contributions from other source types interfere with the source profile.

Grab Sampling

Grab sampling involves removal of a bulk sample of material, resuspension and sampling onto substrates through size-selective inlets, and analysis for the selected species. A simple sample swept, shoveled, or vacuumed from a storage pile, transfer system, or roadbed can be taken to represent these source types. A number of different samples from the same source are generally averaged to obtain a representative source profile. The advantage of grab sampling and resuspension is that they are inexpensive and can be completed under controlled laboratory conditions. The disadvantage is that they are only applicable to fugitive dust sources from which large quantities of sample may be easily obtained.

2.2 Size Resolution with Impactors

The size resolution of particulate samples in the ground-based sampler, in the hot exhaust dilution samplers, and in the resuspension chamber system was achieved with impactors.

Impactors have a long history of use for aerosol sampling (Marple, 1970; Rau, 1986) and commercial units are available (Tuchman et al., 1986; Marple et al., 1987). To meet the four size categories required in this study and to produce particulate filters with uniform loadings desirable for multi-component chemical analyses, a custom impactor system was developed. For an ideal single-stage impactor, all particles with aerodynamic diameters larger than some design value (the cut-point) are captured by the impactor and all particles with aerodynamic diameters less than the cut-point diameter remain in the flowstream, passing the impactor. The term *Aerodynamic diameter* relates to the diameter of a spherical particle with a density of one gram per cubic centimeter that will have the same Stokes settling velocity as the actual particle being considered. As with any size-segregating technique, real impactors pass some particles which have aerodynamic diameters greater than the cut-point and capture some which have aerodynamic diameters smaller than the cut-point. However, sharp cut-points can be obtained with appropriate and relatively simple impactor design (Figure 2.2-1). Impactors segregate particles by interaction of viscous and inertial forces. Figure 2.2-1 shows a schematic drawing of an impactor. The jet increases the velocity of the flow stream and the particles within it so that particles which are acted upon by larger inertial forces than viscous drag forces, i.e., particles whose aerodynamic diameters are larger than the impactor cut-point, will impact on the impaction plate. Particles for which viscous drag forces are higher than inertial forces will remain in the flow stream. The impactor cut-point is defined as that particle diameter for which 50 percent of the particles are caught by the impactor and 50 percent are passed. In a well-designed impactor, particles which are not very much larger than the cut-point will be 100 percent captured by the impaction plate and particles which are not very much smaller than the cut-point will be 100 percent passed.

Impactor performance can be described in terms of Stokes' number (Marple et al., 1974) as shown by Equation 2.2-1:

$$Stk_{50} = \frac{CV(D_{P50})^2}{9\mu W} \qquad \text{(Equation 2.2-1)}$$

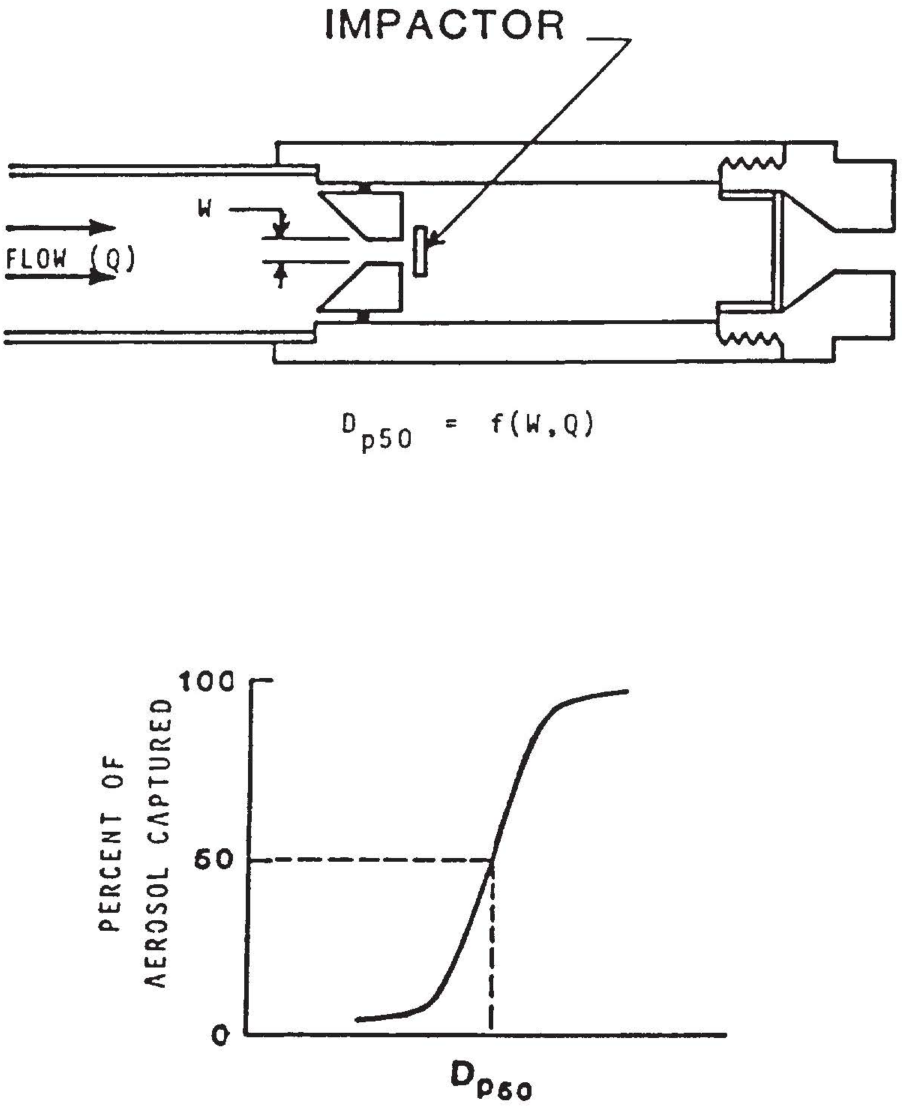


Figure 2.2-1. Impactor assembly schematic drawing (a) and generalized impactor performance curve (b).

Where $D_{p,50}$ = particle aerodynamic diameter (at 50% capture or cut-point);
V = jet velocity;
W = jet diameter;
C = Cunningham slip correction factor; and
μ = absolute viscosity of air.

Table 2.2-1 gives a summary of example impactor design parameters.

For very small impactor cut-points (such as the 0.3 and 0.6μ data in Table 2.2-1), other modifications need to be applied to Equation 2.2-1. For the cut-points of interest in this project (1, 2.5 and 10μ), direct calculations with Equation 2.2-1 provide a very accurate prediction of actual cut-points.

Table 2.2-2 gives the impactor design parameters used in the impactor developed for the sampling equipment deployed in this study. Figure 2.2-2 shows the impactor design details.

A series of tests were run to evaluate the performance of the impactors. Mono-dispersed latex aerosol particles were added to a filtered airstream for the evaluation. Figure 2.2-3 shows the test setup. The test aerosol was added to the airstream using a nebulizer. The test aerosol in a liquid suspension was added to deionized water in the nebulizer fluid reservoir. A clean airstream entering the nebulizer caused the test aerosol to be suspended in water droplets in the airstream leaving the nebulizer. The airstream leaving the nebulizer was then passed through a chamber containing a radioactive source, which removes static charge from the particles. It then went to a large glass flask where the aerosol aged and remaining water on the test aerosol particles evaporated. The stream containing the test aerosol was discharged to the atmosphere through a bell jar. The impactor to be tested was inserted into the bell jar where it sampled the test aerosol. Since the volumetric flow of the test aerosol was always greater than the sampling rate of the impactor, ambient air did not enter the bell jar. This allowed sampling of the test aerosol at atmospheric pressure. The impactor support assembly was first run without the impactor inserted through the flow range to be used in the test. Particle concentration leaving the impactor support assembly was determined as a function of flow through the impactor support assembly using a Royco (model 3050) optical particle counter. The impactor was then placed in the support assembly and the flow range was again traversed. Impaction plates were greased with Apiezon grease by troweling the grease with a razor blade. The ratio of the particle concentration measured with the impactor in to the particle concentration measured with the impactor out was the fraction of particles passed by the impactor. One minus this value expressed as a percent is the percent captured. Impactor performance was graphed by plotting the square root of the Stokes number versus the percent captured. Theory predicts that the 50% capture point should occur at the square root of the Stokes number value of 0.47.

Table 2.2-1
Example Impactor Design Parameters

Cut-point (μ)	W (mm)	n	V (cm/sec)	P_2/P_1	Re	Q_T (lpm)
2.5	3.15	1	1755	1.00	7250	8.3
1.2	1.97	1	4500	0.99	11618	8.3
0.6	1.30	1	10430	0.94	17782	8.3
0.3	0.60	4	15700	0.89	12354	10.7
0.1	0.15	20	19300	0.78	3796	4.1

W = jet diameter
n = number of jets
V = velocity through jet
P_1 = pressure upstream of the jet
P_2 = pressure downstream of the jet
Re = Reynolds number
Q_T = total flow through all the impactor jets

Table 2.2-2
California Study Impactor Design Parameters

Cut-point (μ)	W (mm)	T (mm)	S (mm)	n	Inlet Cone (°)	V (cm/sec)	P_2/P_1	Re	Q_T (lpm)
10	8.45	8.45	8.45	1	60	296	1.00	1668	10
2.5	3.40	3.40	6.81	1	60	1828	1.00	4131	10
1	1.91	1.91	3.81	1	60	5804	0.99	7381	10

W = jet diameter
T = throat length
S = jet-to-plate distance
n = number of jets
V = velocity through jet
P_1 = pressure upstream of jet
P_2 = pressure downstream of jet
Re = Reynolds number
Q_T = flow through impactor jet

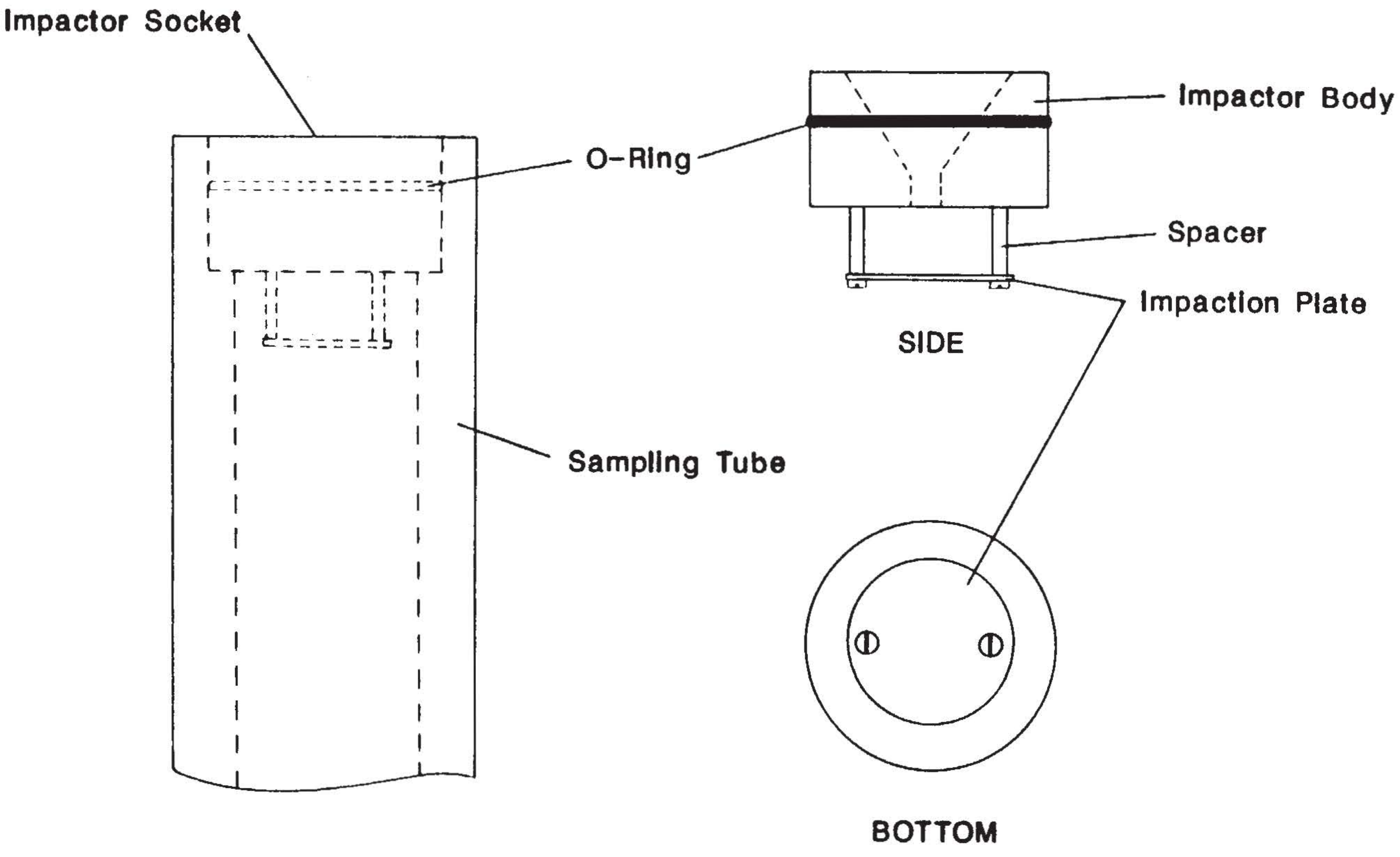


Figure 2.2-2. Impactor design.

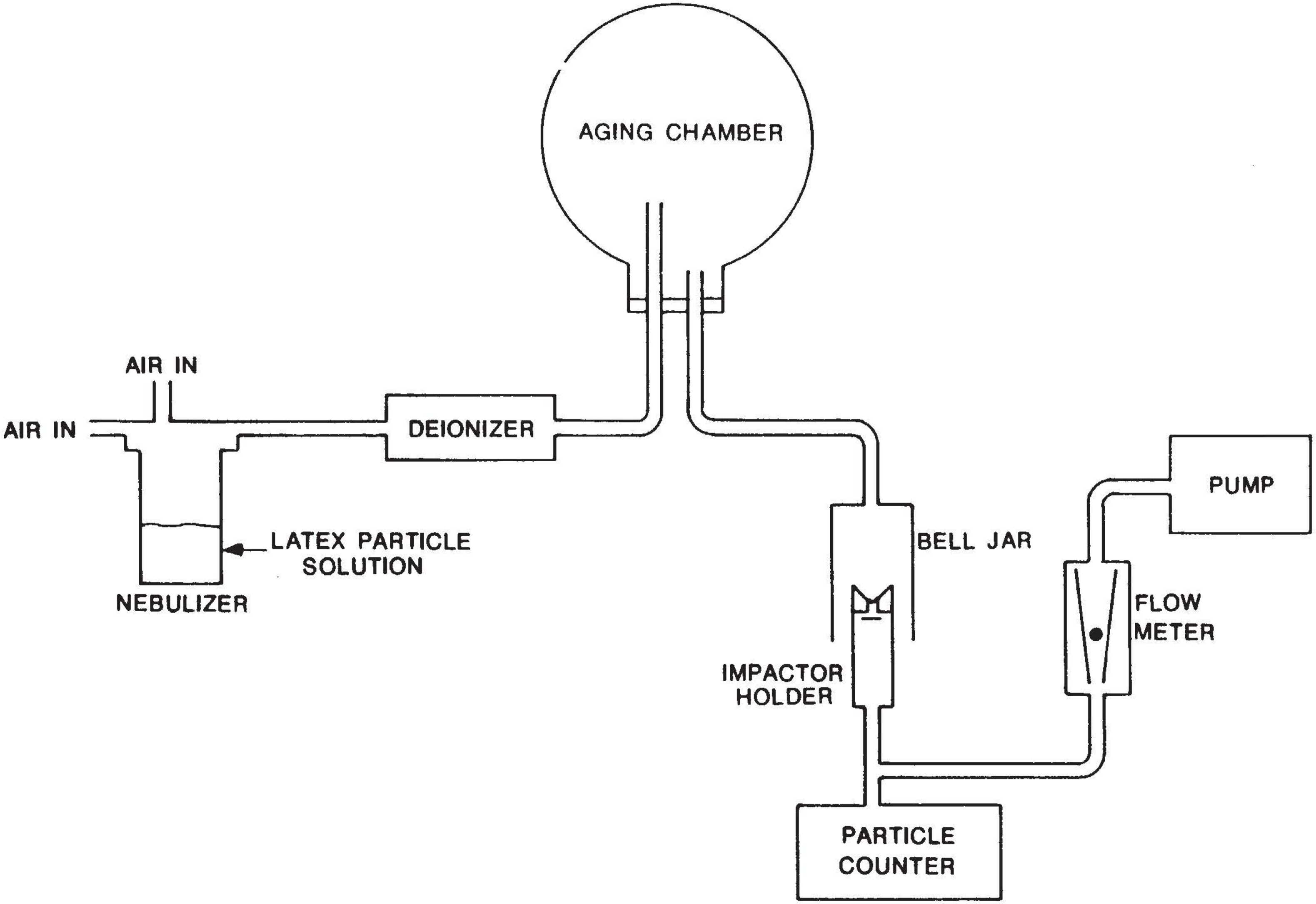


Figure 2.2-3. Schematic of impactor test system.

Performance of the 1.0μ impactor runs with 1.1μ latex particles is shown in Figure 2.2-4. This figure shows that the impactor performs as predicted by theory. Figure 2.2-5 shows the performance of the 2.5μ impactor run with 2.06μ particles. Again, the impactor performed as expected.

Performance evaluation of the 10μ impactor with the test system illustrated in Figure 2.2-3 was not possible because the particle concentrations were too low at that size, due to loss within the system. The theoretical performance of the 10μ impactor was confirmed by the near-simultaneous operation of three 10μ impactors along with a commercially available PM_{10} medium-volume sampler in a relatively clean ambient setting. The medium-volume sampler used in the comparison met the criteria for the PM_{10} federal reference method (U.S. EPA, 1987). Table 2.2-3 summarizes the comparison data for the 10μ impactor design and the commercial PM_{10} sampler.

To reduce particle bounce problems often associated with impactors, two steps were taken. These were: (1) all impaction stages were coated with Apiezon grease; and (2) cyclones were placed on front of the 1μ and 2.5μ impactors. Cheng and Yeh (1979) and Esmen et al. (1978) have demonstrated that greasing impaction plates significantly reduces particle bounce. Either Apiezon type M or Apiezon type T grease was used, depending on the sampling temperature expected. Due to the preponderance of particles larger than 2.5μ in many sampling environments, a pre-separator cyclone was placed in front of the 1μ and 2.5μ impactors to prevent the impaction plates from overloading. A single cyclone mounted on a manifold was installed in front of the 1μ and 2.5μ impactors. The flow through the cyclone was subsequently 20 lpm, which produces a cut-point of approximately 4μ (Chan and Lippman, 1974). Figure 2.2-6 illustrates the performance of the cyclone. While cyclones do not become "overloaded" as do impactors, their cut-points are less sharp. The combination of a cyclone pre-separator followed by an impactor for the final size cut provides the ideal solution for the overloading problem, as well as providing a particulate sample with a sharp cut-point.

Samples which were collected for this study consisted of particles which remained in the flowstream after passing the impactors and were collected on filters after the flow was collimated. Total aerosol mass and the chemical composition between two impactor cut-point values were determined by subtracting the mass and mass-weighed chemical composition collected behind the impactor from those of the next largest cut-point. By using data from a series of impactors in this way, the size distribution of particulate mass or the distribution of any other particulate property such as chemistry could be determined. Similarly, by subtracting the mass collected behind the 10μm impactor from the mass collected by the "total" sampler (no impactor) a measure of the aerosol mass above 10μm was obtained. The size categories are summarized in Table 2.2-4.

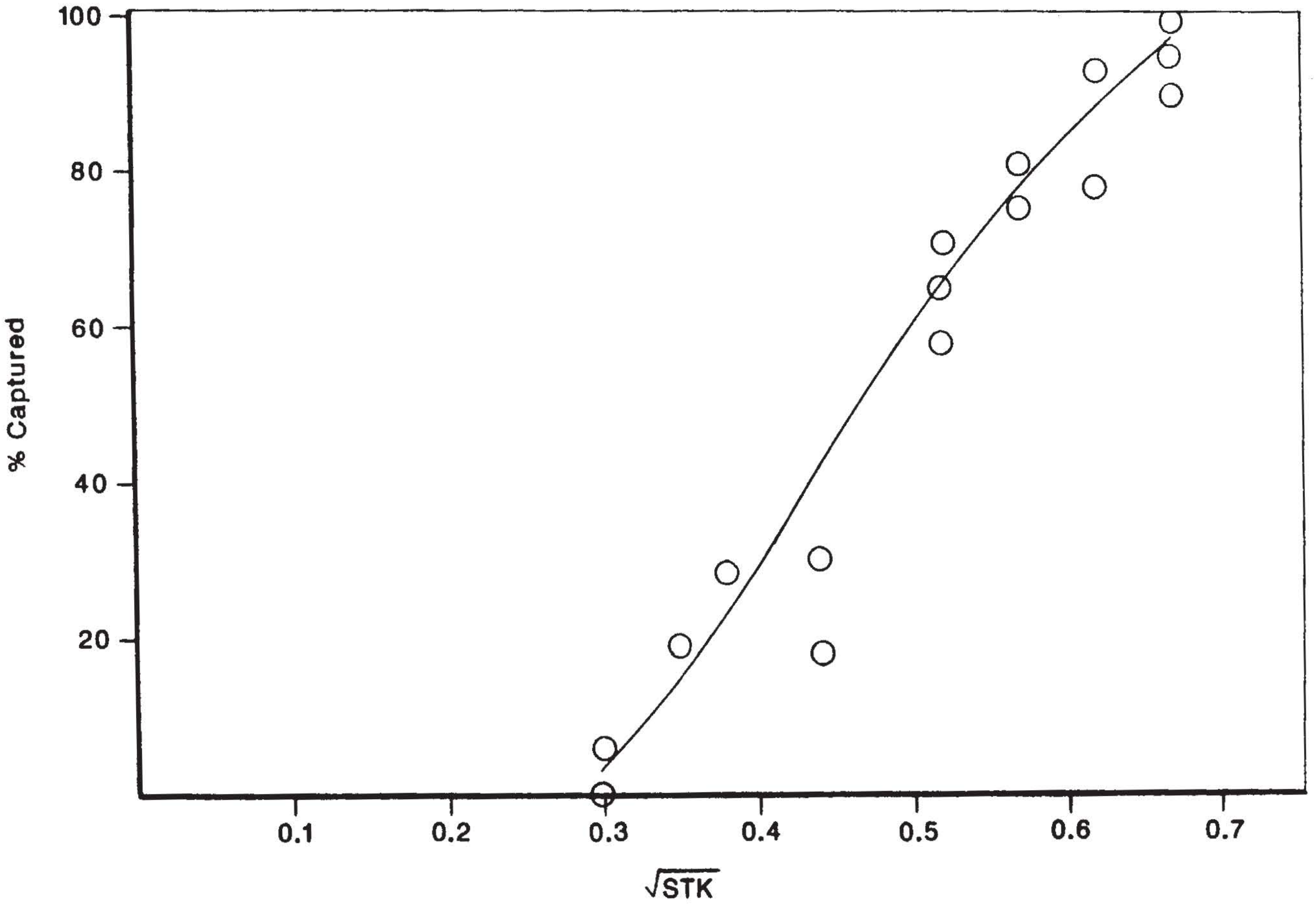


Figure 2.2-4. Impactor performance, 1.0μ impactor, 1.1μ test aerosol.

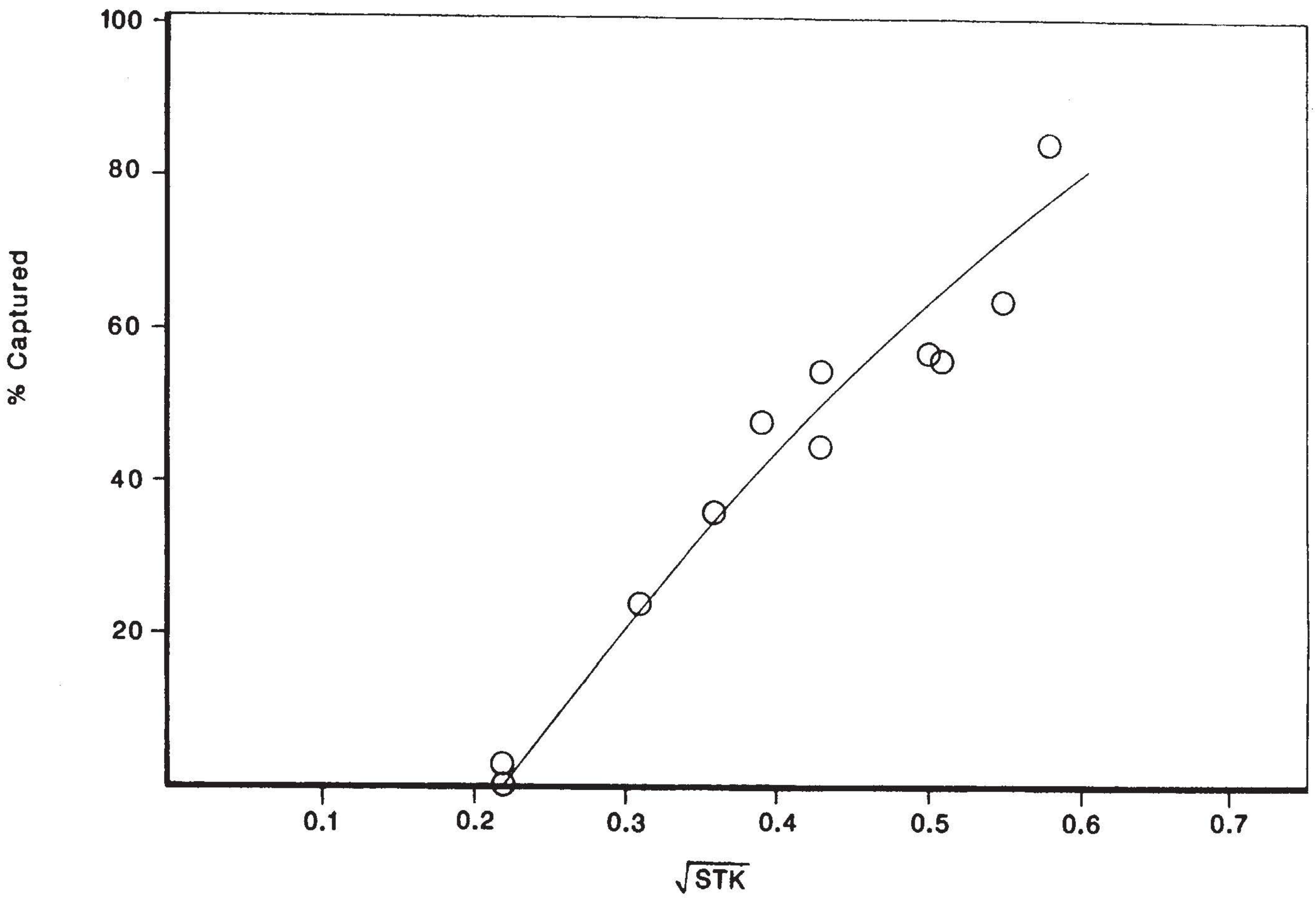


Figure 2.2-5. Impactor performance, 2.5μ impactor, 2.06μ test aerosol.

Table 2.2-3
Comparison of 10μ Impactor Performance with Commercial PM_{10} Sampler

Sampler	Calculated Mass Concentration ($\mu g/m^3$)
10μ impactor #1	27.8
10μ impactor #2	27.2
10μ impactor #3	25.2
Medium-volume PM_{10} sampler	29.8

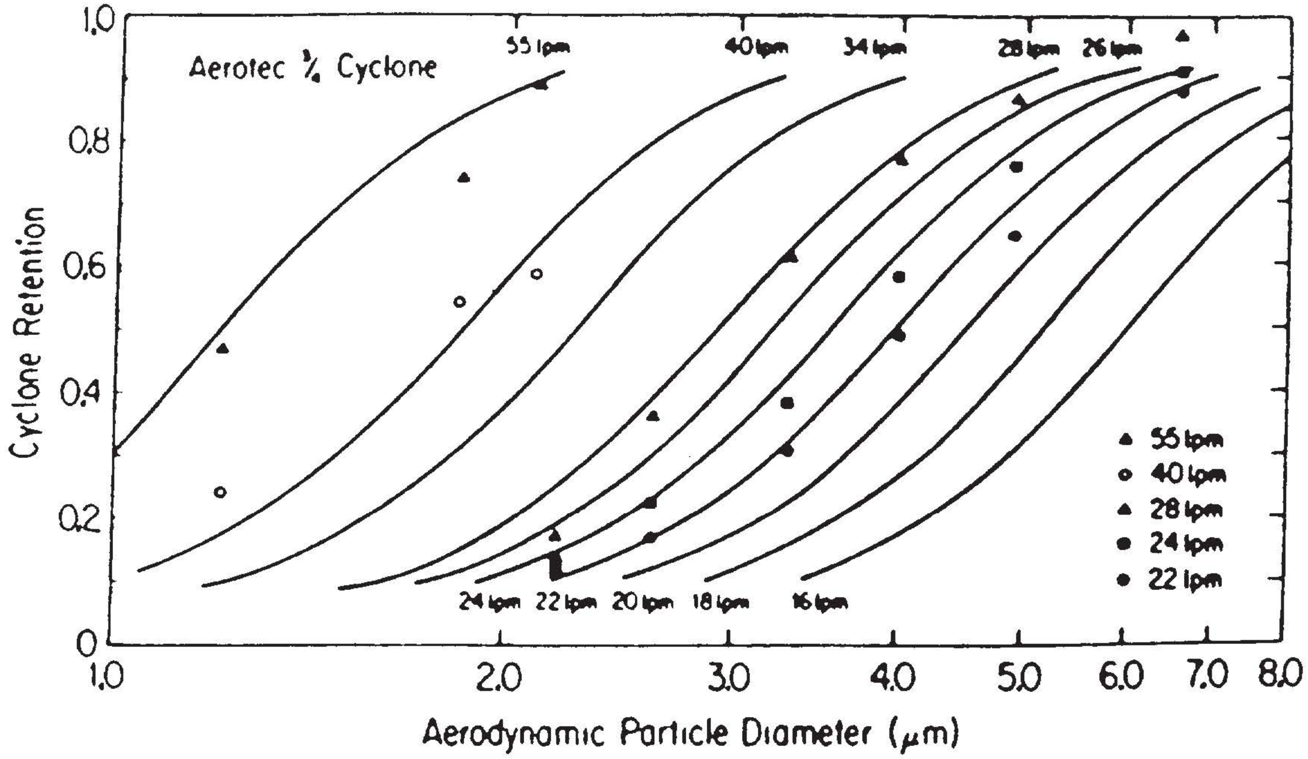


Figure 2.2-6. Collection efficiency of Aerotec $^3/_4$-in. cyclone (data from Chan and Lippmann [1974]).

Table 2.2-4
Size Categories

Size Range[a]	Method of Determination	Comments
< 1.0μ	impactor cut-point	
1.0μ-2.5μ	subtraction of < 1.0μ data from < 2.5μ data	
< 2.5μ	impactor cut-point	Often referred to as respirable fraction or PM$_{2.5}$.
2.5μ-10μ	subtraction of < 2.5μ data from < 10μ data	
< 10μ	impactor cut-point	Often referred to as inhalable fraction or PM$_{10}$.
10μ-30μ (> 10μ)	subtraction of < 10μ data from < 30μ data	Particles greater than approximately 30μ are not generally collected with most ambient or source sampling equipment and their half-life in the atmosphere is short. The 10μ-30μ size category can be referred to in essence as > 10μ and the < 30μ size category as total suspended particles (TSP).
< 30μ (TSP)	no impactor in sampler	

a. Effecive Aerodynamic Diameter (spherical, ρ = 1g/cm^3)

2.3 PISD Ground-Based Sampler

A parallel impactor sampling device (PISD) was used for ground-based sampling. The PISD used the impactors and the cyclone described in Section 2.2. Figure 2.3-1 is a schematic diagram of the PISD. Figure 2.3-2 is a sketch of the system and Figure 2.3-3 is a detail drawing of the PISD sampling tubes. The sampler consists of two basic parts: the sampling module and the control module. The sampling module consists of a tripod-supported platform to which are attached four sample inlet tubes, the pre-separator cyclone, vacuum gauges, a manifold containing four critical orifices for flow control, and a flexible hose connecting the manifold to the control module. The control module contains a rotary vane pump, a cooling fan, an on/off switch, a non-resettable elapsed time meter, and a master vacuum gauge.

The PISD system is reasonably portable and rugged for field deployment. The tripod legs, sampling tubes, and rain caps are held in place with set bolts for rapid attachment and removal. The vacuum hose is attached to both the control module and sampling module by quick disconnects. The cyclone manifold is held in place with an air-tight gasket collar. The complete standard operating procedure (SOP) for the parallel impactor sampling device is provided in Appendix B.

2.4 Hot Exhaust Dilution Sampler for Industrial Sources

Point source and combustion emissions represent a special problem for source sampling and subsequent receptor modeling. The alteration in particulate chemistry and size distribution which occurs when combustion emissions cool and mix with ambient air requires that a dilution/cooling tunnel be utilized prior to aerosol sample collection. Condensation, agglomeration, volatilization, and secondary chemical reactions can all modify the character of source particles.

Figure 2.4-1 is a general schematic of the dilution source sampling system (DSS) which was used in the study. Figure 2.4-2 is a sketch of the system. Several different dilution chamber and inlet geometries were necessary to pragmatically position the sampler adjacent to each specific source, since it is desirable to minimize the inlet probe length as it has been found the principal point of particle loss is within the sampling probe and inlet line (McCain and Williamson, 1984). The dilution systems were designed to be "broken down" to be easily transported and cleaned in the field. The system has interchangeable dilution chamber lengths and bends, as well as various diameters and lengths of inlet probes. The dilution chamber components are constructed of light gauge 316 stainless steel to minimize sample contamination.

Characteristic temperatures, flow rates, particulate loading, and water vapor content (condensed water is deleterious to sample collection) vary dramatically with source type; consequently, the dilution ratio is

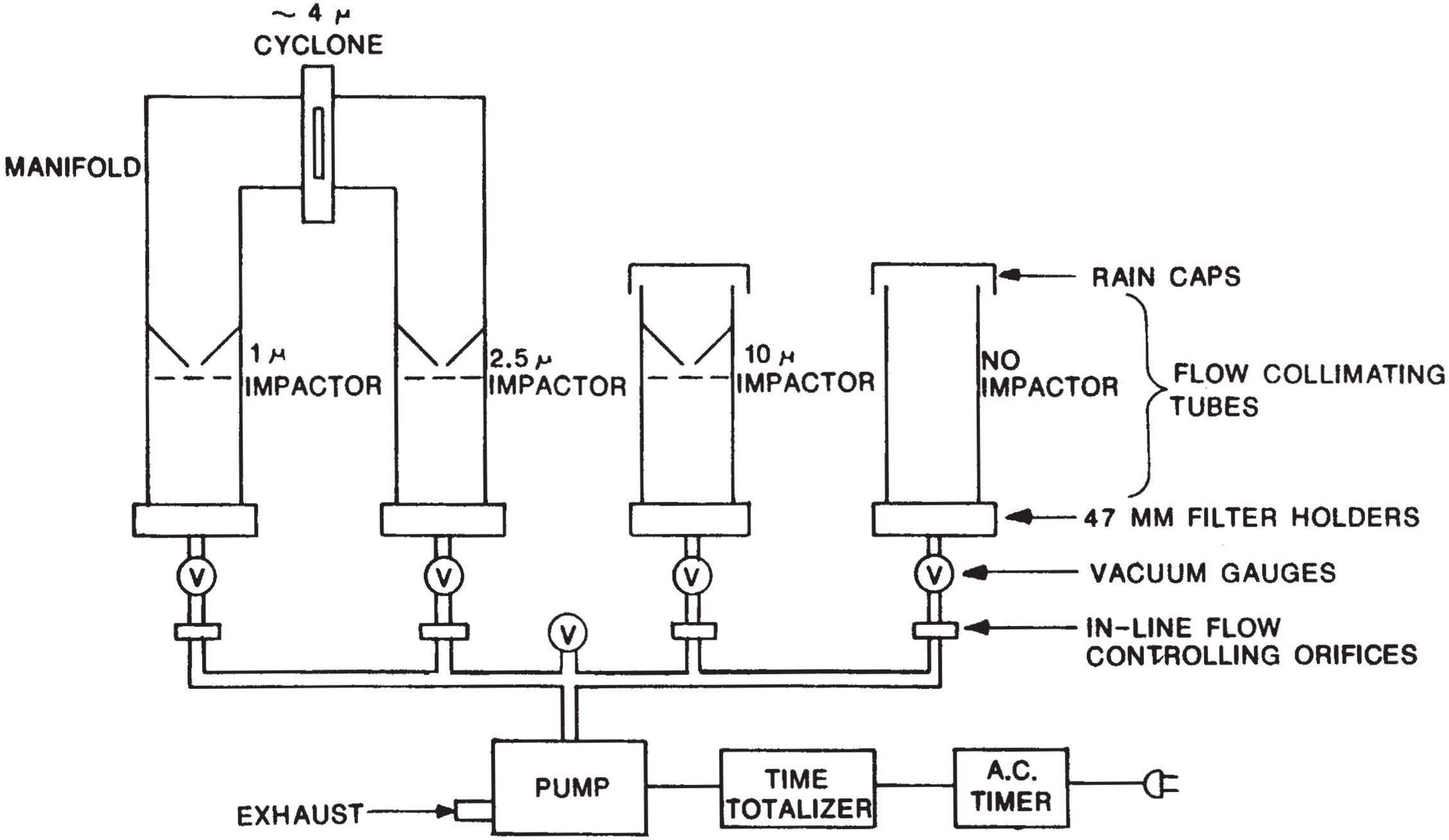


Figure 2.3-1. Schematic diagram of parallel impactor sampling device (PISD).

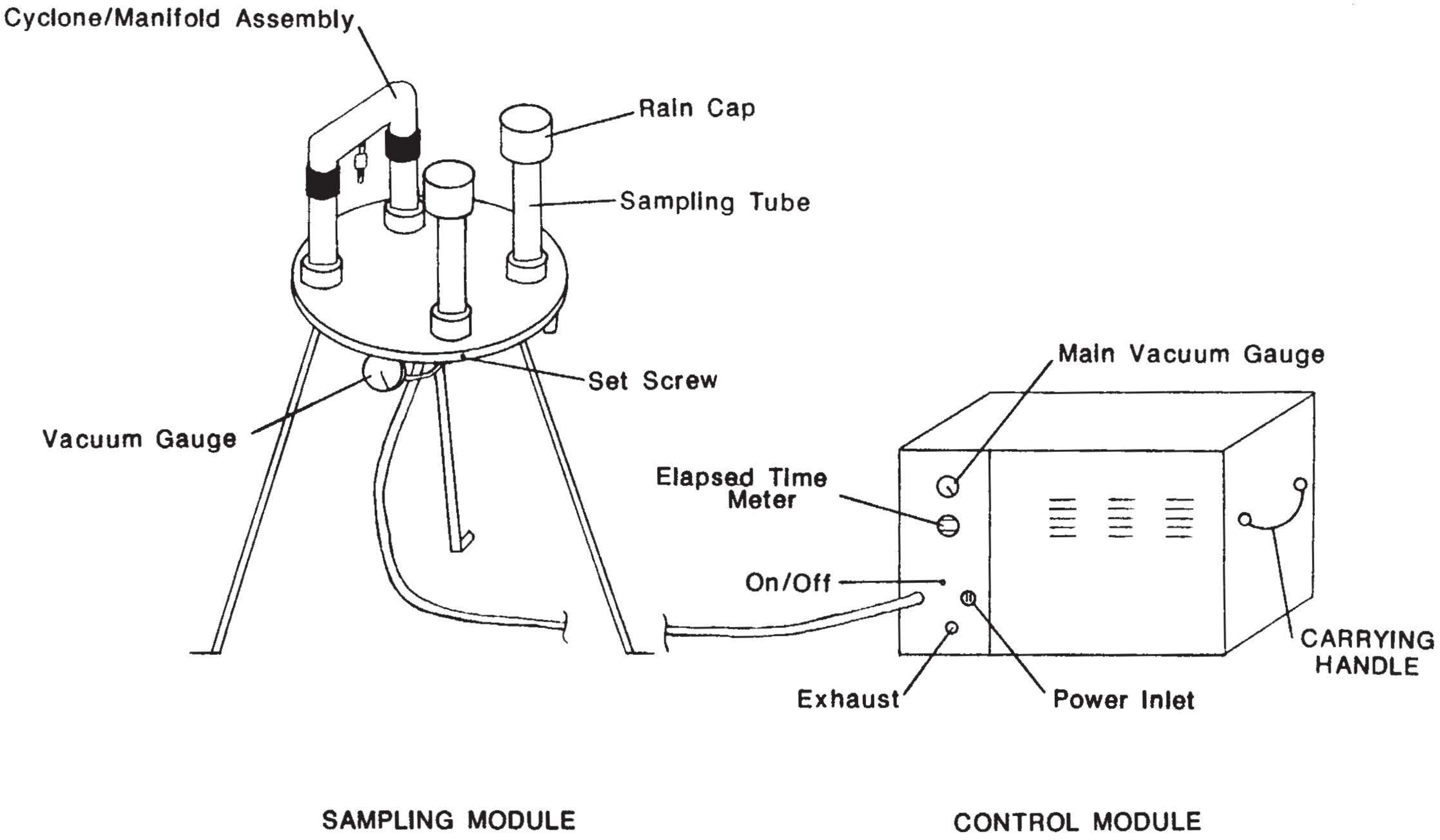


Figure 2.3-2. Sketch of the parallel impactor sampling device (PISD).

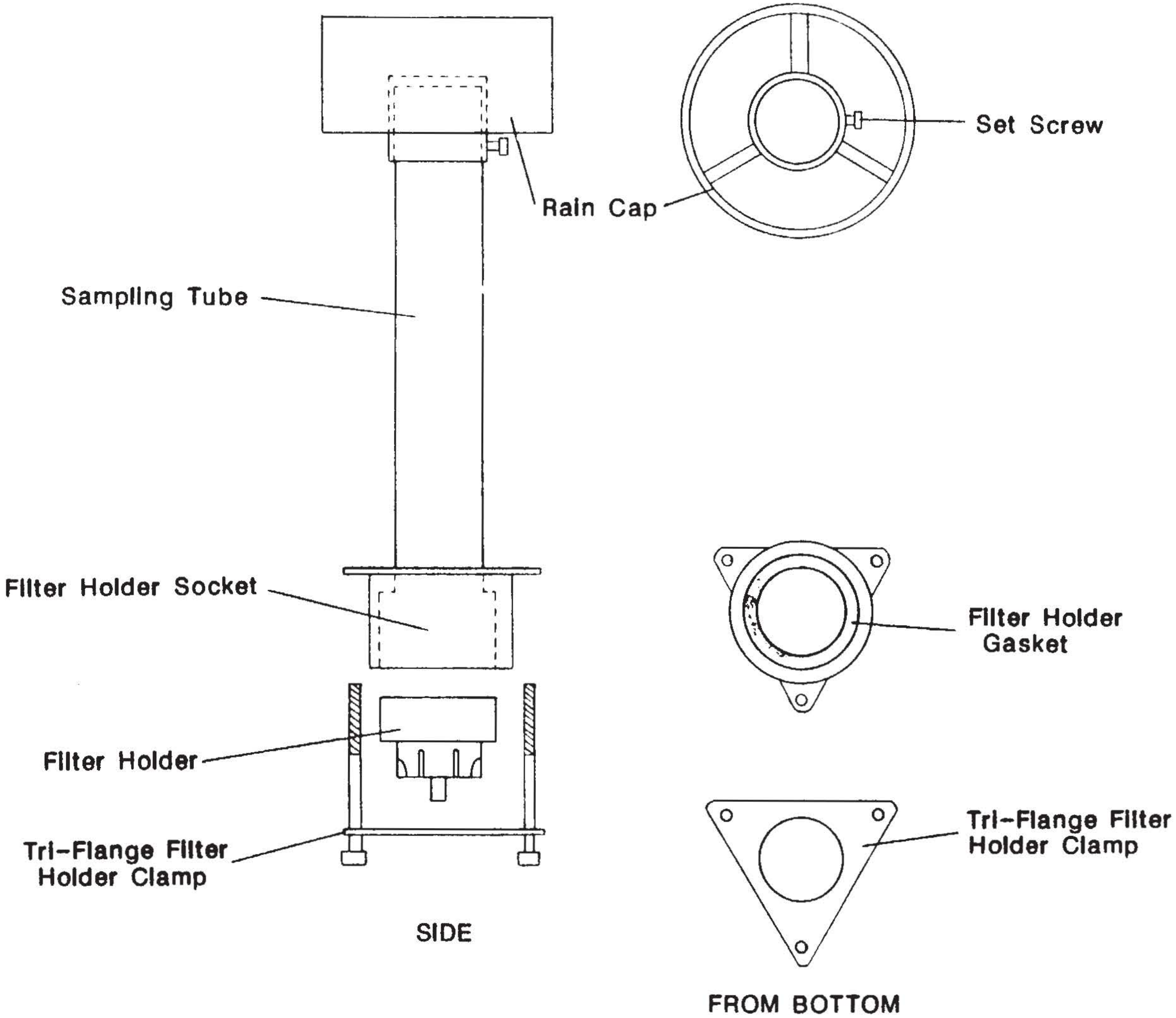


Figure 2.3-3. PISD sampling tube detail.

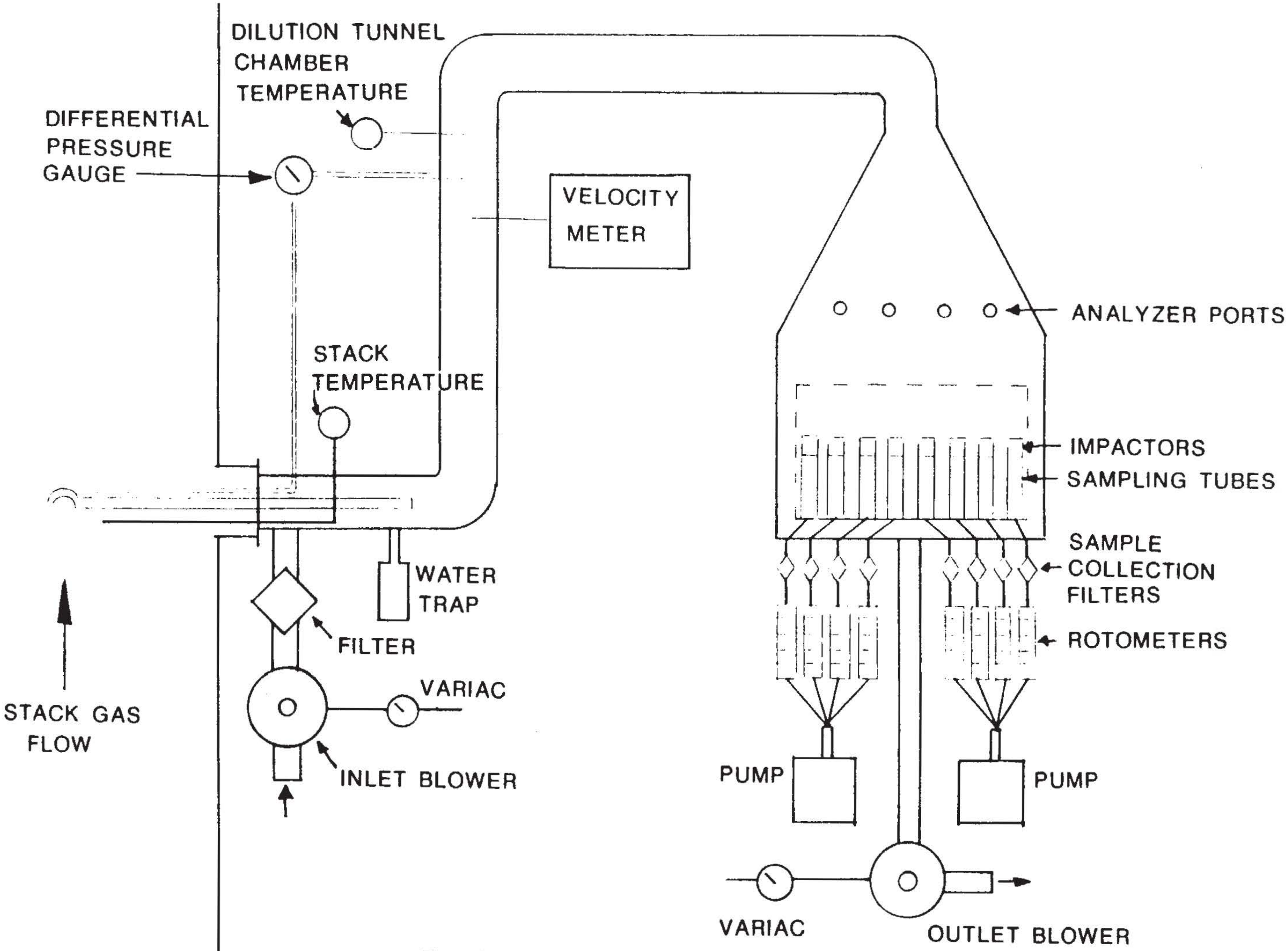


Figure 2.4-1. Schematic of the dilution sampling system.

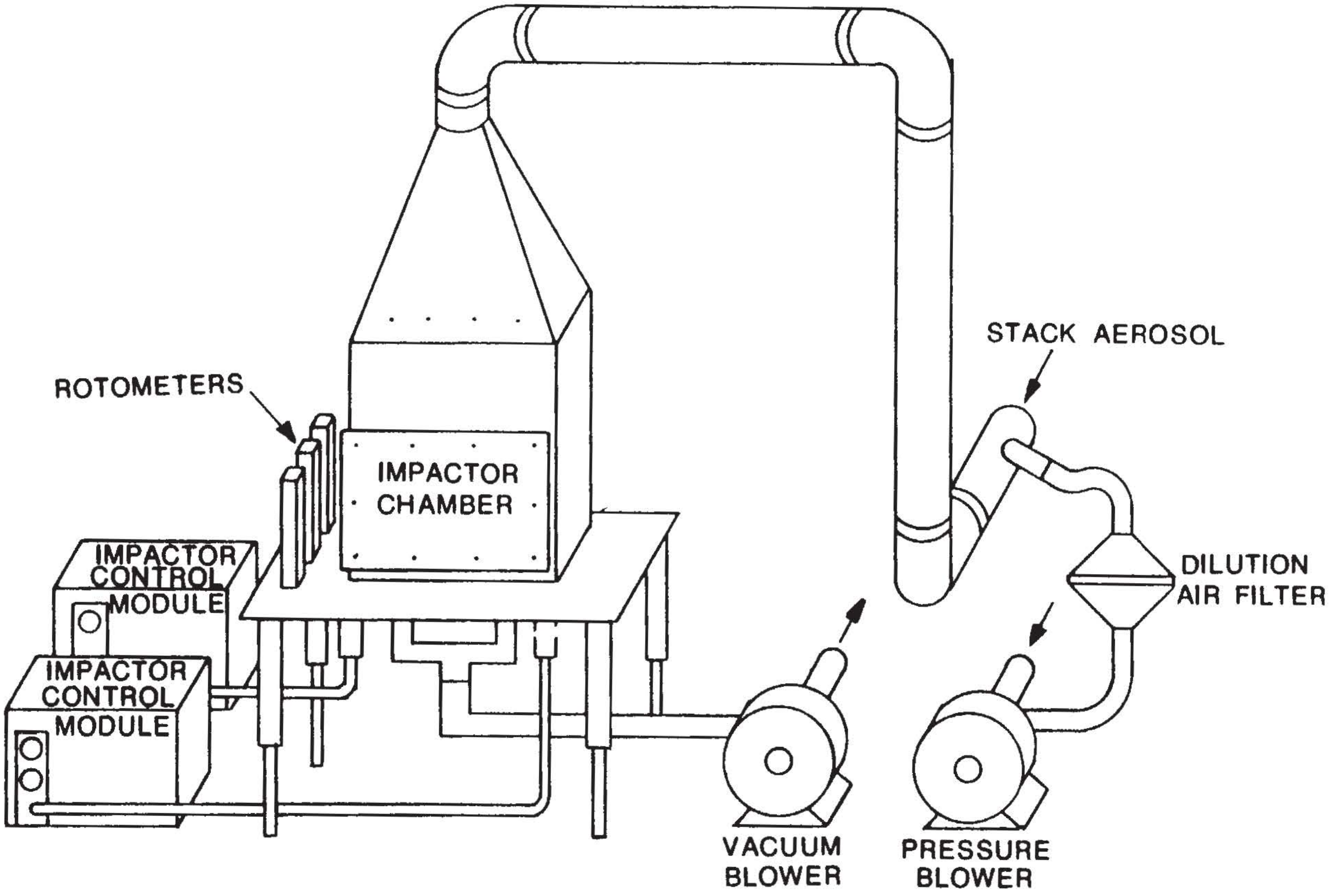


Figure 2.4-2. Sketch of the dilution sampling system.

adjustable (approximately 10:1 to 100:1) for general application. Additionally, because the sampler is often inherently in an area of high ambient particulate concentration, and because of the high ambient air/sample ratio, the dilution air is well filtered to prevent sample contamination. The dilution ratio is adjustable at any reasonable inlet flow by the combined control of an inlet blower and outlet vacuum pump. Both are controlled by variable transformers (Variacs). Inlet air is filtered with a standard high-volume 8 by 10 inch filter. The dilution ratio can be set at any predetermined value, since the inlet airflow rate is monitored with a thermal anemometer and the pressure difference between the interior of the dilution chamber and the source is monitored with a pressure gauge or manometer. The flow-versus-pressure difference is determined in the laboratory prior to field deployment. Dilution chamber temperature is monitored to ensure that the chamber temperature is a few degrees within ambient, and for documentation of the aerosol sampling environment. Two impactor systems (one for Teflon filters and one for quartz filters) withdraw samples from the dilution chamber. As with the PISD systems (Section 2.3), a flow collimating tube is placed in front of the impactors. While the diameter of the inlets of the collimating tubes could be restricted to achieve isokinetic sampling conditions, this is not essential since the majority of particles originating from combustion sources are significantly less than 5μ in aerodynamic diameter. Similarly, the flow in the inlet to the dilution chamber can be adjusted to remove the aerosol from the source isokinetically although, as mentioned, it is not critical.

The transfer of particulate-bearing stack gases via the heated probe to the dilution chamber is accomplished by maintaining a pressure differential between the dilution chamber and the interior of the stack. From Bernoulli's equation of continuity, it can be shown that the linear velocity of gas entering the inlet is dependent only on the pressure drop (ΔP) and density of the source gas (ρ), i.e.,

$$V = \sqrt{\Delta\rho/0.5\rho} \qquad \text{(Equation 2.4-1)}$$

Bernoulli's equation is only strictly applicable to idealized fluids but is illustrative for design consideration. Since the inlet will collect gas parallel with the direction of flow, the pressure value used to calculate ΔP in Equation 2.4-1 must take into account the effect of velocity pressure, i.e.,

$$\Delta P = [P_{S,S} + 0.5\,\rho_S V_S^2] - P_{d,S} \qquad \text{(Equation 2.4-2)}$$

where $P_{S,S}$ is the static pressure within the source;
ρ_S is the density of gas within the source;
V_S is the linear velocity of gas within the source; and
$P_{d,S}$ is the static pressure within the dilution chamber.

Measurement of ΔP can be accomplished by the use of commercially available tips connected to a manometer or Magnehelic gauge.

Reduced pressure and flow within the dilution chamber is produced by a vacuum pump. If the blower (Figures 2.4-1 and 2.4-2) is removed, each flow rate across the high-volume filter has a corresponding pressure drop associated with it which is determined by the filter medium. The addition of a Variac-controlled blower reduces the pressure drop and permits a wide range of combinations of dilution chamber pressure and flow rate. For example, if a high dilution flow rate (i.e., high dilution ratio) and a low pressure drop (low linear velocity in the sampling inlet) are desired, the vacuum pump would be operated at near-maximum power and the blower would be adjusted until the pressure drop across the high-volume filter was lowered to the point where low inlet velocities were obtained.

Some limited source data are generally collected prior to sample collection. Stack (or ducted exhaust) flow rate, temperature, water vapor content, and particulate concentration are helpful in estimating appropriate dilution ratios for selection on inlets and in estimating the duration of sample collection periods. Adequate data are frequently obtained from records of previous tests or characteristics of the source. Typical sampling periods are between 15 minutes and 2 hours. Sampling periods as short as five minutes have been encountered (a coal-fired power plant operating without emission controls) and as long as 14 hours (at efficient baghouses) have also been necessary with systems similar to the one developed for this study. Generally, the proper mass loading on the collection filter (approximately 0.5 to 2 mg) dictates the length of the sampling period required. In some cases during previous studies, long sampling durations have been required because a very high dilution ratio was needed to prevent water condensation from occurring. The standard operating procedure for the DSS system is included as Appendix C.

2.5 Hot Exhaust Dilution Sampler for Residential Wood Combustion

Residential wood combustion (RWC) appliances present special problems for dilution sampling, and producing representative source profiles is a complex task due to the inherent number of variables associated with them. Notable among these are: (1) appliance types and installation factors; (2) fuels; (3) fueling practices; and (4) burn conditions. Table 2.4-1 presents these variables in detail.

To further complicate the development of representative source profiles, woodburning appliances are difficult to sample because: (1) the emissions are tar-like; (2) the average stack gas velocity is low; (3) the average concentration of particulate material in the stack gas is high; (4) there is a high water vapor content in the stack gas; and (5) emission rates and gas velocities are very variable. In addition, the difference between particulate (solid and liquid) emissions and gaseous emissions is a matter of definition, since many of the

Table 2.4-1
Woodburning Appliance Variables

Source Type	Key Variables
Appliance Types and Installation Factors	Woodstove versus fireplace Woodstove firebox size Model (fundamental design) Woodstove technology type (catalyst versus noncatalyst) Damper (draft) control (excess air) Airtight versus non-airtight woodstove (excess air) Chimney system (draft)
Fuels	Species Moisture content Seasoned versus non-seasoned Size of fuel pieces Density Extent of decomposition
Fueling Practices	Burn rate Burn duration (all day versus evenings only) Fuel load amount Frequency of fueling Kindling (start-up) procedure Household trash
Burn Conditions	Kindling phase Main burn (dampered-down cool burn versus hot burn with excess air) Charcoal phase (end of burn) Damper (draft) settings

chemical compounds contained in wood smoke are semi-volatile. Woodburning appliances are also pragmatically difficult to sample as their stacks obviously have no sampling ports and in-field sampling requires the positioning of heavy, cumbersome, and noisy sampling equipment on private residences.

Due to the inherent variability among woodburning appliances and the difficulty of obtaining samples in the field from a meaningful number of appliances, a laboratory sampling methodology has been developed (Watson et al., 1988). The approach entails: (1) determination of the most abundant cordwood type(s), burn rates, appliance types, and burn cycles for a given geological area from existing literature, surveys, or from other studies; and (2) long-term, in-laboratory sampling of emissions from the most representative woodburning appliance types, operating under the mean burn rate and most common cycles, and using the most abundant wood type(s).

Since particulate emission rates, stack velocities, and apparently the chemical character of particles, vary dramatically over the course of a normal burn cycle (Burnet et al., 1986; Shelton and Gay, 1986), the DDS system used for industrial sampling is not appropriate for residential woodburning appliance application. Rapid changes in velocity and particulate loading levels over short time periods would be nearly impossible to follow in a proportionate manner with the DSS. In addition, the very high particulate concentration characteristic of residential wood combustion as compared to most controlled industrial sources makes the direct use of the DSS less than ideal.

To rectify these problems, a modified U.S. EPA reference Method 5G dilution tunnel system (U.S. EPA, 1987a) was used to dilute the entire appliance emissions with ambient air. From the diluted stream a fixed-flow aliquot was removed and passed through the parallel impactor system described in Section 2.2. Figure 2.4-3 is a schematic of the system. The most significant modification made in the Method 5G protocol was the increase in flow rates when fireplaces were tested to compensate for increased stack gas volumes characteristic of residential fireplaces as compared to woodstoves (Shelton and Gay, 1987). Since unfiltered ambient air was used for dilution/cooling, particulate samples of the dilution air were taken simultaneously with the source tests so that the contribution of the dilution air could be accounted for in the chemical composition of the samples collected. The ground-based PISD samplers were used to sample the dilution air.

The moisture content of the cordwood was measured with a Delmhorst Instrument Company model RC-IC moisture meter. A spring scale was used to pre-weigh appropriate amounts of each species of wood prior to the beginning of each test. Wood addition (target and actual), wood moisture content, fuel wood species, and draft control/door positions were recorded on prepared data sheets for each test.

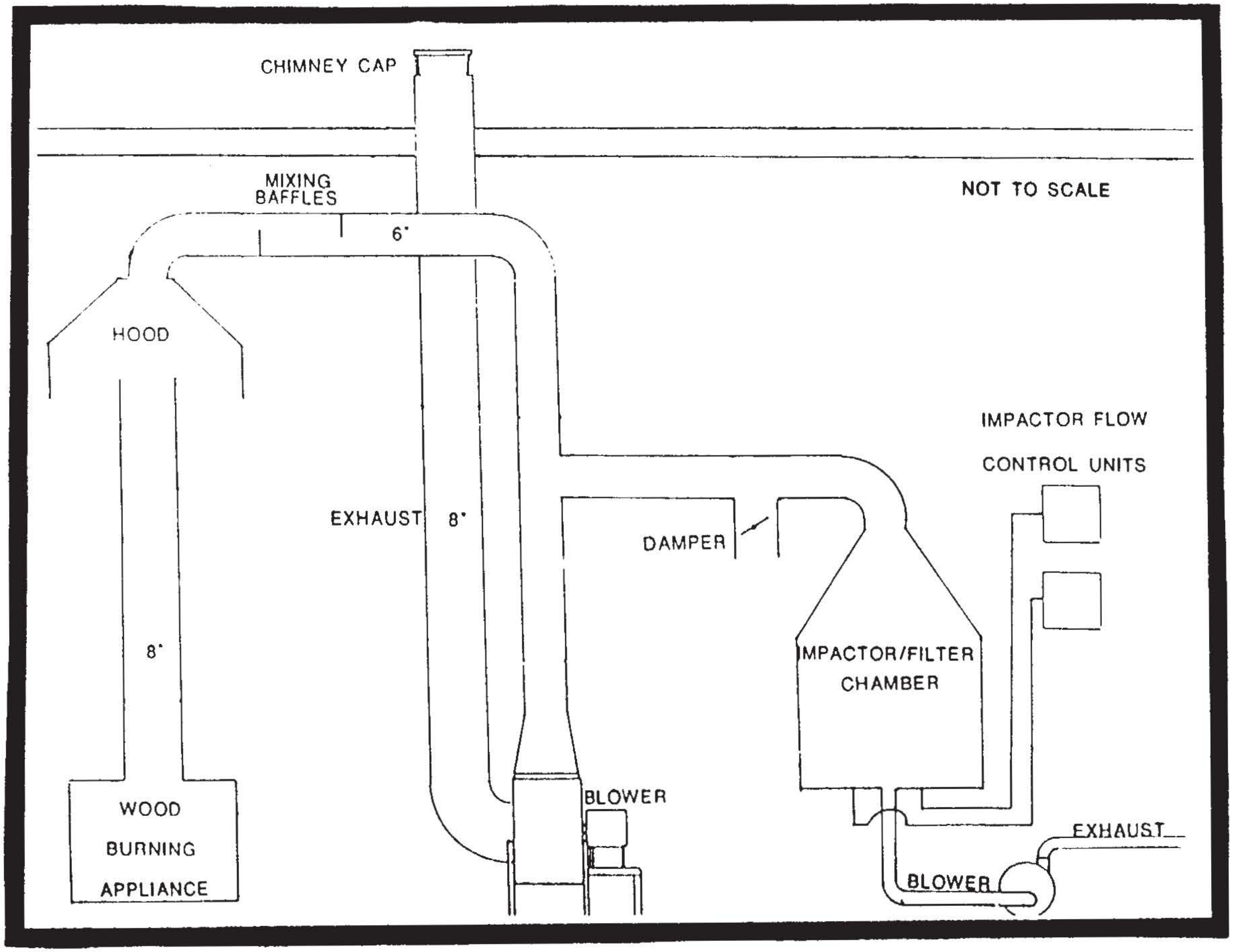


Figure 2.4-3. Sketch of modififed Method 5G dilution tunnel interfaced with impactor system.

2.6 Soil, Road Dust, and Bulk Sampling Procedures

Dust from roadways, from agricultural tillage, and from suspension by wind is recognized as being a major source of particles in most airsheds. Standard protocols have been developed for the sampling and analysis of dust (Core and Houck, 1987). Sampling protocols include procedures for sampling: (1) paved roads; (2) unpaved areas which have a surface layer with a distinct chemical character due to anthropogenic impact (e.g., unpaved roads and parking lots); and (3) dust sources with a relatively homogeneous near-surface chemical composition (e.g., tilled agricultural soils, native soils, and bulk material storage piles). Samples from paved roads were collected with a high-volume vacuum cleaner-like device, or with a small broom and dust pan. The high-volume road dust sampler is simply a modified high-volume ambient air sampler and has been deployed in numerous studies (e.g., Houck et al., 1981 and 1982). Samples from unpaved roads and parking lots were obtained by removing approximately the top centimeter of material with a masonry trowel. Samples of agricultural soils, native soils, and bulk materials were simply collected with a small shovel, although care was taken not to exceed approximately ten centimeters in sampling depth. While the actual physical collection of the dust samples is relatively simple, ensuring representative samples is not. Factors which need to be taken into consideration include: (1) proximity to receptor (ambient) monitoring sites; (2) traffic counts for roads; (3) industrial or agricultural track-out on roads; (4) soil wind erodibility; (5) soil types; (6) dust-producing agricultural activities; (7) predominant wind velocities; and (8) agricultural and industrial impacts on soil chemical composition. Compositing samples is a useful technique to ensure that representative chemical source profiles are produced. Collection of sub-samples at regular intervals along a roadway or at various points in an agricultural field or fields is a reasonable approach to compositing. Once bulk samples were collected, laboratory drying at low temperatures to avoid loss of volatile compounds, sieving to less than 38μ (400 mesh), resuspension, particulate collection with the PISD size-segregating samplers, and analysis by routine analytical techniques were conducted. Dust sampling procedures are given in Appendix D. Pre-analysis laboratory treatment and resuspension of samples are discussed in Section 3.3 and Appendix D.

2.7 Source Sampling Summary

Five types of source sampling procedures were performed in this study. They were: (1) ground-based sampling with a PISD sampler; (2) paved road dust sampling with a high-volume road dust sampler or hand broom; (3) grab sampling of soil, bulk material or unpaved road dust; (4) hot exhaust dilution sampling with an industrial dilution source sampler (DSS); and (5) hot exhaust dilution sampling of residential wood combustion with a modified Method 5G-type dilution sampler. A total of forty sources were sampled. Three to six replicates were collected for each source. The air quality at a number of the sources during sampling was such that background air sampling needed to be conducted simultaneously with the source sampling so that the source profile could be corrected for background air contamination. Appropriate field blanks were also collected in all cases. Table 2.7-1 summarizes the sources and source sampling procedures. Figure 2.7-1 illustrates the approximate locations of the dust sampling areas. Figure 2.7-2 illustrates the approximate location of other area and point sources which were sampled.

The source sampling was conducted during five periods: (1) All dust samples and cordwood for the Mammoth Lakes area were collected during September of 1987. (2) The diesel trucks at the Wheeler Ridge Weigh Station and a crude oil combustion unit in the west Kern County Oilfield (Santa Fe Energy Company) were sampled during November of 1987. Cordwood from the Bakersfield area was also collected during November of 1987. (3) Samples of fireplace emissions burning both Mammoth Lakes cordwood and Bakersfield cordwood, as well as emissions from a woodstove burning Mammoth Lakes cordwood, were collected at OMNI's Beaverton facilities in February of 1988. (4) Exhaust from diesel ski tour buses was sampled in Mammoth Lakes in February of 1988. (5) A Visalia area dairy, construction activities in the Fresno area, a crude oil combustion unit in the Kern River Oilfield (Chevron), and agricultural burning in the San Joaquin and Imperial River Valleys were sampled in June and July of 1988. Upon collection, all samples were delivered to the Desert Research Institute located in Reno, Nevada for analyses.

Three replicates were collected for each of the twenty-seven dust samples in the San Joaquin Valley, Great Basin Valleys, and Southeast Desert Air Basins. A detailed description of the samples is given in Table 2.7-2. The source types of the dust samples can be categorized into five sub-groupings: (1) agricultural soil. (2) paved roads; (3) unpaved roads and urban areas; (4) alkaline playa sediments and desert soils; and (5) sand and cinder storage areas. All sampling locations were selected based on their potential impact to ARB ambient monitoring sites from which data may eventually be used for CMB modeling and where future PM_{10} violations are anticipated based on historical ARB data.

Agricultural Soils

Nine agricultural soils were collected in the San Joaquin and Imperial Valleys. All samples were composite samples with the sub-samples that make up the composites representing the major soil series categories as well as areas of major agricultural crop types upwind (under predominant wind conditions) of a relevant ARB monitoring site. Soil Conservation Service surveys provided detailed aerial photographs on which soil series boundaries are superimposed. (U.S. Dept. Agr. Soil Conservation Service, undated; U.S. Dept. Agr. Soil Conservation Service, 1980; Perrier et al., 1974). Agricultural land use data, agricultural activities most likely to produce dust, and soil amendment information were obtained from the University of California Extension Service and California County Agricultural Commissioners publications (Watkins, 1987; Kunkel, 1987; Wilbur, 1987; Finnel, 1987; Karlik, undated; Gonzalez, 1985), and interviews with staff members.

Table 2.7-1
Source Sampling Summary

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Stockton Area ag. soil (peat)	SOIL 01	1	GS/RS	3	NA	Composite of peat soils from delta area NW of Stockton
Stockton Area ag. soil (mineral)	SOIL 02	2	GS/RS	3	NA	Composite of mineral soils in the predominantly upwind (NW) direction of Stockton
Fresno paved road (city street)	SOIL 03	3	PRD/RS	3	NA	Collected along Olive Street near monitoring site
Visalia Area ag. soil (cotton/walnut)	SOIL 04	4	GS/RS	3	NA	Composite of sandy loam soils in predominantly upwind (NW) direction of Visalia, cotton fields & walnut grass
Visalia Area ag. soil (raisin)	SOIL 05	5	GS/RS	3	NA	Composite of sandy loam soils in Dinuba area, raisin vineyards
Visalia Sand and Gravel storage	SOIL 06	6	GS/RS	3	NA	Commercial sand and gravel operation 3 blocks east of monitoring site
Visalia urban unpaved (parking lots)	SOIL 07	7	GS/RS	3	NA	Composite of 3 unpaved lots in vicinity of monitoring site
Visalia paved road (city street)	SOIL 08	8	PRD/RS	3	NA	Composite from 4 streets around monitoring site
Bakersfield Area ag. soil (alkaline)	SOIL 09	9	GS/RS	3	NA	Composite of alkaline soils in Wasco area
Bakersfield Area ag. soil (sandy)	SOIL 10	10	GS/RS	3	NA	Composite of sandy loam soils, 11 km NW of Bakersfield

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Bakersfield Area unpaved roads (Oildale)	SOIL 11	11	GS/RS	3	NA	Composite of unpaved roads in Kern River Oilfield north of Oildale monitoring site
Bakersfield paved road (city street)	SOIL 12	12	PRD/RS	3	NA	Chester Street near monitoring site
Bakersfield urban unpaved (parking lots and alleys)	SOIL 13	13	GS/RS	3	NA	Composite of 3 unpaved areas near monitoring site
Bakersfield Area ag. soil (sandy loam)	SOIL 14	14	GS/RS	3	NA	Composite of Wasco Series sandy loam soils west of Bakersfield
Bakersfield Area ag. soil (cajon)	SOIL 15	15	GS/RS	3	NA	Composite of Cajon Series sandy loam soils west of Bakersfield
Bakersfield Area unpaved roads (residential)	SOIL 16	16	GS/RS	3	NA	Unpaved residential roads west of Bakersfield
Taft unpaved roads	SOIL 17	17	GS/RS	3	NA	Road leading to monitoring site
Brawley urban unpaved (parking lots)	SOIL 18	18	GS/RS	3	NA	Composite of 3 unpaved parking lots near monitoring site
Brawley paved roads (city streets)	SOIL 19	19	PRD/RS	3	NA	Composite of Main Street, and post office and police station paved parking lots

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
El Centro paved roads (city streets)	SOIL 20	20	PRD/RS	3	NA	Composite of streets around monitoring site
El Centro Area ag. soil	SOIL 21	21	GS/RS	3	NA	Composite of silty clay, silty clay loam, and clay loam soils found in El Centro and Brawley areas
Trona Area desert soil	SOIL 22	22	GS/RS	3	NA	Composite of 5 Searles Lake lake bed sediments
Lone Pine Area desert soil (lake bed)	SOIL 23	23	GS/RS	3	NA	Composite of Owens Lake lake bed sediments
Lone Pine Area desert soil (alkaline)	SOIL 24	24	GS/RS	3	NA	Composite of Owens Lake lake bed alkaline sediments
Lone Pine Area desert soil (sandy)	SOIL 25	25	GS/RS	3	NA	Composite of sandy soils between Lone Pine and Independence
Mammoth Lakes road cinder	SOIL 26	26	GS/RS	3	NA	Volcanic cinders from McGee Creek Storage Area
Mammoth Lakes paved road (city streets)	SOIL 27	27	PRD/RS	3	NA	Main Street and Laurel Mt. Road
Diesel Truck Emissions	WHDIEC	DE	PISD	6	2	174 diesel trucks sampled; engines "revved up" and idled; Wheeler Ridge Weight Station

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Oil Field Crude Oil Boiler Emissions (west-side Kern County oilfield)	SFCRUC	SF	DSS	4	NA	Santa Fe Energy Unit 118
Oil Field Crude Oil Boiler Emissions (Kern River oilfield)	CHCRUC	CH	DSS	3	NA	Chevron Racetrack Steam Plant
Bakersfield Area ag. burning (wheat & barley)	BAAGBC	BB	PISD	3	NA	Composite of 3 wheat and barley stubble burns
El Centro Area ag. burning (wheat)	ELAGBC	BE	PISD	3	NA	Composite of 3 wheat stubble burns
Stockton Area ag. burning (wheat)	STAGBC	BS	PISD	3	NA	Composite of 3 wheat stubble burns
Visalia Area ag. burning (wheat)	VIAGBC	BV	PISD	4	NA	Composite of 3 wheat stubble burns
Visalia Area dairy/feedlot dust	DIDAIC	DR	PISD	3	NA	Dairy north of Visalia
Fresno Area construction emissions (freeway)	FRCONC	CS	PISD	3	NA	Construction, Highway 40

(continues)

Table 2.7-1 (continued)

Source	Source Profile Mnemonic	Map ID[a]	Sampling Procedure[b]	Number of Replicates	Number of Background Samples	Comments
Mammoth Lakes diesel ski tour buses	MADIEC	TB	PISD	3	NA	Composite of 3 parking lots (idling)
Bakersfield fireplace	BAMAJC	FB	MM 5G	3	3	Bakersfield cordwood, Majestic fireplace
Mammoth Lakes fireplace	MAMAJC	FM	MM 5G	3	3	Mammoth Lakes cordwood, Majestic fireplace
Mammoth Lakes woodstove[c]	MAFISC	WM	MM 5G	3	3	Bakersfield cordwood, Fisher Mama Bear stove

a. Figures 2.7-1 and 2.7-2.

b. GS/RS = grab sampling/resuspension
PRD/RS = paved road dust sampling/resuspension
PISD = Parallel Impactor Sampling Device (ground-based)
DSS = Dilution Source Sampler
MM 5G = Modified U.S. EPA Method 5G dilution tunnel

c. Two sequential filter sets made up one of the three runs with the woodstove burning Mammoth Lakes cordwood.

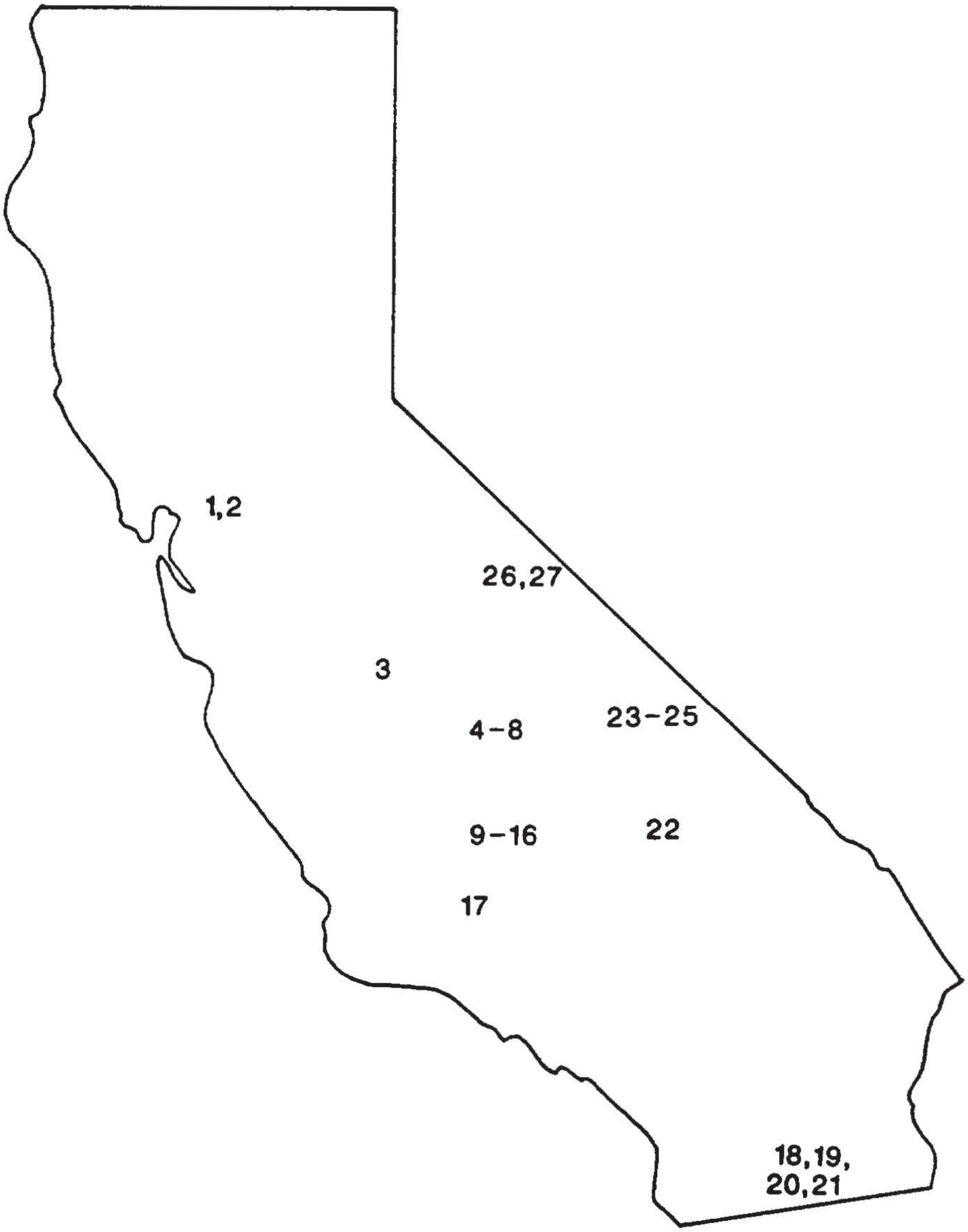


Figure 2.7-1. Approximate location of dust sampling areas. Sample identification numbers are listed in Table 2.7-1.

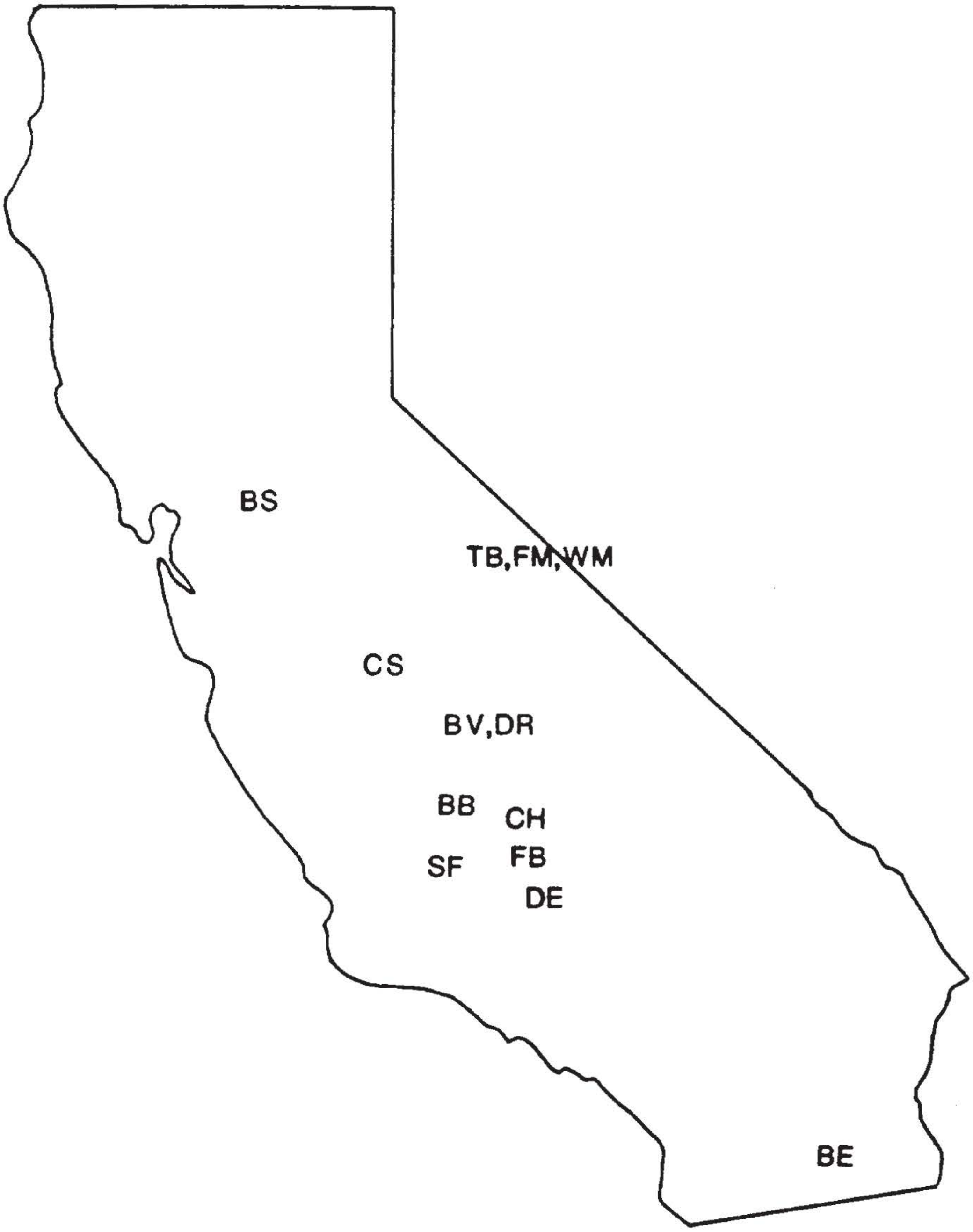


Figure 2.7-2. Approximate location of point and area sources. Sample identification codes are listed in Table 2.7-1.

Table 2.7-2
Detailed Dust Sample Description

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 01	1	9/15/87	Agricultural Soil	Stockton, Hazelton St.	Peat Soil collected along Eight Mile Rd. Four soil types (KL, KI, RI, and RN of Kingile and Rindge series) used for soil composite. This soil is suspected to be the source of "the black cloud" seen in Stockton. Soil collected from the Empire Tract and King Island "Delta" areas.
SOIL 02	2	9/15/87	Agricultural Soil	Stockton, Hazelton St.	"Mineral" soil, collected along Mueller Rd. Three soil types (EF, EA, and ME of Egbert and Merritt series) used for soil composite. These are common mineral soils upwind of Stockton (to the NW).
SOIL 03	3	9/16/87	Paved Road	Fresno, Olive St.	Composite sample collected along Olive St. on north and south sides of street from corner of Fisher St. to 75 meters to the west.
SOIL 04	4	9/16/87	Agricultural Soil	Visalia, Church St.	Composite of 4 samples from cotton and walnut fields NW of Visalia. Four samples: (1) cotton field near intersection of Demurre Rd. and Goshen Ave.; (2) walnut field near intersection of Demurre Rd. and Goshen Ave.; (3) cotton field south of Ave. 328 (Co. Rd. J34) along Demurre Rd.; and (4) cotton field near intersection of J34 and J19. All soils collected are recent alluvium soils and are of the Foster series sandy loam.
SOIL 05	5	9/16/87	Agricultural Soil	Visalia, Church St.	Composite of three soil samples from raisin vineyards in the Dinuba area. Three samples collected: (1) near interesection of Nebraska and J19; (2) along J19 appx. 2 km south of Dinuba; and (3) near intersection of Nebraska and J19. All soils are from raised ancient alluvium of the Greenfield sandy loam series.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 06	6	9/16/87	Sand & Gravel Storage	Visalia, Church St.	Sand and gravel from sand and gravel mixing operation three blocks east of Church St. monitoring stations. Collected from storage pile and from under conveyor belt. The sand and gravel operation is potentially a major fugitive source impacting the sampling site.
SOIL 07	7	9/16/87	Unpaved Urban Area	Visalia, Church St.	Material from three unpaved parking lots near ambient monitoring site were composited. These were from: (1) parking lot 30 meters west of monitoring site; (2) dirt from between two railroad tracks near intersection of Gordon and Oak Sts. which is approximately 100 meters west of monitoring site.
SOIL 08	8	9/16/87	Paved Road	Visalia, Church St.	Numerous samples were collected from the four streets that surround the monitoring site.
SOIL 09	9	9/17/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Garces alkaline soil series samples collected from cotton fields, north of Hwy. 46 along Gun Club Rd. in the Wasco area. Several soil samples were collected and composited.
SOIL 10	10	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Kimberlina sandy loam soils collected from cotton fields approximately 11 km NW of Bakersfield along 7th Standard Rd. near intersection of Calloway Dr. Several samples collected and composited.
SOIL 11	11	9/18/87	Unpaved Road	Bakersfield, Chester St.; Oildale, Manor St.	Numerous unpaved road soil samples were collected and composited in the Kern River Oilfield north of the Oildale monitoring site.
SOIL 12	12	9/18/87	Paved Road	Bakersfield, Chester St.	Samples collected along Chester St. on both sides of street near ambient monitoring site.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 13	13	9/18/87	Unpaved Urban Area	Bakersfield, Chester St.	Sample is a composite of three samples collected from unpaved parking lots near the ambient monitoring site.
SOIL 14	14	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Several Wasco series sandy loam soils were collected and composited from tilled fields near intersection of Stockdale Hwy. and Old River Rd. west of Bakersfield.
SOIL 15	15	9/18/87	Agricultural Soil	Bakersfield, Chester St.; Oildale, Manor St.; Taft, 10th St.	Several Cajon series sandy loam soils were collected and composited from alfalfa field along Stockdale Hwy. 1.3 km west of Hwy. 43.
SOIL 16	16	9/18/87	Unpaved Road	Bakersfield, Chester St.; Oildale, Manor St.	Three dirt roads adjacent to residential land use, intersecting Rosedale Hwy. (Hwy. 58) approximately 9 miles west of Bakersfield were sampled and composited.
SOIL 17	17	9/18/87	Unpaved Road	Taft, 10th St.	Several soil samples were collected and composited from unpaved road leading to Moose Lodge 143 behind fire station. It appears that the unpaved road has a heavy impact on the ambient monitoring instruments due to proximity, dusty conditions, and the fact that the ambient monitors were only approximately 0.7 meters above the ground.
SOIL 18	18	9/20/87	Unpaved Urban Area	Brawley, Main St. (Hwy. 78 & 111)	Three unpaved parking lots near monitoring sites were sampled and samples were composited.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 19	19	9/20/87	Paved Road	Brawley, Main St. (Hwy. 78 & 111)	Composite sample consists of roughly 70% of material collected on both sides of Main St. (Hwy. 78 & 111) in front of ambient monitoring site and 30% from Post Office delivery vehicles and police paved parking lots immediately adjacent to monitoring site.
SOIL 20	20	9/21/87	Paved Road	El Centro (corner of Ninth and State Sts.)	Several paved road dust samples were collected on both sides of the streets around the block on which the ambient monitoring site is located. The samples collected were composited.
SOIL 21	21	9/21/87	Agricultural Soil	El Centro (corner of Ninth and State Sts.); Brawley, Main St. (Hwy. 78 & 111)	Imperial-Holtville-Glenbar silty clay, silty clay loam, and clay loam series were collected. Four samples were collected along Forrester Rd. between Worthington Rd. (S28) and Aten Rd. in Bermuda grass fields. The four soil samples were composited. This soil series is very common in the Imperial River Valley and, according to the Soil Conservation Service, is highly wind-erodible. It is believed that this soil type impacts both the Brawley and El Centro sites.
SOIL 22	22	9/22/87	Alkaline Playa Sediments and Desert Soil	Trona, Market St.	A composite of five samples was taken from Searles lakebed east of Trona. The samples were from: (1) 4.8 km east of Trona Rd. and 1.6 km north of monitoring site; (2) 10 km east of Trona Rd. and 0.8 km north of South Trona; (3) approximately 4 km east of Trona monitoring site near roadside rest area; (4) approximately 200 meters east of Trona and 0.8 km south of Westend; (5) 6 km east and 2 km north of the Trona Pinnacles.

(continues)

Table 2.7-2 (continued)

Source Profile Mnemonic	Map ID[a]	Date Collected	Sample Category	Impacted PM_{10} Monitoring Sites	Sample Description
SOIL 23	23	9/23/87	Alkaline Playa Sediments and Desert Soil	Lone Pine, Locust St.	Desert sand collected from Owens lake. A composite was made from numerous samples collected at two locations. Location #1 was 1.6 km ESE of Swansea and Location #2 was near the Phase 2 sand fence site.
SOIL 24	24	9/23/87	Alkaline Playa Sediments	Lone Pine, Locust St.	A composite of four Owens Lake alkaline sediments was made from numerous samples collected east of the DRI test site (southern section of lake).
SOIL 25	25	9/23/87	Desert Soil	Lone Pine, Locust St.	Composite was made of soils collected at five locations in Owens Valley between Lone Pine and Independence. Location #1 consisted of Winnedumah-Mazourka-Cajon-Eclipse series. These were sands, loamy sands, loams, and silty loams 0.8 km north of Lone Pine monitor along Lone Pine Station Rd.; Location #2, common undescribed river silt 200 meters west of Owens River on Lone Pine Station Rd.; Location #3, Mazourka-Cajon-Eclipse series, sands and sandy loams, 1.4 km south of Mazourka Canyon Rd., 8 km west of Independence; Location #4, same soils series as Location #3, soils collected on a "slick," 1.0 km north of Mazourka Canyon Rd., 8 km west of Independence; and Location #5, Winnedumah soil on dirt road, .8 km north of Mazourka Canyon Rd., 4 km west of Independence.
SOIL 26	26	9/24/87	Cinder Storage	Mammoth Lakes, Gateway	Sample collected from the CALTRANS McGee Creek Storage Area. Material is from the Black Point Cinder Pit, near Mono Lake.
SOIL 27	27	9/24/87	Paved Road Dust	Mammoth Lakes, Gateway	Composite of samples collected along Main St. (Hwy. 203) and Laural Mountain Rd. around Mammoth Lakes Gateway monitoring site.

a. Map ID: Figure 2.7-1.

The agricultural soil samples collected were:

- Peat soils from the Delta region northwest of Stockton (source of Stockton "black cloud") (Schultz and Carlton, 1959);
- Mineral soils collected northwest of Stockton;
- Soils collected in cotton and walnut growing areas northwest of Visalia;
- Soils collected in raisin vineyards northwest of Visalia;
- Four composite soil samples representing the major soil types and agricultural crop areas west and northwest of Bakersfield; and
- A composite of predominant Imperial Valley agricultural soils.

Paved Roads

Six paved road dust samples were collected adjacent to ARB PM_{10} monitoring sites. The paved road samples were collected at the following locations:

- Fresno - Along Olive Street from the corner of Fisher Street to 75 meters west of monitors;
- Visalia - Sample collected from all four streets making up block where monitors were located (Church Street);
- Bakersfield - Along Chester Street, approximately 100 meters on either side of monitors;
- Brawley - Highways 78 and 11, and post office and police parking lots adjacent to the city block were monitors are located;
- El Centro - Ninth and State Streets near monitors; and
- Mammoth Lakes - Main Street (Highway 203) and Laurel Mountain Road near monitors.

Unpaved Roads and Urban Areas

Six samples were collected from unpaved roads and urban areas. As with the paved road dust samples, locations were selected near ARB PM_{10} monitoring sites. The unpaved road and urban samples were collected at the following locations:

- Visalia - Three unpaved parking lots near the Church Street monitoring site;
- Oildale - Unpaved roads in Kern River Oilfields north of Manor Street monitoring site;
- Bakersfield - Unpaved parking lots near Chester Street monitoring site;
- Bakersfield - Unpaved roads in residential areas west of Bakersfield;

- Taft - Unpaved road adjacent to monitors; and
- Brawley - Three unpaved parking lots near monitoring site.

Alkaline Playa Sediment and Desert Soils

Material was collected on and around Searles Lake (dry), around Owens Lake (dry), and in the desert range land between Lone Pine and Independence in the Owens Valley. The alkaline material of the Searles and Owens Lakes has been well quantified, as have the dust storms originating in their playas (Kerr-McGee Chemical Corporation, undated; Barone et al., 1979; Kusko et al., 1981; Kusko and Cahill, 1984; Saint-Armand, 1986).

Due to the lowering of the water table in the Owens Valley by the withdrawal of water by the Department of Water and Power of the City of Los Angeles (LADWP), vegetation has died, producing a number of barren areas in the Owens Valley which are sources of wind-blown dust. The four samples of alkaline playa material and desert soils were:

- Searles Lake - Five locations on and around Searles Lake East of Trona
- Owens Lake - Desert Sands.
- Owens Lake - Alkaline Crusts.
- Desert Soil, Owens Valley - Five locations between Lone Pine and Independence.

Sand and Cinder Storage Areas

Two samples were collected in this category. Sand was collected from a commercial sand and gravel mixing operation three blocks east of the Visalia Church Street monitoring site. While the storage and mixing operation is clearly not an important area-wide dust source, it was sampled due to its proximity to the ambient monitoring site. A road cinder sample was collected from Caltrans' McKee Creek cinder storage area outside Mammoth Lake. The cinder has been recognized as a wintertime particulate source after it is applied to roads in the area (Kemp, 1986). It is a volcanic cinder material, and it is suspected that crushing by vehicular traffic increases the fine fraction percentage. This sample was ground with a ceramic ball mill before laboratory sieving and resuspension procedures (Appendix D). This was conducted to simulate crushing by vehicular traffic.

In addition to the twenty-seven dust sample categories, thirteen other area and point source categories were sampled. These samples were collected with the ground-based PISD sampler, the industrial dilution source sampler (DSS), or the modified Method 5G-type dilution tunnel. Appendix E is a summary of point and area source filter samples.

Crude-Oil-Fueled Steam Generators

Emission samples were collected from two crude-oil-fueled steam generating units with the industrial dilution source sampler (DSS). Four replicate samples were collected from a unit operated by the Santa Fe Energy Company in the West Kern County Oilfield. Three replicate samples were collected from a unit operated by Chevron USA in the Kern River Oilfield. A unit from the West Kern County Oilfield and another from the Kern River Oilfield were sampled due to the possibility that differences in the crude oil chemical makeup between the two oilfields might influence the chemical composition of the particulate emissions. Tables 2.7-3 and 2.7-4 list the stack and sampler operation parameters during sampling at the two sites.

Diesel Truck Emissions

Integrated samples of commercial diesel truck traffic emissions were collected at the Wheeler Ridge Weigh Station located south of the intersection of Interstate Highway 5 and Highway 99 south of Bakersfield. The weigh station was operated by the California Highway Patrol (CHP). Six replicate runs were conducted with the PISD samplers. The PISD samplers were placed on a catwalk above inspection bay 3 of the inspection building. A CHP officer periodically directed trucks through the building specifically for the sampling effort. After deceleration, drivers were asked to maintain engine speeds of 1200 RPM. Consequently, emissions during deceleration, during a constant operating speed, and during acceleration as they were leaving were sampled. Emissions from a total of 174 trucks were sampled over the course of the six replicate runs (Table 2.7-5). Two upwind ambient background PISD samplers were situated approximately 100 meters northwest of the weigh station.

Diesel Ski Tour Bus Emissions

The emissions from ski tour buses operating in the Mammoth Lakes area were sampled with the PISD samplers situated in their exhaust plumes. Three replicate runs were conducted (these were not true replicates since different buses were sampled during each run). The ski tour buses, which are tuned for lower elevations and warmer temperatures than encountered at Mammoth Lakes, require long warm-up idling periods. Frequently, when temperatures are very low, they are idled all night. The long idling periods represent an air quality problem in the Mammoth Lakes area during the ski season. Most of the sampling was conducted in the Sierra Nevada Inn parking lot during the morning and in the Mammoth Mountain Ski Area parking lot in

Table 2.7-3
Stack and Sampler Operation Parameters, Oil-Fired Steam Generator: Chevron Racetrack Steam Plant

Company: Chevron

Plant: Racetrack Steam Plant, Sec. 27 29S/29E

City: Bakersfield, California

Fuel: Crude oil

No. of Generators: Seven

No. of Stacks: One

Port: Female, east side of stack, $1^1/_2$ meters below top of stack and approximately $1^1/_2$ meters above platform

Platform: Approximately 20 meters from ground

Scrubber Technology:

- Manufacturer: Neptune Airpol, Inc.; Serial #4041
- Date of Manufacture: 9/30/82
- Description: Two levels of water spray.
  - Water level maintained approximately 1 meter at bottom of scrubber.
  - Soda ash added to control pH; kept at pH 6.8 (gauge shows 6.85).
  - Density and level of solution in bottom of scrubber maintained automatically.
  - Includes set of anti-mist screens to prevent liquid fall-out.

Meaurements:

- Date: 6/14/88
- Time: 1430
- Ambient Temperature: 85° F (29° C)
- Stack Temperature: 134° F (57° C)
- Stack Velocity Pressure: 0.05 inch H_2O
- Stack Static Pressure: 0 to +0.05 inch H_2O
- Calculated Stack Velocity: 4.1 meters per second

Sampling Parameters:

- Nozzle Size: $^1/_2$ inch
- Dilution Ratio: 1 : 15
- Distance of Nozzle from Stack Wall: 48 inches

Table 2.7-4
Stack and Sampler Operation Parameters, Oil-Fired Steam Generator: Santa Fe Energy Unit 118

Company: Santa Fe Energy Company
Plant: Santa Fe Energy Unit 118
City: Fellows, California
Stack: #118 steam generator emissions, after scrubber
Fuel: Crude oil
Port: 4 inch female NPT, north side of stack, approximately 1 meter from top of stack
Platform: Approximately 10 meters from ground

Scrubber Technology:
  Manufacturer: Air Pol
  Description: Two levels of water sprays
  Water level maintained to approximately 1 meter at bottom of scrubber
  Soda ash solution added for control of pH within 7.0 to 7.2
  Density and level of solution in bottom of scrubber maintained automatically
  Includes set of anti-mist screens to prevent liquid fall-out

Plume: Heavily loaded with water vapor; appearance of plume after water dissipated was blue and carried horizontally, with little vertical climb

Meaurements:
  Date: 11/19/87
  Time: 0900
  Ambient Temperature: 65° F (18° C)
  Stack Temperature: 147° F (64° C)
  Stack Velocity Pressure: 0.05 inch H_2O
  Stack Static Pressure: 0 to +0.05 inch H_2O
  Calculated Stack Velocity:4.1 meters per second

Sampling Parameters:
  Nozzle Size: $^3/_8$ inch
  Dilution Ratio: 1 : 30
  Distance of Nozzle from Stack Wall: 48 inches

Table 2.7-5
Truck Count, Diesel Emissions;
Wheeler Ridge Weigh Station

Run #	Number of Trucks Counted					
	Freightliner	Peterbilt	Kenworth	International	Other*	Total
1	13	7	13	6	5	44
2	12	6	7	8	7	40
3	10	4	4	2	1	21
4	7	5	5	2	1	20
5	8	2	5	4	1	20
6	10	5	5	7	2	29
Totals	60	29	39	29	17	174

* *Other* includes GMC, Ford, and Mack.

the afternoon. No background air samples were collected due to the relatively good surrounding air quality during the sampling program and the short-duration, high-impact source samples which were collected.

Agricultural Burning

Three or four replicate runs of agricultural burning emissions were collected using the PISD samplers in each of four areas. It should be noted that the multiple runs were not true replicates as each sample was from a different agricultural burning event. No background air samples were collected due to the short-duration, high-impact source samples which were collected. The four agricultural burning sample sets that were collected are as follows:

- Two wheat stubble fires and a barley stubble fire were sampled in the Bakersfield area. All three locations were in Kern County, 20 kilometers south of Bakersfield, 10 kilometers west of Bakersfield, and 5 kilometers south of Shafter, respectively.

- Three wheat stubble fires were sampled in the El Centro area. They were collected in Imperial County fields, 7 kilometers northwest of El Centro, 10 kilometers southwest of El Centro, and 8 kilometers south of El Centro.

- Three wheat stubble fires were sampled in the Visalia area. They were collected in Tulare county in fields 20 kilometers east of Tipton, 5 kilometers west of Tulare, and 3 kilometers east of Tulare.

- Three wheat stubble fires were sampled in the Stockton area. They were in San Joaquin County. One was 25 kilometers northwest of Stockton and two sets were 10 kilometers north of Tracy.

It should be noted that the burning of other agricultural crop residues also occurs, but that wheat stubble is one of the major crop residues burned in the study areas.

Dairy/Feedlot Dust

Dairies and feedlots have been recognized as significant potential sources of particles in California (Azevedo, 1974; California Cattle Feeders Assoc., 1971; Miller, 1962; Miller et al., 1974). Three replicates of emissions generated at a dairy in the Visalia area were sampled with PISD samplers. No background samples were collected, as the emissions from the dairy dominated the samples.

Construction Emissions

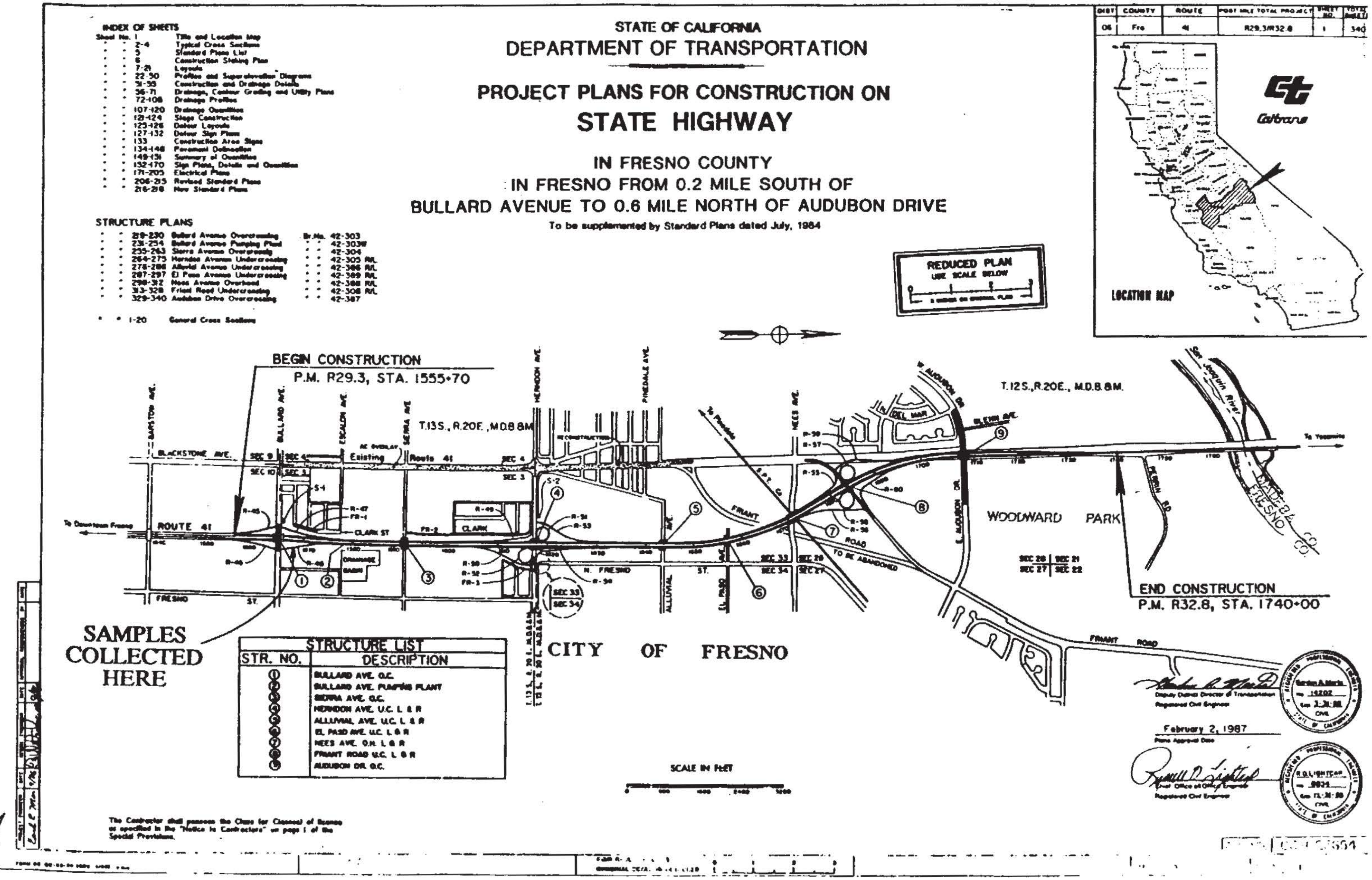
Three replicate samples were collected of dust and emissions generated by Highway 40 construction in Fresno (Figure 2.7-3). The samples were collected using the PISD samplers situated downwind of the construction activity. No background samples were collected, as the dust and emissions from the construction dominated the samples.

Residential Wood Combustion

Residential Wood Combustion (RWC) has been demonstrated as being a significant source of particulate material in California High Sierra communities (Ipps, 1987) and in San Joaquin Valley communities (Engineering Science, 1982; Inouye, 1985). In High Sierra resort communities such as Mammoth Lakes, both fireplaces and woodstoves are significant. In the San Joaquin communities with milder climates, fireplaces are much more predominant than woodstoves. It has been estimated, for example, that the total number of woodstoves (including fireplace inserts, which function like woodstoves) in the Fresno area in 1984 was 7,556 as compared to 51,339 fireplaces (Inouye, 1985). The corresponding estimated ratio of inhalable particulate emissions between fireplaces and woodstoves was 12:1. Since Bakersfield has a slightly milder climate than Fresno (2128 versus 2601 heating degree days), it was assumed that fireplaces represent even a larger fraction of the total residential wood combustion emissions in Bakersfield as compared to Fresno.

As discussed in Section 2.5, laboratory sampling of woodburning appliances with a modified Method 5G-type sampler appears to be the most appropriate approach to obtain RWC source profiles. Three replicate runs each simulating fireplace use in Bakersfield, fireplace use in Mammoth Lakes, and woodstove use in Mammoth Lakes were conducted at OMNI's testing facility in Beaverton, Oregon. Since unfiltered laboratory air was used for dilution, background PISD samplers were run simultaneously with the modified Method 5G-type sampler.

Fuel wood and woodstove dealers were surveyed in both the Bakersfield and Mammoth Lakes areas to determine the principal wood types burned. An official with the Inyo National Forest was also interviewed regarding wood types cut for use in Mammoth Lakes. Table 2.7-6 lists the consensus of opinions as to the major wood types used in both communities with an estimated relative percent usage. Of course, many miscellaneous wood types are burned in both communities but apparently none at more than a few percent level each. Interestingly, almond is a major wood type burned in the Bakersfield area due to the abundance of almond orchard trimmings. During the tests the wood types were burned in the same proportion as the estimated usage for the Mammoth Lakes and Bakersfield sampling runs. The percent moisture on a dry basis of the cordwood which was obtained is also given in Table 2.7-6.



STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

PROJECT PLANS FOR CONSTRUCTION ON
STATE HIGHWAY

IN FRESNO COUNTY
IN FRESNO FROM 0.2 MILE SOUTH OF
BULLARD AVENUE TO 0.6 MILE NORTH OF AUDUBON DRIVE
To be supplemented by Standard Plans dated July, 1984

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" " 1-20 General Cross Sections

STRUCTURE LIST

STR. NO.	DESCRIPTION
①	BULLARD AVE. O.C.
②	BULLARD AVE. PUMPING PLANT
③	SIERRA AVE. O.C.
④	HERNDON AVE. U.C. L & R
⑤	ALLUVIAL AVE. U.C. L & R
⑥	EL PASO AVE. U.C. L & R
⑦	NEES AVE. O.H. L & R
⑧	FRIANT ROAD U.C. L & R
⑨	AUDUBON DR. O.C.

The Contractor shall possess the Class for Classes of license as specified in the "Notice to Contractors" on page 1 of the Special Provisions.

DIST	COUNTY	ROUTE	POST MILE TOTAL PROJECT	SHEET NO.	TOTAL SHEETS
06	Fre	41	R29.3/R32.8	1	340

February 2, 1987
Plans Approval Date

Figure 2.7-3. Location of construction sampling.

Table 2.7-6
Mammoth Lakes and Bakersfield Cordwood

Area/Species	Estimated Usage (percent)	Moisture Content (percent dry basis)
Mammoth Lakes		
Lodgepole Pine	20	14
Jeffrey Pine	60	15
Red Fir	20	13
Bakersfield		
Almond	60	13
White Oak	40	13

A more-or-less typical fireplace and airtight woodstove (non-catalytic) were used for the tests. These appliances were well broken in before use. (New appliances may give erroneous particulate source profiles due to the burning of paint and oil.) The target burn rate for the woodstove tests was approximately 1.5 kg(dry)/hr. The target burn rate for the fireplace tests was between approximately 3 to 4 kg(dry)/hr. The wood addition period for all tests was 5 hours, which represents a typical evening burn period for fireplaces and woodstoves in communities such as Mammoth Lakes and Bakersfield. Sampling was continued until the flue temperature (30 cm above the appliance) was less than 100°F (38°C). The dilution ratio was lower for the fireplace tests than for the woodstove tests since flue gas flows are much higher for fireplaces than for airtight woodstoves. Tables 2.7-7 through 2.7-9 give the woodstove and sampler operation parameters for the simulated Mammoth Lakes woodstove runs. Tables 2.7-10 through 2.7-12 give the fireplace and sampler operation parameters for the simulated Mammoth Lakes fireplace runs. Tables 2.7-13 through 2.7-15 give the fireplace and sampler operation parameters for the simulated Bakersfield fireplace runs. Two sequential filter sets were used on one of the three Mammoth Lakes woodstove runs. A weighted averaged (based on volume sampled) was calculated for that overall run profile.

Table 2.7-7
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 1

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in doors

Operation

Date:	February 10, 1988
Wood Addition Period:	5 hours
Burn Period:	10.52 hours
Burn Rate:	1.53 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
1146	Jeffrey Pine	0.43 (kindling)	Door open
1146	Jeffrey Pine	0.87 (starter logs)	Door closed
1150	Jeffrey Pine	1.30	Both dampers open
1212	—	—	One spin draft open; other closed
1222	Jeffrey Pine	1.74	One spin draft open; other closed
1244	—	—	Both spin drafts open one-half turn
1420	Lodgepole Pine	1.93	Both spin drafts open one-half turn
1524	Jeffrey Pine	4.00	Both spin drafts open 2 $^1/_2$ turns
1550	—	—	Both spin drafts open two turns
1646	Red Fir	3.89	One spin draft $^1/_2$ open; other $^3/_4$ open
1646	Lodgepole Pine	1.05	One spin draft $^1/_2$ open; other $^3/_4$ open
1646	Jeffrey Pine	0.87	One spin draft $^1/_2$ open; other $^3/_4$ open
2217	Test terminated		

Sampler:

Total Sampling Time:	10.52 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	297° F/147.2° C
Typical Chamber Temperature:	76° F/24.4° C
Typical Ambient Temperature:	61° F/15.9° C

Table 2.7-8
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 2

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in door

Operation

Date:	February 11, 1988
Wood Addition Period:	5 hours
Burn Period:	10.32 hours
Burn Rate:	1.60 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0914	Jeffrey Pine	0.43 (kindling)	Door open
0914	Jeffrey Pine	0.87 (starter logs)	Door open
0919	Jeffrey Pine	1.30	Dampers open/door closed
1000	Lodgepole Pine	1.23	Drafts open two turns
1047	Jeffrey Pine	2.26	Drafts open two turns
1154	Lodgepole Pine	2.11	Drafts open two turns
1308	Jeffrey Pine	1.65	Drafts open two turns
1341	Jeffrey Pine	1.22	Drafts open two turns
1414	Red Fir	3.63	Dampers open three-quarter turn
1414	Jeffrey Pine	1.83	Dampers open three-quarter turn
1932	Test terminated		

Sampler:

Total Sampling Time:	10.32 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	289° F/142.8° C
Typical Chamber Temperature:	75° F/23.6° C
Typical Ambient Temperature:	62° F/18.3° C

Table 2.7-9
Appliance and Sampler Operation Parameters
Woodstove, Mammoth Lakes Cordwood, Run 3

Appliance

Firebox Size:	2.73 cubic feet
Diameter of Flue:	6 inches
Combustion Air Control:	Two spin drafts in door

Operation

Date:	February 12, 1988
Wood Addition Period:	5 hours
Burn Period:	9.47 hours
Burn Rate:	1.72 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0918	Jeffrey Pine	0.43 (kindling)	Door open
0918	Jeffrey Pine	0.87 (starter logs)	Door open
0925	Jeffrey Pine	1.65	Drafts open/door closed
0956	Red Fir	1.59	Drafts open two turns
1103	Jeffrey Pine	1.74	Drafts open two turns
1217	Red Fir	1.86	Drafts open two turns
1307	Red Fir	0.53	Drafts open two turns
1329	Lodgepole Pine	1.84	Drafts open two turns
1349	Jeffrey Pine	0.78	Drafts open two turns
1425	Jeffrey Pine	3.91	Drafts open three-quarter turn
1425	Lodgepole Pine	1.05	Drafts open three-quarter turn
1846	Test terminated		

Sampler:

Total Sampling Time:	9.47 hours
Approximate Dilution:	1 : 70
Typical Stack Temperature:	316° F/157.8° C
Typical Chamber Temperature:	78° F/25.6° C
Typical Ambient Temperature:	66° F/18.9° C

Table 2.7-10
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 1

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 5, 1988
Wood Addition Period:	5 hours
Burn Period:	6.9 hours
Burn Rate:	3.67 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0930	Jeffrey Pine	0.43 (kindling)	Open
0930	Jeffrey Pine	0.87 (starter logs)	Open
0934	Lodgepole Pine	1.84	Open
1047	Jeffrey Pine	2.09	Open
1104	Jeffrey Pine	3.04	Open
1145	Jeffrey Pine	2.52	Open
1255	Lodgepole Pine	1.84	Open
1321	Jeffrey Pine	3.48	Open
1356	Jeffrey Pine	2.70	Open
1356	Lodgepole Pine	1.32	Open
1430	Red Fir	5.22	Open
1624	Test terminated		

Sampler:

Total Sampling Time:	6.9 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	291° F/144.0° C
Typical Chamber Temperature:	121° F/49.6° C
Typical Ambient Temperature:	55° F/12.5° C

Table 2.7-11
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 2

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 8, 1988
Wood Addition Period:	5 hours
Burn Period:	6.34 hours
Burn Rate:	4.15 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0945	Jeffrey Pine	0.43 (kindling)	Open
0945	Jeffrey Pine	0.87 (starter logs)	Open
0948	Jeffrey Pine	2.26	Open
1008	Jeffrey Pine	1.48	Open
1048	Jeffrey Pine	3.39	Open
1141	Jeffrey Pine	3.65	Open
1218	Lodgepole Pine	2.46	Open
1305	Jeffrey Pinee	1.83	Open
1327	Red Fir	4.96	Open
1445	Red Fir	0.71	Open
1445	Jeffrey Pine	1.91	Open
1445	Lodgepole Pine	2.37	Open
1605	Test terminated		

Sampler:

Total Sampling Time:	6.34 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	369° F/187.2° C
Typical Chamber Temperature:	105° F/40.6° C
Typical Ambient Temperature:	60° F/15.6° C

Table 2.7-12
Appliance and Sampler Operation Parameters
Fireplace, Mammoth Lakes Cordwood, Run 3

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 9, 1988
Wood Addition Period:	5 hours
Burn Period:	6.12 hours
Burn Rate:	4.10 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0810	Jeffrey Pine	0.43 (kindling)	Open
0810	Jeffrey Pine	0.87 (starter logs)	Open
0815	Jeffrey Pine	1.83	Open
0830	Lodgepole Pine	2.02	Open
0856	Jeffrey Pine	0.96	Open
0927	Jeffrey Pine	1.91	Open
0947	Lodgepole Pine	3.07	Open
1025	Red Fir	2.21	Open
1046	Jeffrey Pine	2.00	Open
1107	Jeffrey Pine	3.04	Open
1153	Jeffrey Pine	2.78	Open
1231	Jeffrey Pine	1.04	Open
1310	Red Fir	2.92	Open
1417	Test terminated		

Sampler:

Total Sampling Time:	6.12 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	261° F/127.2° C
Typical Chamber Temperature:	107° F/41.5° C
Typical Ambient Temperature:	56° F/13.3° C

Table 2.7-13
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 1

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 2, 1988
Wood Addition Period:	5 hours
Burn Period:	6.68 hours
Burn Rate:	3.75 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0844	Almond	0.44 (kindling)	Open
0844	Almond	0.88 (starter logs)	Open
0855	Almond	1.42	Open
0909	Oak	1.24	Open
0922	Oak	3.36	Open
0949	Almond	3.36	Open
1040	Oak	3.98	Open
1142	Almond	1.68	Open
1210	Almond	3.45	Open
1313	Almond	1.77	Open
1344	Almond	2.30	Open
1344	Oak	1.15	Open
1525	Test terminated		

Sampler:

Total Sampling Time:	6.68 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	240° F/115.6° C
Typical Chamber Temperature:	94° F/34.4° C
Typical Ambient Temperature:	51° F/10.6° C

Table 2.7-14
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 2

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 3, 1988
Wood Addition Period:	5 hours
Burn Period:	6.54 hours
Burn Rate:	3.83 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
0821	Almond	0.44 (kindling)	Open
0821	Almond	0.88 (starter logs)	Open
0828	Almond	1.86	Open
0835	Almond	2.65	Open
0922	Oak	3.45	Open
1001	Almond	4.07	Open
1043	Oak	3.81	Open
1129	Oak	2.92	Open
1158	Almond	1.42	Open
1258	Almond	1.06	Open
1321	Almond	2.48	Open
1453	Test terminated		

Sampler:

Total Sampling Time:	6.54 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	288° F/142.2° C
Typical Chamber Temperature:	107° F/41.7° C
Typical Ambient Temperature:	59° F/15.0° C

Table 2.7-15
Appliance and Sampler Operation Parameters
Fireplace, Bakersfield Cordwood, Run 3

Appliance

Firebox Size:	3.75 cubic feet
Diameter of Flue:	8 inches
Combustion Air Control:	None

Operation

Date:	February 4, 1988
Wood Addition Period:	5 hours
Burn Period:	6.44 hours
Burn Rate:	3.90 dry kilograms per hour

Wood Addition and Draft Control/Door Position Chart

Time	Wood Species	Actual Dry Wood Mass (kg)	Draft Control/Door Position
1201	Almond	0.44 (kindling)	Open
1201	Almond	0.88 (starter logs)	Open
1213	Almond	1.95	Open
1227	Almond	2.65	Open
1317	Oak	3.54	Open
1412	Oak	3.89	Open
1551	Almond	6.19	Open
1646	Oak	2.48	Open
1701	Almond	3.10	Open
1828	Test terminated		

Sampler:

Total Sampling Time:	6.44 hours
Approximate Dilution:	1 : 6
Typical Stack Temperature:	268° F/131.1° C
Typical Chamber Temperature:	90° F/32.2° C
Typical Ambient Temperature:	58° F/14.4° C