BEIJING (CHINA) AEROSOL CHARACTERIZATION STUDY:
INFLUENCE OF COAL BURNING

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DEDICATION

If my thesis is a brick for coal burning control construction, I will dedicate the honor to James Huntzicker for his help, encouragement and understanding.

I had a dream that one day I could control coal burning pollution when I had to work with coal boilers as "re-education" for a college graduate like myself during the Cultural revolution. It is James who helps my dream come true.

My father Cheng-lin Ge and my mother Zhao-ren Duan have done so much on this project because the communication with China was so difficult. The project could not be successful without their help.

Likewise I dedicate my thanks to those who have helped me with this project.

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Because political and financial reasons, this was an extremely difficult project to do. I will remember all friends who have contributed so much to this project.

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GLOSSARY OF ABBREVIATIONS

$PM_{2.5}$	The aero-dynamitic diameters of particles $\leq 2.5\ \mu m$
TSP	total suspended particulate material
OC	organic carbon
EC	elemental carbon
TC	total carbon
XRF	x-ray fluorescence
DRI	Desert Research Institute
RPDDM	relative percent difference of duplicate measurement
CMB	Chemical Mass Balence
HONEYC	honeycomb coal burning when closed mode
HONEYO	honeycomb coal burning when open mode
BALLC	ball coal burning when closed mode
BALLO	ball coal burning when open mode
INDST	industrial coal burning
POWER	coal-fired power station burning
BOILER	residential coal boiler burning
CEMENT	cement dust
UDUST	urban dust
PDUST	plant road dust
FRIED	cooking emission
MVHDDS	heavy duty diesel emission
SO_4	sulfate

ABSTRACT

BEIJING (CHINA) AEROSOL CHARACTERIZATION STUDY: INFLUENCE OF COAL BURNING

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Coal is expected to surpass petroleum as the world's most used fuel within the next 20 years. Coal currently generates more than half of U.S. electricity, and this percentage is predicted to increase. Coal usage may grow by a factor of two or three in the next decade. China's main energy source is coal, which provides 76% of china's energy. Coal burning is one of major sources of air pollution in China. The burning of 100 million tons of coal per year in China probably also contributes greatly to the global greenhouse effect.

The purpose of this research was to determine the impact of industrial and residential coal burning on air quality in Beijing, China. $PM_{2.5}$ (the aero-diameters of particles collected are smaller than 2.5 μm) samples were collected at two sites from April 30, 1989 to May 16, 1989 and May 20, 1989 to May 14,1990 separately. The samples were analyzed by thermal-optical carbon analysis at Oregon Graduate Institute (OGI) for organic (OC) and elemental carbon (EC) and X-ray fluorescence at Desert Research Institute for 32 elements and components. A variety of different data analysis approaches including multiple linear regression and CMB modeling were used to determine the sources of $PM_{2.5}$ and the role of coal burning in Beijing air pollution.

The results indicate that organic and elemental carbon are important components of aerosol throughout the year in Beijing. During the autumn, winter, and spring, combustion appears to be the main source of particulate organic carbon. The eleven sources of aerosol included in honeycomb coal burning when closed mode (HONEYC), residential boilers

(BOILER), industrial burning (INDST), power station coal burning (POWER), heavy duty diesel emission (MVHDDS), secondary sulfate, soil, urban dust, plant dust, cement dust, and cooking emissions. Based on the low chi-squared, high R-squared and high fraction of mass accounted for, the results of the CMB on Beijing data can be considered good. In the winter at the west site in Beijing the total coal burning contribution was 43%; in the summer it was 18%. The average winter HONEYC and BOILER contributions were 6% and 14%, while the INDST and POWER were 10% and 13% respectively. MVHDDS is an another important source as its annual average contribution was over 30%. The average dust contributions were as high as 34% and 32% in the spring and summer, but 17% and 10% in the autumn and winter. Those sources and their contributions were supported by east site results in Beijing.

The source profiles of honeycomb and ball coal were compared with piece coal including their smoke, ash and coal. For open-vent burning the source profiles of honeycomb and ball coal are very similar. The EC content of honeycomb coal open-vent burning and ash are much less than that of ball coal. Thus, the coal shape might be an important factor for coal burning pollution control and energy saving. Honeycomb and ball coals and their ashes show less sulfate and chloride and much less EC content than piece coal's ash. That implies that research of honeycomb, ball and other kind of coal may be important for new clean and cheap fuel in power station, industry and residential usage. The source libraries and CMB modeling from the U.S. are good tools for studying other countries' air pollution control strategies. Therefore, this project is an example for other countries' air pollution research.

CHAPTER 1.
INTRODUCTION

This project is concerned with coal burning pollution research. The sampling was done in Beijing, China, which is the first country that began to use coal in the metallurgical industry and for domestic heating and cooking from 300 A.D. From 1000 A.D. until now, coal has been used as an important and even the dominant fuel and energy source in China. Knowledge of coal use was first brought to the west by the Venetian traveler Marco Polo in 1295 (Schobert H. H., 1987).

Coal is being indicted as a major greenhouse gas culprit, and because more than half of American's electricity is currently generated from coal and this percentage is predicted to increase. However, coal is vital to many countries' economic and social life, so major steps have been taken to abate toxic emissions from the combustion process to preserve coal's strategic importance in the U.S., China and world economies (Cruver, P. C. 1989).

Coal usage in the world is expected to grow by a factor of two or three in the next decade. On a global basis, even under a moderate energy growth scenario, coal will probably supply between one-half and two-thirds of the additional energy needs of the world during the next 20 years because the price of coal is stable and there is a plentiful global supply of coal. To meet these needs, world coal production will have to increase 2 to 3 times, and the world trade in steam coal (for power plant usage) will have to grow 10 to 15 times above 1979 levels.

Within the next 20 years, coal is expected to surpass petroleum as the world's most used fuel. U.S. coal accounts for approximately a quarter of the world's total reserves, a major assert to be exploited in the future. Coal makes up about 80% of the U.S. fossil fuel reserves, which is adequate to meet domestic energy needs for several hundred years (Cruver P. C. 1989).

Coal provides 76% of the total energy utilized in China. China ranks third in the world in coal reserves with 1,440 billion tons (13% of the world's reserves). Domestic oil, gas, and hydropower resources are small and the nuclear power industry is not well developed. In 1980, 649 million tons of coal were mined, of which 600 million tons were consumed domestically (China Daily, 1987). 980 million tons of coal were produced in 1988, 1,054 million tons in 1989 and in 1990 1,400 million tons (Zhang, Her-ping, 1990). The fraction of total energy supplied by coal in China is more than three times greater than that in the U.S. So, energy supply in China is more dependent on coal than most other countries in the world. However, the energy intensity index appears to indicate an inefficient use of the fuel as shown in Table 1-1. The main reasons are as following: First, residential coal burning in China is in either small housestoves or small boilers in apartments or commercial center. In the United States, 85 percent of coal is burned to generate electric power, at an average efficiency of 36 percent. By contrast, 22 percent of Chinese coal is converted to electric power, with an overall efficiency of only 29-31 percent (Kinzelbach, 1989; Xi et al., 1989). The bulk of Chinese coal is burned at still lower efficiencies, in industry (46 percent of 1985 coal use) and for commercial and residential heating (26 percent). Residential coal stoves often have only 10-18 percent efficiency (Xi et al., 1989). Adoption of more efficient furnaces and replacement of boilers with combined heating and power installations proceed very slowly for lack of capital. Second, policy sets coal prices for the state-owned mines artificially low, below the cost of production (Paul et al., 1992). However, the second reason will not be discussed in the thesis because it is related to the economy, and politics. Since the rate of coal consumption is increasing, Chinese experts estimate that the country will consume two billion tons of coal in the year 2000. Since fossil fuel consumption accounts for over half the human contribution to the greenhouse effect, chiefly through the emission of carbon dioxide (Paul et al., 1992), also through the emission of methane (Su et al., 1988), so it is extremely important to research coal burning control in China to abate greenhouse effect.

On a national scale about 73% of the particulate material and 90% of the sulfur dioxide emitted into the Chinese atmosphere could be attributed to coal burning. Coal is expected to be the major energy source in China until the year 2030 exceeding 2 billion tons per year. After that, it is anticipated that nuclear energy will dominate. Therefore, coal burning has the potential of creating a much larger pollution problem in the next few decades. What is the impact of coal burning pollution? What are the chemical and physical characteristics of coal burning aerosol? How do we control coal burning pollution? The goal of this project is to address these questions.

The project was done in Beijing, a typical coal burning city with 70% of energy provided by coal burning. Wang Ming-xing (1985) measured an average concentration of total suspended particulate material (TSP) of 596 $\mu g/m^3$ in March and 338 $\mu g/m^3$ in April of 1984, and in June of 1984 the TSP average concentration was 281 $\mu g/m^3$. The yearly average TSP concentration in Beijing is above 300 $\mu g/m^3$.

The National Aerometric Bank described the annual average TSP concentrations in other Chinese coal burning cities prior 1986. In all cases the air quality was quite poor. For example, the annual average TSP concentration in Shanghai was 410 $\mu g/m^3$, and the annual average in Shenyang, a northeast city, was 512 $\mu g/m^3$. Chongqing is a city like London located in southwest China; the TSP concentration there was 1240 $\mu g/m^3$. The annual average TSP concentration in the Northwest city of Lanzhou was 1320 $\mu g/m^3$. Taiyuan, in the center of China, had an annual average concentration of 1000 $\mu g/m^3$. Nanjing is a clean city; it had a TSP concentration of 195 $\mu g/m^3$. The annual average TSP concentration in Fuzhou, a southeast city, was 1730 $\mu g/m^3$. In July 1988 the air above Benxi in northeast China, was so dirty that the city was invisible on satellite photographs. The air quality of these cities has improved since 1982, But the TSP concentrations in most Chinese cities still exceed the Chinese national standards, which are composed of three classes: class I, 150 $\mu g/m^3$, class II, 300 $\mu g/m^3$, class III, 500 $\mu g/m^3$ as a daily average. However, the $PM_{2.5}$ particle research has not started yet in China. Because 30% fine particle of TSP in Beijing < 2 μm, and most of organic components are absorbed by fine particle (< 3 μm) (Mong, Zhi-hong, 1989), so this project will focus on $PM_{2.5}$ particle research in Beijing.

During the winter in Beijing, 1,500,000 small-sized furnaces and household stoves emit TSP at a total rate of about 22 tons/day (or 8,000 tons/year). In addition, there are many boilers for hot water, and building heating purposes. For this reason, local residential sources are likely to be important sources of air pollution in Beijing. In contrast, the Chinese EPA authorities believe that industrial power plants are the major sources of air pollution. Therefore, the EPA abatement strategies emphasize reduction of the industrial smoke stack emissions. Wilson (1987) reported that it is of interest to the U.S. to participate in a study of a general characterization of Chinese air quality. The large amount of coal burned for electrical power, cooking and heating should produce higher SO_2 and aerosol concentrations in China than the U.S. It is believed that China should have less NO_x, hydrocarbons and less ozone than the U.S.A. because of a smaller population of motor vehicles. Therefore, Chinese cities are ideal places to study coal burning. Epidemiological studies indicated (Liu, Tian-ji, 1984) that lung cancer in Beijing have shown the highest mortality in the downtown city, and the far away from the city, the lower and lower of the mortalities of lung cancer it was shown.

My previous research suggested that particles from coal burning influenced solar attenuation from 1963 to 1980 in Beijing. In Figure 1-1 the top line is solar attenuation in Beijing during 1963 to 1979, the middle is the particle emission line and the bottom line is SO_2 emission line during the same period. The top line was from calculations of monitoring data (Pan, 1983), and the middle and bottom lines come from a paper (Beijing environmental protection institute, 1982). The solar attenuation increased during 1964-1966, because of the fast development and reindustrialization. Hence, air quality deteriorated. During the period of 1967-1971, the air quality improved again due to the anti-industrial policies of the Cultural Revolution. As a result, some of factories were shut down, the output of production decreased and the industrialization also decreased. From 1972 and especially from 1976, when the "Gang of Four" was thrown out , the solar attenuation started increasing again signaling renewed industrial development and high particulate levels. On the whole, the three lines correlate reasonably well which suggests that coal burning aerosol is an important component of Chinese air pollution. Figure 1-2 shows the good correlations between Beijing's population and the attenuation of solar radiation reaching ground in Beijing from 1963 to 1978. The more people were born, the more energy was needed from coal burning. For these reasons it is extremely important to understand aerosol pollution from coal burning in China in order to protect public health and the global environment.

Diawu Zhao (1986) concluded that TSP presently poses the most serious air pollution problems in China. Moreover, measurements showed that particles were generally of an alkaline nature in the north, whereas they were acidic in the south. As a result Southern China experiences acid rain, whereas in Northern China acid rain does not exist despite high SO_2 concentrations in cities throughout China. In the last ten years, the Chinese EPA has spent a large amount of money and effort on acid rain monitoring and research. They have made significant progress. They know that aerosol emissions from coal burning are a major air pollution problem, but little coal burning research has been conducted yet on aerosols from coal burning.

In recent years, Chinese scientists from Academia Sinica, National Environmental Institute, Beijing University and Nan Kai University have begun work on receptor modeling and factor analysis. They have made progress and have gotten interesting results. For example, Dr. Dai Shugui (1986) found that industrial coal sources contribute 22.4% of ambient TSP in Tianjing, while residential coal combustion contribute 22.2%. The problems encountered in Chinese Chemical Mass Balance modeling are: (1) samples were all total suspended particulate samples, so, coarse particles such as soil were included too much; (2) OC and EC concentrations, which comprise a high percent of the weight, were not reported; (3) the elemental analysis was carried out by different instruments for different elements rather than the most by XRF; (4) quality control procedures were not reported; (5) Chinese source profiles were not available. Despite the drawbacks, they have done important research which will greatly help our project. A research project in the Beijing and Tianjing area in 1983-1984 indicated that soot is one of the main air pollutants in Northern China. The average particulate carbon concentration was about 30 $\mu g/m^3$ and source was mainly coal combustion. Soot contributions to the visibility reduction were on the order of 22%-29% (Su, W. H. 1989).

Coal has been used in China for over a thousand years. It can be divided into three types: piece coal, honeycomb coal, and ball coal. Piece coal is as-mined coal broken into convenient sized pieces and treated in coal shops to reduce sulfur content. Honeycomb coal is a briquette material made up of powdered coal, clay, and wood powder formed into a cylinder with many holes from top through bottom. Ball coal is similar to honeycomb coal but the shape is different and it looks like a flattened ball. The distribution of coal consumption in Beijing in 1983 is shown in Figure 1-3. Two-thirds of consumed residential coal is honeycomb coal.

In 1987, a small project to study coal burning was conducted at O.G.I. where both Chinese and American coal were burned in a box type, conventional, wood stove. CMB modeling was used to make a preliminary evaluation of the contributions of residential coal burning and power plant coal burning emissions to Beijing air pollution. Figure 1-4 shows that coal source compositions are significantly different depending on the combustion temperature. Therefore, the result is that the compositions of coal burning emissions will be strongly dependent on burning temperature. Based on this point of view, housestove sampling in

Beijing project was divided into closed-door mode which is in low temperature and open-door mode which is in high temperature. Since CMB model can be used in this small project, it also can be used in the Beijing project for coal burning control strategy determination.

Our project measured the fine aerosol (particle diameter < 2.5 μm). This minimizes the influence of wind - entrained soil, which is an important consideration since Beijing's average wind velocity is much higher than in Portland's. This is the first time this sampling method has been used for a year long sampling in China. Since the environment in Beijing might be dominated by coal burning, our site was located in the downtown center of Beijing where some coal household stoves are used even in summer. Sampling was conducted for one year. visibility, and meteorological data have all been measured together. Residential coal burning sampling (i.e., honeycomb and ball coal) and industrial coal burning sampling have been conducted. Soil dust, ash, different kind of coal have been sampled and interpreted as ambient and source profiles. Quality controls have been carefully considered from filter preparation through sampling and data management.

The goal of this project is to determine the characteristics of aerosol and contributions of power plant coal burning, industrial coal burning, residential coal boilers, and residential housestove emissions to particulate air pollution in Beijing. To do this, we identified the chemical composition of emissions from different types of coal burning, such as residential honeycomb stove emissions, residential boiler contributions, industrial boiler emissions, and power plant emissions. We measured the diurnal, monthly, seasonal, and yearly changes in ambient $PM_{2.5}$ concentration, sampled residential housestove and industrial smoke, soil, different coals and their ashes. The organic carbon, elemental carbon, and ambient element concentrations of these samples have been analyzed. The source composition profiles and ambient concentration profiles were used with Chemical Mass Balance models to determine the major contributions to air pollution in Beijing. This project provided a better understanding of the sources of ambient pollution in Beijing and thus enabled more effective environmental protection strategies to be developed in coal burning cities. This knowledge could also contribute to global air pollution abatement strategies.

Table 1-1. The most energy-intensive economies in the world, 1987

country	energy intensity*	productivity** $
China	1.81	76
Poland	1.75	78
Yemen	1.68	82
Zambia	1.52	90
Hungary	1.37	100
South Africa	1.3	106
Trinidad and Tobago	1.23	112
Jamaica	0.91	151

*: Kilograms of oil equivalent per U.S. dollar of GNP.

**: U.S. dollars of GNP per barrel of oil equivalent (1 barrel = 137.2 k).

Source: Calculated from data in World Bank (1989).

(Paul et al. 1992)

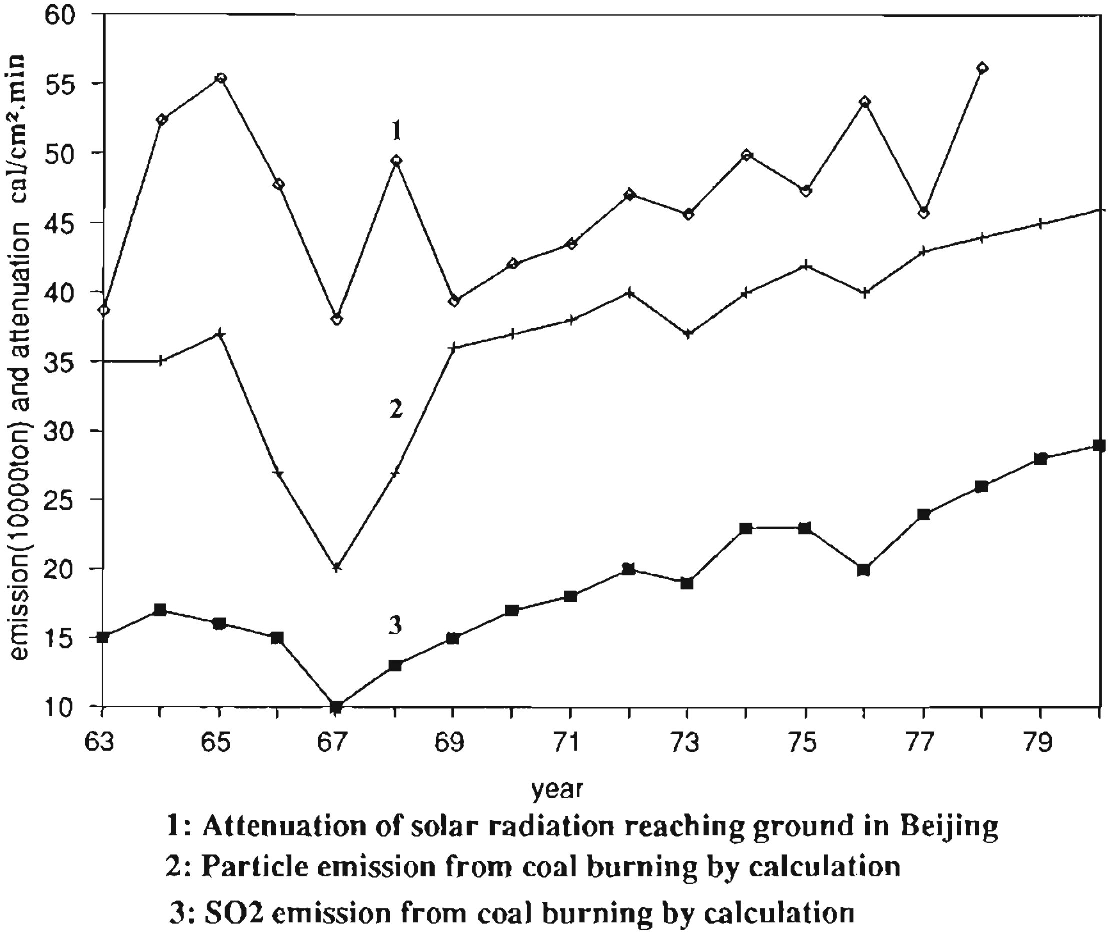


Figure 1-1. The correlation of attenuation of solar radiation, particles and SO_2 in Beijing from 1963 to 1978.

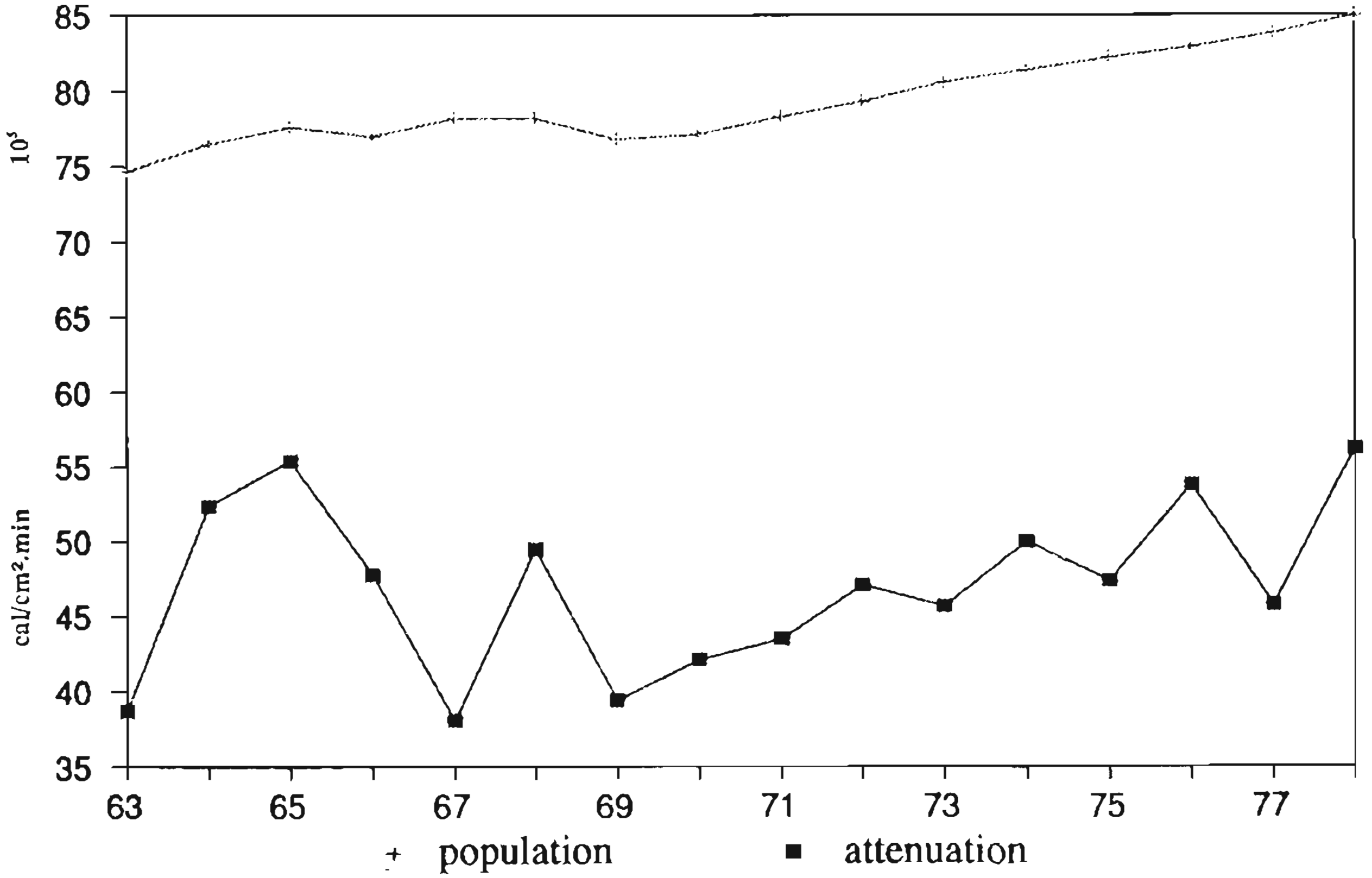


Figure 1-2. The correlation of population and attenuation of solar radiation reaching ground in Beijing from 1963 to 1978.

	piece coal	honeycomb coal (percent)	ball coal
residential	2	2.7	1.6
cooking		3.8	1.6
public building	1	0.5	1.6

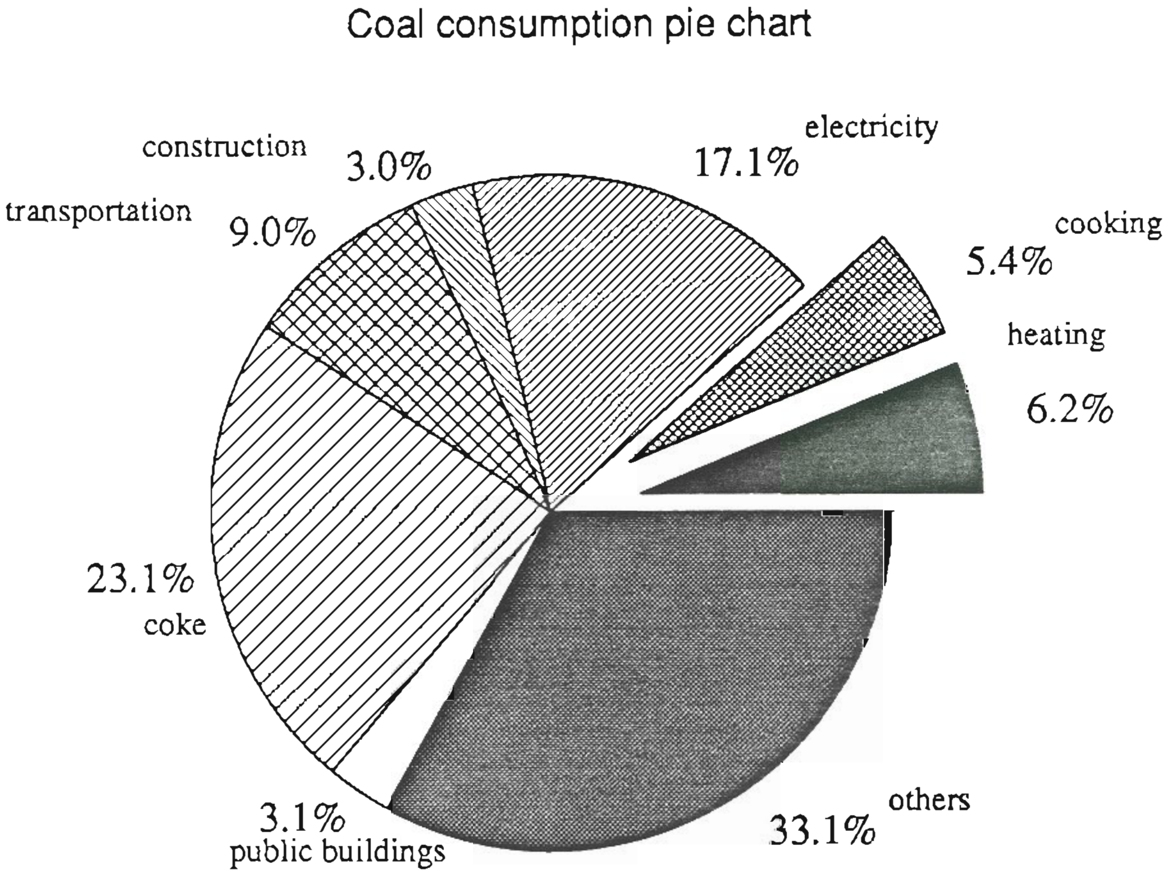

Coal consumption pie chart

Figure 1-3. Coal usage distribution in Beijing in 1983.

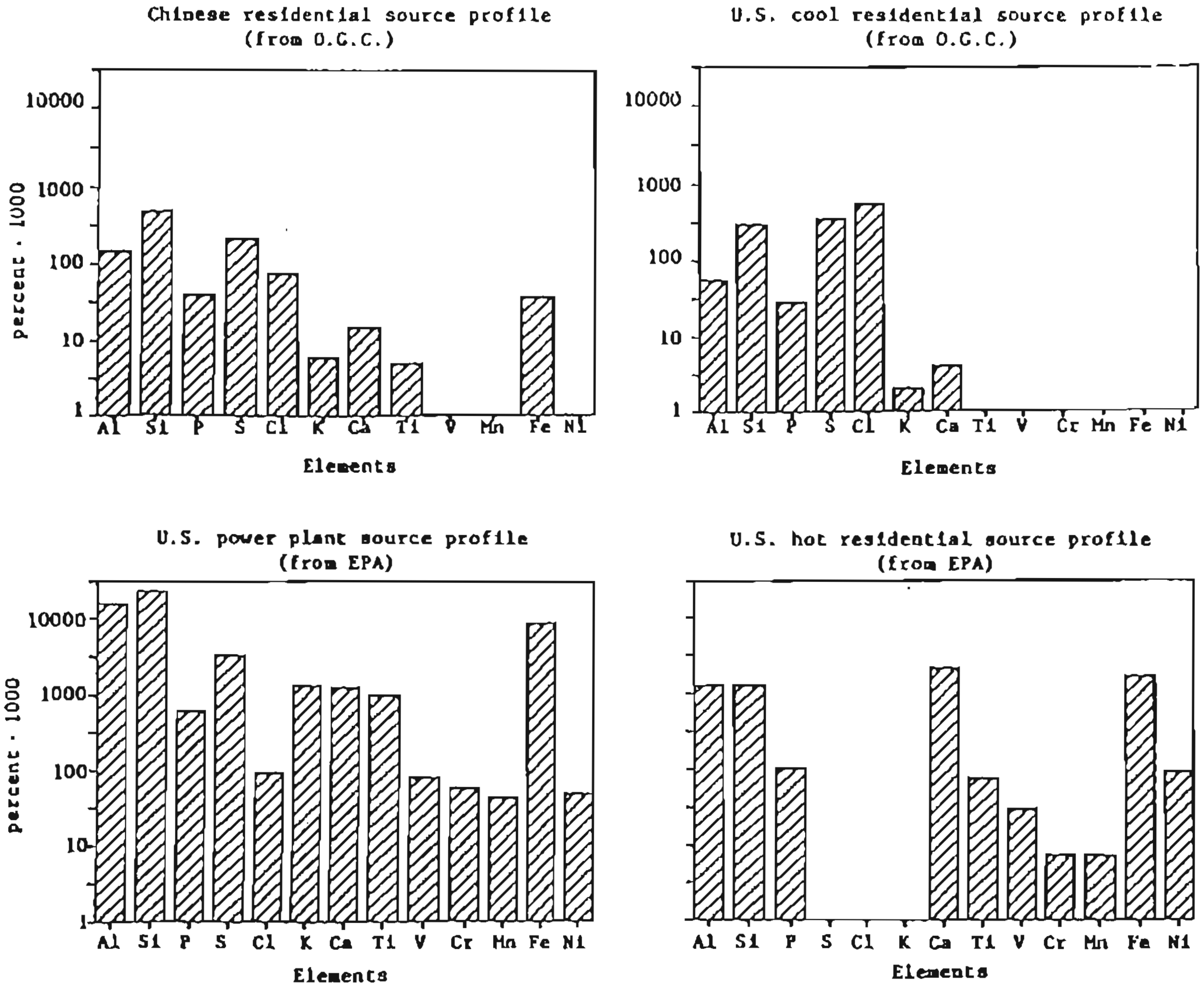


Figure 1-4. Source profiles of different temperature coal burning.

CHAPTER 2.

SAMPLING HANDLING AND THERMAL-OPTICAL CARBON ANALYSIS OF COLLECTED SAMPLES

INTRODUCTION

The ambient sampling sites were located in downtown Beijing. Air samples were collected from May, 1989 until May 1990 every six days at the west site and from April 30 to May 16 at the east site. In addition, a monitoring and analysis system was developed to determine the source fingerprints of different types of coal burning. Filters were analyzed for organic carbon (OC) and elemental carbon (EC) at the Oregon Graduate Institute (OGI) and for elemental composition at the Desert Research Institute (DRI). The process flow diagram is shown in Figure 2-1.

SAMPLING PREPARATION

Each quartz filter was baked in an oven at 1000°C for two hours, and aluminum foil disks were baked at 800°C for two hours. Plastic petri dishes were lined with the baked aluminum foil disks and a baked filter was placed in each dish with forceps. Three quartz filters were stored immediately at below 0°C in the freezer for use as laboratory blanks, and thirty quartz filters were kept with the sample filters for field blanks. Teflon filters were stored in a glove box with controlled humidity and temperature for 48 hours. Each Teflon filter was weighed by a Cahn 25 electrobalance. The Teflon filters were also kept in petri dishes. After collection, the Teflon filters were reweighed, yielding aerosol mass measurements.

SAMPLING STRATEGY

Since combustion-generated particles are concentrated in the fine particle size range (particle diameter less than 2.5 µm), source samples were taken in PM 2.5 size ranges. Air passing the impactor enters a plenum from which the fine aerosol samples were collected. One sampling port was a 2.5 µm impactor followed by one 47mm quartz fiber filter (2500QAT-AP, Pallflex) in series. One other port contained a 2.5 µm impactor followed by a 47 mm Gelman Teflon membrane filter (0.2 µm pore size) which was followed by a quartz fiber filter. Flows were calibrated with a dry test meter before beginning source sampling. Aerosol mass collected on quartz fiber and Teflon filters were measured with the Cahn electrobalance after equibrating at 30% humidity. The quartz fiber filter following the Teflon filter, which essentially removes all particles, measures the amount of organic vapor adsorbed on the quartz fiber front filter in the other port (McDow, 1986). Adsorbed organic vapor on this quartz fiber "back up filter" were measured with thermal-optical carbon analysis and subtracted from the quartz fiber front filter in the parallel sampling port to yield a measurement of organic carbon associated with particulate material. The materials collected on Teflon filters were analyzed for trace element species using X-ray fluorescence at Desert Research Institute (DRI). A total of 137 (83 from ambient sampling, 25 from source sampling, 24 from field blanks and 5 from lab blanks) Teflon filter and 253 quartz fiber filter samples (176 from ambient sampling, 40 from source, 37 from field blanks and 3 from lab blanks) were obtained.

SAMPLING SYSTEM

Figure 2-2 shows a schematic drawing of the sampling system. There were two sampling ports in this system. Particles smaller than 2.5 µm in the flow were drawn into two sampling ports, and the particles were collected by filters following the impactors. Flows for all sampling ports were controlled by a carbon vane pump, two flowmeters, and two flow valves. The sampler was connected to the flow control module downstream of the filters by Tygon tubing and calibrated by a dry test meter.

AMBIENT SAMPLING

The primary ambient site was located in the west center of downtown Beijing, three miles northwest of Tian Anmen square (Figure 2-3). It was a typical residential area surrounded by many old one story houses which were over 100 years old. There were no tall buildings in that area, except a few trees. The site was on the roof of a house which was three meters tall. The house was nearby a small lane, which was used by bicycles but not many trucks or cars. The residents in this area use both liquid gas and honeycomb coal to cook but only coal to heat houses. Liquid gas is popular for cooking purposes, but it's limited by the government to two tanks per month. Thus, some families must also use honeycomb coal to fulfill their cooking needs.

The sampling was carried out from May 20, 1989, to May 20, 1990. One sample was collected every six days. Sampling started at 7 AM or 8 AM since the highest concentration during a day occurs in the morning in Beijing(Su, Wei-han, 1985), and collection lasted three hours in the spring, summer and fall. In the winter, the sampling duration was 2 hours. On one day per month three samples were collected, and sampling periods began at 8 AM, 1 PM and 7 PM. Meteorological data during sampling were provided by a national meteorological station nearby and included temperature, wind speed, azimuth, mixing height and stability class. Visibility during sampling days were also measured.

The other sampling site was located east of downtown Beijing. The sampling methodology was identical to the west site, but meteorological data are only for west site. The second site was chosen to provide a backup.

The average height of inversion layer in the winter was lower than other seasons (Table D-2), which caused heavy air pollution in the winter in Beijing. However, the inversion layer influence will not be discussed further, and the carbonaceous species and source apportionment are researched in this project.

SOURCE SAMPLING

The following sources were sampled:

1. Coal burning sampling:
    - A. Residential heating and cooking
    - B. Coal boiler in industrial plant

The coal used in Beijing can be divided into three types: piece coal, honeycomb coal, and ball coal as described in Chapter 1. Emissions from all three kinds of coal in closed mode (i.e., minimal air) or open mode (i.e.,excess air) were sampled.

2. Sampling different kind of coal ashes.

3. Different kind of coal samples: piece of coal, honeycomb coal, ball coal.

SOURCE SAMPLING METHODS

Residential coal burning samples was taken from smoke plumes that were cooled and diluted by ambient air. When a moderate breeze was blowing, this could be easily accomplished by positioning the sampling system inlet several meters from the stack. This procedure has been used in an extensive series of tests on conventional wood stoves at the Oregon Graduate Institute.

Source samples and ambient samples were taken concurrently, enabling the contribution of ambient aerosol to be subtracted from the source samples. The field samples were identified by: source name, address, date of sampling, source fuel, source operating mode, data validation summary, pollution controls, source sampling, and analytical protocol.

SOURCE SAMPLING SCHEDULE

A. A portable stove with honeycomb coal is used to do source sampling at Xi Chen site in Beijing (Xi-Chen), According to the position of vents: if the vent is totally open, the temperature of honey comb coal burning is hot. The temperature is intermediate if the vent is at halfway position, and the temperature is "cool" if the vent is closed. Three hot and three cool burning samples were selected. B. A portable stove with ball coal was used to do source sampling in Xi Chen. Three hot and cool burning samples were chosen.

C. Manufacturing plants Since we were not able to ship source equipment to Beijing, the same ambient equipment was used here to sample directly from the boiler smokestack. Three industrial coal burning samples were done in a medicine manufactory.

SOIL SAMPLING

Roughly half of the coarse aerosol was contributed by soil dust (Chen Zong-lian and Wang Ming-xing, 1983). thus soil source sampling is very important. Fifty soil samples from the Xi Cheng area in Beijing representative of Beijing soil were collected and mixed.

EXPERIMENTAL PROCEDURE

The chemical species that were measured are: Aerosol Components.

Carbon by thermal optical carbon analysis: elemental carbon (EC) and organic carbon (OC).

Elements by X-Ray fluorescence (XRF): Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Zr, Mo, In, Sb, Ba, Pb.

1. CARBON ANALYSIS

Thermal-optical carbon analysis as shown in Figure 2-4, developed at the Oregon Graduate Institute, measures particulate organic and elemental carbon deposited on quartz fiber filters. Organic carbon is volatilized from the filter sample by heating in an atmosphere of pure helium at temperatures of 450°, 500° and 650°C. The volatilized organic carbon is converted to CO_2 in a 1000°C, MnO_2 oxidation oven. Then it is reduced to CH_4 in a nickel-firebrick methanator and measured by a flame ionization detector. Then the sample is heated in an atmosphere of 10% O2 - 98% He to 450°, 550° and 800°C removing elemental carbon which is also measured as CH_4. To correct for pyrolytic conversion of organic carbon to elemental carbon (charring) which occurs during the organic analysis, the filter reflectance is continuously monitored with a He-Ne laser (633 nm). Pyrolysis causes the filter to darken. The correction is taken to be the amount of elemental carbon oxidation necessary to return the filter reflectance to its initial value before pyrolytic conversion of organic to elemental carbon occurred (Figure 2-5). This determination is based on the following assumptions: 1. elemental carbon is the only component of the sample that affects the optical transmittance, 2. the pyrolytically generated EC and the original EC have the same extinction coefficient, 3. the pyrolytically generated EC is removed first (Turpin, 1989). To achieve an accurate pyrolysis correction, it is necessary to align the FID and reflectance signals. This is accomplished by measuring the time between sample insertion and FID response for clean filter punches doped with sucrose (Turpin, 1989).

The valve switching and temperature control sequences, measurements of temperature, laser, FID signals, and output were all accomplished by an Apple IIe computer equipped with a Sunset Laboratories I/O board and a Grappler printer card (Figure 2-3).

The full temperature program was used to analyze the front quartz samples in order to distinguish the split point between OC and EC. A shorter temperature program can be run on the backup filter for total OC since there was no EC on it.

The thermal-optical carbon analysis used in this project was rebuilt in order to keep the accuracy.

A. QUALITY ASSURANCE

Three or more instrument blank punches from lab blank filters were run each day of operation. The instrument blanks should be subtracted by measured carbon mass basis. The calibration of the instrument with external standards was accomplished with known amounts of sucrose (Table 2-1).

During Sep. 1990, an interlaboratory comparison was conducted between KEYSTONE/NEA, Inc. and the OGI covering organic carbon TC, EC, and OC. The comparison study involved the exchange of ten quartz filter samples. Table 2 shows the data from this interlaboratory study. OGI lab precision expressed as relative percent difference of duplicate measurements (RPDDM) was OC (7%), EC (12%), and TC (4%). KEYSTONE/NEA method precision for the carbon analyzer was OC (6%), EC (21%), and TC (8%). OGI demonstrated less internal variability on elemental carbon analysis than KEYSTONE/NEA (Table 2-2).

Twenty four long and short blank field samples analyses were run using three punches. Those data were subtracted from the sample carbon data.

OGI Thermal-Optical carbon analysis precision for this project analysis were OC (7%), EC (9%), and TC (3%).

2. X-RAY FLUORESCENCE

X-ray fluorescence (XRF) analysis of filters were conducted at DRI. Dr. John Watson and Dr. Judith C. Chow graciously offered us free analyses.

XRF is an ideal tool for air pollution research because of its low detection limits, simultaneous multi-element determination capability and non-destructive treatment of samples. The XRF-ray tube with a metal anode generates X-rays which can be filtered or focused on a secondary target to produce nearly monochromatic radiation. Atoms in the sample are excited from their ground state to higher energy levels. As the atoms return to their ground state energy levels, they emit characteristic X-rays which are used to identify the element. The number of observed x-rays is proportional to the number of atoms. This is used to quantitatively determine a specific element's concentration through a direct comparison with standards (Watson, 1979).

Table 2-1. The external standards for OC and EC analysis of Beijing's samples.

DATA ANALYSIS	INJECTED mg (a)	MEASURED mg (b)	MEASURED- INS. BLAN(c)	RATIO a/c
89111502	24.95	24.36	24.41	1.02
89111602	24.95	25.64	25.69	0.97
90031403	25.05	24.48	24.53	1.02
90031503	25.05	24.98	25.03	1
90031802	25.05	23.76	23.81	1.05
90031903	25.05	25.88	25.46	0.98
90032602	25.05	25.22	25.27	0.99
AVG				1
90062505	25.05	24.69	24.74	1.01
90080904	25.05	25.46	25.39	0.98
90081009	25.05	24.88	24.93	1.01
90081306	25.05	25.393	25.44	0.98
90090503	25.05	25.47	25.37	0.99
90090603	25.05	24.99		1
AVG				1
90081402	25.05	25.9	25.84	0.97
90081502	25.05	25.45	25.43	0.99
90081703	25.05	25.31	25.35	0.99
90090703	25.05	24.95	24.89	1.01
AVG				0.99
90091302	25.05	25.553	25.557	0.98
90091403	25.05	25.55	25.556	0.98
90091603	25.05	25.236	25.24	0.99
90091803	25.05	25.37	25.373	0.99
90091903	25.05	25.165	25.169	1
AVG				0.99

Table 2-2. The external standards for TC measurement.

	EXTERNAL STANDARDS(mg)			
DATA ANALYSIS	INJECTED µg (a)	MEASURED µg (b)	MEASURED- INS. BLAN(c)	RATIO a/c
89110802	24.95	24.46	25.28	1.01
89110902	24.95	24.72	25.55	1.02
89111004	24.95	24.85	24.86	1
89111202	24.95	24.41	24.48	1.02
90032004	15.03	15.1	15.17	0.99
90032102	15.03	15.08	15.15	0.99
90032004	15.03	14.944	15.02	1
AVG				1
90082103	25.05	24.81	24.84	1.01
90082201	25.05	24.97	25	1
90082808	25.05	24.76	24.79	1.01
90082907	25.05	25.07	25.1	1
AVG				1.01
90083002	25.05	24.84	25.09	1
90083103	25.05	25.02	25	1
AVG				1

Table 2-3. OC/EC interlaboratory comparison between NEA and OGI.

	SAMPLE NUMBER	NEA	OGI	RELATIVE PERCENT DIFFERENC
OC	Z1869	12.2	11.1	9.5
	Z1871	10	9	10.5
	Z1973	11.2	12.9	14.2
	Z1875	14.6	13.8	5.6
	Z1877	7.2	9.8	30.6
	Z1879	12.5	12.8	2.4
	Z1881	11.8	12.9	8.9
	Z1883	10.4	10	3.9
	Z1885	11	11	0
	Z1887	7.4	7.4	0
EC	Z1869	2.1	2.1	0
	Z1871	1.2	1.1	8.7
	Z1873	1.6	1.3	20.7
	Z1875	2.5	2.8	11.3
	Z1877	1.3	1.6	20.7
	Z1879	2.4	2.9	18.9
	Z1881	2.8	2.9	3.5
	Z1883	1.4	1.3	7.4
	Z1885	2.2	2	9.5
	Z1887	1.9	1.9	0
TC	Z1869	14.2	13.3	6.5
	Z1871	11.2	10.2	9.3
	Z1873	12.7	14.1	10.4
	Z1875	16.9	16.6	1.8
	Z1877	8.4	11.4	30.3
	Z1879	14.9	15.6	4.6
	Z1881	14.6	15.8	7.9
	Z1883	11.6	11.3	2.6
	Z1885	13	12.9	0.8
	Z1887	9.3	9.3	0

Springfinger, J. 1990.

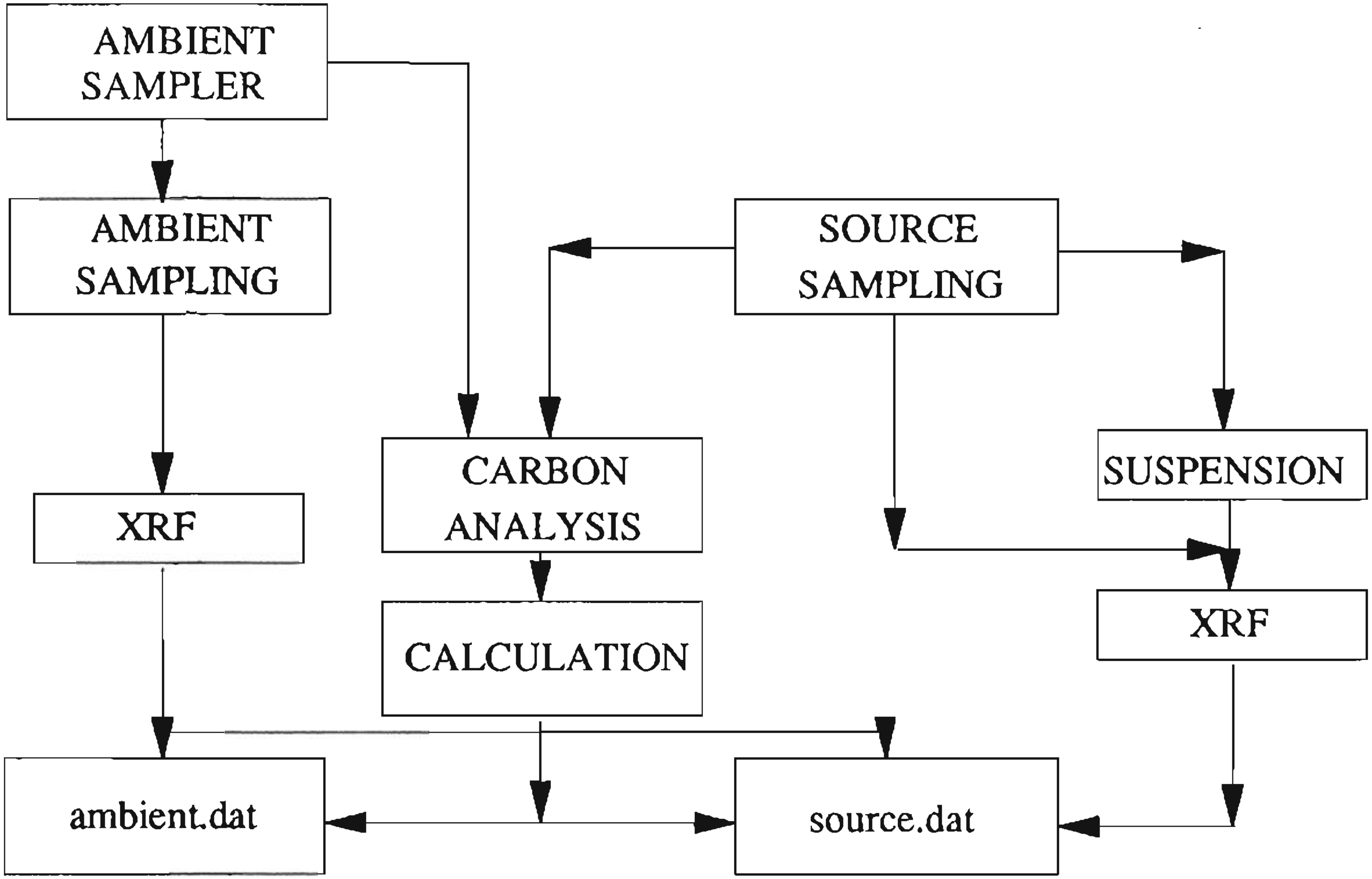


Figure 2-1. The flow diagram of the ambient and source sampling and analysis process.

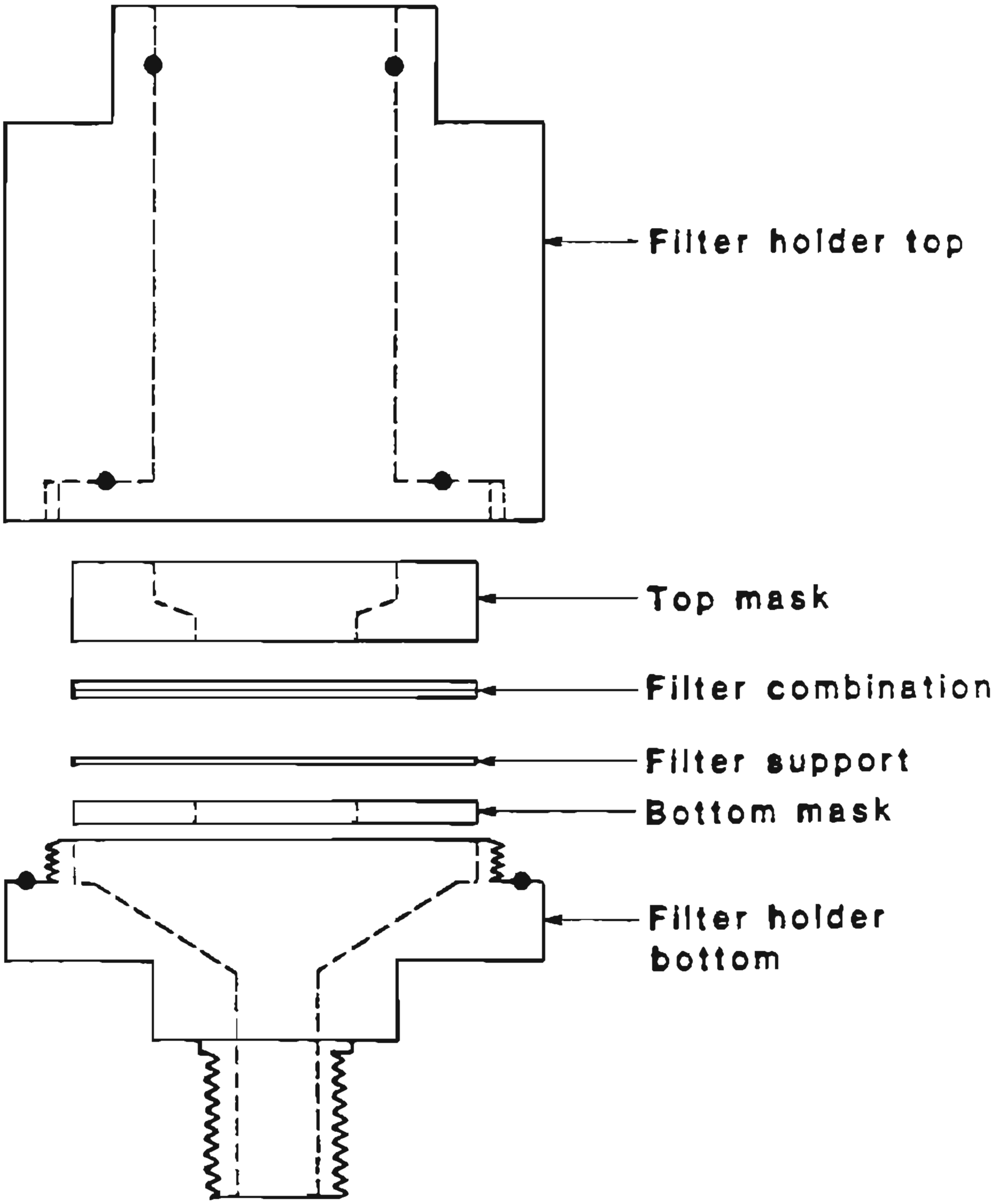


Figure 2-2. Aerosol fiber holder with annular masks used in Beijing's project. (McDow, 1984)

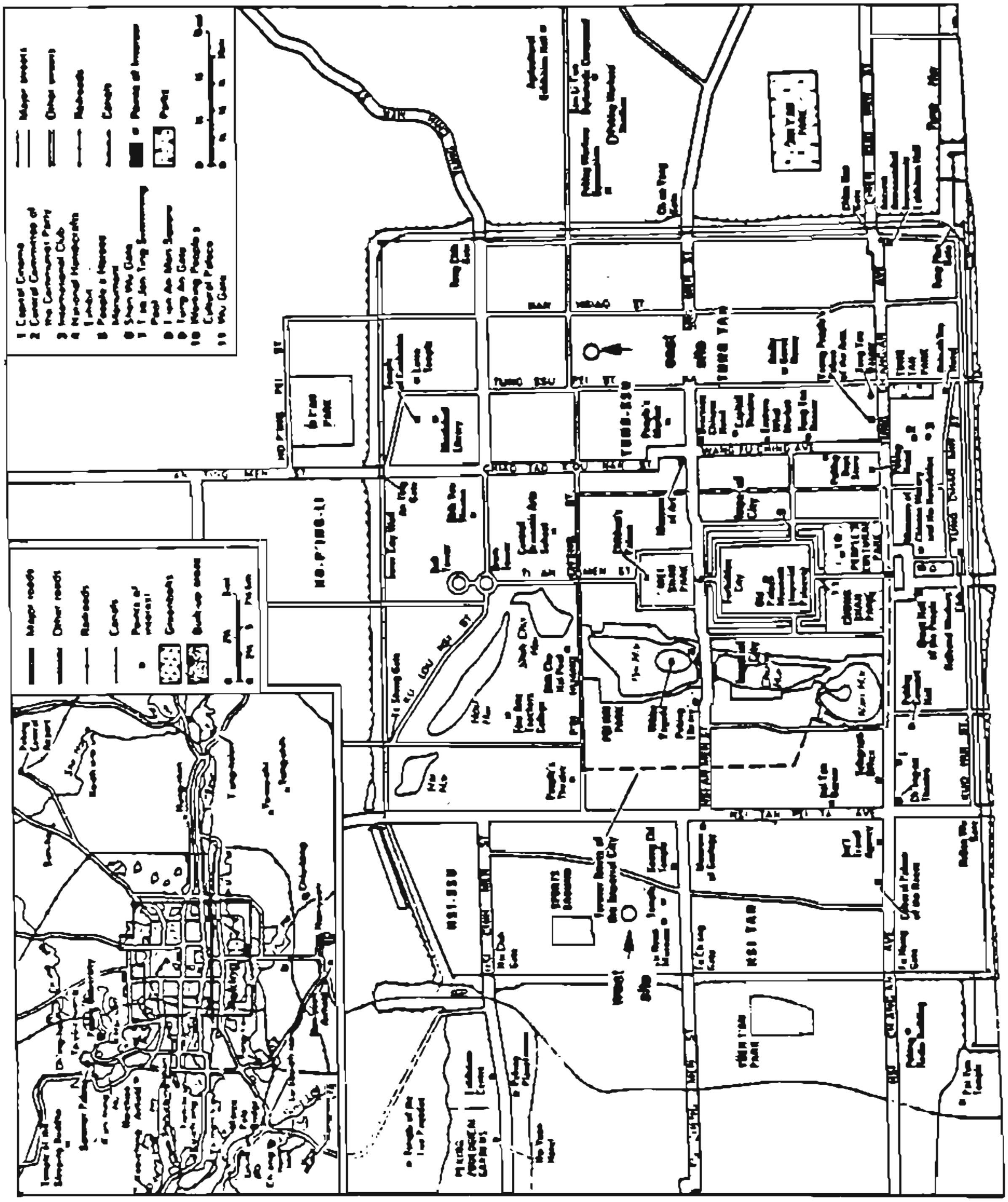


Figure 2-3. Beijing geographic map.

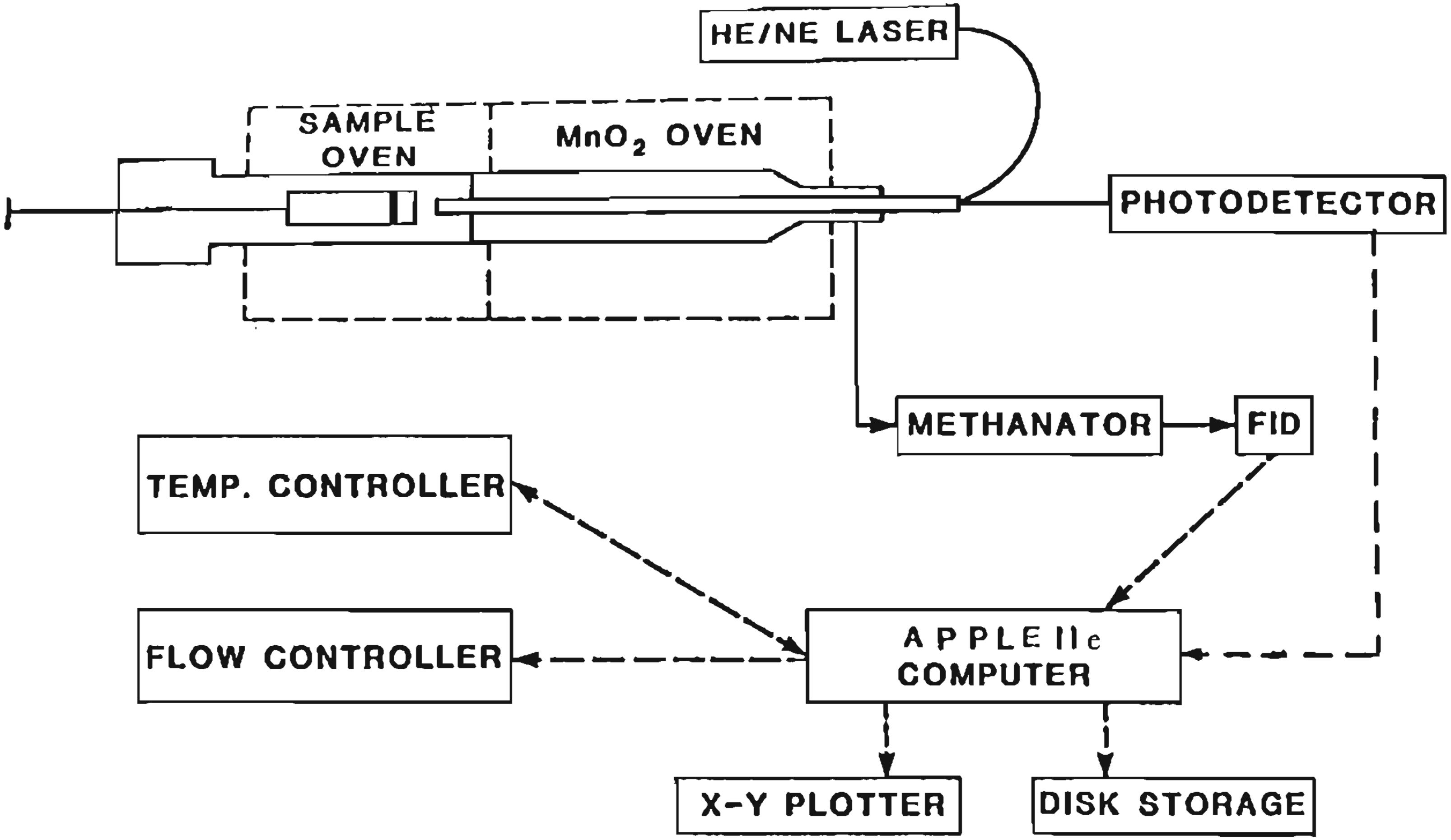


Figure 2-4. Thermo-optical carbon analysis system (Rau, 1986).

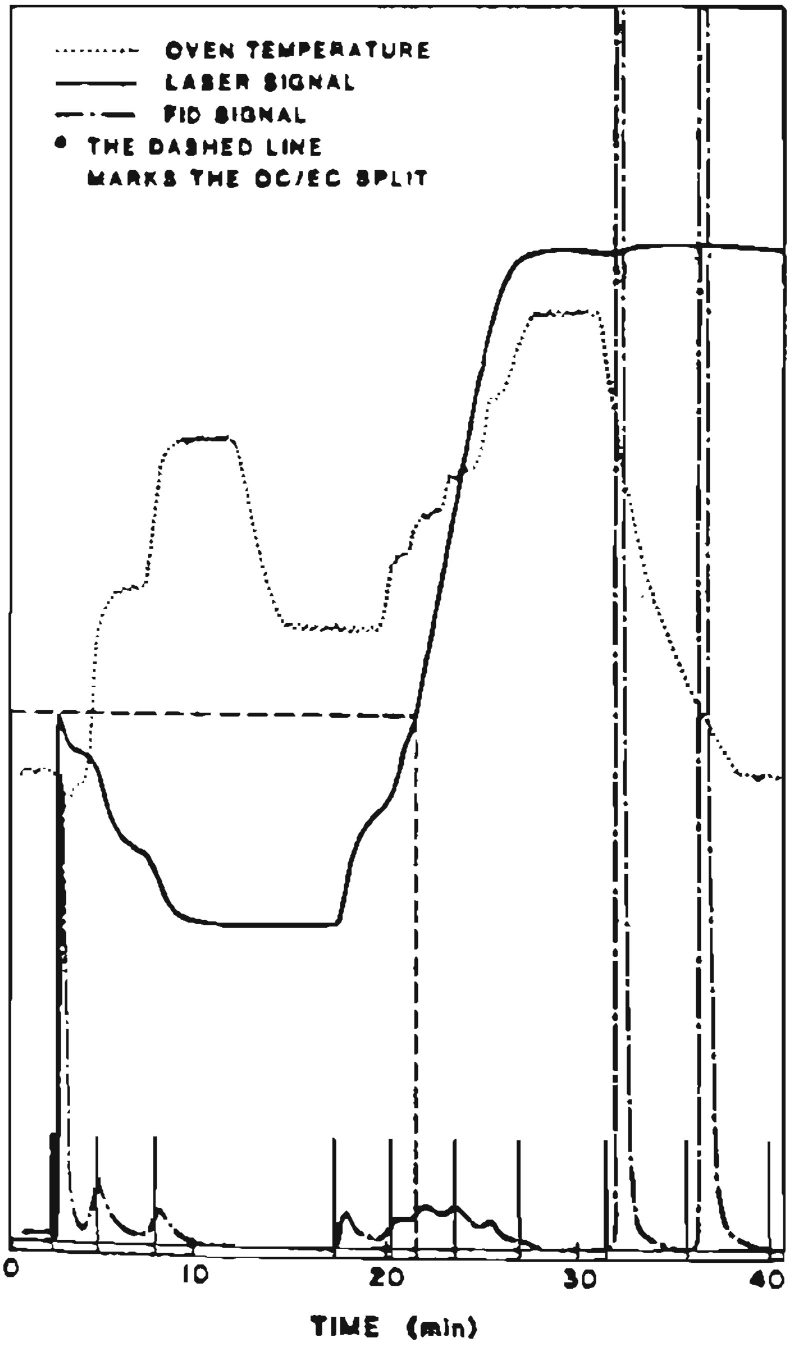


Figure 2-5. typical output for laboratory thermal-optical carbon analyzer. Oven temperature, optical reflectance, and flame ionization detector. The dashed line at about 21.3 minutes is the split point between organic and elemental carbon (Turpin, 1989).

CHAPTER 3

THE COMPARISON OF HONEYCOMB COAL, BALL COAL AND PIECE COAL

INTRODUCTION

The coal used in Beijing can be divided into three types: piece coal, honeycomb coal, and ball coal. 95% of residential coal consumption is honeycomb and ball coal, and honeycomb coal is about 64% of total residential coal consumption.

Piece coal is mined coal which is later broken into convenient sized pieces and treated in coal shops to reduce the sulfur content. Honeycomb coal is made up of 90% powdered coal, clay, less than 5% wood powder and other ingredients, and pressed into a cylinder with many holes from top to bottom. Ball coal is similar to honeycomb coal, but it shaped like a flattened ball.

During the heating season, the honeycomb coal housestove is burned continually 3/4 of the 24 hour day in closed-vent mode and 1/4 of the time in open-vent mode. It is therefore important to compare the source profiles of closed-vent stove emissions and open-vent stove emissions.

$PM_{2.5}$ smoke samples were collected when vents were in both the closed mode and open mode for honeycomb and ball coal housestove respectively, and industrial coal burning smoke was also sampled. All smoke samples as well as ash and coal were analyzed by thermal-optical carbon analysis and X-ray fluorescence. The source profiles of honeycomb and ball coal were compared with piece coal including their smoke, ash and the coal in order to have better idea about coal usage strategies in the future.

BACKGROUND

A new type of coal for industrial usage called the third coal generation is being researched in Chinese Mineral University now (Hu, Zhi-jian, 1991). It was reported by People's Daily May 15, 1991 that the new industrial coal which is a composite of briquette-like honeycomb and ball coal with different ingredients can be burned without smoke, and total suspended particulate (TSP) in the smoke of the coal burning can be decreased by 70%-80%, and SO_2 and NO_x by 50% respectively. Therefore, six factories have been built up for new coal production and the total annual output is 470 thousand tons in China now. The different kinds of new coal char can be used for steel industrial, coal boilers and residential heating respectively.

There was a project researching top-fired and bottom-fired of new type of coal in China which found that emissions of PAH from char of up type of burning are reduced by 17 to 18 times relative to bottom-fired burning. But even bottom-fired type of burning of coal emitted 15-20% less PAH than piece coal (Zhang Yueying, 1990).

In Great Britain two commercial processes are used for producing smokeless fuels by low temperature carbonization (Schobert, 1987).

In the homefire process, high-volatile bituminous coal is crushed to 6 mm particles and devolatilized for 20 minutes at 800 degrees Fahrenheit in a fluid-bed reactor. This relatively quick carbonization reduces the volatile matter content of the coal to about 20%. The hot char is fed directly to a hydraulic press, where it is formed into briquettes that are a premium-grade domestic fuel.

The Phurnacite process starts with fines of low-volatile bituminous coal blended with pitch and formed into briquettes. The briquettes are then carbonized for about 4 hours at 1400 degrees Fahrenheit. The tars and gases are recovered, similar to their recovery in a coke oven. The solid product consists of strong, hard briquettes that make excellent domestic furnace fuel.

The difference between British briquettes and Chinese briquettes is that the British coal briquettes are produced by low-temperature carbonization to reduce the volatile matter content, while the Chinese new type of coals are a mixture with coal, clay, and ingredients to react with the pollutants in order to reduce the pollutants of coal burning emission. There are different recipes for different new type of coal, which are used for different purposes such as steel, industrial, boilers and residential heating. It's very possible that the Chinese new types of coal are much cheaper than the Britain coal briquettes since their manufacture consumed less energy.

EXPERIMENTAL

The three different kind of coal and their ash were sampled based on the established grid-like transect at Xi-chen district in Beijing. Bulk samples were resuspended by Keystone/NEA lab and analyzed at DRI. The carbon contents of samples were analyzed at OGI using Optical thermal carbon analysis.

The methods of sampling honeycomb and ball coal smoke were discussed in Chapter 2. The industrial source sampling was conducted with the ambient samplers introduced in Chapter 2 at a Beijing medicine factory.

THE COMPARISON OF HONEYCOMB COAL IN CLOSED AND OPEN MODES

The elemental source profile of honeycomb coal smoke in closed-vent mode (Figure 3-1) is compared with that in open-vent mode (Figure 3-3). The emission factors of Cl and Se in closed-vent mode were significantly greater than in open mode. But the emission factors of other elements in open mode were higher than in closed mode. The OC in open mode was 40%, as opposed to 1% in closed mode since insufficient combustion, and elemental carbon (EC) for open modes was 4.7% vs. 3% in closed mode. The same situation exists in the comparison of open mode and closed mode burning of ball coal. The profile change is caused by temperature difference; based on Su Ge's (1988) experiment, the compositions of coal burning emissions is strongly dependent on burn temperature.

THE COMPARISON OF HONEYCOMB AND BALL COAL COMPOSITION

The source profiles of coals, ash, open-vent burning, and closed-vent burning of honeycomb and ball coal were compared as follows:

The elemental profiles of honeycomb coal and ball coal are very similar (Figure 3-9 and Figure 3-10), except that the OC content of ball coal was 15%, while for honeycomb coal it was 5%.

The ash profiles for honeycomb and ball coal are very similar (Figure 3-6 and Figure 3-7). However, the EC component for honeycomb coal ash was only 0.02%, while for ball coal it was 5.14%, which means that honeycomb coal burns more efficiently than ball coal. The difference between honeycomb and ball coal are the shape, which causes one kind of coal to burn more efficiently and the other less efficiently.

The open-vent honeycomb burning profile was similar to the open-vent ball coal profile (Figure 3-3 and Figure 3-4). However, ball coal burning emitted more Cl, while honeycomb produced more OC.

There are big differences between closed-vent honeycomb and ball coal closed-vent burning (Figure 3-1 and Figure 3-2). Honeycomb closed-vent emissions did not contain Mn, Ni, Cu, and Zn but did contain As. Furthermore, all those elements were present in ball coal closed-mode emissions, except for As. The emission factors of Se and Pb for ball coal closed-mode emissions were smaller than honeycomb coal closed-mode and the Cl factor was the same. Other than that, the rest of the elemental emission factors for ball coal closed-mode burning were all larger than honeycomb burning closed-mode burning.

The source profiles of coals, ash, and open-vent burning of honeycomb and ball coal are very similar. But there is big difference between closed-vent burning of honeycomb and ball coal, which means that the cool combustion with insufficient air which is common in China is a kind of complex burning. The EC content difference between honeycomb coal ash and ball coal ash indicates that shape might be an important factor for clean burning and energy saving.

THE COMPARISON BETWEEN INDUSTRIAL AND HONEYCOMB OPEN-MODE BURNING

Honeycomb and ball coals have been used in China for a long time. The new types of coal are designed for industrial usage, although the honeycomb and ball coal are only used for residences. The goal of comparison between industrial and honeycomb open-mode burning which is very common in China is to research clean and cheap fuel and provide a method for new fuel analysis.

Because honeycomb coal usage is much more prevalent than ball coal usage and honeycomb coal profiles are similar to ball coal, honeycomb source profiles were chosen to represent ball coal and compare with piece coal, which is widely used in Chinese industry.

There was less S content (0.26%) in honeycomb coal emission than in piece coal emission (0.6%). There was no Cl present in honeycomb coal emission, although Cl was present in piece coal emissions. The OC content in honeycomb coal itself was 5%, while in piece coal itself the OC content was much higher. (Figure 3-9 and Figure 3-11). Similar conclusions can be drawn from the comparison between ball coal and piece coal (Figure 3-10 and Figure 3-11).

There was no Cl and less S (0.38%) in the honeycomb coal ash profile , while in the industrial coal ash the S content was 0.44% and Cl was present (Figure 3-6 and Figure 3-8). There was 17% EC in piece coal ash and only 0.02% EC in honeycomb coal ash. The sulfate content of ball coal ash is also less than piece coal ash (Figure 3-7 and Figure 3-8).

The emission factors of industrial coal are less in S, Cl, As, Se, Zn, Pb, K, and OC than that of honeycomb coal in open mode. For some of elements like Al, Si, P, Ca, Ti, Mn, Fe, and Cu, the emission factors of honeycomb coal are less than that in piece coal (Figure 3-3 and Figure 3-5). The elements of Ni, Sr, and Ba exist in piece coal but not in honeycomb coal.

Honeycomb and ball coal and their ashes show less sulfate, chloride and much less EC content than piece coal and piece coal's ash.

CONCLUSIONS

The major conclusions to be drawn from above comparisons are as follows:

- For open-vent burning the source profiles of honeycomb and ball coal are very similar; it is even similar for both coal and ash comparison. For closed-vent burning honeycomb and ball coals have very different source profiles. So the honeycomb closed-vent burning, which is insufficient combustion, but very common in China, is a important source to be studied.
- The elemental carbon (EC) content of honeycomb coal open-vent burning and its ash are much less than that of ball coal. Thus, the coal shape might be an important factor for coal pollution control and energy saving.
- Honeycomb and ball coal and their ashes show less sulfate, chloride and much less

EC content than piece coal and piece coal's ash. So the new types of coal research may be important for new clean and cheap fuel research in the future.

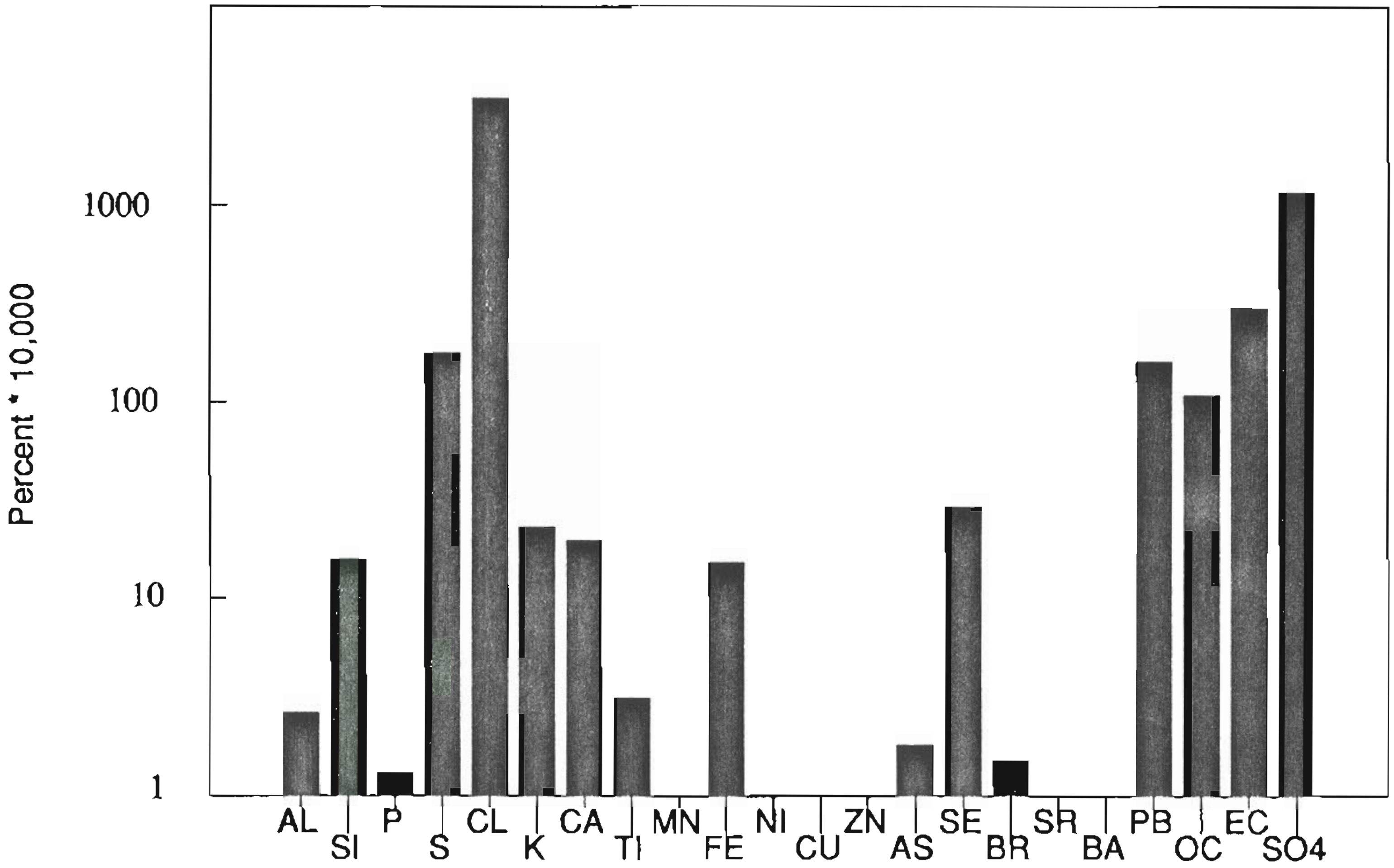


Figure 3-1. Honeycomb coal burning profile when closed mode.

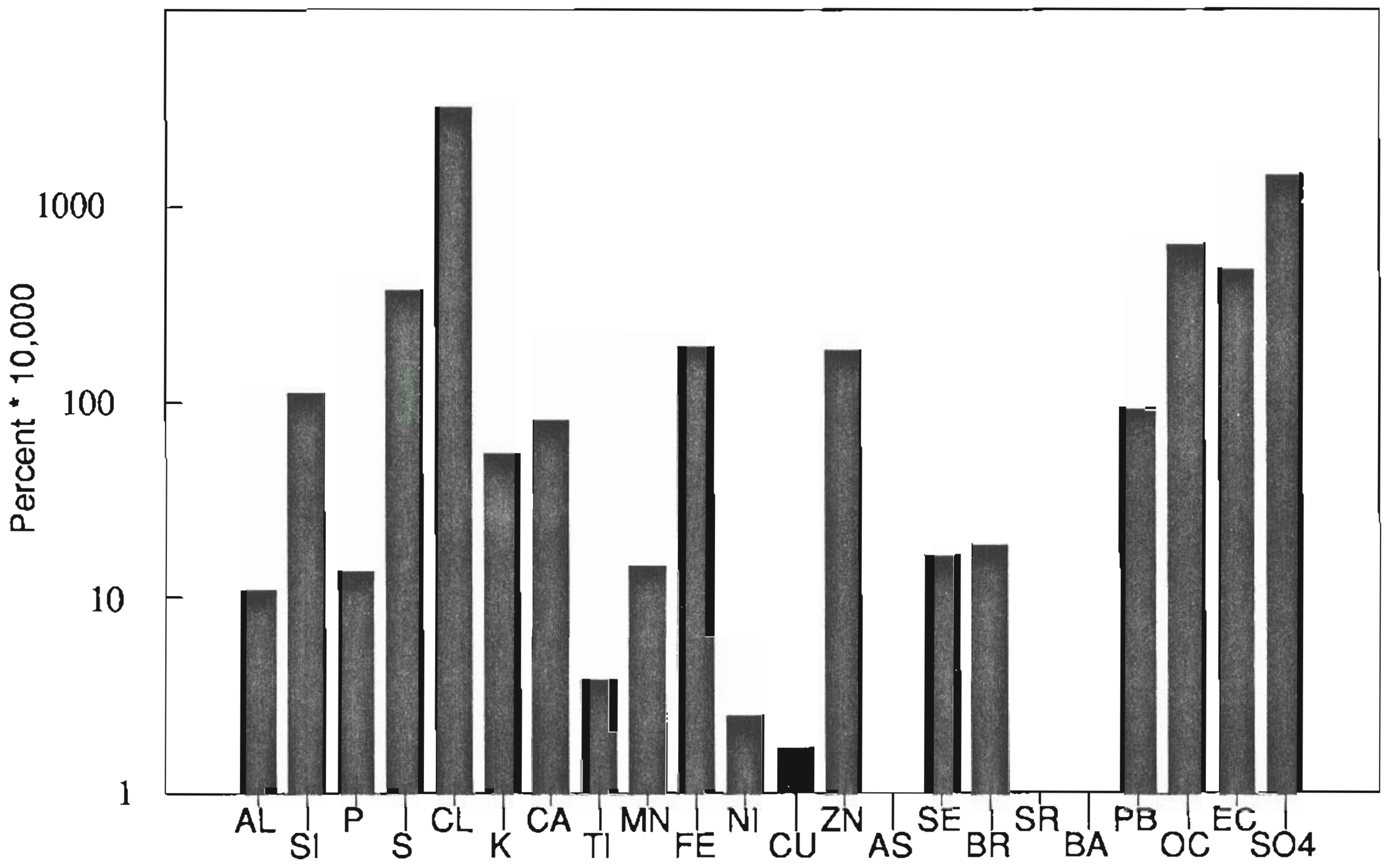


Figure 3-2. Ball coal burning profile when closed mode.

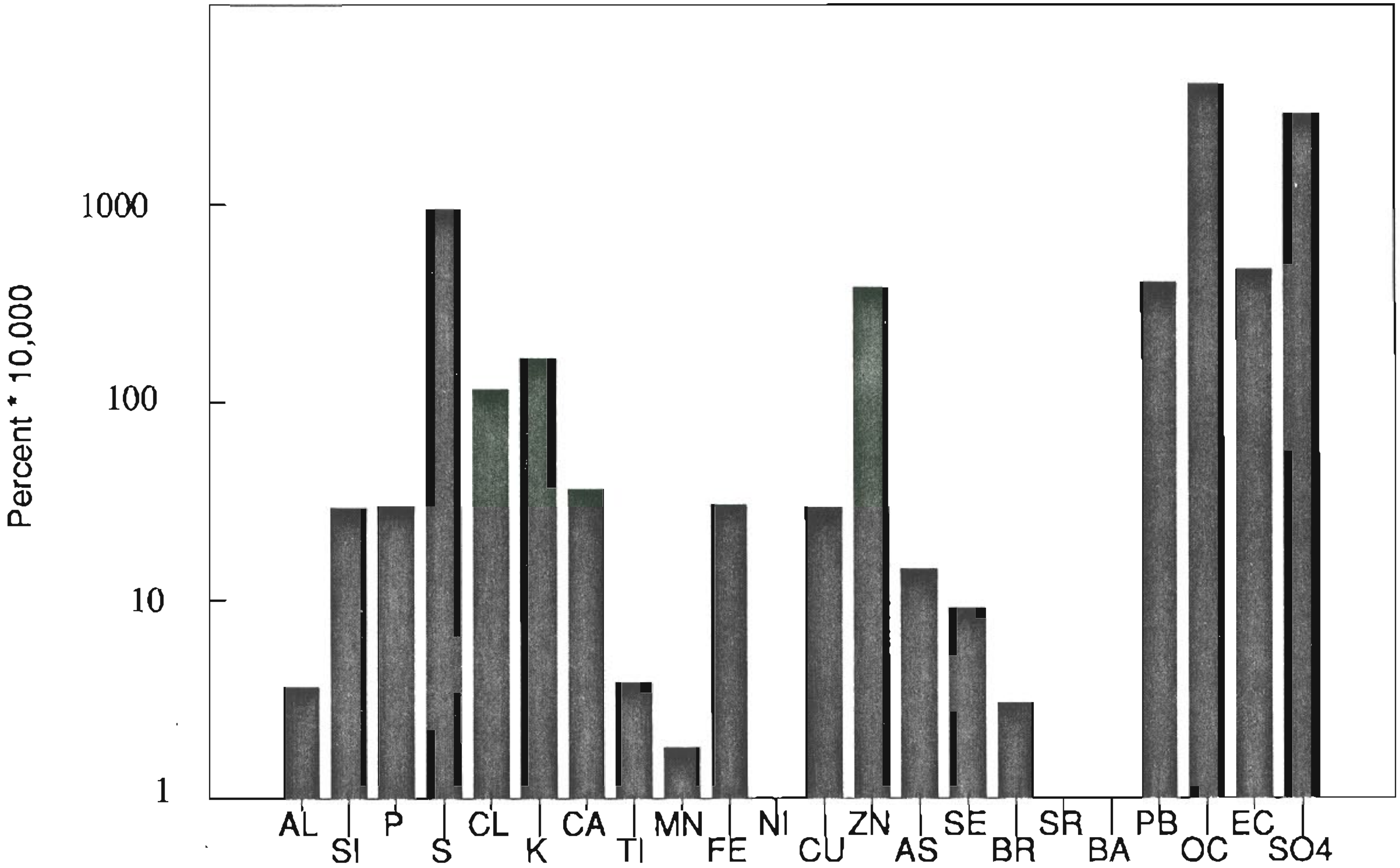


Figure 3-3. Honeycomb coal burning profile when open mode.

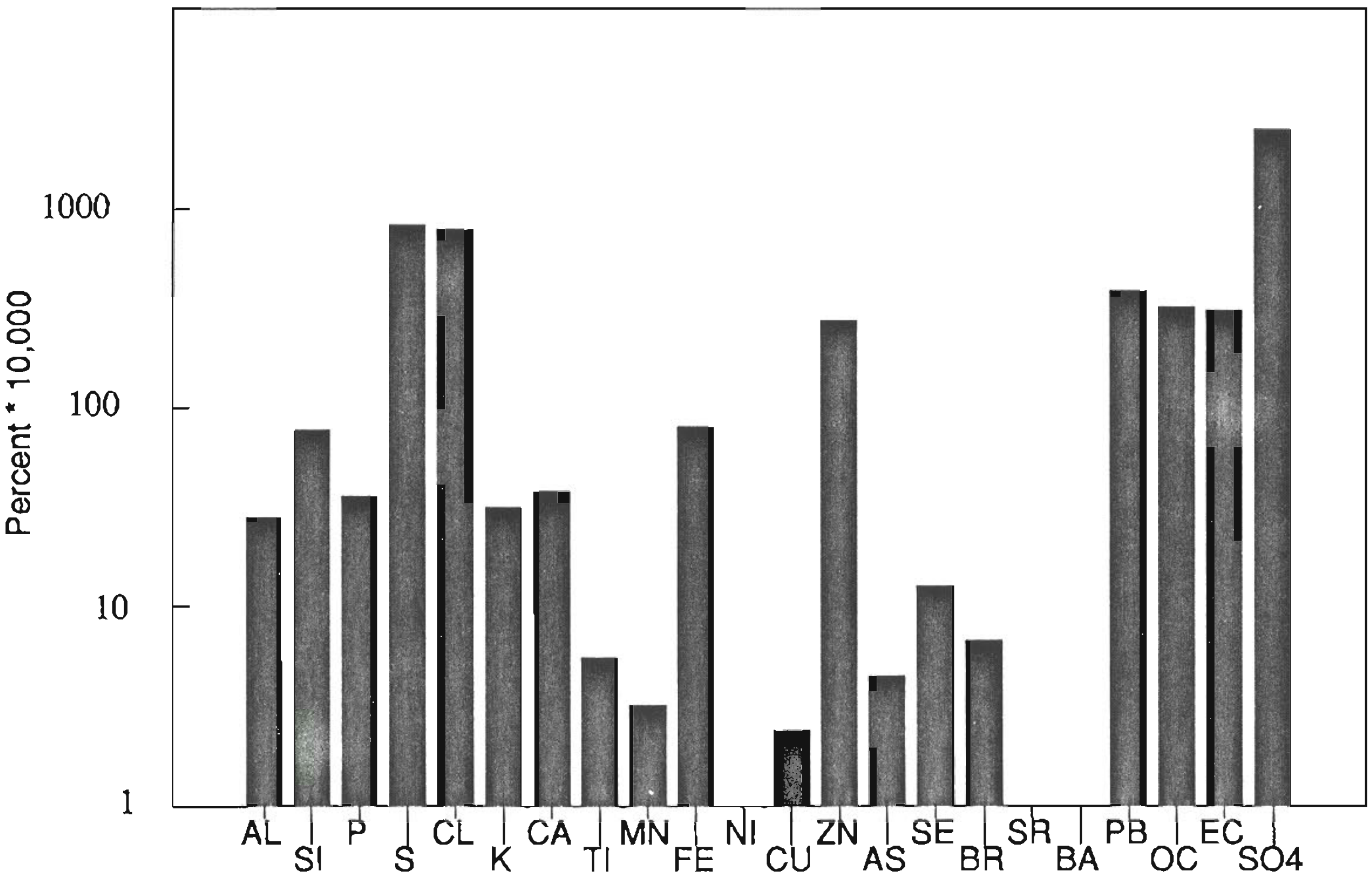


Figure 3-4. Ball coal burning profile when open mode.

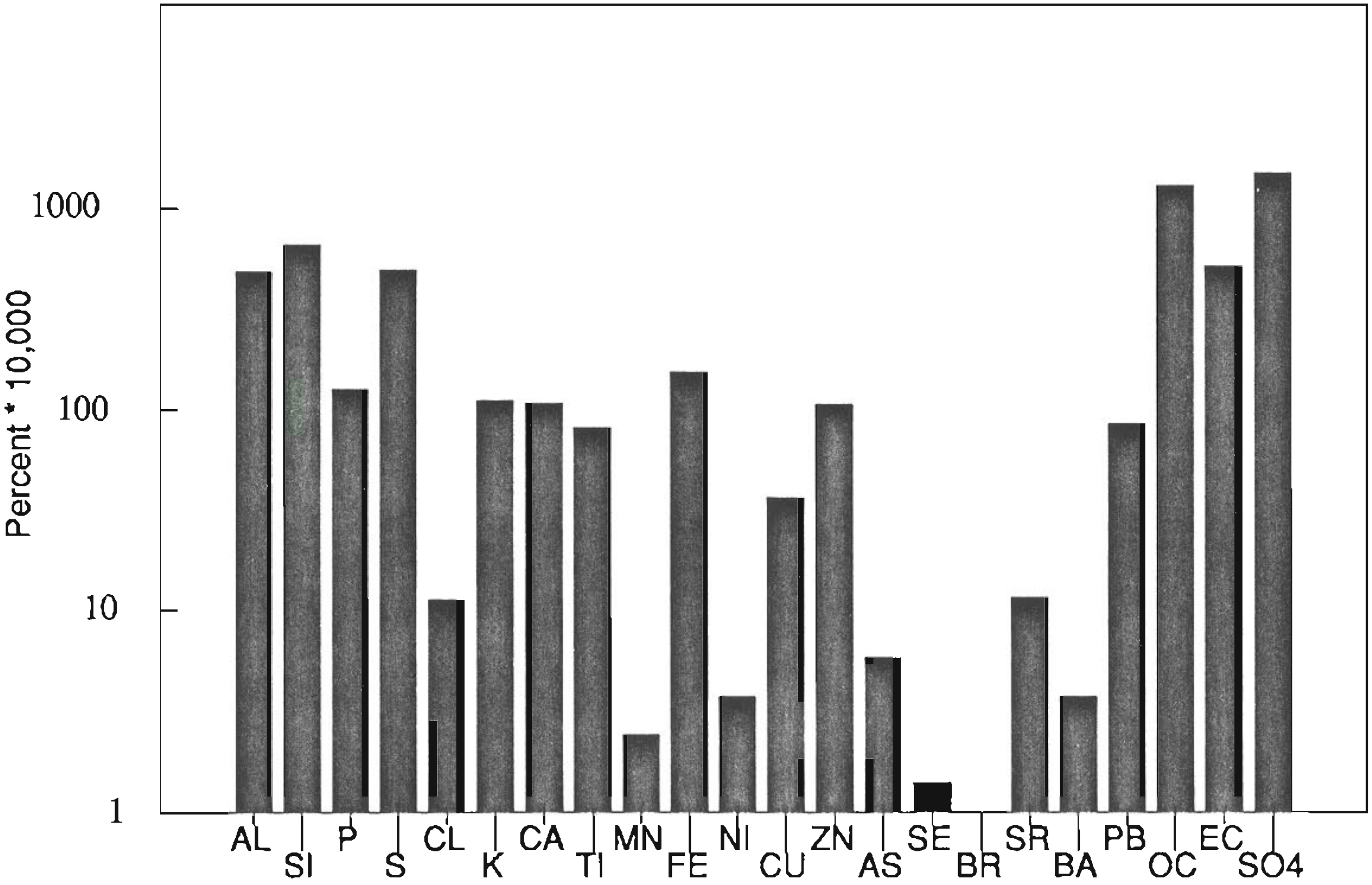


Figure 3-5. Industrial coal burning source profile.

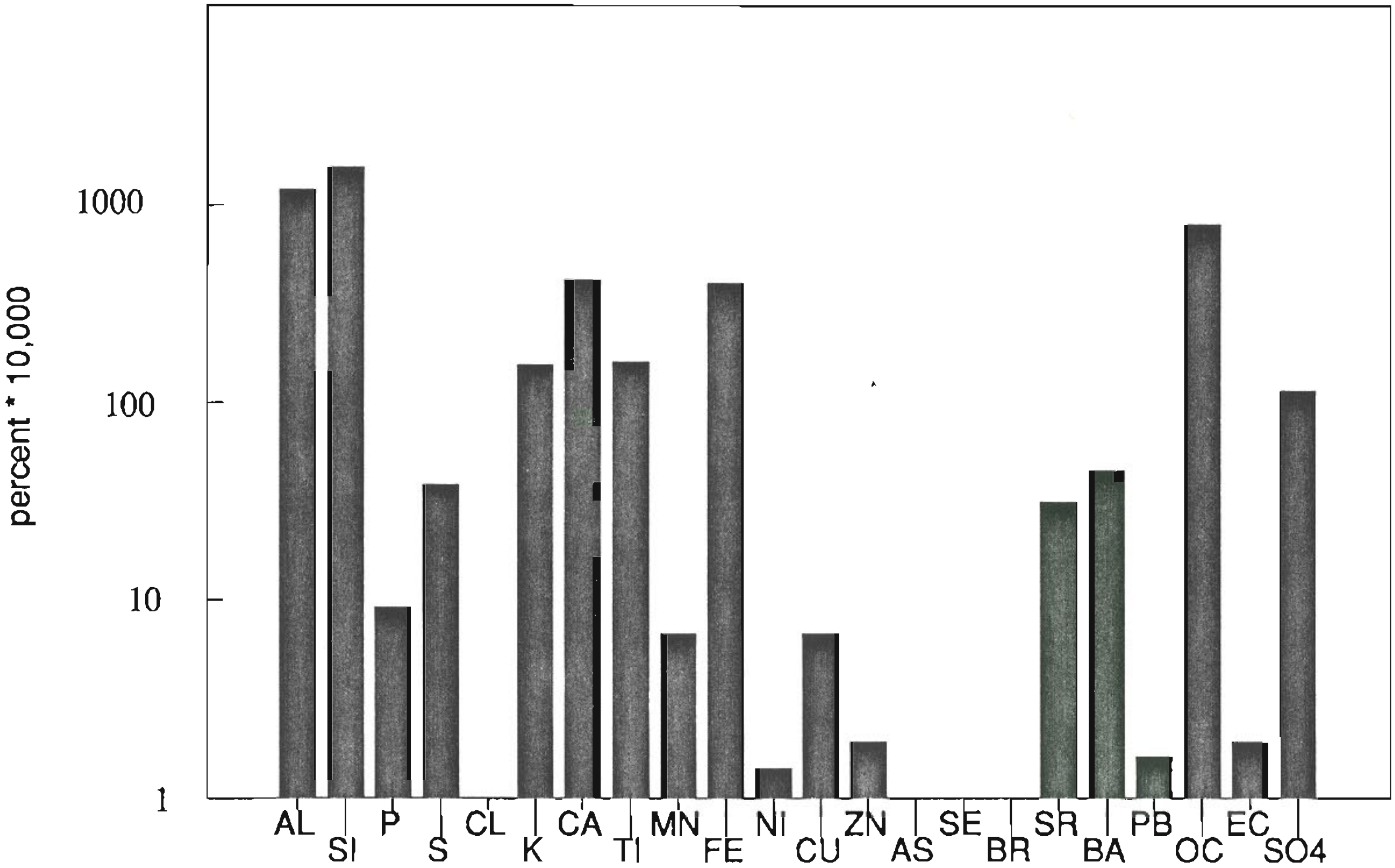


Figure 3-6. Honeycomb coal ash source profile.

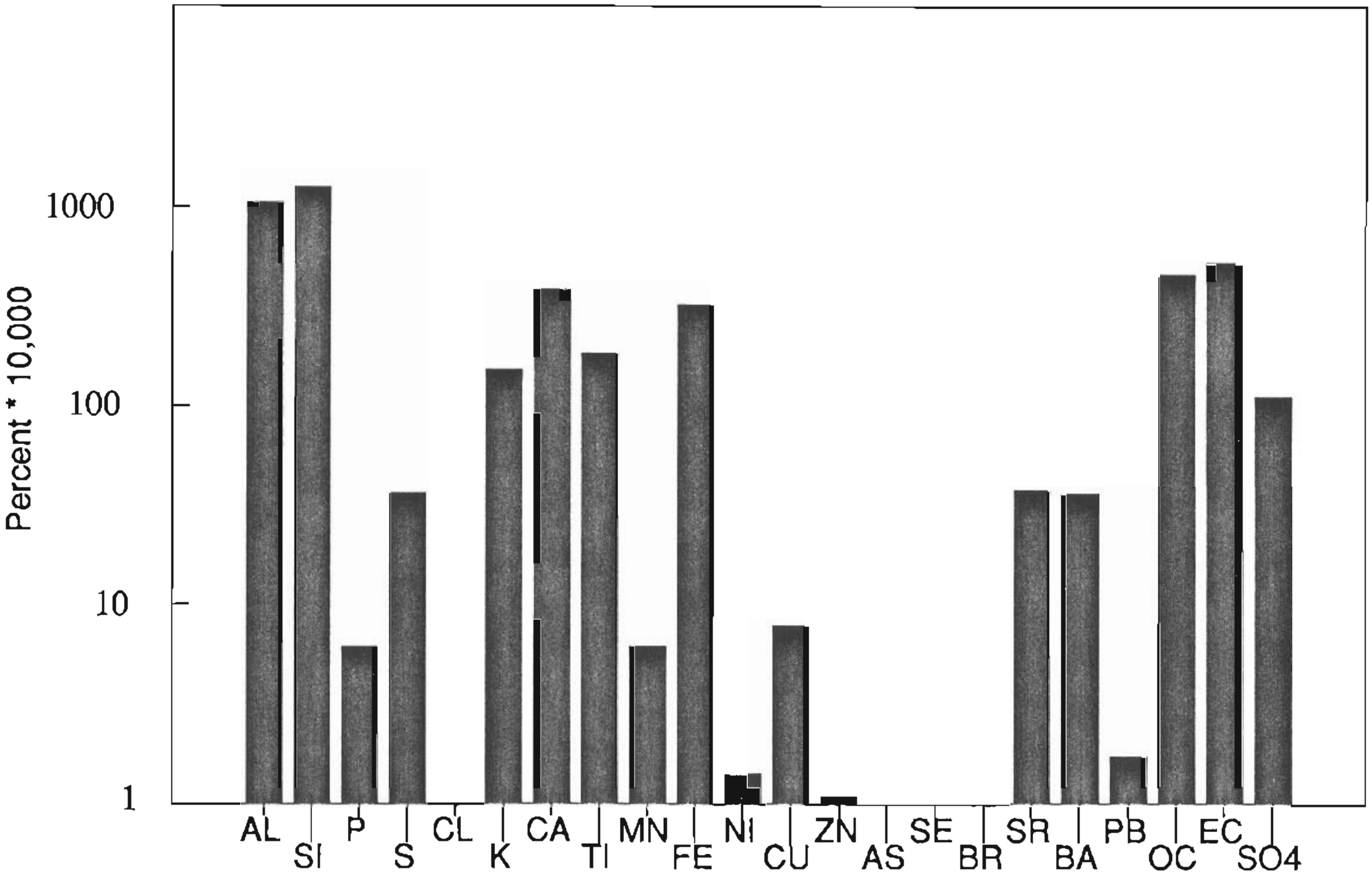


Figure 3-7. Ball coal ash source profile.

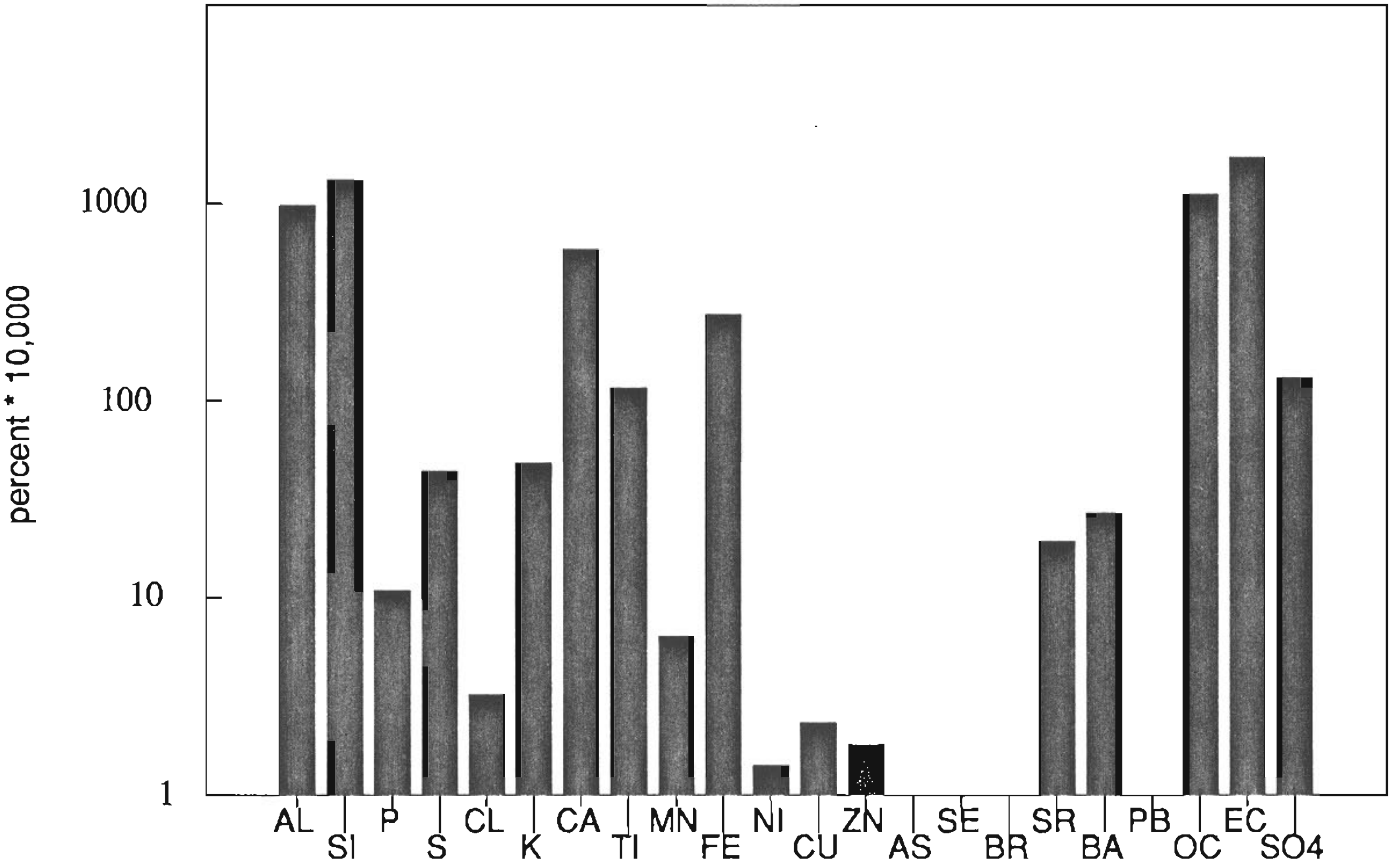


Figure 3-8. Industrial coal ash source profile.

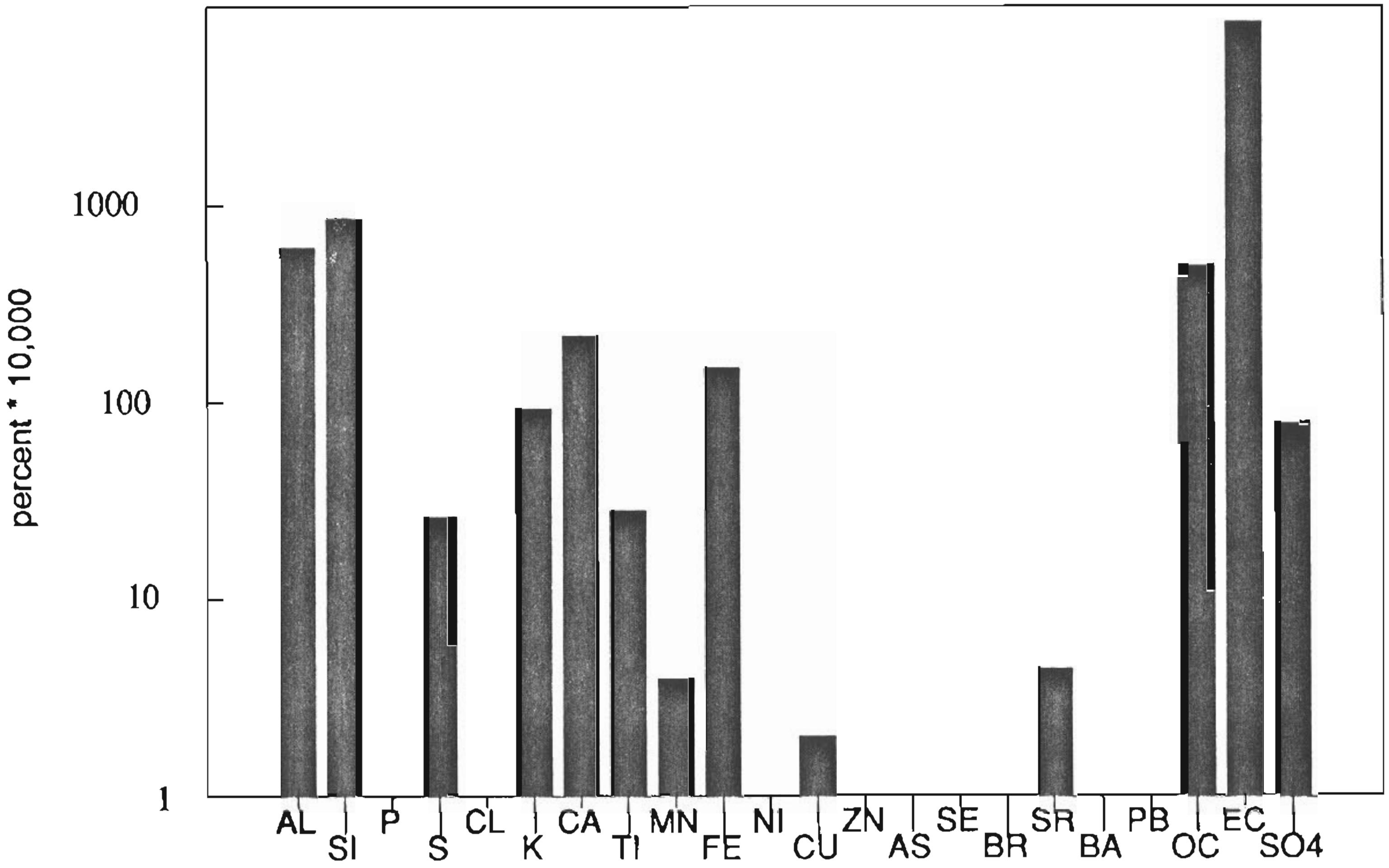


Figure 3-9. Honeycomb coal elemental profile.

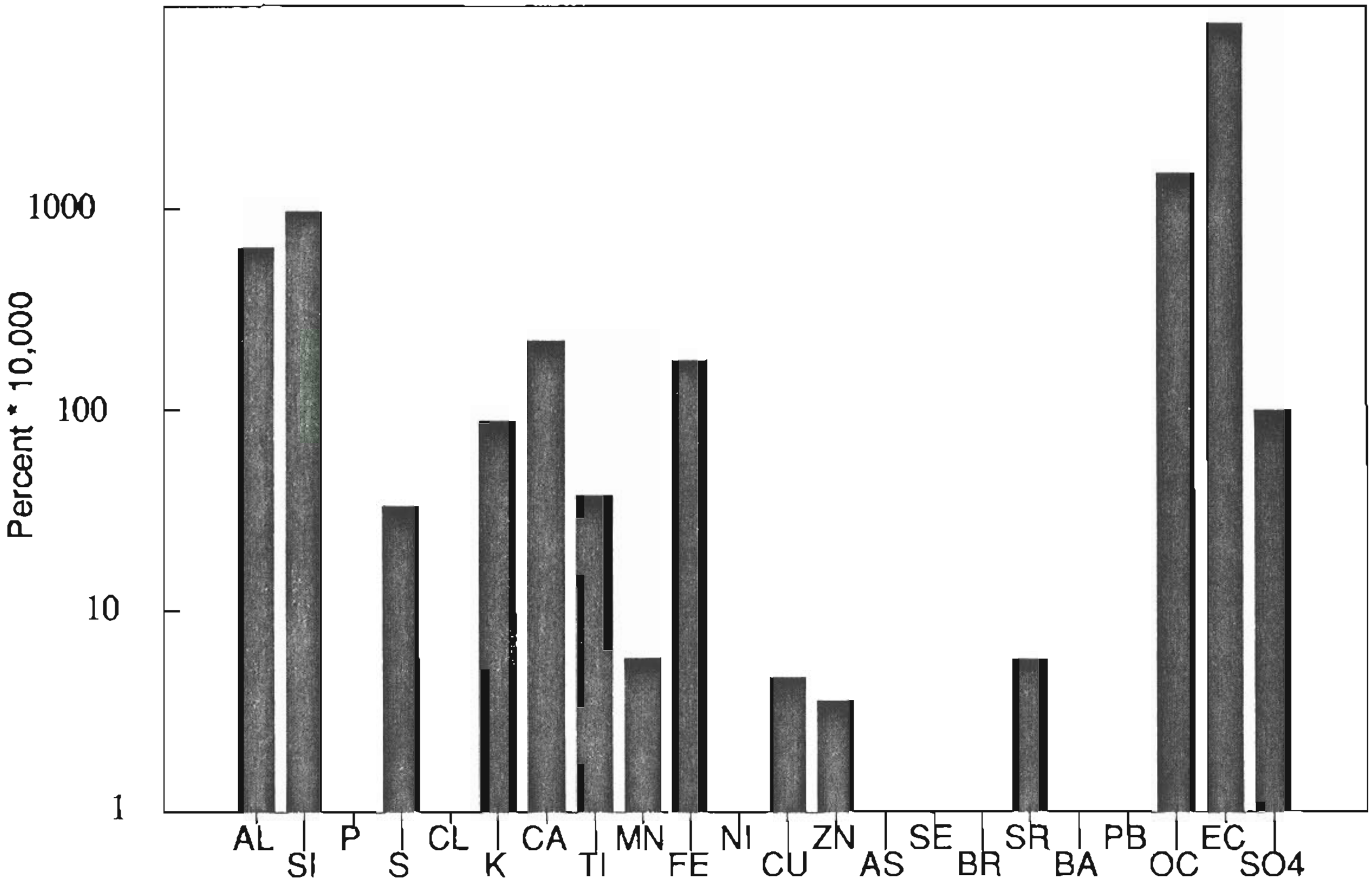


Figure 3-10. Ball coal elemental profile.

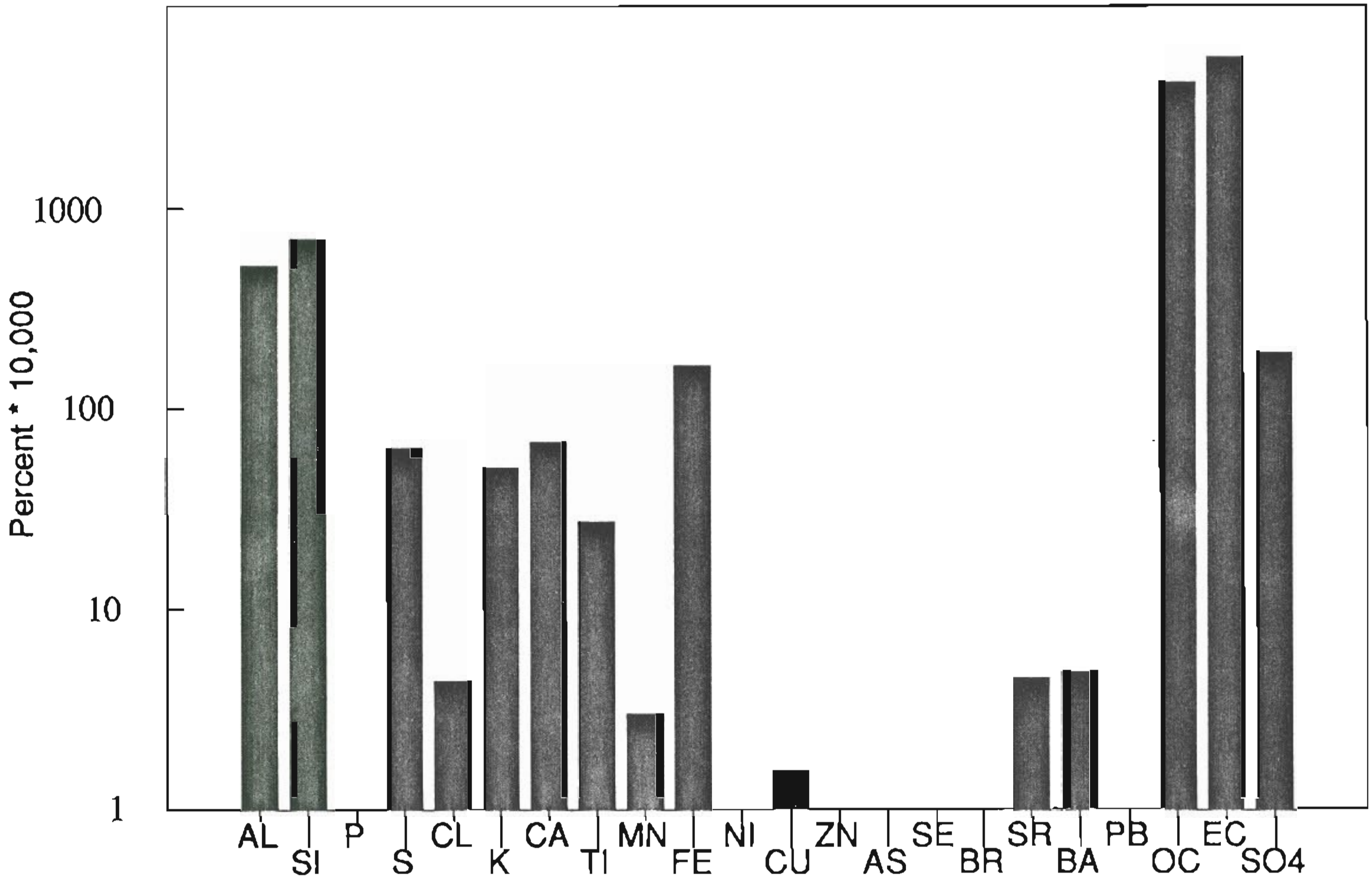


Figure 3-11. Piece coal elemental profile.

CHAPTER 4.

A STUDY OF PARTICULATE CARBON IN BEIJING

INTRODUCTION

Although carbonaceous species comprise a large fraction of urban aerosol (Shah et al., 1986), the carbonaceous species research in China and other developing countries have not started yet. Su, Wei-han et al. indicated in 1989 that soot is one of the main air pollutants in Northern China. The average particulate carbon concentrations was about 30 $\mu g/m^3$. These data are close to the annual carbon concentration 38 $\mu g/m^3$ in Beijing determined from this project and are close to the average concentrations (between 23 and 42 $\mu g/m^3$) measured in 1982 the metropolitan Los Angeles area (Gray, 1986). Carbonaceous species also exists in all sources in China, and some important sources collected in China such as smoke of different kinds of coal show large fractions of OC and EC species. It's important to research the carbonaceous species in Beijing ambient air and different sources in order to picture air pollution in Beijing.

RESULTS

Average morning concentrations of organic carbon(OC), elemental carbon(EC), and OC/EC for 64 days throughout the sampling periods from May, 20, 1989 to May, 14, 1990 at west site are given in Table 4-1. Annual average concentrations of OC, EC and TC at the west site were 19±1, 19±2 and 38±2 $\mu g/m^3$ respectively. The highest seasonal average values of OC and EC were 22±2 and 23±2 $\mu g/m^3$ in the winter, (Nov. 20, 1989 and Feb. 20, 1990), while the lowest average value was 16±1 and 16±1 $\mu g/m^3$ in the summer, (May 20 to August 20, 1989). The yearly OC and EC concentration variations are shown in Figure 4-1. The OC/EC ratio showed little seasonal dependence. The highest OC/EC ratio, the summer average, was 1.3, while the lowest ratio, the winter and spring average, was 1.0 (Figure 4-3).

The yearly average for OC/EC was 1.1 at the west site. The ratio of OC/EC at the east site for five days between April 30 and May 20, 1989 was 1.0. For comparison, the 1986 annual OC/EC ratio in downtown Los Angeles was 2.6 (Turpin, 1989). These was no statistically significant seasonal difference in OC/EC at the Beijing sites.

Table 4-2 shows OC-EC regression coefficient results where OC = a + b*EC. The constant factor "a" can be interpreted as non-combustion OC, and the slope 'b' is related to the OC/EC ratio of the combustion sources contributing to the particulate pollution. There were high correlations between OC and EC in the winter (R^2=0.84), autumn (R^2=0.91), spring (R^2=0.77). The high correlations of OC and EC in the autumn, winter and spring suggest a combustion origin for OC. The high value of "a" in the summer suggests that the major portion of OC is from sources other than combustion. This is supported by the lower value of R^2 (0.30).

Previous research (Gray et al., 1986; Grosjean, 1984; Wolff et al., 1983; Novakov, 1982; Chu and Macias, 1981) indicated that the ratio of OC/EC can be used to investigate the importance of primary and secondary organic aerosol, and elevated ratios can indicate secondary formation. In order to explain the other sources of OC in the summer in Beijing, mid-day ratios of OC to EC concentrations in different seasons were examined as shown in Figure 4-3. The mid-day OC/EC ratio during summer is larger than in the other seasons, but the OC and EC concentrations in the summer mid-day are much lower than in the winter mid-day as shown in Figure 4-4, and the biases of the ratios of OC to EC are all within the conclusions (Figure 4-3). The high OC/EC ratio during the summer might result from secondary OC formation (i.e. gas to particle conversion), however there are geographical and meteorological factors in Beijing which must be considered. The city is located at the edge of Mongolian plateau, which opens onto the great plain to the south and east part of China. In the summer, warm and humid air from the southeast penetrates into North China and into Beijing. Mean turbulent dispersion and horizontal transport factors in the city are stronger than in Los Angeles. Thus, summertime organic aerosol could result not only from local combustion sources, but also secondary formation or biogenic emissions from long distance transport. The much stronger OC-EC correlation in the autumn and winter indicates combustion as an important source of OC. Additionally, the values of the regression coefficient "b" for autumn and winter are close to the measured OC/EC ratios from the closed-vent burning of honeycomb and ball coal as shown in Figure 4-4. Because emission inventory information indicates that approximately twice as much honeycomb coal as ball coal is consumed, it is likely that the burning of honeycomb coal is one of the major sources of OC in the fall and winter. Figure 4-4 shows that the OC/EC ratios for of honeycomb and ball coal burning when a vent is closed near 1, which is close to the ratios of ambient particles. Therefore, the burning of honeycomb coal when a vent is closed is likely to be a important source in Beijing.

CONCLUSION

Particulate organic and elemental carbon concentrations were sampled at two sites in Beijing between May, 20, 1989 and May, 14, 1990. The conclusions are drawn as follows:

- The results indicated that high levels of organic and elemental carbon are important components of aerosol throughout the year in Beijing.
- During the autumn, winter, and spring combustion appears to be the principal source of organic carbon.
- The preliminary results suggest that the closed vent burning of honeycomb charcoal is one of important combustion source.

Table 4-1. Seasonal average value of OC, EC, TC and OC/EC.

Summer: May 20 - Aug. 20,1989
Autumn: Aug. 20 - Nov. 20, 1989
Winter: Nov. 20, 1989 - Feb. 20, 1990
Spring: Feb. 20 - May 14, 1990

TC = OC + EC

location of site	time season	OC µg/m3	EC µg/m3	TC µg/m3	OC/EC
west site	summer	15.9	15.6	30.2	1.3
	autumn	18.4	18.5	37.4	1.1
	winter	22.2	23.3	45.5	1.0
	spring	20.5	19.4	39.9	1.0
annual average		19.0	18.6	37.7	1.1
west site	4/24 to 5/14/90	17.1	17.7	34.8	1.0
east site	4/30 to 5/16/89	23.6	23.5	47.1	1.0
uncertainty		7%	9%	2%	

Table 4-2. Seasonal OC-EC regression and correlation coefficient results.

$OC = a + b*EC$

season	a	b	n	R
summer	11.8±2.5**	0.28±0.13*	17	0.30
autumn	3.6±1.8*	0.79±0.08**	12	0.91
winter	6.4±2.5**	0.68±0.09**	12	0.84
spring	0.6±4.6	0.98±0.22**	17	0.77
annual	4.1±1.5**	0.80±0.07**	58	0.72

* Significantly > 0 at 90% level of confidence.

** Significantly > 0 at 95% level of confidence.

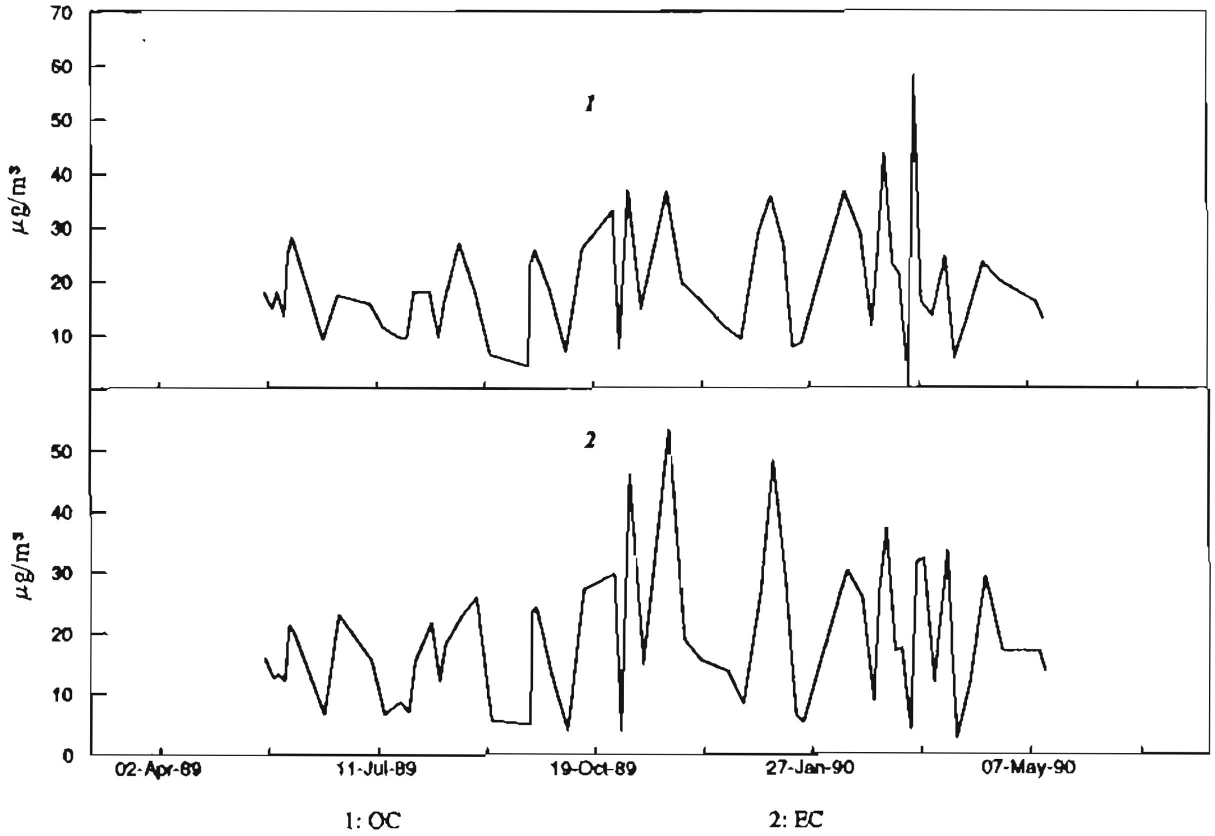


Figure 4-1. OC and EC concentration variation in Beijing from May 1989 to May 1990.

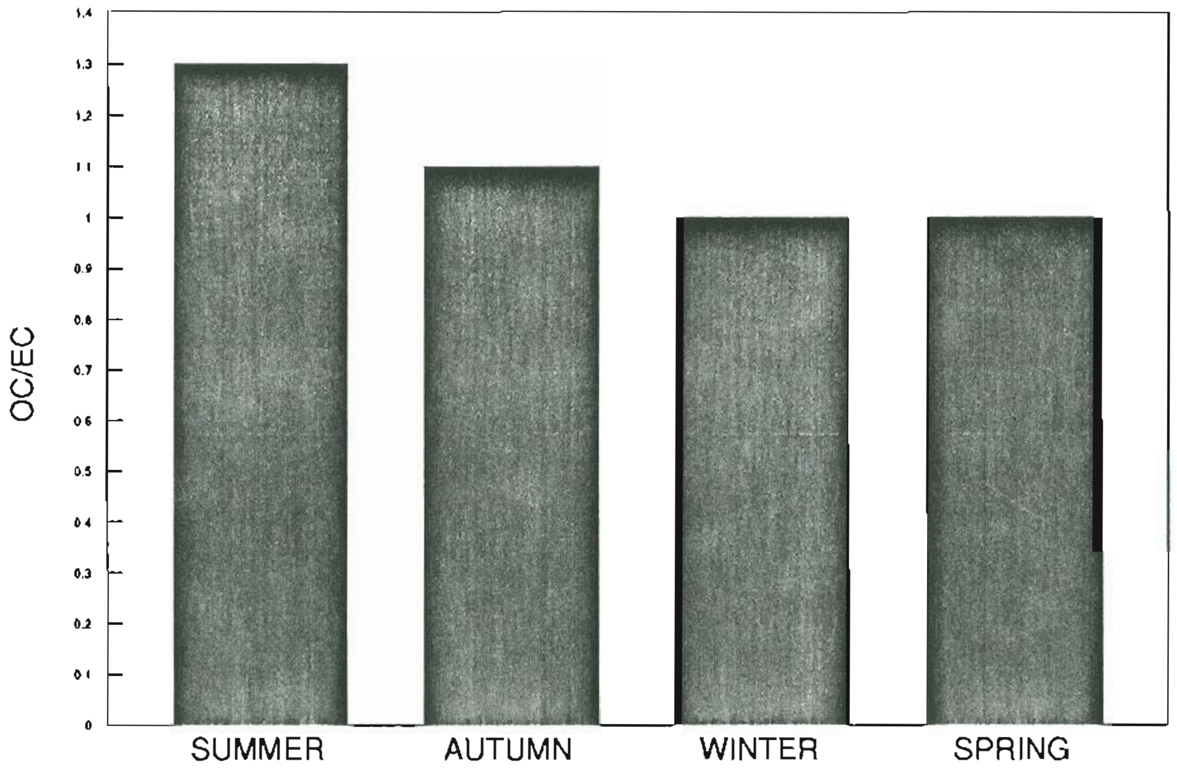


Figure 4-2. Seasonal average of ratios of OC to EC in Beijing May 20, 1989 to May 14, 1990.

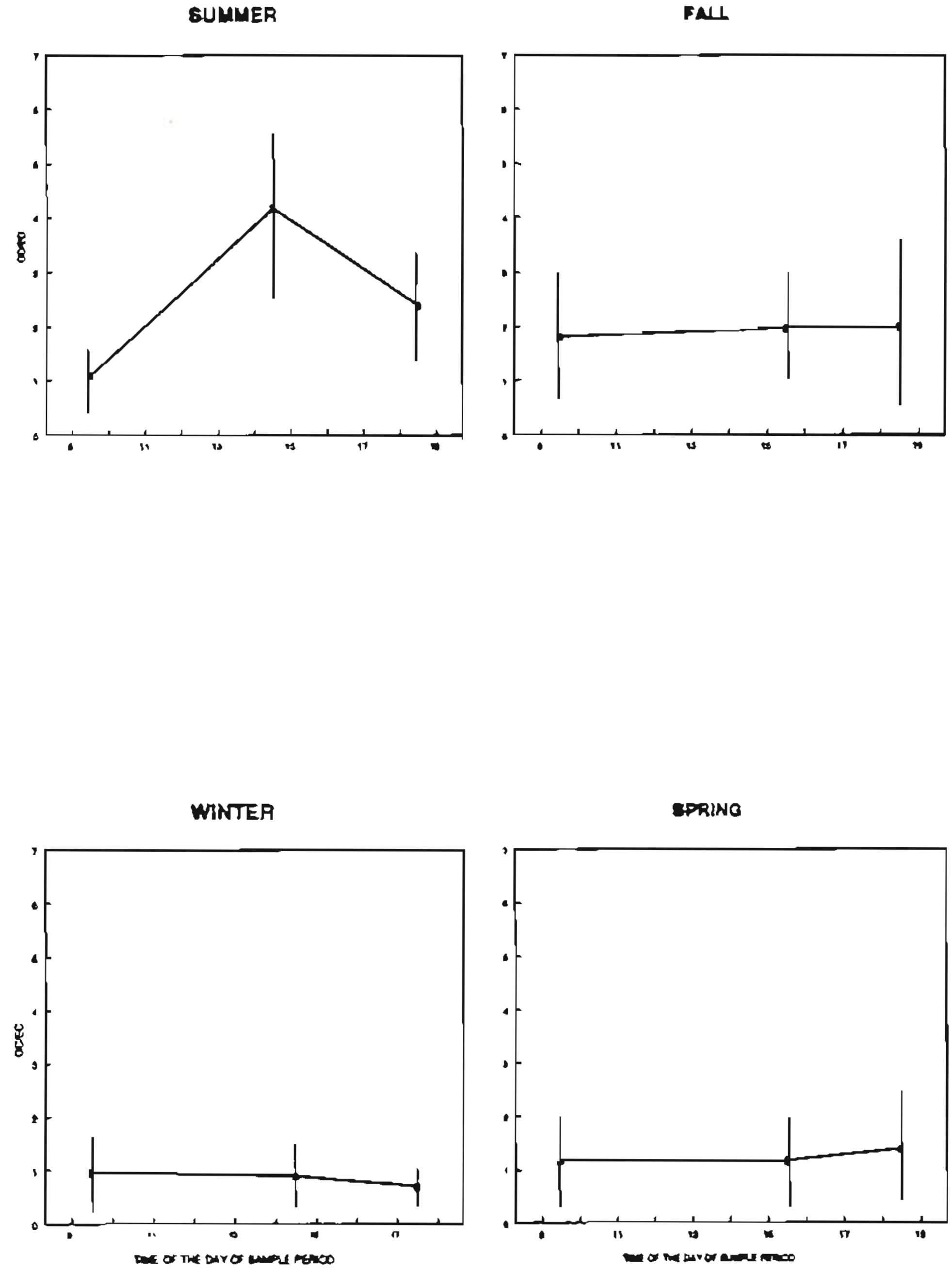


Figure 4-3. Daily average ambient ratios of OC to EC in Beijing.

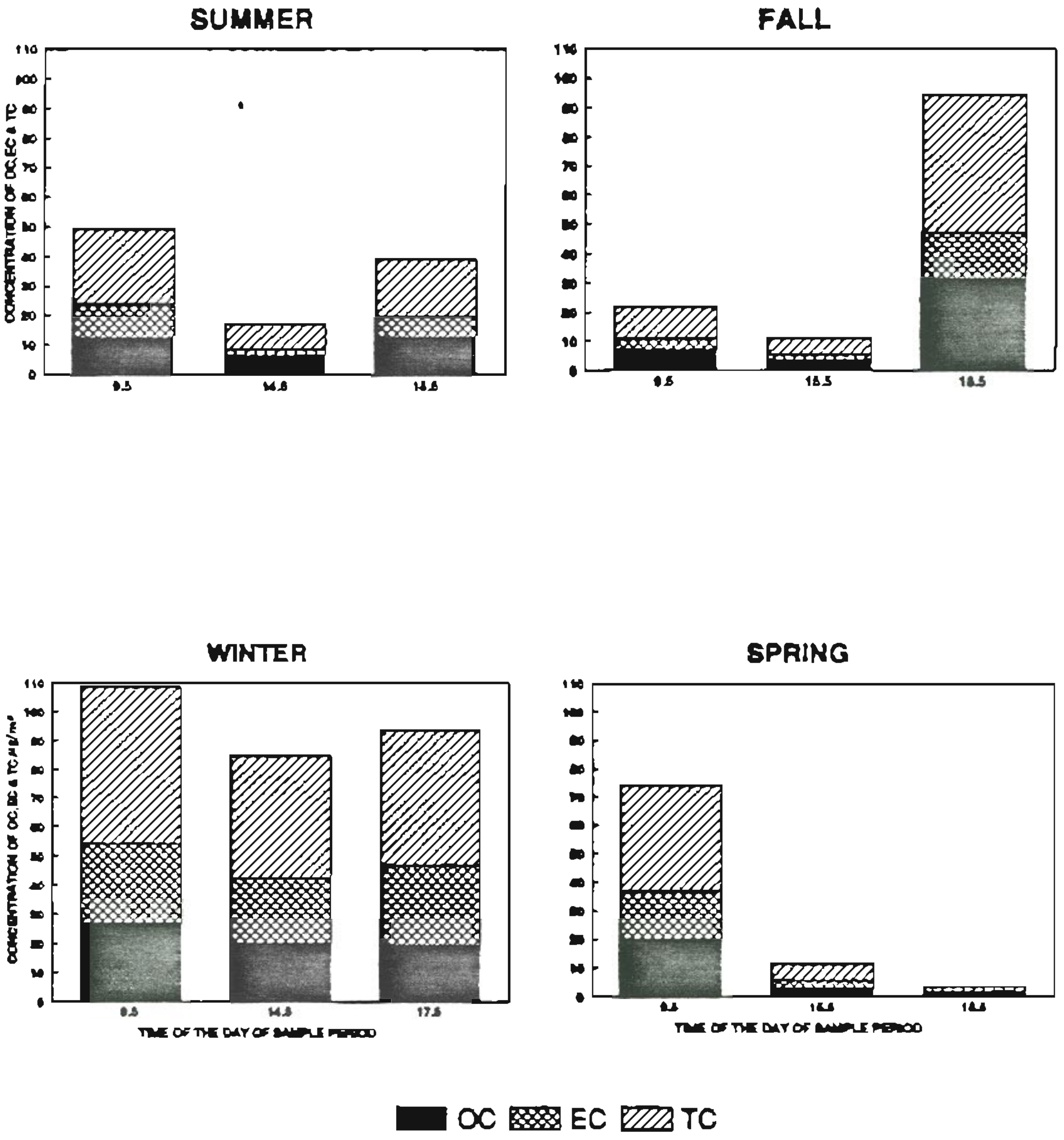
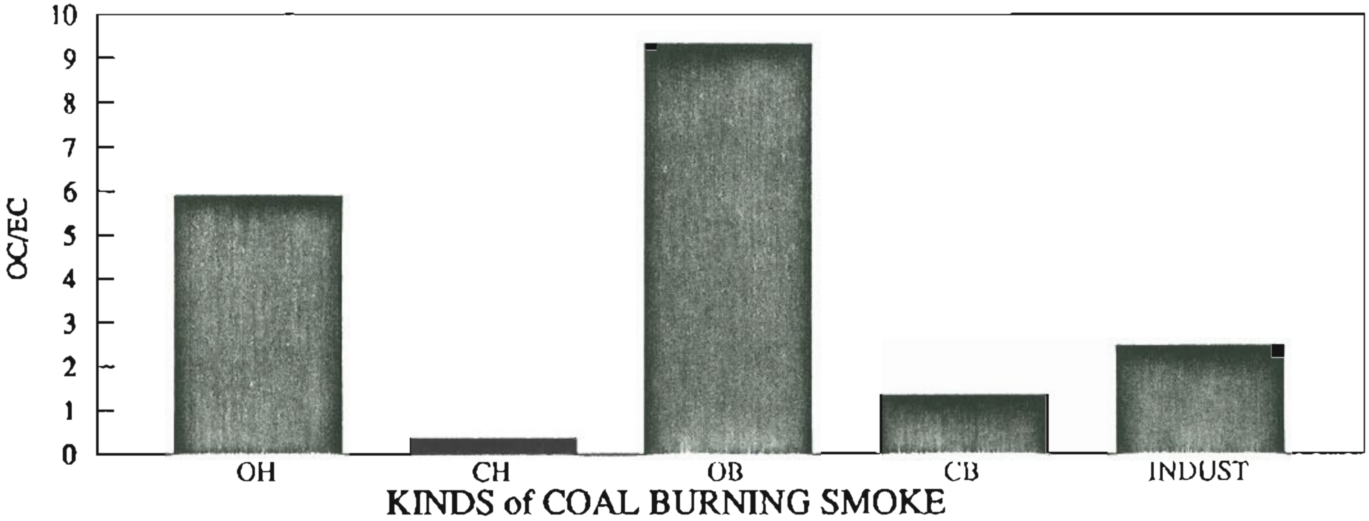


Figure 4-4. Daily average ambient concentrations of OC, EC and TC ($\mu g/m^3$) in Beijing from May 1989 to May 1990.



OH: Honeycomb coal burning when vents are open

CH: Honeycomb coal burning when vents are closed

OB: Ball coal burning when vents are open

CB: Ball coal burning when vents are closed

INDUST: Industrial coal burning

Figure 4-5. Source ratios of of OC to EC for different kinds of coal burning smoke samples in Beijing.

CHAPTER 5.

A SURVEY OF EXISTING AND REPRESENTATIVE SOURCES

INTRODUCTION

In the last ten years, Chinese scientists from Academia Sinica, the National Environmental Sinica, Beijing University, and Nan Kai University have begun to work on factor analysis and receptor modeling. Wang (1983) used factor analysis on Chinese ambient particulate data to conclude that the major particulate sources in Beijing were: dust, coal burning, petrochemical emission, biomass burning emission, vehicle emission, secondary sulfate and unknown sources. Dai (1986) described the source apportionment of CMB model in Tianjing were: dust, industrial coal burning, residential coal burning, steel industrial, automobile emission, oil burning, ocean emission and construction dust. However, the problems encountered in Chinese CMB modeling were (1) samples were total suspended particulate samples; (2) OC and EC concentrations were not reported; (3) the elemental analysis were carried out by different instruments for different elements rather than all by XRF; (4) quality control procedures were not reported; (5) Chinese source profiles were not available. Despite the drawbacks, they have done fundamental research which indicated the Chinese source identification.

The source identification of Beijing ambient data of this project was done by factor analysis in the Chinese Environmental Research
Sinica in 1991. For some reason, no good results were obtained. Based on the source apportionment mentioned above, the CMB model calculations were done with Beijing ambient data (from this project) and a part of Chinese source profiles derived from this project and a part of American source profiles which fit Beijing's ambient concentration data.

The CMB model, the CMB calculation results and discussion are described in Chapter 6, while the eleven sources which fit Beijing's ambient data are introduced in Chapter 5. The eleven sources were carefully chosen, and which are the best fit sources based on lower chi^{2}value, high R^2 value and high mass percent. The examples show in Table 5-2, 5-3 and 5-4.

Because the political and financial reasons, it was impossible to sample all possible sources in Beijing during the project sampling period when Beijing's student demonstrated in 1989. It is also impossible for all countries in the world to develop their own source libraries. Since American environmental scientists have already done so much research on source library development; therefore, one of purpose of this project is to expect the possibility of combination of Chinese source profiles with American source profiles. Which means that the typical sources, like residential coal burning sources in Beijing, should be derived from the specific country like China; but the common sources, such as vehicle emission, could be found in the U.S. EPA source data library or other sources. In fact, this idea is practical in this project, which makes the CMB model application possible in many countries.

Most source profiles in Beijing, China are area sources. It is very difficult to get information on these sources because no single emitter is representative of entire population of emitters. The same ambient $PM_{2.5}$ samplers which were used for ambient $PM_{2.5}$ sampling were used for source sampling. In order to obtain quality data, it was important to assure that the source sampling was done under cold, stable meteorological conditions at times and places for which other source influences are negligible.

SOURCE SAMPLER PREPARATION

The impactors were cleaned before every source type was sampled, and a leak check was performed. System blank samples were taken with filters at the site in order to find any potential contaminants.

Each sample was labeled with sampling location, type of sources, date of sampling, and sampling method, and packaged vary well for transport. The sampling handling was done carefully and storage was in refrigerators. Those samples were dried at 30°C for three hours before analysis.

SOURCES TESTED BY DILUTION SAMPLING

Source samples were collected from cooled, diluted plumes. In order to sample less ambient air, the impactors were as close to the chimney outlet as possible without significantly heating the impactors.

COAL SMOKE

The samples of the honeycomb coal burning in open and in closed-vent mode, as well as ball coal burning in open and closed-vent mode were all done by dilution sampling in Beijing. The coal sampling was first done on May, 7 and 8, 1990, in an indoor lab at the Xichen monitoring station. Source profiles compared with the ambient data collected on the same day at a nearby outside site to make sure that source profile was significantly different from ambient air. The same sampling was repeated on July 25, 1990, at an outdoor site. The results were bad because that was a windy day and there was not enough loading on the samples. So the first group of data was accepted for these source types.

When honeycomb and ball coal sources were used in the CMB models, a collinearity between the two sources occurred. Therefore, only one kind of coal source profiles can be used. It is not possible to distinguish between honeycomb and ball coals. Honeycomb coal was used because it dominates residential coal consumption in Beijing and closed-vent mode burning for honeycomb coal (HONEYC) is much more common than ball coal.

INDUSTRIAL COAL BURNING

Three KZL4-13 type industrial-scale water-tube boilers (steam capacity 4 x 10^3 kg/h) were tested with coal fuel at a medical factory in Beijing. For each test the boilers being sampled were operated in steady-state mode at 100% of capacity. The sampling was conducted at the bottom corner of the stacks using two $PM_{2.5}$ impactors built into the exhaust stacks. The samples were taken at the centers of the stacks for 20 minutes.

COAL-FIRED POWER STATION 1

This source profile was provided by Dr. Jim Houck of OMNI Environmental Services,Inc. and is the profile of Cherokee coal-fired power plant, Denver, CO. This source profile is used because there is a higher EC emission (6.7%) than other coal power station profiles we found. Information on Chinese coal-fired power station profiles can not be found. But we assume that there are not as efficient as their typical American counterpart. Since the coal power stations in the U.S. have better environmental controls than in China, so this profile is likely similar to Chinese coal power plant source profile. Therefore, this source profile was used in source data base as POWER 1.

COAL-FIRED POWER STATION 2

This is a chemical composition of fly ash emissions from Navajo generating station submitted by Keystone/NEA to the Salt River project. Since the burning temperature of the power station varied, the trace chemical species changed as well. This source profile is an average of four tests during the burning process with higher mass fraction. So this is a good power plant profile since it is close to the real nature of coal power plant profile.

Glen E. Gordon (1989) indicated that there is enormous variation in the composition of particles released by coal-fired power plants, depending on the type of coal burned, boiler design, and the type and efficiency of pollution controls. Therefore, coal power plant profiles are most variable in coal burning population. In this project, two power plant profiles have to be used instead of single power profile in order to obtain a good CMB fit because POWER 1 profile is similar to Chinese less efficient power plant profile, and POWER 2 profile is a average of measurement which is closer to the nature of power plant combustion. Hence, this power plant profile was used in the source data file as POWER 2.

HOG-FUEL BOILER

Residential coal boilers are widely used in Beijing for residential central heating system, commercial hotels, shopping centers, hospital and big restaurant. But the corresponding coal boiler source profile can not be found in the U.S and China. If we only use three coal sources which are HONEYC, INDST, and POWER, then the CMB results did not give fits to the data (Table 5-2). Previous Su Ge's (1988) research found that the burning temperature of the coal is extremely important. In general, elemental emissions from coal burning sources increase with increasing temperature. Since the industrial coal boiler sampled for this project was four ton capacity, which capacity is the bottom capacity of industrial boilers but the top line of the residential boilers. That means that the temperatures of residential boilers are higher than housestove and lower than industrial coal boilers; therefore, an intermediate source profile between INDST profile and HONEYC profile was sought. A hog-fuel boiler profile was discovered in the Pacific Northwest Source Profile Library, which is the University of Oregon Hogged Fuel Boiler. Figure 5-1 shows that for the four species Cl, Ca, Fe and OC, the hog fuel boiler profile is intermediate between the INDST and HONEYC profiles. For Si, S, TI, Zn, EC, and So they show correspondence between the three source profiles. Only K in the hog fuel boiler profile is higher than INDST and HONEYC profiles. But Watson (1984) indicated that K concentration has been assigned higher uncertainty. Four CMB runs showed that the percent of mass accounted for and chi-square improved slightly after K was removed from source data base (Table 5-1). Table 5-2 shows that BOILER source, which represent hog fuel boiler, can not be taken away in order to keep the chi^2 value reasonable. Therefore, this hog-fuel boiler source was chosen to represent the coal boiler profile.

SOIL

Soil samples were obtained by resuspension and filtration. Since soils vary chemically due to their geological origin and addition of agricultural amendments, a transect grid was established within a circle of a several kilometer radius of the west site in Xi-chen district of Beijing. Twenty samples were initially collected. After mixing, five samples were chosen, finally a small bottle of soil was taken back to OGI. After that, it was sieved by 400 mesh to remove coarse particles. Then the powder were suspended in a chamber to get $PM_{2.5}$ samples at KEYSTONE/NEA, and analyzed at DRI. Those sample were used to make source profiles. The soil profile is shown in Figure 5-2.

CEMENT DUST

Beijing is both an old and a new city. A lot of old houses are being torn down, and there is much new construction everywhere. The most popular materials are bricks and lime in China. So the lime dust is one of sources in Beijing. American EPA CEMENT source profile (coal fired) was chosen as CEMENT source in this source data file (Figure 5-3).

URBAN DUST

This data (Figure 5-4) are from source data of CMB 7.0 disk program of DRI, which is used as urban dust in urban area in Beijing and named as URDUST.

PLANT DUST

Hildemann found that urban vegetative detritus is represented, with an urban dry deposition component similar in its characteristics to paved road dust superimposed on a background of organic carbon and phosphorus contributed from the leaf material. In addition, there are similarities between Beijing and Los Angeles: first, they are both dry cities. Second, both cities have heavy air pollution episodes. The last is the time of stagnant pollution in LA is about two or three days before it is removed by wind. For lack of horizontal direction transport, pollutants are accumulated in the urban areas of Beijing. It has been found that during times of heavy pollution, the emission of pollutants from three industrial sources (suburbs of west, southwestern and southeastern direction) overlap in Beijing and its north suburb. After one and two days, the pollutants are sent in northwest direction out of Beijing.

The geological and environmental similarities between two cities are so important that the vegetative detritus profile (Figure 5-5) fits Beijing's ambient data very well. Table 5-3, and 5-4 shown that CMB calculations fit better with vegetative detritus profile in Because the similarities between vegetative detritus and plant road dust, the vegetative detritus profile is accepted and named PDUST in this project.

HEAVY DUTY DIESEL EMISSION

This source profile was provided by Dr. John Rau of OMNI Environmental Services, Inc.

From 1980 to 1990, the total number of vehicles in Beijing increased by a factor of four. Of this the motorcycles increased by a factor of 7.5 and cars by 6.0. Buses and trucks increased by about a factor of 2. Most the cars in Beijing are imported from abroad, but the most of buses and trucks are made domestically. Since there is not vehicle emission monitoring system available in China, there is no efficient emissions control equipment in the big vehicles. Different vehicles emission profiles from different fuels were run with CMB modeling. Only the heavy duty diesel emission source profile fits well. Thus, it is used as MVHDDS in the source data base.

COOKING EMISSION

Fried cooking, (i.e. hot oil cooking) has been very popular in China for over a thousand years. Beijing residents have fried cakes as a breakfast in the morning. There are a few restaurants near the east sampling site, and one could smell the fried cooking in the morning.

Hildemann has developed meat-cooking source profile. In her experiment, frying regular hamburger meat gave a fine aerosol emission rate of 1 g/kg of meat. and 68%-73% of the fine mass was organic carbon and only little or no element carbon was present.

This source data was used in the source data file as FRIED.

SO_4

The concentration of SO_2 in Beijing in 1982 was higher by a factor up to 18 compared to Portland. Therefore the level of SO_4 in Beijing's air quality is high, which is not only caused by coal burning emission and vehicle emissions, but also emitted by a few chemical factories in Beijing.

The SO_4 source data was obtained from source file of CMB 7.0 program.

CONCLUSION

A key point of the CMB modeling study is the source profiles for the ambient aerosol mass contribution in the receptors. Developing countries often do not have enough money and scientists to develop their own source data libraries. Because American scientists have done solid work on source profile research and there are source data libraries provided by the U.S. EPA, American source profile libraries could be an important source of information for CMB modeling projects of other developed and developing countries. Based on the detailed knowledge of this project, the follow conclusions can be made:

- Try to limit the ambient and source data uncertainties as much as possible through filter preparation, sampling, storage, analysis, and data interpretation.
- The source profiles should include all important elements and carbon constituents.
- If the American geological material profiles are chosen as source profiles for other countries, it's important to consider the similarity of the geological characteristics of the material profiles in the U.S. and the other countries.
- If motor vehicle exhaust profiles derived in the U.S. are selected as the source data base for other countries, the types of vehicles, engines and fuels used in both countries have to be taken into account. In addition, the ratio of OC/EC of the U.S. profile has to be compared and judged with the real situations of the vehicle exhaust emissions in the country being studied.
- The temperature influence for coal burning profiles described in Chapter 1 are acceptable for residential and industrial small boilers. For power plant source profiles, the type of coal burned, the boiler design, the type and efficiency of pollution controls have to be taken into account for power plant source profiles.

Table 5-1. CMB calculation comparisons between same data with K and without K.

WITH K			
	CHI^2	R^2	PERCENT MASS
7/28/89	2.15	0.95	129
9/20/89	2.76	0.98	113
11/29/89	2.28	0.97	120
5/14/90	1.89	0.95	117

WITHOUT K			
	CHI^2	R^2	PERCENT MASS
7/28/89	2.05	0.95	129
9/20/89	2.68	0.98	119
11/29/89	1.98	0.97	128
5/14/90	1.59	0.96	136

Table 5-2. Different CMB results for 1/09/90 data.

1/09/90

NUMBER	TYPE		R^2	CHI^2	PERCENT
3	HONEYC	*	0.98	3.05	102.4
5	INDST				
6	SOIL				
13	POWER				
20	BOILER				
25	SO4				
26	MVHDDS				
3	HONEYC		0.91	53.04	90.7
5	INDST				
6	SOIL				
18	POWER				
25	SO4				
26	MVHDDS				
3	HONEYC		0.96	7.18	96
5	INDST				
21	PDUST				
25	SO4				
26	MVHDDS				

*: These CMB results have been chosen.

Table 5-3. Different CMB calculations for 5/14/90 data.

5/14/90

NUMBER	TYPE		R^2	CHI^2	PERCENT
5	INDST				
14	LIMED		0.95	1.88	133
20	BOILER	*			
21	PDUST				
26	MVHDDS				
5	INDST				
6	SOIL				
15	UDUST		0.95	8.99	77.8
20	BOILER				
26	MVHDDS				
5	INDST				
6	SOIL				
20	BOILER		0.95	10.75	79.5
25	SO4				
26	MVHDDS				
5	INDST				
6	SOIL		0.95	10.36	78.8
20	BOILER				
26	MVHDDS				

*: This CMB results were chosen.

Table 5-4. Different CMB calculation results for 5/20/89 data.

5/20/89

NUMBER	TYPE	R^2	CHI^2	PERCENT
5	INDST			
14	LIMED	0.98	1.18	118
20	BOILER *			
21	PDUST			
25	SO4			
26	MVHDDS			
5	INDST			
6	SOIL	0.97	5.21	98.7
20	BOILER			
25	SO4			
26	MVHDDS			
3	HONEYC			
5	INDST	0.98	5	99
6	SOIL			
20	BOILER			
25	SO4			
26	MVHDDS			
6	SOIL	0.97	1.37	110.7
13	POWER			
20	BOILER			
25	SO4			
26	MVHDDS			
6	SOIL	0.97	1.37	107.3
20	BOILER			
25	SO4			
26	MVHDDS			

*: These CMB results have been chosen.

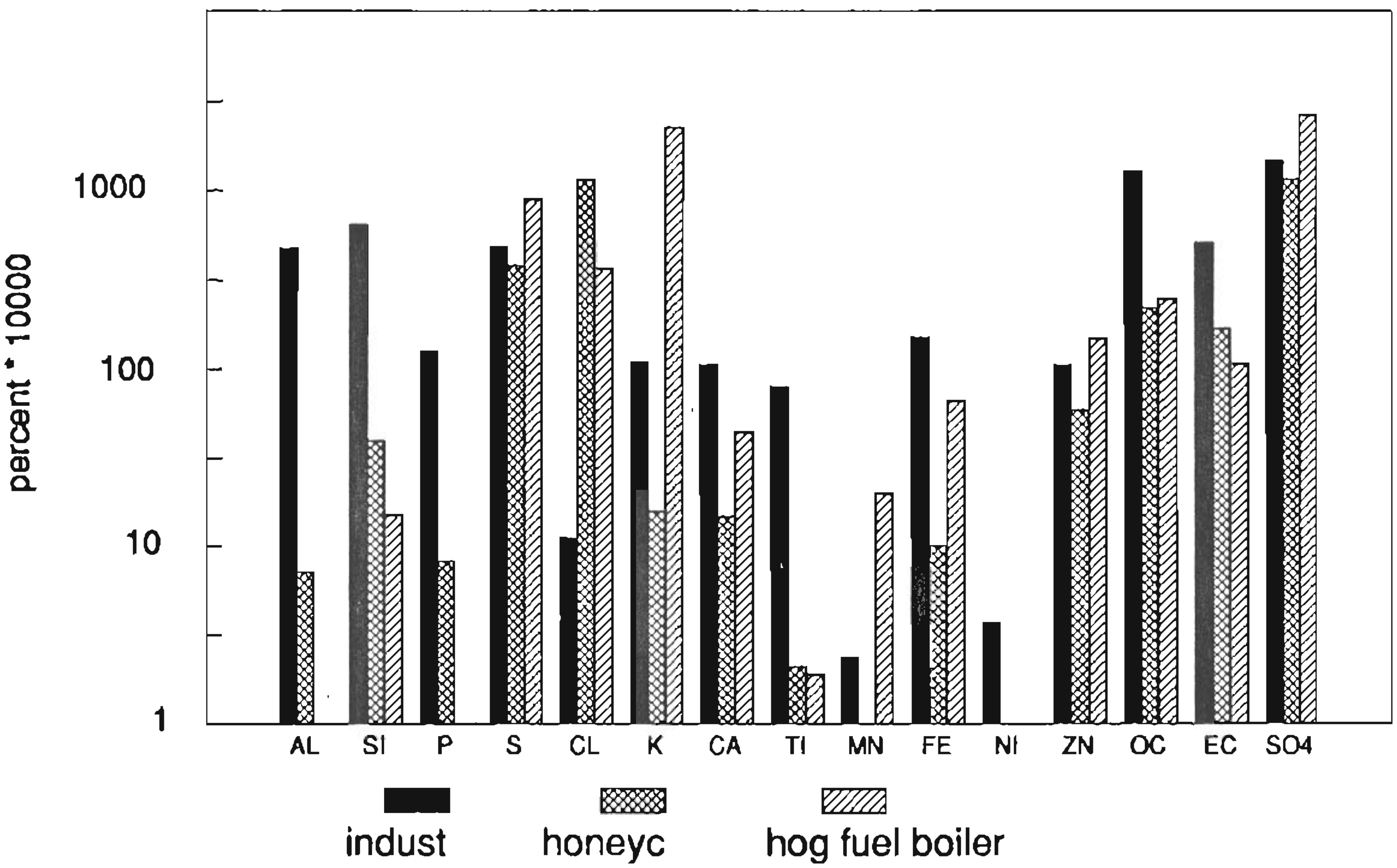


Figure 5-1. The source profile comparison of industries, honeycomb coal closed mode and hog fuel boiler.

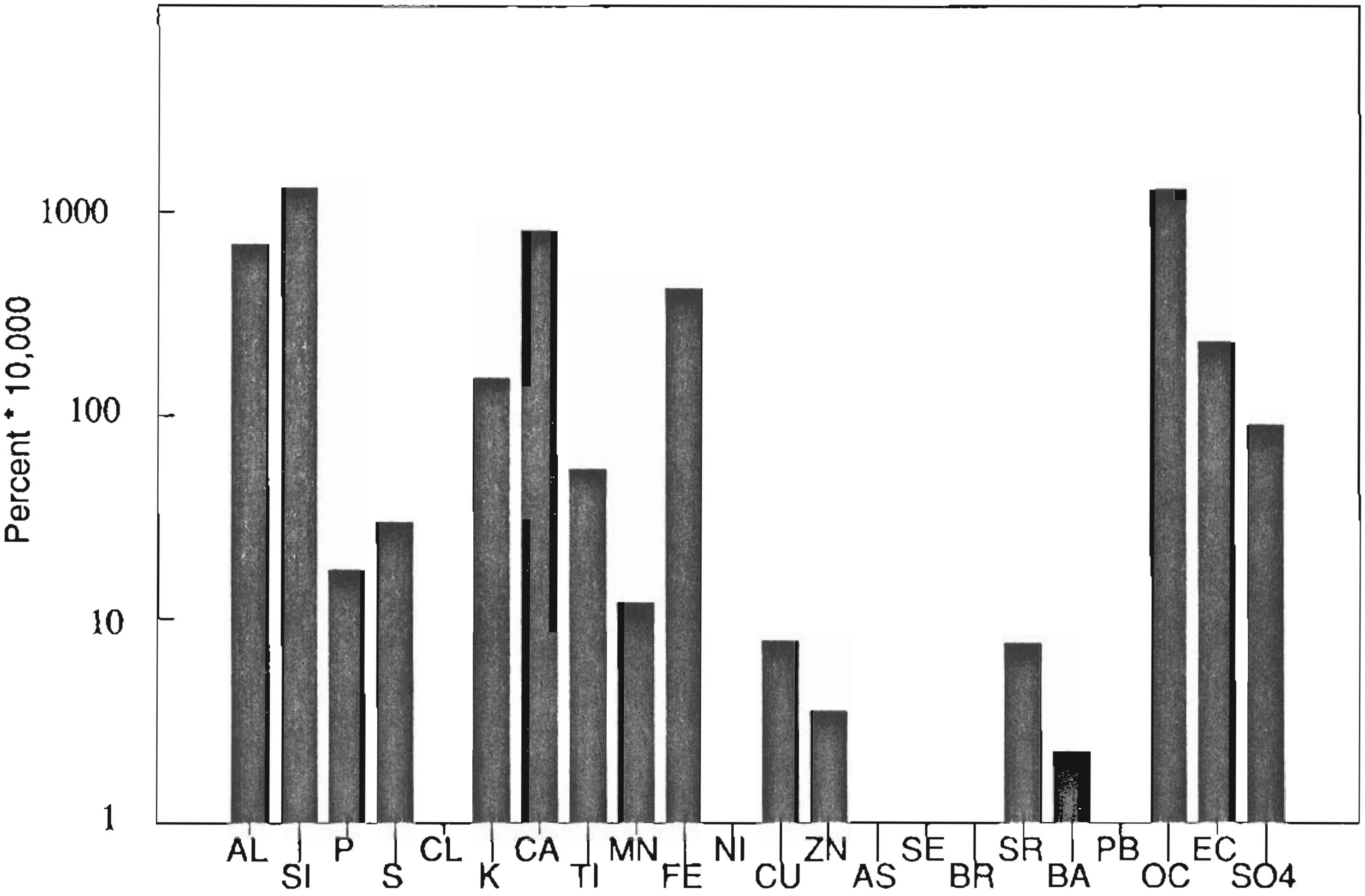


Figure 5-2. Soil source profile.

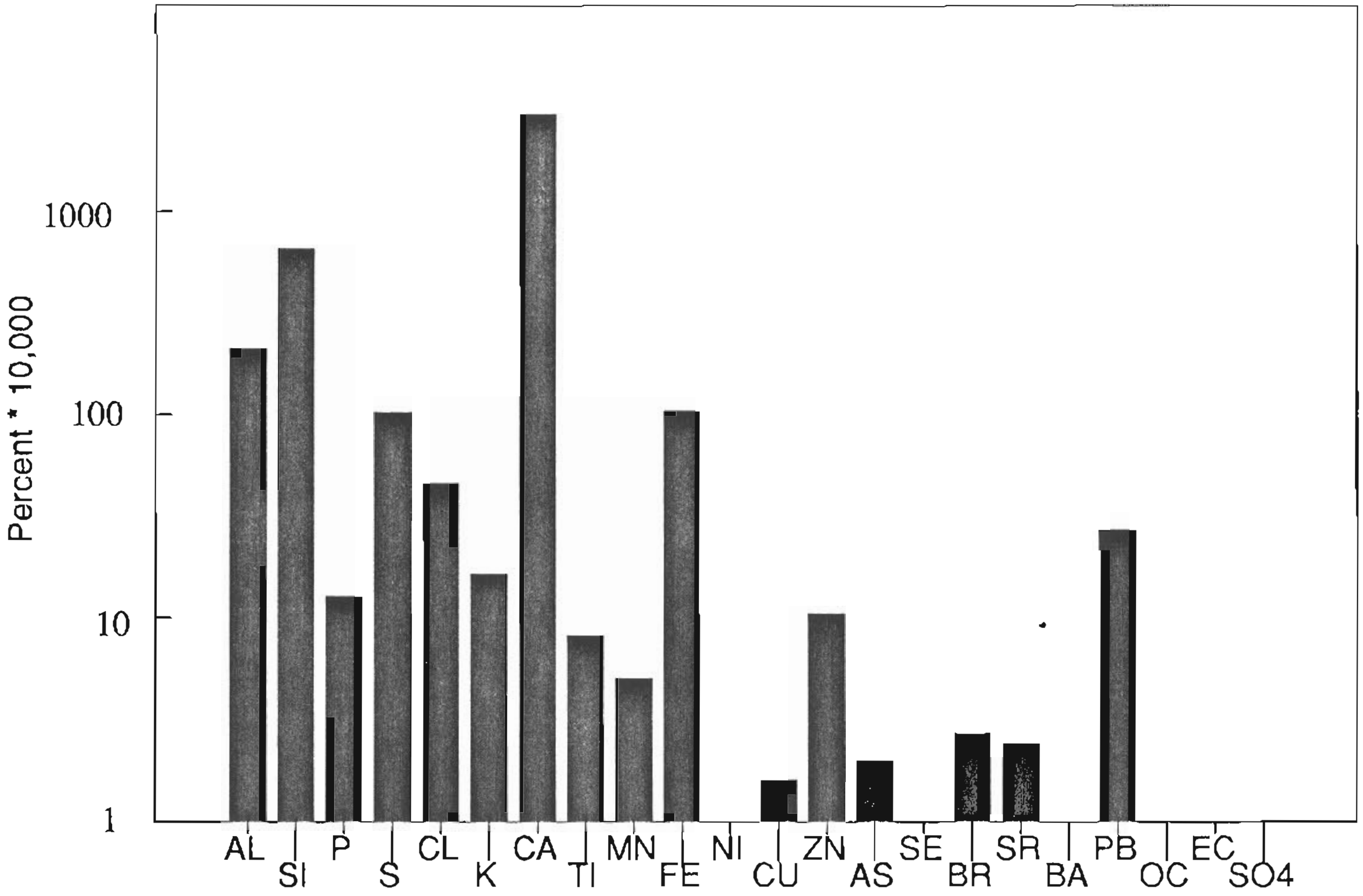


Figure 5-3. Lime dust source profile.

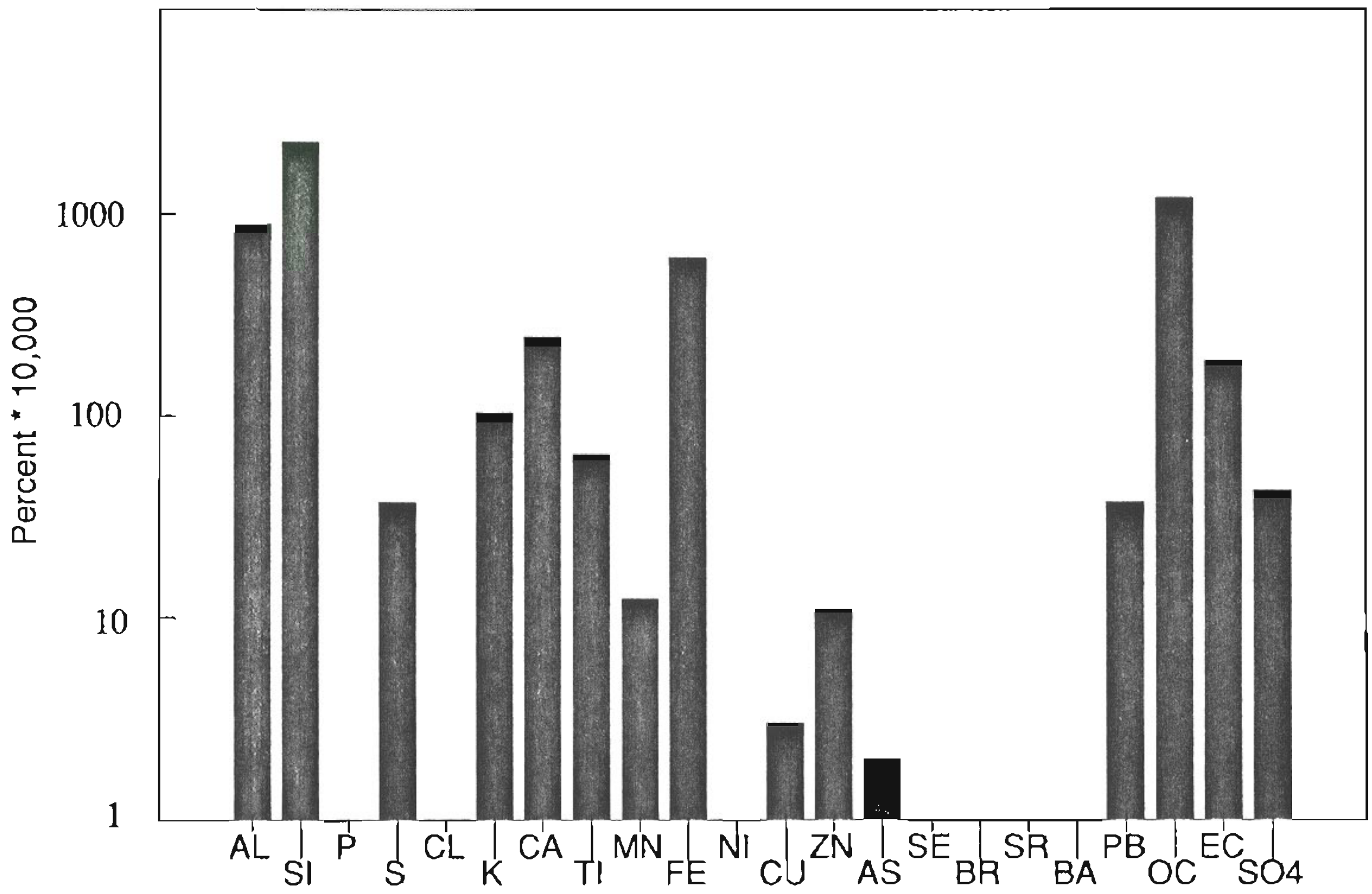


Figure 5-4. Urban dust source profile.

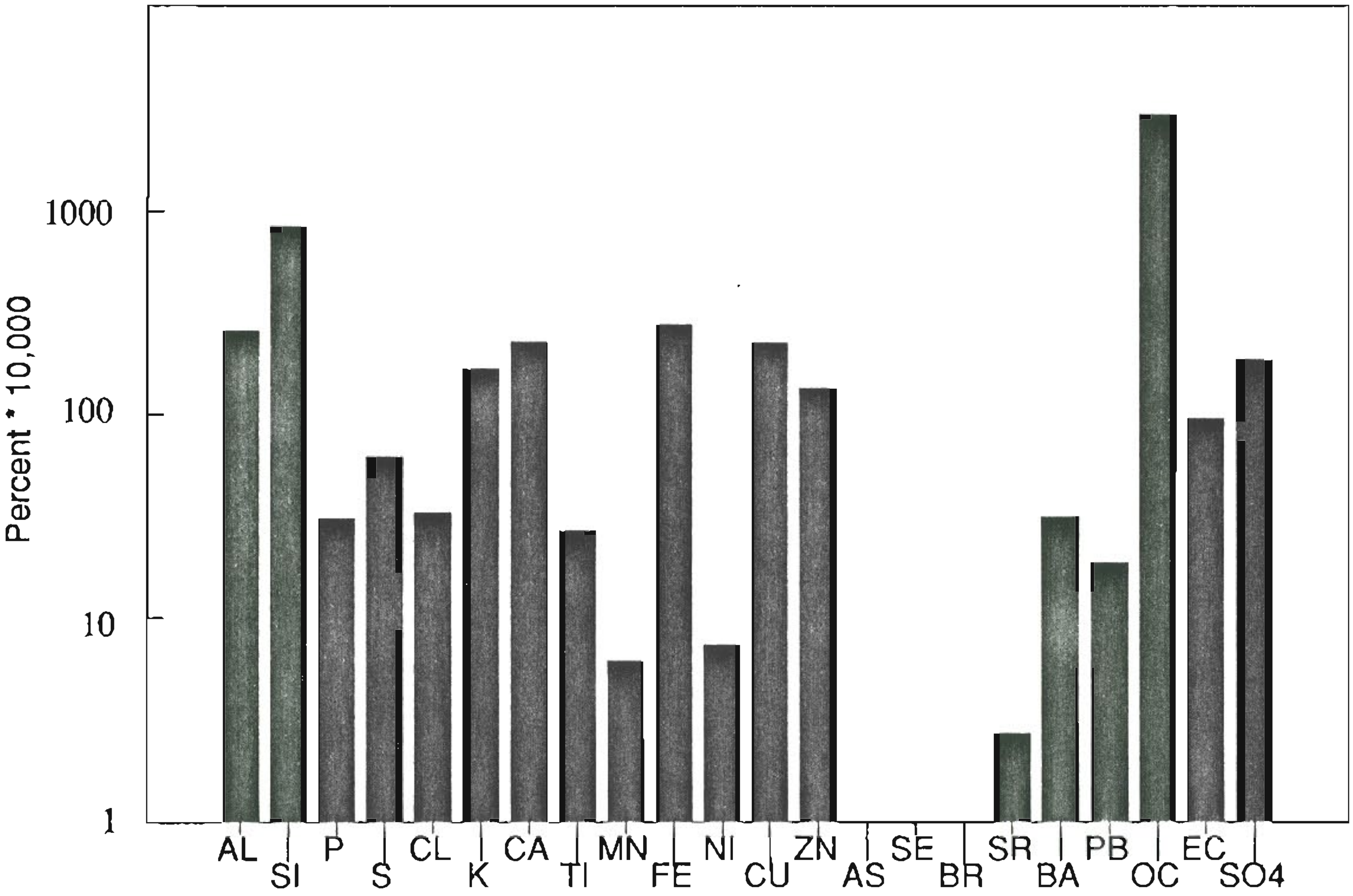


Figure 5-5 Plant dust source profile.

CHAPTER 6.

CMB SOURCE APPORTIONMENT OF $PM_{2.5}$ BEIJING AEROSOL

INTRODUCTION

The first formal statement of equation of CMB model was given by Miller et al. (1972) and Friedlander (1973). They called their method chemical element balance (CEB). In recent years, Watson and Cooper (1980) have suggested that chemical mass balance (CMB) is a more appropriate name for the methodology.

The Chemical Mass Balance approach has been described by Watson (1979 and 1990) and involved the following assumptions. (1). The compositions of source emissions are constant over the period of ambient and source sampling. (2). The chemical species do not react with each other; therefore, the chemical concentrations observed at the receptor are linear sums of the chemical species contributions from the various sources. (3). All sources with a potential for significantly contributing to the receptor have been identified and have had their emissions characterized. (4). The source compositions are linearly independent of each other. (5). The number of sources or source categories is less than or equal to the number of chemical species. (6). Finally, the measurement uncertainties are random, uncorrelated, and normally distributed.

The CMB model consists of a least-squares-solution to a set of linear equations which expresses each receptor concentration of a chemical species as a linear sum of products of source profile species and source contributions. And the CMB model is given by:

$$C_{ik} = \sum_{i=1}^{I} a_{ij} S_{jk} \qquad (6\text{-}1)$$

Where:

C_{ik} = Concentration ($\mu g/m^3$) of aerosol component i measured
at the receptor for sample k.

a_{ij} = Mass fraction of source-type j possessing
property i at the source.

S_{jk} = Contribution ($\mu g/m^3$) of source-type j to sample k.

The total aerosol mass, C_k measured at the receptor k, is a linear sum of the contributions from the individual sources.

$$C_k = \sum_{j}^{J} \sum_{i}^{I} a_{ik} * S_{jk} = \sum_{j=1}^{J} C_{ik} \qquad (6\text{-}2)$$

Where the source contribution a_{ik} composed of chemical species i.

The reduced chi squared, R-squared, degrees of freedom, and percent mass are goodness of fit measures for the least squares calculation.

The chi squared is the weighted sum of squares of the differences between the calculated and measured fitting species concentrations.

$$\text{Where } X^2 = \frac{1}{I - J} \sum_{i=1}^{I} [(C_i - \sum_{j=1}^{J} a_i * C_{ik})^2 / W_{ii}] \quad (6\text{-}3)$$

I = Number of elemental species.

J = Number of sources.

C_{ii} = The measured i mass.

W_{ii} = A diagonal matrix of i.

A value of chi squared less than one indicates a very good fit to the data, while values between 1 and 2 are acceptable. If chi squared is greater than 4, that indicates one or more fitting species are not well-explained by the source contribution estimates.

R-squared is determined by the linear regression of measured to calculated values for the fitting species. This value ranged from 0-1.0. The closer the value is to 1.0, the better the calculated source contributions explain the measured ambient concentrations.

$$\text{Where } R^2 = 1 - [(I-J)X^2] / [\sum_{i=1}^{I} C_i^2 / W_{ii}] \quad (6\text{-}4)$$

Percent mass is the percent ratio of the sum of the calculated source contribution to the measured mass concentration.

$$\text{Where Percent Mass} = 100\left(\sum_{j=1}^{J} C_{jk}\right)/C_t \qquad (6\text{-}5)$$

C_t = The total measured mass. (Watson, et al. 1990)

Theoretically the a_{ij} values should represent the concentration of element i from source j as it exists at the receptor, after any changes due to atmospheric processes. Since this property a_{ij} can't be measured, the next best thing to do is to measure the property after the source aerosol has entered the atmosphere and has been cooled and diluted by ambient air.

PREVIOUS CMB MODELING RESULTS

A small source sampling project was conducted at O.G.I. in 1987 where both Chinese and U. S. coal were burned in a box type, conventional, wood stove. Because only a small amount of Chinese coal was available (less than 2 kg) the burn was cooler than coal burning in a U.S. residential furnace, but was typical of the type of residential burning for cooking and heating purpose in China. The smoke was sampled by two PM_{10} impactors and two $PM_{2.5}$ impactors together and a gas tank. The Teflon filter samples were analyzed at NEA, and quartz fiber filter samples were analyzed at OGI with thermal-optical carbon analysis. The Chinese coal source profile developed from this test was utilized in the CMB modeling described below.

CMB modeling was used to make a preliminary evaluation of the contributions of residential coal burning and power plant coal burning emissions to Beijing air pollution. These analyses used published ambient data collected in Beijing (Table 6-1), a residential coal burning source profile measured at OGI as mentioned above, and power plant coal burning source profiles published in the U.S. EPA Source Library (Table 6-2) (Core et al., 1984). This modeling effort was not completely successful because the available TSP value wasn't provided in the published ambient data. However, there are some qualitative features of the results that stand out. First, although industries in Beijing account for around 70% of total coal usage and residential coal is around 10%-15% of total coal consumption (Figure 1-3), residential coal burning appears to be a larger source of pollution than coal fired power plants (Table 6-3). Secondly, the contribution of residential coal burning is greater in the winter than the summer. In addition power plant emissions, which are solely the result of high temperature coal burning, contributed only 4 to 8% of the total particle emissions over the year. On two December days the residential coal burning contribution was about 30% of the aerosol mass while for two March days it was only about 3 to 7% (Khalil,1987). Therefore, these results suggest that pollution from coal burning in the winter could be significantly reduced by controlling residential coal burning.

There are some qualitative features of the results that stand out. First, the compositions of coal burning emissions will be strongly dependent on burn temperature. Comparison of the coal burning power plant and residential coal burning composition profiles from the EPA source library with the preliminary low temperature coal burning emissions composition profile in Figure 1-4 shows that these source compositions are significantly different. Chinese and U.S. cool burning residential source profiles look quite similar, and the source profile of intermediate temperature coal burning falls somewhere between cool and hot temperature source profiles. Secondly, thermal-optical carbon analysis along with measurement of sample particulate material emitted from cool coal burning showed that it was 65% to 90% carbon and that 92%-98% of the carbon was organic.

An important goal of this project was to provide quantitative relationships among source emissions, meteorology, and ambient pollutant levels. Air quality modeling in this project included both source and receptor models which quantitatively relate ambient concentrations to source emissions.

QUALITY ASSURANCE

Quality control included:

1. Standard operating procedures to be followed during source and ambient sampling, analysis, and data interpretation.
2. Periodic calibrations and performance tests.
3. Lab blanks, instrument blanks, field blanks and replicate analysis.
4. Data interpretation such as blank subtraction and data validation.

The standard operating procedures of source and ambient sampling, and data assurance were described by Core and Watson (1987), and thermal carbon analysis process has been described by Turpin (1989).

It's important to make sure that all seasonal average blanks have been subtracted from raw data. And even more important thing to do is to check all data over and over again to confirm the data validation.

Sample validation took place after ambient and source data bases were ready. Suppose the sums of all chemical species for every day ambient data should be ± 20% of gravimetric mass of the sample. If the differences between sum and gravimetric mass were more than 20%, then the weight of the sample has to be rechecked.

The checked results of most samples in this project were fine. A few samples had problems because quartz fibers were found on the back of Teflon samples reducing the accuracy of weighing. The few weight percents still didn't look good even cleaning off the quartz filter and rebalance has been done. The few unreliable weights might be caused by transportation or too long time storage.

MASS BALANCE

Figure 6-1 and 6-2 display the mass balance obtained for some of the Beijing samples. The reconstructed data are calculated from measured chemical species to reconstruct the concentrations of SiO_2, $CaCO_3$, Fe_2O_3, Al_2O_3, K_2O, PbBrCl, CuO, TiO_2, ZnO, NiO, V_2O_5, Mn_2O_3, As_2O_3, SeO_3, $(NH_4)_2SO_4$, EC and 1.2 OC, then all values are summed to get reconstructed mass. There are no nitrate and water data available in data base. However, Dr. William Wilson believed that China should have less nitrate and hydrocarbons than the U.S (William, 1987). Because of the low population of motor vehicles. Water vapor should not be taken into account since the samples have been dried before sampling and analysis. The measured gravimetric mass concentrations are plotted against reconstructed mass concentrations and are shown in Figure 6-2. Most of the data are acceptable, however, a few data points fall away from the 1:1 line. This may be due to quartz fiber on the back of Teflon samples which did not separate from samples completely. Figure 6-3 shows the calculated mass concentration (from CMB 7.0 modeling) versus reconstructed data. All of the data look good, suggesting that the reconstructed data are a practical alternative to the measured data. This theory was proposed and applied by Gray et al. in 1986 and Valaoras et al in 1988. Table 6-5 indicated $PM_{2.5}$ mass balance for Beijing ambient data at east site. The good percent mass for both $PM_{2.5}$ and reconstructed mass strongly supported this idea. Since a few samples at west site were contaminated with quartz fiber shown in Table 6-4, the reconstructed mass were chosen in the data base.

THE CMB MODELING RESULTS

Chemical Mass Balance Model 7.0 was performed on ambient, daily particulate data from April 1989 to May 1990 at sites in Beijing and measured at OGI and the Desert Research Institute for 32 elements and chemicals. The flow diagram of the source type apportionment process is shown in Figure 6-3. The eleven source profiles included in the initial CMB fit were: honeycomb coal burning (closed-vent) (HONEYC), residential boilers (BOILER), industrial burning (INDST), power station coal burning (POWER), heavy duty diesel emission (MVHDDS), secondary sulfate (SO_4), soil, paved road dust, unpaved road dust, limed dust, and cooking emission (FRIED). The results of the CMB on Beijing data can be considered good based on average chi-square value was 2.26 (target < 4), all T statistics of greater than 2, no uncertainty/similarity clusters, the average R-square value was 0.95 (target > 0.8), and the average fraction of measured mass accounted for was 82.3% (target > 0.8), and the average of calculated mass over reconstructed mass was 122.0% (Table 6-6, 6-7).

Twenty four separate CMB calculations were run on samples for the west site, and five CMB calculations were performed for the east site in Beijing. A hundred source profiles collected from a U.S. nationwide search have been evaluated in order to find the best fit sources. The best twenty nine CMB results which are described below were selected from a few thousand calculations.

The residential coal sources are made up of honey coal burning in closed mode (HONEYC) and residential boiler burning (BOILER). The industrial coal emissions are composed of power coal burning and industrial boiler burning. The DUST emission is formed by plant road dust, urban road dust, soil and limed stone dust (Table 6-8).

The dominant air pollution sources in Beijing are: coal burning emissions, heavy duty diesel vehicles emission and dust. The yearly average contributions for the three main sources account for approximately one third each of the total particulate concentration. Coal burning contributions are derived approximately equally from residential coal burning and industrial coal burning emission, although the residential coal consumption is only a small fraction, perhaps only around 10%-15% of total coal consumption in Beijing.

In the winter at the west site the total coal burning contribution was 43%; in the summer it was only 18%. The average winter HONEYC and BOILER contributions were 6% (6 ± 2 $\mu g/m^3$) and 14% (11 ± 3 $\mu g/m^3$), while the INDST and POWER were 10% (9 ± 2 $\mu g/m^3$) and 13% (12 ± 3 $\mu g/m^3$) respectively. In the summer the average BOILER emission was 9% (7 ± 2 $\mu g/m^3$), and INDST contribution was 9% (9 ± 2 $\mu g/m^3$). The average spring HONEYC, BOILER, INDST and POWER contributions were 2% (1.4 ± 0.4 $\mu g/m^3$), 19% (14 ± 6 $\mu g/m^3$), 13% (9 ± 3 $\mu g/m^3$), and 7% (5 ± 1 $\mu g/m^3$). In the autumn the average HONEYC, BOILER, INDST, and POWER contributions were 6% (4 ± 2 $\mu g/m^3$), 10% (7 ± 2 $\mu g/m^3$), 4% (3 ± 1 $\mu g/m^3$), and 7% (5 ± 1 $\mu g/m^3$) respectively. MVHDDS was another important source as its annual average contribution was 35% (28 ± 5 $\mu g/m^3$). The average dust contribution was as high as 39% (28 ± 9 $\mu g/m^3$) and 36% (28 ± 2 $\mu g/m^3$) in the spring and summer, but 20% (14 ± 3 $\mu g/m^3$) and 10% (6 ± 2 $\mu g/m^3$) in the autumn and winter. Those sources and their contributions were supported by east site in Beijing (Table 6-9, Figure 6-4 and 6-5).

Figure 6-6 shows that the highest contributions of HONEYC was in the winter, while the lowest emission occurred in the summer. The second highest average concentration was in the fall since many residents start house heating in September. There was HONEYC emission in the Spring because house heating continues until April.

Residential boilers are very popular in Beijing for hot water cooking and heating purposes. In recent years, there have been a large number of boilers in private enterprises in counties and countryside surrounding Beijing. It is reasonable that boiler contribution in the winter was higher than in summer and autumn because residential boilers for heating purpose start working from Nov. 15 to March 15 every year. The boiler contribution in the spring was slightly higher than in the winter because the strong north wind came from the north suburbs brings coal boilers pollution in. The west site was located in the old residential area of Beijing downtown, and there were not many coal boilers in that area. Thus, particulate matter from boiler emissions were mainly from wind transport.

The averages of industrial coal burning emission in summer, winter and spring were around 7 to 9 $\mu g/m^3$, which is reasonable since industrial emission can be considered to be relatively constant. But the average industrial emission in autumn was as low as 3 $\mu g/m^3$. The average wind speed in autumn in Beijing was quite calm (Table 6-10). In addition, local wind fields formed a weak convergence field centered at Beijing (Zhao, Deshan, 1983), which caused the industrial emission from Beijing suburbs transported less in autumn than other seasons.

The highest average power station concentration was in the winter (12 $\mu g/m^3$); there were only 3-4 $\mu g/m^3$ average concentrations in the autumn and spring. There were no emissions found in the summer. The reason why power plant emissions in autumn were lower is because the average wind speed in autumn in Beijing was quite calm as mentioned in the above paragraph (Table 6-10). There is no power station located in the north suburbs; hence north winds in the spring can not bring more power plant emissions in. The reason that the power station emission was the highest in the winter were because the industrial profile only represents the boiler of 4 ton capabilities, but most industrial boilers, even some residential boilers in Beijing, have capabilities from 4 to 35 tons. Hence, some of the industrial and residential boiler contribution whose capabilities are more than 4 tons were falling into power station contributions to cause the winter emission from power stations was the highest than other seasons.

Figure 6-7 indicates heavy duty diesel emission contributions in different seasons. The highest MVHDDS concentration was in the winter. That occurred because cold temperatures result in higher diesel consumption in the winter. MVHDDS pollution was reduced in the spring in Beijing due to meteorological factors. The north wind existed in Beijing, since the inversion layer is weak and thin in the spring, and the wind speed is higher, the turbulent dispersion and horizontal transport are strong at same time. This is the first time that MVHDDS contributions has been found in Beijing air pollution. A few thousand CMB modeling computations have been made, which all show the importance of the MVHDDS source.

The dust contributions are shown in Figure 6-8. The lime dust and soil contributions were small throughout the year, while the average plant dust concentrations in the summer and spring were surprisingly higher. The summer period was from 20, May, 1989 to 20, August, 1989 and included the period of the student protests. The large gathering of people could have been responsible for the large dust concentrations. The higher concentration of plant dust in the spring was caused by transport of dust by strong northwest winds in spring in Beijing area. The reason that there was not plant road dust concentration in the autumn because the average wind speed in autumn in Beijing was quite calm as shown in Table 6-10.

The average sulfate concentration in the summer was 12 $\mu g/m^3$ (Figure 6-9), while it was around 6 $\mu g/m^3$ in the autumn and winter. The average sulfate concentration was only 1 $\mu g/m^3$ in the spring because northwest wind blew off the regional sulfate component in the air. The summer in Beijing is hot and wet, 75% of precipitation drops in the summer. Thus, the source of this sulfate aerosol might be (secondary) gas to particles conversion reactions. Another possibility are primary emissions of sulfate aerosol from industrial factories.

DISCUSSION

Figure 6-6 shows that power plant emissions can not be found in the summer. Corresponding wind data in Table 6-10 indicate that all sampling days in the summer have an average wind direction from the west where there is no power plant in Beijing.

The east site was located at Tong-si district, one of the busiest and most crowded areas in Beijing. In order to convince Chinese Scientists that the CMB model can be used in China, the east site was on the second balcony of a five story building, and a hot water boiler was only 20 meters away. Thus power plant emissions and transport of industrial pollution have been blocked by the tall building. This may be the main reason why there were no power plant contributions in the east site pie chart (Figure 6-10) and only a little industrial emissions as well. The average of $PM_{2.5}$ concentration at east site was 124 $\mu g/m^3$, while it was 70 $\mu g/m^3$ at west site because the west site was located in a quieter area. The boiler contribution at east site (27.2%) was more than that at west site (18.8%) since there was a hot water boiler twenty meters away from east site. The MVHDDS emission at the east site was 30.5%, while it was only 20.0% at the west site because the east site was nearer to main transport roads than the west site. The sulfate source concentrations at the east site was 4.7% which is more than west site (1.1%) since most chemical factories are in eastern suburbs such as Beijing dye plant (one of it's products is sulphuric acid), Beijing cake plant and Beijing second chemical plant that all emit SO_2 in their smoke emissions. Additionally 5.9% of the $PM_{2.5}$ come from cooking emissions at the east site because there were restaurants surrounding east site.

Figure 1-1 suggests that emissions from coal burning was an important factor influencing the solar radiation attenuation in Beijing from 1963 to 1980. However, data from this project indicates that one third of Beijing's $PM_{2.5}$ concentration was from heavy duty diesel emission. It can be explained as follows: since in 1978 the government reform policies started in China, from 1980 to 1990, buses and trucks in Beijing increased from 50,000 to 100,000; motorcycles increased from 20,000 to 120,000; and the cars in Beijing increased 30,000 to 200,000. Most buses and trucks are domestic-made with little or no control equipment. In addition, no motor vehicle exhaust test system is available now. So the MVHDDS contribution was one of dominant pollution contributions in Beijing.

The OC/EC ratio of ambient air in Beijing is 1.1, which is close to the OC/EC ratio of honeycomb coal burning when closed vent (0.36) comparing with other coal burning sources (Figure 4-5). In addition, the OC/EC ratio of honeycomb coal burning when closed vent is not constant, it does above o.36 and around 1. More accurate monitoring needs to be done in the future with sampling periodically through whole closed vent burning process (around eight hours), and the 0.36 of OC/EC was from three data average and the total sampling periods were two hours. So the one of conclusions in Chapter 1 is that the HONEYC is one of important sources in Beijing. However, the MVHDDS source found in this project is another dominant source. The ratio of OC/EC of MVHDDS is 0.69 which is also close to the ambient ratio 1.1. Therefore, it is reasonable that the MVHDDS is another one of important $PM_{2.5}$ sources in Beijing.

Su Ge (1988) indicated that residential coal burning appears to be a larger source of pollution than coal fired power plants. But the CMB results from this project shows that coal burning contribution were composed of a half of residential coal burning emission and a half of industrial coal burning emission. The difference was caused by different source data. The residential coal burning data from the previous project were developed at OGI by burning Chinese and U.S. piece coal in a U.S. wood burning stove. Also the residential boiler contribution was not taken into account in previous data base. Furthermore the important OC and EC species were removed from the data base since the ambient data in the earlier study did not have OC and EC (Table 6-1). Another reason is that the power plant source profile was only a single profile in the previous source data base (Table 6-3), and even the industrial boiler contribution was not included. Therefore, the CMB results from this project are more accurate than in the previous project. The common conclusions for the two projects are that the residential coal pollution is higher in the winter and lower in the summer in Beijing.

The temperature of Chinese piece coal burning in the previous project was too low because only two kilogram coal was burned in a big woodstove. Hence the OC and carbon ratio from smoke was not as accurate as this project.

The last conclusion from the previous project was that the composition of coal burning emissions will be strongly dependent on burning temperature, which is a very important guide to choosing the residential boiler profile in this project. But the CMB model didn't work well if there was only one power plant profile in the source data base. Two power plant source profiles were used in this project to get a good fit. The temperature principle can be used for residential coal burning and for industrial boilers. For power plant source profiles, the type of coal burned, the boiler design, and the type and efficiency of pollution controls have to be taken into account in the source composition variation.

UNCERTAINTY

The following sources of uncertainty were encountered in this research.

1. Some of the source profiles used in this project were derived from the U.S. data, such as power plant, cement dust, plant road dust, cooking emission, heavy duty diesel emission etc.

2. More CMB models should be run in the spring for the west site. The reason why only three CMB models were run because the other ambient data for the spring was of poor quality due to low particle-loading and leaks in the system.

3. The group of samples chosen from a particular source type like soil and coal burning smoke may not exactly represent the true average of that source type.

4. The capability of the industrial boiler which was sampled as the industrial source profile for this project was 4 metric tons. However, the capabilities of most industrial boilers, even some residential boilers, in Beijing are 4-35 metric tons. Therefore, some of industrial and residential boiler contribution may fall into power plant profile range.

5. The average sampling time at west site was three hours. It was obviously short. A longer sampling period would have been better.

CONCLUSION

Some conclusions are drawn based on the results and discussion above:

- The eleven sources included in the Beijing's initial CMB fit were: honeycomb burning (closed-vent) (HONEYC), residential boilers (BOILER), industrial burning (INDST), power plant coal burning (POWER), heavy duty diesel emission (MVHDDS), sulfate, soil, road dust, urban road dust, cement dust, and cooking emission.

- The dominant air pollution sources in Beijing were: coal burning emission, heavy duty diesel vehicle emissions and dust. The yearly average contributions for each source were approximately one third of the total emissions.
- Coal burning emissions were derived approximately equally from residential coal burning and industrial coal burning, although the residential coal consumption is only around 10%-15% of total coal consumption in Beijing.
- The honeycomb closed-vent burning, which is an inefficient combustion, is an important source of pollution and waste energies.
- The residential boilers, a lot of which are located in downtown Beijing, are very important sources for air pollution abatement.
- CMB modeling can be used in China for research urban air pollution control strategy purpose.

Table 6-1. Average semi-monthly particulate elemental composition (ng/m^3).

Element	March		July		December	
	1-15	16-31	1-15	16-31	1-15	16-31
c	55,400	49,500	27,600	35,800	11,540	98,000
s	6,010	5,390	4,190	6,370	6,440	5,910
k	3,420	3,470	2,140	2,730	3,590	3,120
Ca	10,400	12,500	7,530	9,400	7,490	10,800
Ti	903	749	432	547	850	991
V	94	97	44	49	71	85
Cr	76	66	32	40	156	36
Mn	205	216	166	165	175	226
Fe	7,410	7,040	4,230	4,950	5,920	7,170
Ni	31	31	17	18	25	29
Cu	24	28	28	31	112	49
Zn	511	476	338	344	1050	490
Ga	29	20	12	113	52	51
As	29	27	18	22	50	45
Pb	301	250	143	229	531	401
Se	16	14	10	12	41	28
Br	27	24	19	21	138	39
Rb	18	18	13	16	23	23
Sr	158	124	60	74	175	197
Si	22,000	21,000	10,000	12,000	16,000	21,000
Cl	840	870	34	26	2,400	1,500

Dod et al., 1986

Table 6-3. Chinese CMB modeling with American source profile.

source	March		July		December	
($\mu g/m^3$)	1-15	16-31	1-15	16-31	1-15	16-31
soil	100	120	76	102	96	148
res. coal	53	46	24	23	102	95
coal.Fpp	20	16	14	14	75	32
X^2	2.7	3.3	3.6	2.7	4.1	5.1

*Coal.Fpp = Coalfired power plant.
Chinese residential coal burning source profile is involved in the American source data base.

Table 6-4. $PM_{2.5}$ mass, reconstructed mass, and calculated mass for Beijing ambient data.

DATE	TOT	SUM	CAL	S/T	C/S	C/T
5/20/89	78	65	76	0.83	1.18	0.97
5/24/89	55	43	47	0.78	1.10	0.87
5/26/89	97	57	70	0.59	1.21	0.72
5/29/89	91	57	64	0.63	1.12	0.71
5/31/89	162	101	110	0.62	1.09	0.68
6/02/89	298	117	129	0.39	1.11	0.43
6/23/89	244	94	97	0.39	1.03	0.40
7/28/89	102	70	80	0.69	1.15	0.79
9/19/89	20	19	21	0.95	1.12	1.06
9/20/89	114	85	97	0.74	1.15	0.85
9/22/89	170	113	117	0.66	1.04	0.69
9/29/89	109	68	73	0.62	1.08	0.67
10/06/89	46	22	28	0.48	1.28	0.61
10/28/89	214	110	138	0.51	1.25	0.65
10/31/89	46	24	35	0.52	1.46	0.76
11/10/89	69	47	55	0.68	1.18	0.80
11/29/89	102	68	85	0.66	1.25	0.83
12/07/89	95	67	82	0.70	1.23	0.86
12/26/89	38	32	35	0.83	1.11	0.93
1/09/90	200	175	205	0.88	1.17	1.02
1/23/90	29	22	24	0.75	1.08	0.81
3/13/90	44	19	28	0.43	1.53	0.64
5/11/90	85	82	106	0.97	1.28	1.25
5/14/90	151	61	82	0.40	1.33	0.54

TOT: Total $PM_{2.5}$ mass.

SUM: The reconstructed mass of $Al_2O_{3,SiO}2$, PbBrCl, K_2O, $CaCO_3$, TiO_2, Mn_2O_3, Fe_2O_3, NiO, CuO, ZnO, As_2O_3, SeO_3, 1.2 OC, EC and $(NH_4)_2SO_4$.

Table 6-5. $PM_{2.5}$ mass balance for Beijing ambient data at east site.

DATE	TOT	SUM	CAL	S/T	C/S	C/T
4/30/89	151	122	142	0.81	1.17	0.94
5/03/89	161	150	179	0.93	1.19	1.11
5/05/89	101	97	112	0.96	1.15	1.11
5/10/89	70	64	79	0.91	1.24	1.14
5/14/89	140	127	145	0.91	1.14	1.03

TOT: $PM_{2.5}$ mass.

SUM: The reconstructed data of Al_2O_3, SiO_2, PbBrCl, K_2O, $CaCO_3$, TiO_2, Mn_2O_3, Fe_2O3, NiO, CuO, ZnO, As_2O_3, SeO_3, 1.2 OC, EC, and $(NH_4)_2SO_4$.

CAL: Data reported in CMB model results.

Table 6-6. The goodness of fit measures for the CMB calculations at west site.

DATA	DF*	PERCENT %	R^2	CHI^2
5/20,89	24	118	0.98	1.18
5/24,89	24	110	0.98	0.92
5/26,89	26	121	0.92	2.5
5/29,89	26	112	0.95	1.37
5/31,89	22	109	0.96	3.91
6/02,89	26	111	0.94	2
6/23,89	23	103	0.96	1.52
7/28,89	23	115	0.95	2.15
9/19,89	25	112	0.97	0.75
9/20,89	22	115	0.98	2.76
9/22,89	24	104	0.98	1.81
9/29,89	24	108	0.98	0.91
10/06,89	25	128	0.96	0.83
10/28,89	23	125	0.94	2
10/31,89	25	146	0.80	4.01
11/10,89	22	118	0.98	1.25
11/29,89	24	125	0.97	2.28
12/26,89	22	83	0.95	2.2
12/07,89	24	123	0.95	3.75
1/09,90	23	117	0.98	3.05
1/23,90	25	108	0.94	1.69
3/13,90	24	153	0.89	5.09
5/11,90	23	128	0.96	1.93
5/14,90	25	133	0.95	1.89
AVG	24	83.7	0.95	2.16

*DF: Degrees of freedom.

Table 6-7. The goodness of fit measures for the CMB calculations of east site.

DATA	DF*	PERCENT %	R^2	CHI^2
4/30/89	22	117	0.96	2.21
5/03/89	22	119	0.94	3.54
5/05/89	22	115	0.95	3.34
5/10/89	23	124	0.95	2.34
5/16/89	23	114	0.95	2.51
AVG	22	118	0.95	2.79

DF*: Degree freedom.

Table 6-8. Dust distributions at west site from 5/20/89 to 5/14/90.

	LIME	PDUST	SOIL
SUMMER	1.50 ± 0.32	26.22 ± 1.23	0.00 ± 0.00
AUTUMN	1.87 ± 0.47	0.00 ± 0.00	1.64 ± 0.79
WINTER	0.36 ± 0.10	3.98 ± 1.87	1.80 ± 1.20
SPRING	4.91 ± 1.79	22.69 ± 2.56	0.00 ± 0.00

Table 6-9. Seasonal source apportionment concentrations at west and east site in Beijing.

WEST SITE								
	HONEYC	INDUST	POWER	BOILER	DUST	SO4	FRIED	MVHDDS
SUMMER	0.00 ± 0.00	7.72 ± 1.87	0.00 ± 0.00	7.16 ± 1.66	27.72 ± 1.47	11.75 ± 1.27	0.00 ± 0.00	29.91 ± 3.24
AUTUMN	4.15 ± 1.98	3.09 ± 0.99	5.25 ± 0.89	7.33 ± 1.74	13.93 ± 2.82	6.25 ± 0.89	1.13 ± 0.58	29.46 ± 3.48
WINTER	5.75 ± 2.07	8.85 ± 1.73	11.88 ± 2.57	11.23 ± 2.67	6.13 ± 2.38	5.52 ± 1.27	0.00 ± 0.00	36.37 ± 4.31
SPRING	1.40 ± 0.41	9.25 ± 2.57	4.89 ± 1.18	13.49 ± 5.73	27.60 ± 9.47	0.77 ± 0.30	0.00 ± 0.00	14.35 ± 6.34

SUMMER: May 20, 1989-Aug 20, 1989　　AUTUMN: Aug. 20, 1989-Nov. 20, 1989
WINTER: Nov. 20, 1989-Feb. 20, 1990　　SPRING: Feb 20, 1990-May 14, 1990

EAST SITE							
	HONEYC	INDUST	BOILER	DUST	SO4	FRIED	MVHDDS
SPRING	3.04 ± 0.35	1.43 ± 0.57	35.34 ± 4.05	37.75 ± 3.56	6.07 ± 1.64	7.71 ± 3.27	39.56 ± 5.04

SPRING. April 30, 1989-May 16, 1989

Table 6-10. Corresponding meteorological data when sampling in Beijing.

DATA	WIND SPEED(M/S)	AZIMUTH
5/20,89	2	220
5/24,89	2.5	290
5/26,89	0	280
5/29,89	1	250
5/31,89	0	100
6/02,89	0	0
6/23,89	0	0
9/19,89	0	30
9/20,89	0	0
9/22,89	0	320
9/29,89	0.2	330
10/06,89	0.4	240
10/20,89	0	270
10/28,89	0	0
10/31,89	1.2	0
11/10,89	0.2	0
11/20,89	0.8	0
12/07,89	0.6	0
12/20,89	0.4	150
12/26,89	1.2	300
1/09,90	3	270
1/23,90	0.5	300
3/13,90	0	0
5/11,90	0.4	180
5/14,90	1	0

*: The data were provided by meteorological observatory near by sampling site.

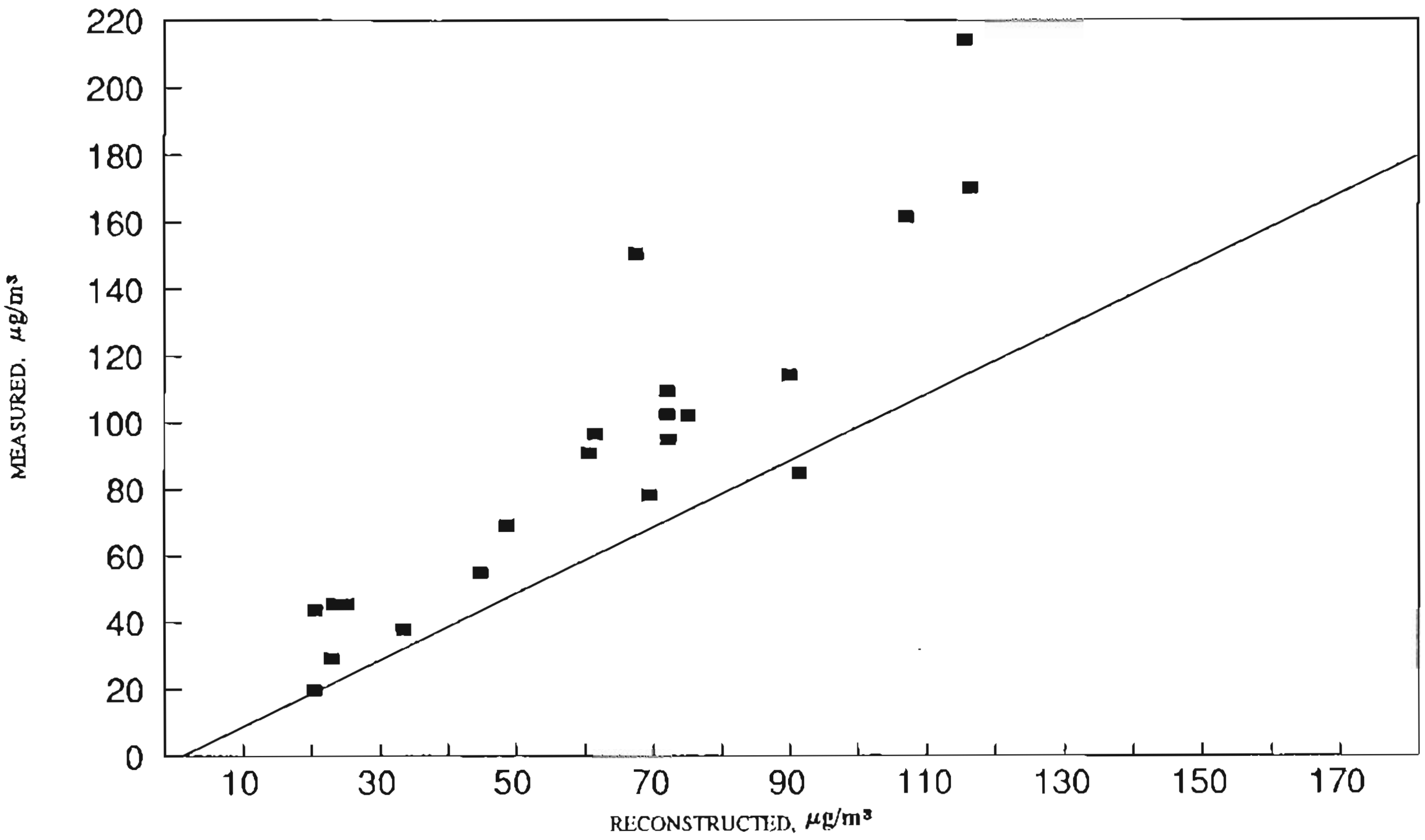


Figure 6-1. The measured gravimetric mass concentrations as a function of reconstructed mass at west site in Beijing.

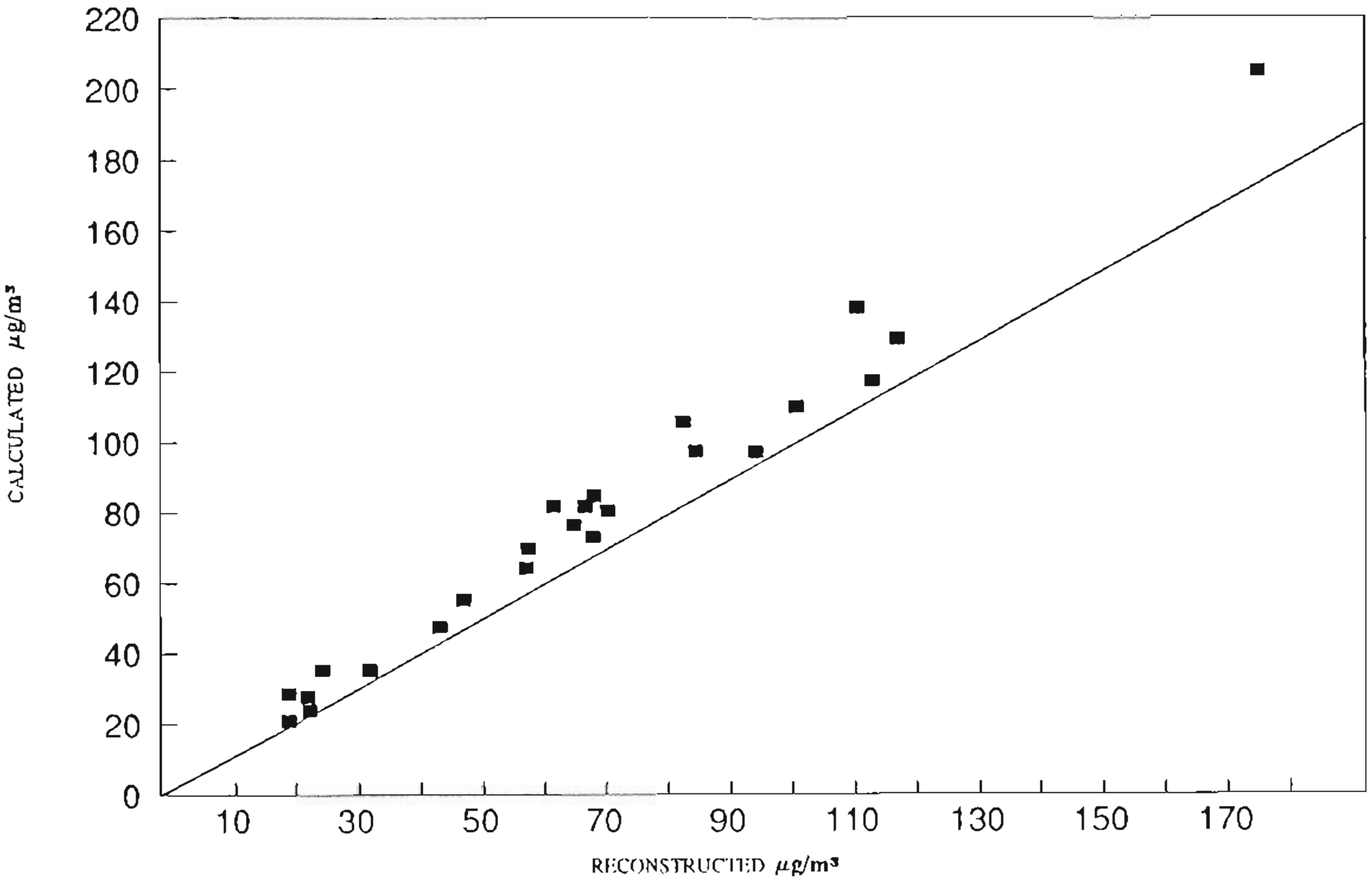


Figure 6-2. The calculated mass by CMB model as a function of reconstructed mass at west site in Beijing.

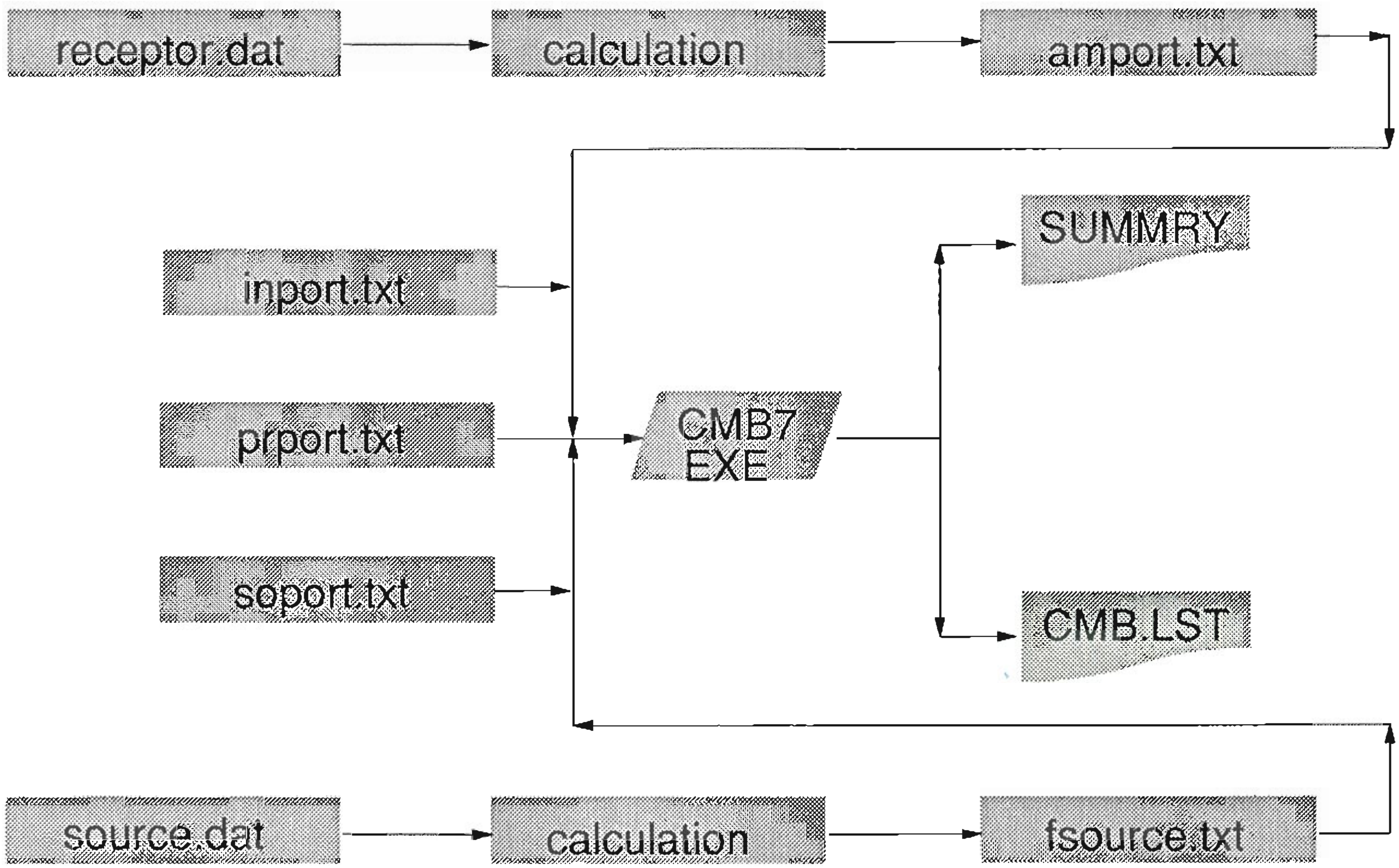


Figure 6-3. Flow diagram of the source apportionment process.

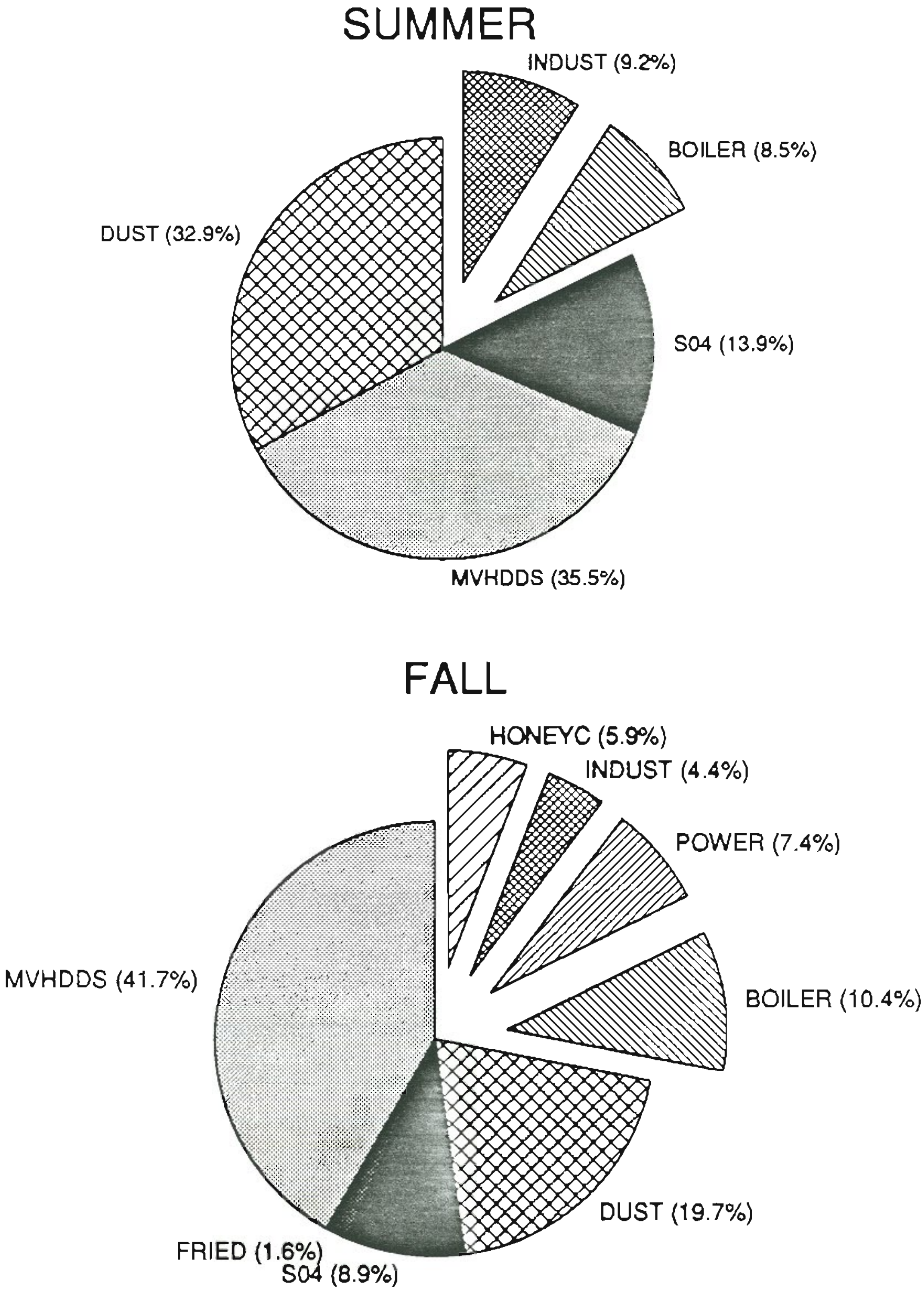


Figure 6-4. The seasonal average source apportionment at west site in Beijing.

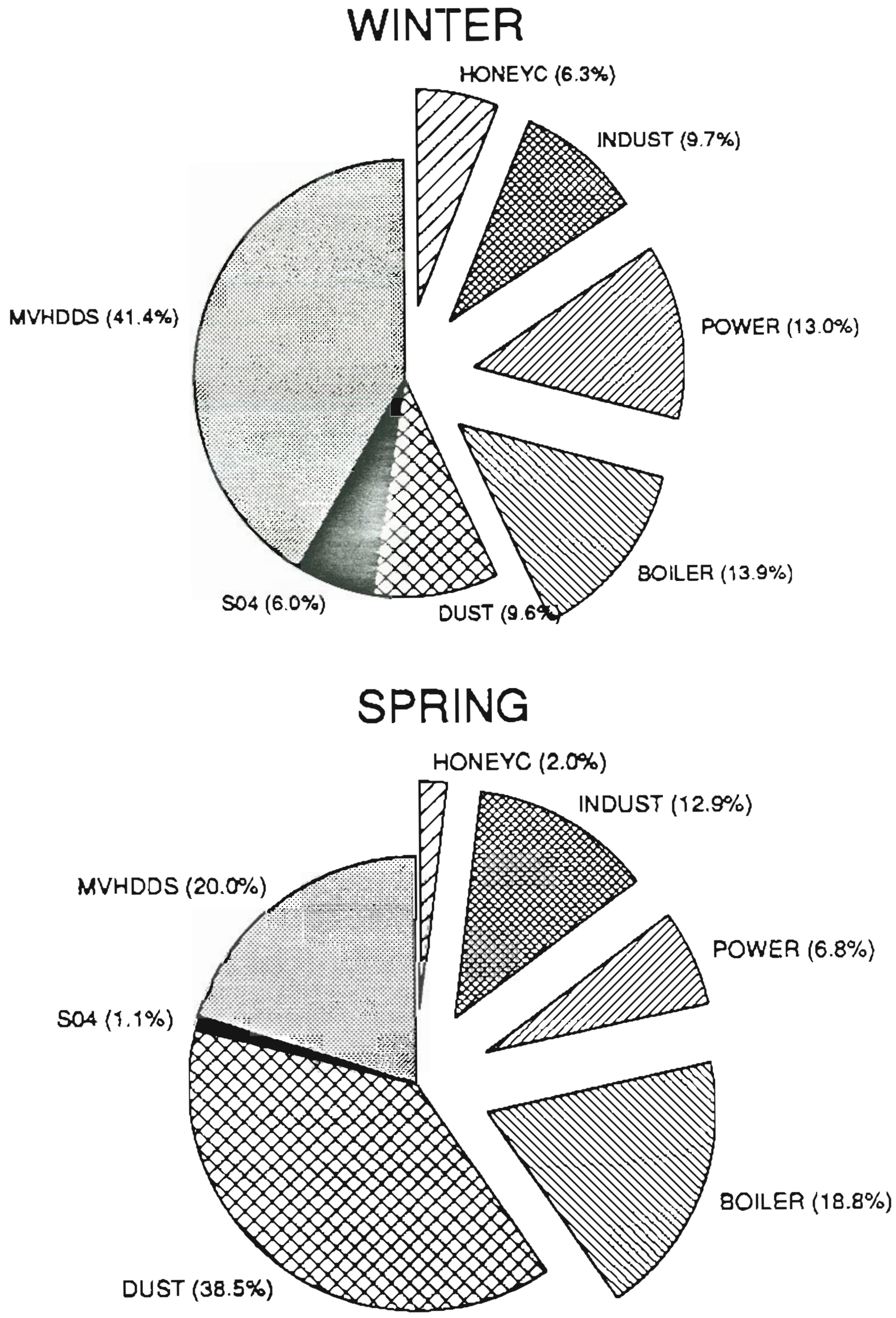


Figure 6-5. The seasonal average source apportionment at west site in Beijing.

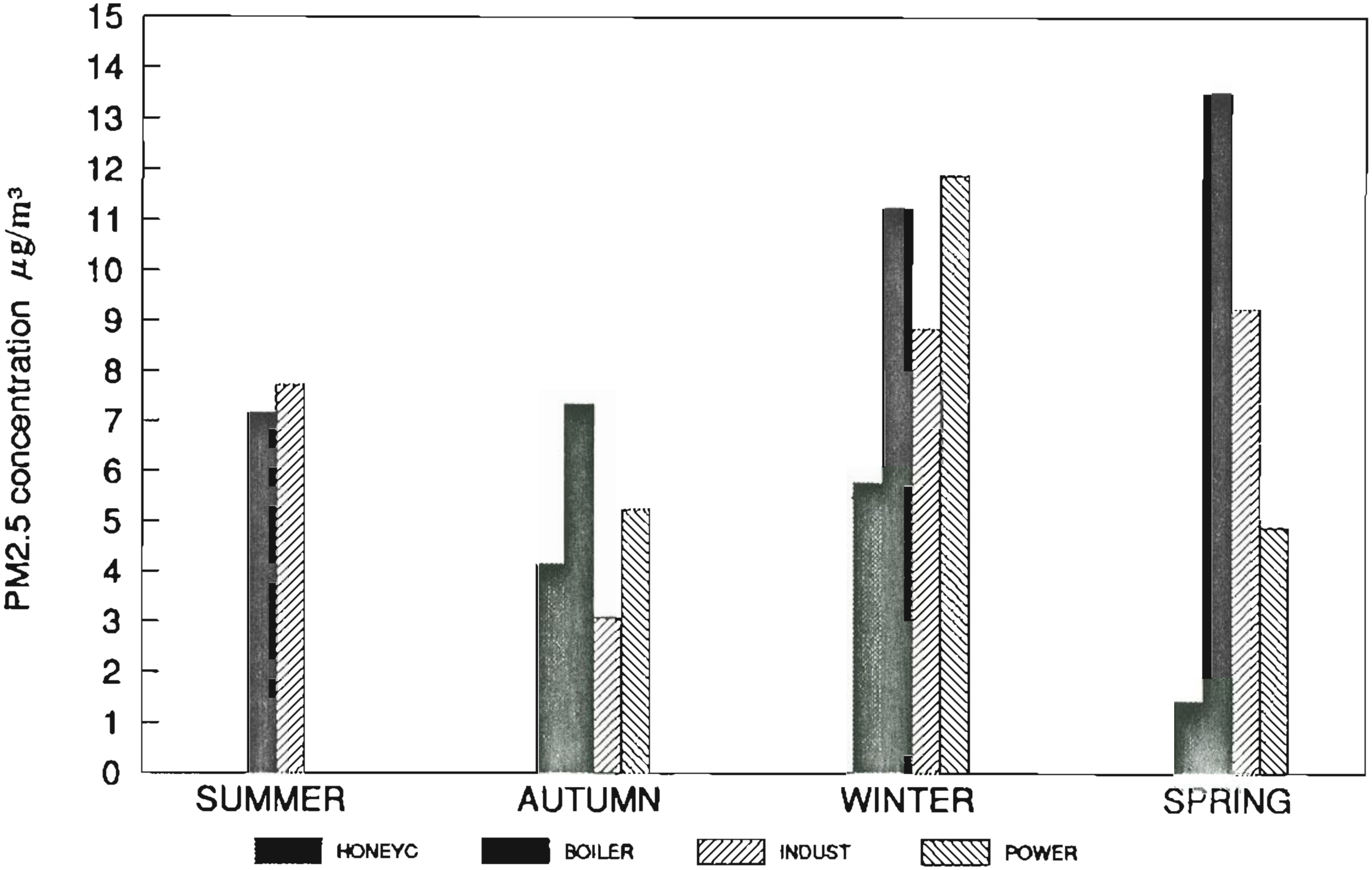


Figure 6-6. The seasonal coal emission contribution at the west site in Beijing.

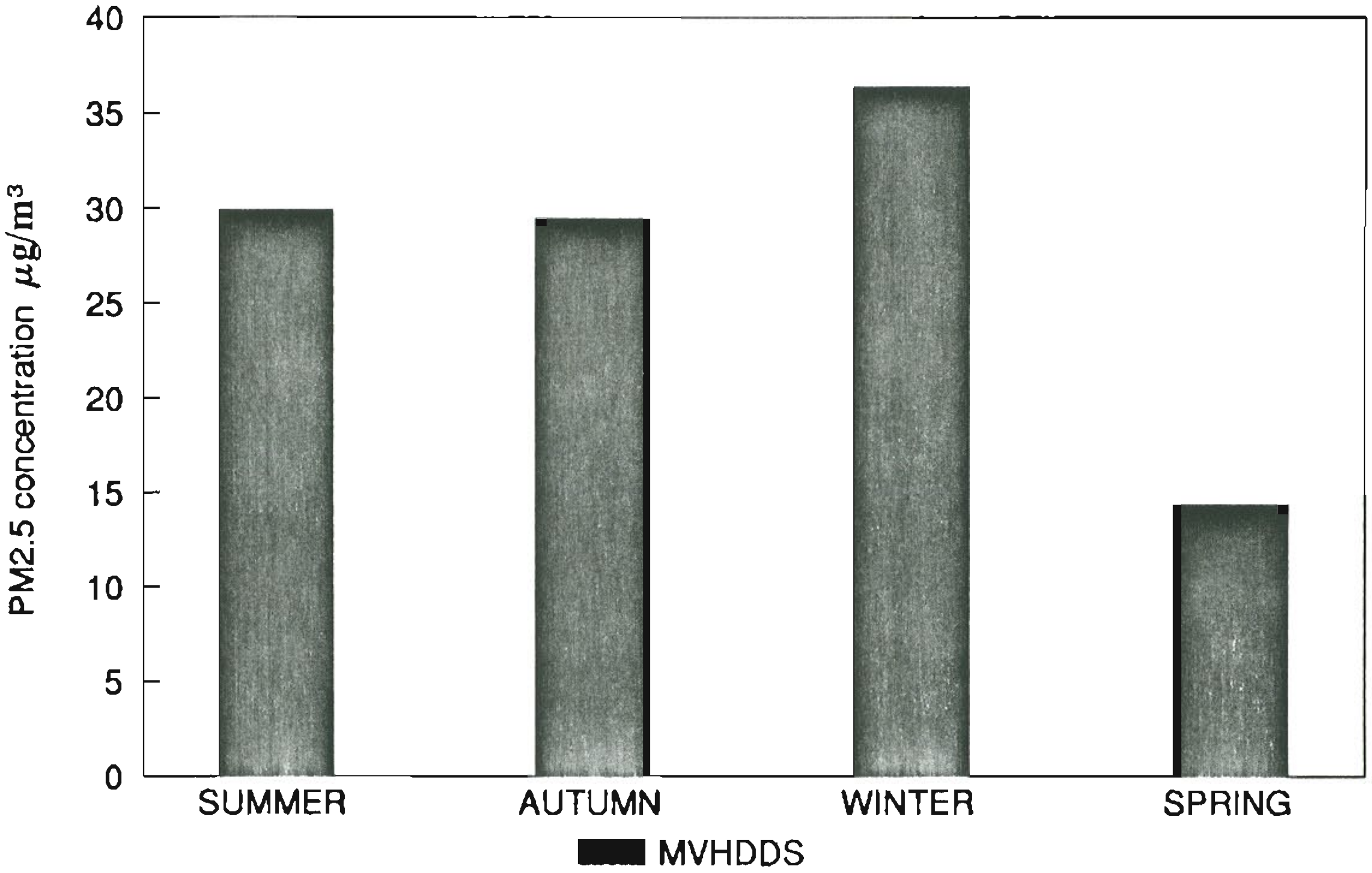


Figure 6-7. The heavy duty diesel emission contributions in different seasons at the west site in Beijing.

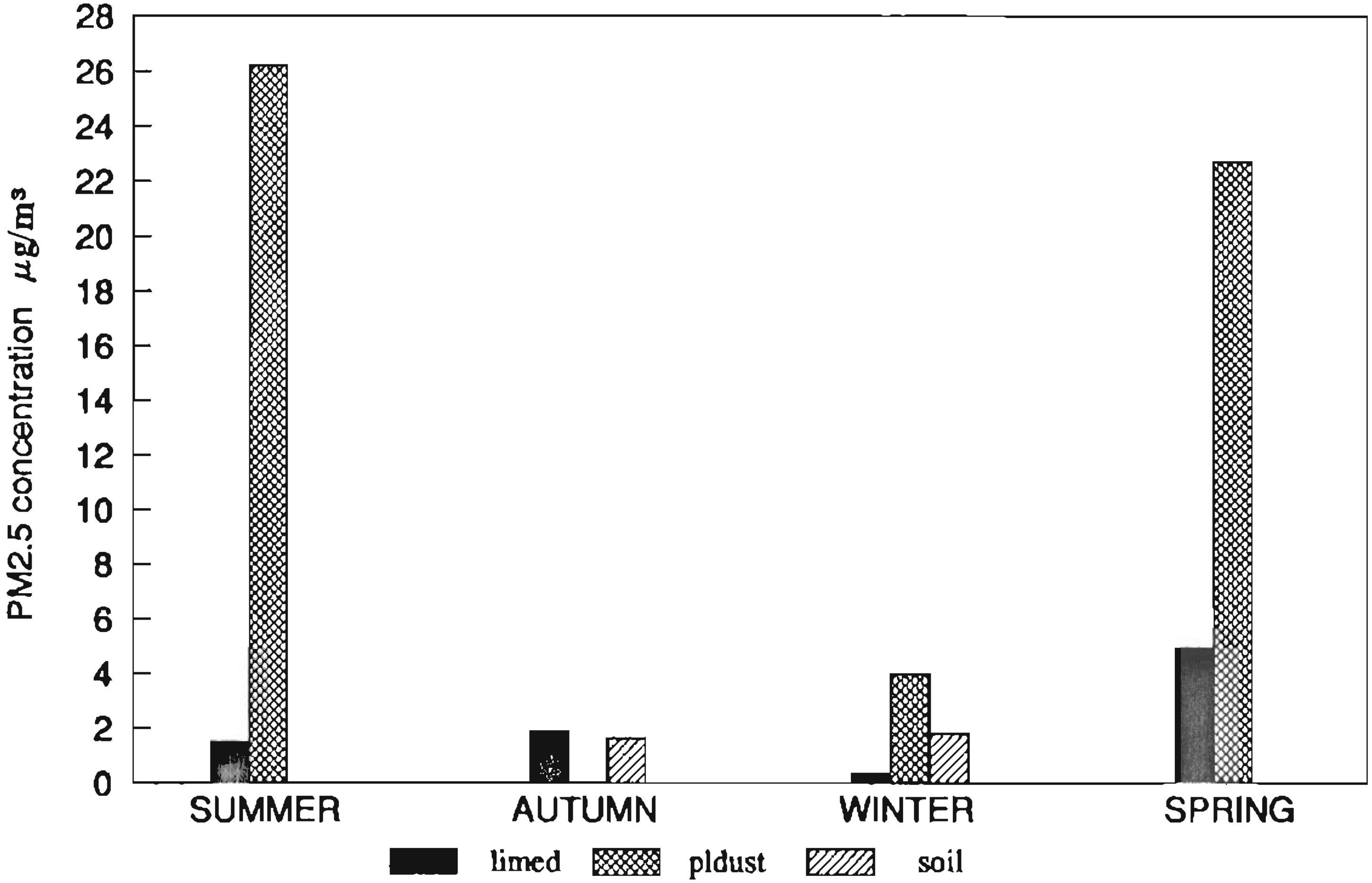


Figure 6-8. The seasonal average dust contributions at west site in Beijing.

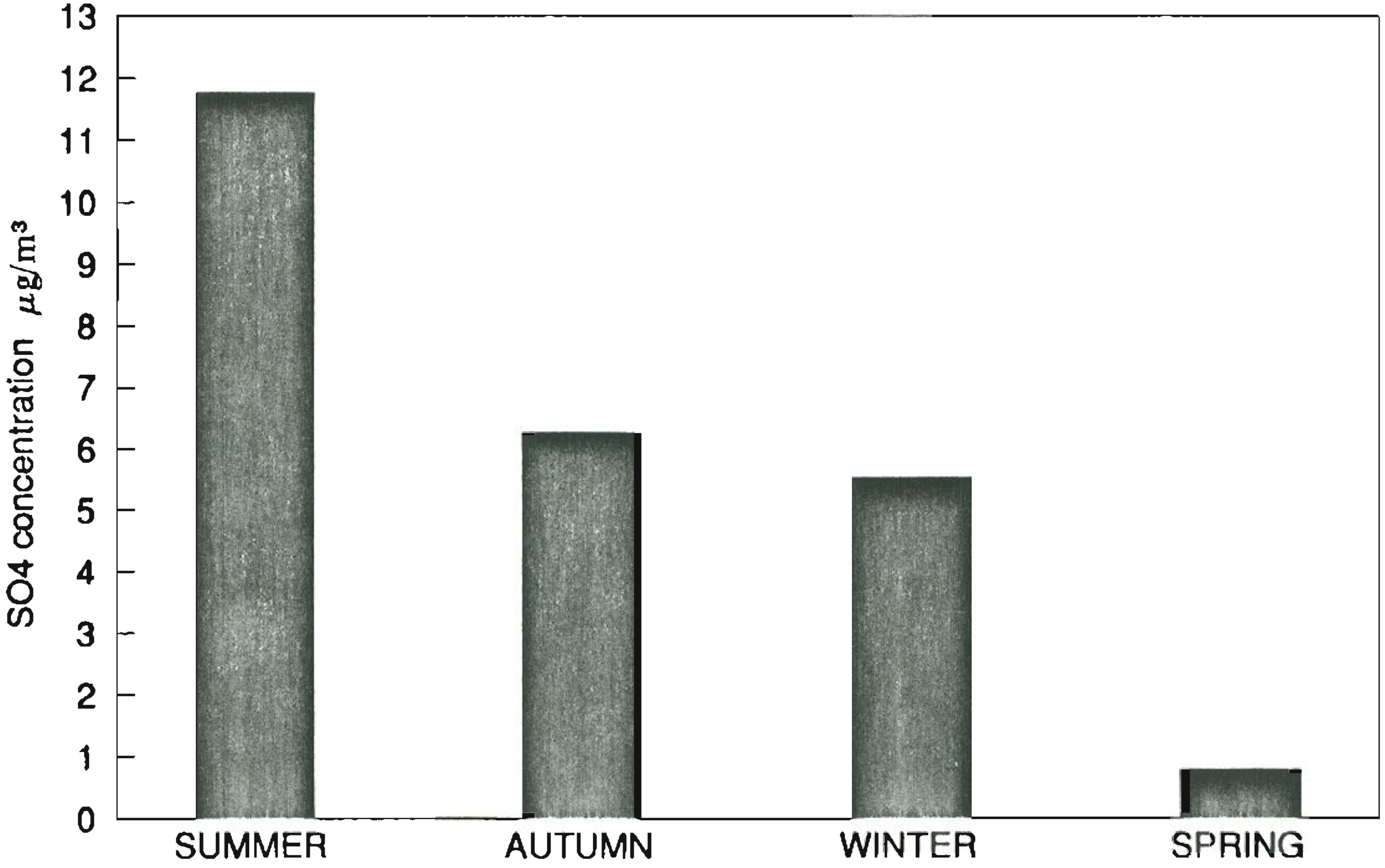
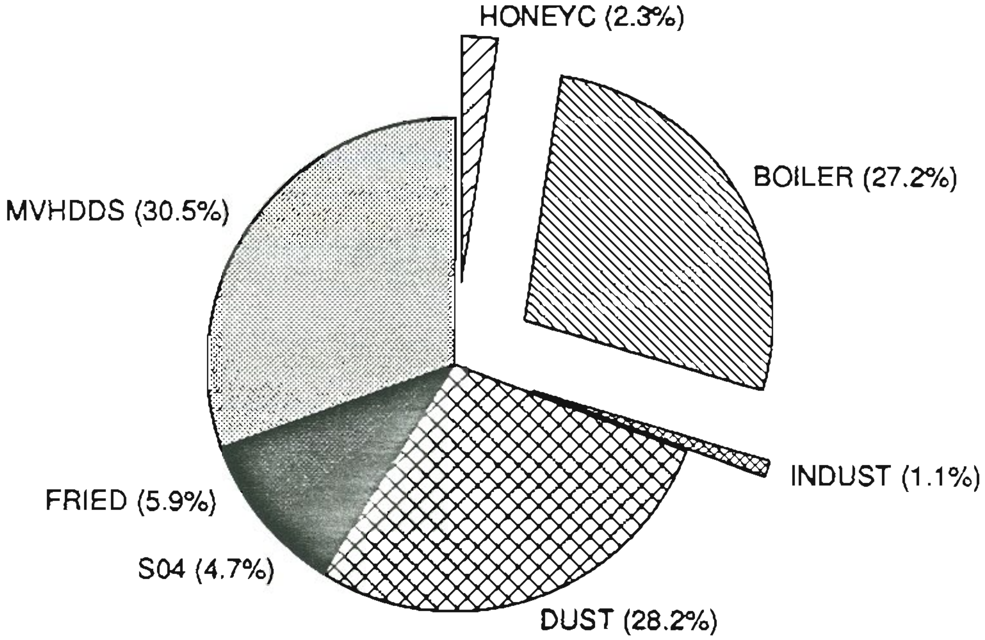
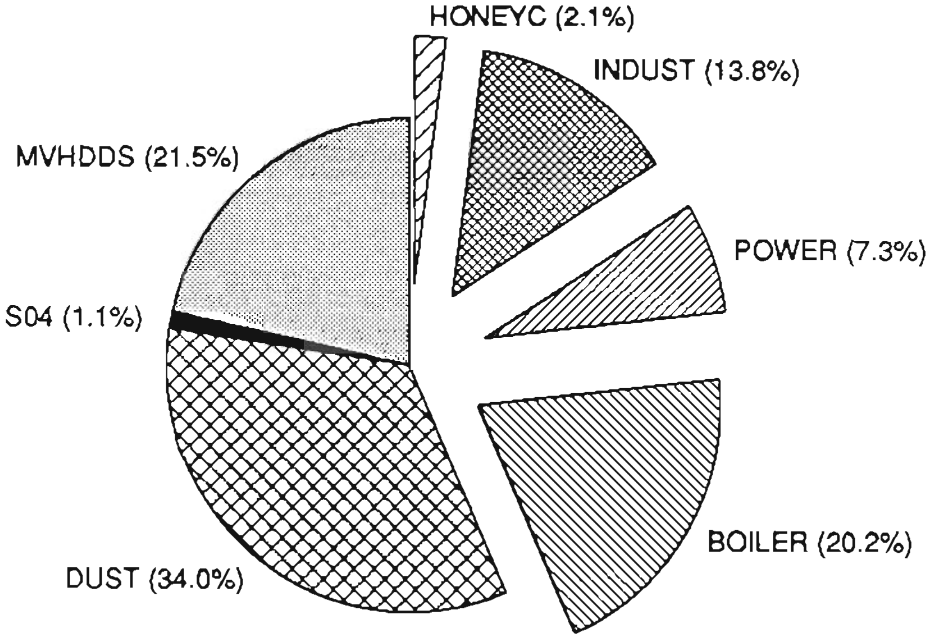


Figure 6-9. Seasonal average sulfate contributions at the west site in Beijing.



EAST SITE

Apr. 30,1989-May 16,1989



SPRING AT THE WEST SITE

Feb. 20, 1990-May 14, 1990

Figure 6-10. The source apportionment comparison between west and east sites in Beijing.

CHAPTER 7.
CONCLUSIONS

The 1989-1990 primary study was designed to evaluate the impact of industrial and residential coal burning on air quality in Beijing, to research the characteristics of OC and EC of Beijing ambient aerosol, to study different emission sources and perform urban source apportionment techniques which can be adopted in future air quality research for other countries where coal is used.

In July 1988 the air above Benxi, in northeast China, was so dirty that the city was invisible on satellite photographs. Mr. Deng Xiaoping set a goal in 1978 that GDP per person will be tripled by the end of the century. That means that China will build more coal power stations and factories which depend on China's own coal, with its average ash content of 27% and sulfur content of up to 5%. If there are not enough efforts on solving coal burning pollution problems, then millions more Chinese may suffer from respiratory disorders, and a few more cities may disappear from satellite photographs (The Economist October 6, 1990).

There are two big problems for Asia's environmental forecast: First, Asia's population is growing roughly twice as fast as Europe's and American's and therefore is the size of Asia's cities. Second, Asia still has a long way to curb pollution from industrial progress (The Economist October 6, 1990).

The key question is how to spend money and manpower efficiently and effectively to solve the coal burning and other pollution problems. This project tried to provide easier ways and less money monitoring, analyzing and modeling to find the pollution targets. The conclusions from this project are as follows:

- The coal charcoal shape might be an important factor for coal burning pollution control and energy efficiency.
- Coal charcoal research may provide new clear and cheap fuel in the future.
- High levels of organic and elemental carbon are important components of aerosol

throughout the year in Beijing.

- During the autumn, winter, and spring combustion appears to be the principal source of organic carbon.
- The composition of coal burning emissions will be strongly dependent on burning temperature, which is an important variable for residential and industrial small boilers. For power plant source profiles, there are more factors which have to be taken into account.
- Source data libraries from the U.S. are good tools for studying other countries' air pollution. However, none of the source profile can be adopted without serious consideration of how they may apply to the specific situation studied.
- The eleven sources included in Beijing's initial CMB fit were: honeycomb coal burning (closed-vent); residential coal boilers; industrial coal burning; power plant coal burning; heavy duty diesel emission, sulfate, soil, road dust, urban dust, cement dust, and cooking emission.
- The dominant air pollution sources in Beijing were: coal burning emission,heavy duty diesel vehicle emissions and dust. The yearly average contributions for each source were approximately one third of the total emissions.
- Coal burning emissions were derived approximately equally from residential coal burning and industrial coal burning, although the residential coal consumption is only around 10%-15% of total coal consumption in Beijing.
- Honeycomb coal closed-vent burning results in insufficient combustion, poor energy efficiency and air pollution.
- Another important source of residential coal burning is residential boilers, which are widely used in Beijing, but have not attracted much attention yet.
- CMB modeling can be used in China for urban air pollution control strategy purpose.

CHAPTER 8.
SUGGESTIONS

In the United States, Congress has appropriated a total budget of about $2.75 billion for the five phases of the clean-coal program. This includes several gasification and liquefaction methods designed to use the coal within environmental limits. These are good methods to reduce coal burning pollution. However, they are also very expensive.

Different kinds of coal in China has been evaluated in this project. The new kids of coal are clean, cheap and easy to transport. Some of the ingredients of the coal recipes can even come from industrial wastes (Yao, Wei-ji, 1990). Although worldwide coal usage will grow sharply this decade, poor developing countries may never afford the expense of coal liquefaction and gasification. Chinese scientists (Hu, 1991) said they already have specific coal for different uses such as for residential consumption, boilers, and steel industries. But to date, the environmental impacts of the new coals have not been fully evaluated yet.

China, with a fifth of the world's population and world's leading producer of coal, burned 76% of her coal output every year. Table 8-1 indicates the comparison of energy production and consumption between China and the world. It shows that much more coal is used than natural gas and waterpower in China. One reason for this situation is that the price of coal has been kept too low to provide any incentive to develop other energies. Both the investment interest and the tax of hydropower are higher than that of coal and oil. China's coal price is so far below the world price that factory managers have no incentive to use it efficiently. They may be punished only if the coal smoke out of the chimneys is black. It is no surprised that environmental scientists can not find enough money for coal pollution control research. The International Newspaper (April 10, 1992) reported that the output of coal product in China is top one in the world now. However, the deficit of coal production is also top one among all products in China, for example, the deficit of coal production in 1990 was about 150 million $ in China. This is because that in China the coal selling price is much cheaper than coal production cost. Therefore, it is important to increase the coal price step by step in order to stimulate alternate energy development in China. Other areas of air quality improvement will come from housestove and boiler design, curbing wasteful coal usage, and abatement of coal burning emissions.

From this year (1992) until 1997, Chinese government has being operating the new eight five plan. The new environmental policies emphasize global climate change research, but not much plan on improving coal burning efficiency study. There are tremendous difficulties in coal burning control research since it is not only related to science and technologies, but also influenced by population growth, economic development and political factors mentioned in Chapter 1. Many Chinese environmental scientists are interested in this topic. But they need more information, they lack money, necessary technology, and equipment. Sometimes they are not sure which data can be published and which can not. It is important to establish wide international cooperation for coal burning control research in China. However, this cooperation can not do well without reforming Chinese policies and more freedom for Chinese environmental scientists. More of an open door policy in China is needed for international cooperation to study coal burning pollution control.

It would be very beneficial for American scientists to cooperate with Chinese scientists on the new kinds of coal research. Coal has been used in China for a long time and new varieties have been created there. American scientists could not only assist in evaluating the environmental impact of the new kinds of coal, but also cooperate with Chinese Scientists to create variable new kinds of coal for next decade.

Table 8-1. The comparison of energy consumption between China and the world

	China % (1985)		world % (1980)
	production	consumption	consumption
coal	72.8	75.8	25.9
fossil oil	20.9	17.1	45.6
natural gas	2.0	2.3	18.5
waterpower	4.3	4.8	6.3
nuclear	0	0	2.6
others	0	0	1.1

(Tian Fang et al., 1988)

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APPENDIX A. SOURCE LIBRARIES OF BEIJING'S PROJECT.

There are thirteen source profiles which were derived from Beijing's source samples. The rest are source profiles from the U.S., which fit Beijing's ambient data.

Table A-1. SOURCE DATA

Type: ball coal when closed-vent mode
Location: Beijing Contributor:
Date: 5/08/90
Cut point: 2.5µm
Unit: element/mass

species number	specie name	% by WT	uncertain
13	AL	0.00110	0.00027
14	SI	0.01124	0.00056
15	P	0.00137	0.00041
16	S	0.03781	0.00045
17	CL	0.32439	0.00150
19	K	0.00551	0.00017
20	CA	0.00820	0.00017
22	TI	0.00038	0.00080
23	VA	0.00016	0.00034
24	CR	0.00024	0.00004
25	MN	0.00146	0.00005
26	FE	0.01943	0.00013
27	CO	0.00014	0.00266
28	NI	0.00025	0.00002
29	CU	0.00017	0.00002
30	ZN	0.01876	0.00009
31	GA	0.00004	0.00014
33	AS	0.00003	0.00094
34	SE	0.00165	0.00003
35	BR	0.00188	0.00004
37	RB	0.00001	0.00004
38	SR	0.00008	0.00003
40	ZR	0.00004	0.00005
42	MO	0.00006	0.00010
49	IN	0.00032	0.00053
51	SB	0.00017	0.00071
56	BA	0.00000	0.00198
82	PB	0.00934	0.00011
201	OC	0.06499	0.00450
202	EC	0.04852	0.00440

Table A-2. SOURCE DATA

Type: ball coal burning when open mode
Location: Beijing
Contributor:
Date: 05/08/90
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00279	0.00061
14	SI	0.00769	0.00264
15	P	0.00359	0.00085
16	S	0.08277	0.00120
17	CL	0.07876	0.00064
19	K	0.00314	0.00010
20	CA	0.00378	0.00009
22	TI	0.00055	0.00038
23	VA	0.00012	0.00023
24	CR	0.00011	0.00004
25	MN	0.00032	0.00002
26	FE	0.00803	0.00006
27	CO	0.00008	0.00011
28	NI	0.00008	0.00001
29	CU	0.00024	0.00002
30	ZN	0.02754	0.00008
31	GA	0.00013	0.00045
33	AS	0.00045	0.00699
34	SE	0.00126	0.00004
35	BR	0.00067	0.00023
37	RB	0.00002	0.00008
38	SR	0.00010	0.00003
40	ZR	0.00004	0.00007
42	MO	0.00010	0.00004
49	IN	0.00008	0.00036
51	SB	0.00008	0.00048
56	BA	0.00000	0.00129
82	PB	0.03870	0.00014
201	OC	0.03210	0.00230
202	EC	0.03070	0.00280
203	SO4	0.24830	0.00360

Table A-3. SOURCE DATA

Type: Honeycomb coal burning when closed mode
Location: Beijing Contributor:
Date: 05/07/90
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00026	0.00006
14	SI	0.00158	0.00024
15	P	0.00013	0.00021
16	S	0.01765	0.00048
17	CL	0.34504	0.00040
19	K	0.00229	0.00003
20	CA	0.00196	0.00003
22	TI	0.00031	0.00004
23	VA	0.00005	0.00002
24	CR	0.00005	0.00001
25	MN	0.00005	0.00001
26	FE	0.00151	0.00001
27	CO	0.00002	0.00002
28	NI	0.00002	0.00002
29	CU	0.00002	0.00006
30	ZN	0.00001	0.00791
31	GA	0.00002	0.00005
33	AS	0.00018	0.00012
34	SE	0.00290	0.00076
35	BR	0.00015	0.00082
37	RB	0.00005	0.00001
38	SR	0.00004	0.00006
40	ZR	0.00001	0.00003
42	MO	0.00003	0.00000
49	IN	0.00001	0.00000
51	SB	0.00008	0.00007
56	BA	0.00000	0.00026
82	PB	0.01599	0.00004
201	OC	0.01078	0.00080
202	EC	0.02974	0.00270
203	SO4	0.11530	0.00119

Table A-4. SOURCE DATA

Type: honeycomb coal burning when open mode
Location: Beijing   Contributor:
Date: 05/07/90
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00036	0.00047
14	SI	0.00291	0.00232
15	P	0.00298	0.00238
16	S	0.09433	0.00124
17	CL	0.01154	0.00029
19	K	0.01656	0.00019
20	CA	0.00364	0.00012
22	TI	0.00038	0.00033
23	VA	0.00011	0.00021
24	CR	0.00009	0.00004
25	MN	0.00018	0.00002
26	FE	0.00302	0.00004
27	CO	0.00009	0.00002
28	NI	0.00010	0.00001
29	CU	0.00292	0.00003
30	ZN	0.03786	0.00009
31	GA	0.00224	0.00016
33	AS	0.00142	0.00725
34	SE	0.00090	0.00004
35	BR	0.00030	0.00029
37	RB	0.00008	0.00002
38	SR	0.00008	0.00002
40	ZR	0.00003	0.00008
42	MO	0.00023	0.00002
49	IN	0.00028	0.00033
51	SB	0.00073	0.00018
56	BA	0.00000	0.00117
82	PB	0.04024	0.00014
201	OC	0.39960	0.02800
202	EC	0.04680	0.00420
203	SO4	0.28298	0.00371

Table A-5. SOURCE DATA

Type: industrial coal boiler
Location: Beijing
Contributor:
Date: 07/25/1990
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.04784	0.00044
14	SI	0.06490	0.00065
15	P	0.01253	0.00054
16	S	0.04924	0.00028
17	CL	0.00112	0.00007
19	K	0.01102	0.00011
20	CA	0.01061	0.00010
22	TI	0.00802	0.00010
23	VA	0.00049	0.00009
24	CR	0.00043	0.00002
25	MN	0.00024	0.00002
26	FE	0.01524	0.00006
27	CO	0.00017	0.00020
28	NI	0.00037	0.00001
29	CU	0.00360	0.00002
30	ZN	0.01054	0.00003
31	GA	0.00268	0.00004
33	AS	0.00058	0.00152
34	SE	0.00014	0.00001
35	BR	0.00007	0.00004
37	RB	0.00008	0.00001
38	SR	0.00115	0.00001
40	ZR	0.00099	0.00002
42	MO	0.00027	0.00001
49	IN	0.00004	0.00014
51	SB	0.00022	0.00016
56	BA	0.00037	0.00053
82	PB	0.00845	0.00004
201	OC	0.12802	0.00900
202	EC	0.05093	0.00460
203	SO4	0.14772	0.00084

Table A- 6. SOURCE DATA

Type: soil
Location: Beijing
Contributor:
Date: 05/08/90
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.06908	0.00097
14	SI	0.13037	0.00061
15	P	0.00172	0.00017
16	S	0.00295	0.00011
17	CL	0.00000	0.00062
19	K	0.01518	0.00048
20	CA	0.08020	0.00053
22	TI	0.00539	0.00041
23	VA	0.00041	0.00057
24	CR	0.00042	0.00007
25	MN	0.00119	0.00008
26	FE	0.04157	0.00021
27	CO	0.00022	0.00056
28	NI	0.00004	0.00011
29	CU	0.00077	0.00005
30	ZN	0.00035	0.00004
31	GA	0.00000	0.00011
33	AS	0.00000	0.00013
34	SE	0.00000	0.00007
35	BR	0.00000	0.00006
37	RB	0.00009	0.00002
38	SR	0.00075	0.00002
40	ZR	0.00023	0.00003
42	MO	0.00000	0.00014
49	IN	0.00017	0.00073
51	SB	0.00000	0.00099
56	BA	0.00022	0.00285
82	PB	0.00006	0.00016
201	OC	0.12718	0.00890
202	EC	0.02269	0.00204
203	SO4	0.00886	0.00032

Table A-7. SOURCE DATA

Type: Ball coal ash
Location: Beijing   Contributor:
Date: 07/25/90
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertainty
13	AL	0.10424	0.00074
14	SI	0.12429	0.00027
15	P	0.00061	0.00014
16	S	0.00360	0.00004
17	CL	0.00000	0.00010
19	K	0.01500	0.00020
20	CA	0.03809	0.00015
22	TI	0.01819	0.00018
23	VA	0.00060	0.00062
24	CR	0.00039	0.00003
25	MN	0.00061	0.00003
26	FE	0.03186	0.00007
27	CO	0.00023	0.00042
28	NI	0.00014	0.00001
29	CU	0.00077	0.00001
30	ZN	0.00011	0.00001
31	GA	0.00008	0.00001
33	AS	0.00000	0.00004
34	SE	0.00000	0.00001
35	BR	0.00001	0.00000
37	RB	0.00010	0.00000
38	SR	0.00371	0.00001
40	ZR	0.00197	0.00005
42	MO	0.00002	0.00005
49	IN	0.00001	0.00012
51	SB	0.00000	0.00016
56	BA	0.00356	0.00017
82	PB	0.00017	0.00001
201	OC	0.04465	0.00313
202	EC	0.05144	0.00463
203	SO4	0.01081	0.00011

Table A-8. SOURCE DATA

Type: industrial coal ash
Location: Beijing Contributor:
Date: 07/25/1990
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.09703	0.00083
14	SI	0.13099	0.00035
15	P	0.00108	0.00022
16	S	0.00435	0.00006
17	CL	0.00032	0.00008
19	K	0.00480	0.00029
20	CA	0.05867	0.00025
22	TI	0.01160	0.00020
23	VA	0.00042	0.00044
24	CR	0.00030	0.00003
25	MN	0.00063	0.00004
26	FE	0.02739	0.00010
27	CO	0.00018	0.00036
28	NI	0.00014	0.00001
29	CU	0.00023	0.00001
30	ZN	0.00018	0.00001
31	GA	0.00001	0.00004
33	AS	0.00002	0.00005
34	SE	0.00000	0.00002
35	BR	0.00000	0.00002
37	RB	0.00003	0.00001
38	SR	0.00192	0.00001
40	ZR	0.00112	0.00003
42	MO	0.00001	0.00005
49	IN	0.00000	0.00024
51	SB	0.00003	0.00032
56	BA	0.00267	0.00032
82	PB	0.00010	0.00002
201	OC	0.11160	0.00781
202	EC	0.17169	0.01545
203	SO4	0.01306	0.00017

Table A-9. SOURCE DATA

Type: industrial coal burning dust
Location: Beijing Contributor:
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.09350	0.00098
14	SI	0.11568	0.00065
15	P	0.00239	0.00028
16	S	0.02133	0.00020
17	CL	0.00076	0.00019
19	K	0.00679	0.00025
20	CA	0.02432	0.00031
22	TI	0.01030	0.00042
23	VA	0.00058	0.00065
24	CR	0.00061	0.00007
25	MN	0.00059	0.00007
26	FE	0.02627	0.00018
27	CO	0.00018	0.00037
28	NI	0.00028	0.00004
29	CU	0.00212	0.00006
30	ZN	0.00082	0.00005
31	GA	0.00007	0.00011
33	AS	0.00026	0.00006
34	SE	0.00003	0.00007
35	BR	0.00008	0.00002
37	RB	0.00003	0.00005
38	SR	0.00171	0.00003
40	ZR	0.00110	0.00004
42	MO	0.00009	0.00013
49	IN	0.00000	0.00071
51	SB	0.00000	0.00097
56	BA	0.00007	0.00285
82	PB	0.00064	0.00006
201	OC	0.40056	0.02804
202	EC	0.57101	0.05139
203	SO4	0.06398	0.00060

Table A-10. SOURCE DATA

Type: honeycomb coal ash
Location: Beijing Contributor:
Date: 07/25/1990
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.11845	0.00098
14	SI	0.15332	0.00043
15	P	0.00091	0.00030
16	S	0.00380	0.00006
17	CL	0.00000	0.00027
19	K	0.01543	0.00026
20	CA	0.04156	0.00024
22	TI	0.01589	0.00027
23	VA	0.00058	0.00061
24	CR	0.00041	0.00004
25	MN	0.00067	0.00005
26	FE	0.03996	0.00013
27	CO	0.00027	0.00053
28	NI	0.00014	0.00002
29	CU	0.00067	0.00002
30	ZN	0.00019	0.00002
31	GA	0.00000	0.00004
33	AS	0.00000	0.00006
34	SE	0.00000	0.00003
35	BR	0.00000	0.00002
37	RB	0.00009	0.00001
38	SR	0.00311	0.00002
40	ZR	0.00151	0.00004
42	MO	0.00001	0.00006
49	IN	0.00000	0.00029
51	SB	0.00000	0.00040
56	BA	0.00448	0.00040
82	PB	0.00016	0.00002
201	OC	0.07923	0.00555
202	EC	0.00019	0.00002
203	SO4	0.01141	0.00019

Table A-11. SOURCE DATA

Type: honeycomb coal
Location: Beijing Contributor:
Date: 05/08/1990
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.06067	0.00063
14	SI	0.08517	0.00036
15	P	0.00000	0.00023
16	S	0.00260	0.00006
17	CL	0.00000	0.00032
19	K	0.00928	0.00019
20	CA	0.02186	0.00021
22	TI	0.00281	0.00021
23	VA	0.00020	0.00030
24	CR	0.00015	0.00004
25	MN	0.00039	0.00004
26	FE	0.01498	0.00009
27	CO	0.00009	0.00021
28	NI	0.00003	0.00006
29	CU	0.00020	0.00002
30	ZN	0.00005	0.00007
31	GA	0.00000	0.00006
33	AS	0.00001	0.00007
34	SE	0.00000	0.00004
35	BR	0.00000	0.00003
37	RB	0.00003	0.00003
38	SR	0.00044	0.00001
40	ZR	0.00010	0.00002
42	MO	0.00000	0.00007
49	IN	0.00000	0.00038
51	SB	0.00000	0.00052
56	BA	0.00000	0.00149
82	PB	0.00001	0.00008
201	OC	0.04963	0.00347
202	EC	0.84925	0.07643
203	SO4	0.00781	0.00019

Table A-12. SOURCE DATA

Type: coal fireplace
Location: Indian area of the U.S.   Contributor: John Houck
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00645	0.00088
14	SI	0.00400	0.00056
15	P	0.00008	0.00145
16	S	0.01824	0.00134
17	CL	0.00101	0.00017
19	K	0.00086	0.00012
20	CA	0.01425	0.00111
22	TI	0.00072	0.00068
23	VA	0.00012	0.00031
24	CR	0.00002	0.00007
25	MN	0.00007	0.00004
26	FE	0.00216	0.00017
27	CO	0.00002	0.00005
28	NI	0.00002	0.00001
29	CU	0.00008	0.00002
30	ZN	0.00065	0.00005
31	GA	0.00002	0.00009
33	AS	0.00005	0.00001
34	SE	0.00007	0.00002
35	BR	0.00004	0.00001
37	RB	0.00000	0.00004
38	SR	0.00058	0.00005
40	ZR	0.00006	0.00007
42	MO	0.00013	0.00008
49	IN	0.00024	0.00041
51	SB	0.00007	0.00061
56	BA	0.00000	0.00226
82	PB	0.00039	0.00005
201	OC	0.61936	0.04587
202	EC	0.26783	0.03351
203	SO4	0.03601	0.00267

Table A-13. SOURCE DATA

Type: coal-fired power station 1
Location: U.S.A. Contributor: John Houck
Date:
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.06390	0.00488
14	SI	0.09130	0.00690
15	P	0.00367	0.00104
16	S	0.00593	0.00212
17	CL	0.00073	0.00029
19	K	0.00491	0.00041
20	CA	0.02561	0.00195
22	TI	0.00402	0.00047
23	VA	0.00000	0.00046
24	CR	0.00015	0.00004
25	MN	0.00034	0.00020
26	FE	0.02712	0.00466
27	CO	0.00000	0.00041
28	NI	0.00009	0.00002
29	CU	0.00023	0.00015
30	ZN	0.00086	0.00049
31	GA	0.00000	0.00013
33	AS	0.00000	0.00021
34	SE	0.00007	0.00003
35	BR	0.00026	0.00015
37	RB	0.00000	0.00006
38	SR	0.00137	0.00028
40	ZR	0.00023	0.00005
42	MO	0.00000	0.00018
49	IN	0.00000	0.00056
51	SB	0.00000	0.00086
56	BA	0.00370	0.00221
82	PB	0.00096	0.00022
201	OC	0.04416	0.04204
202	EC	0.06676	0.02549
203	SO4	0.02120	0.00550

Table A-14. SOURCE DATA

Type: cement Kiln. (coal fired)
Location: U.S.A. Contributor: EPA
Date: 27203
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.02110	0.00211
14	SI	0.06500	0.00650
15	P	0.00126	0.00040
16	S	0.01023	0.00104
17	CL	0.00455	0.00048
19	K	0.00163	0.00042
20	CA	0.29515	0.02951
22	TI	0.00081	0.00008
23	VA	0.00000	0.00001
24	CR	0.00000	0.00001
25	MN	0.00050	0.00001
26	FE	0.01043	0.00104
27	CO	0.00000	0.00001
28	NI	0.00000	0.00001
29	CU	0.00016	0.00002
30	ZN	0.00104	0.00010
31	GA	0.00000	0.00001
33	AS	0.00020	0.00013
34	SE	0.00000	0.00001
35	BR	0.00027	0.00003
37	RB	0.00000	0.00001
38	SR	0.00024	0.00002
40	ZR	0.00000	0.00001
42	MO	0.00000	0.00001
49	IN	0.00000	0.00047
51	SB	0.00000	0.00095
56	BA	0.00000	0.00256
82	PB	0.00270	0.00027
201	OC	0.00000	0.00001
202	EC	0.00000	0.00001
203	SO4	0.00000	0.00001

Table A-15. SOURCE DATA

Type: urban dust
Location: U.S.A. Contributor: DRI
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.08840	0.02710
14	SI	0.22300	0.01100
15	P	0.00000	0.00001
16	S	0.00370	0.00140
17	CL	0.00000	0.00010
19	K	0.01030	0.00060
20	CA	0.02440	0.00400
22	TI	0.00640	0.00120
23	VA	0.00023	0.00005
24	CR	0.00045	0.00017
25	MN	0.00123	0.00017
26	FE	0.06000	0.00600
27	CO	0.00000	0.00001
28	NI	0.00009	0.00003
29	CU	0.00030	0.00012
30	ZN	0.00110	0.00037
31	GA	0.00000	0.00001
33	AS	0.00020	0.00006
34	SE	0.00000	0.00001
35	BR	0.00000	0.00001
37	RB	0.00000	0.00001
38	SR	0.00000	0.00001
40	ZR	0.00000	0.00001
42	MO	0.00000	0.00001
49	IN	0.00000	0.00001
51	SB	0.00000	0.00001
56	BA	0.00000	0.00001
82	PB	0.00370	0.00150
201	OC	0.11800	0.04300
202	EC	0.01850	0.00910
203	SO4	0.00420	0.00310

Table A-16. SOURCE DATA

Type: carborundum manufacturing
Location: U.S.A. Contributor: DRI
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00079	0.00028
14	SI	0.00108	0.00069
15	P	0.00102	0.00023
16	S	0.00068	0.00067
17	CL	0.00088	0.00009
19	K	0.00165	0.00145
20	CA	0.00066	0.00053
22	TI	0.00010	0.00013
23	VA	0.00003	0.00002
24	CR	0.00000	0.00006
25	MN	0.00000	0.00004
26	FE	0.00071	0.00067
27	CO	0.00000	0.00001
28	NI	0.00007	0.00001
29	CU	0.00344	0.00362
30	ZN	0.00216	0.00234
31	GA	0.00000	0.00003
33	AS	0.00020	0.00030
34	SE	0.00001	0.00005
35	BR	0.00009	0.00008
37	RB	0.00000	0.00007
38	SR	0.00004	0.00008
40	ZR	0.00000	0.00001
42	MO	0.00027	0.00039
49	IN	0.00029	0.00044
51	SB	0.00000	0.00027
56	BA	0.00199	0.00195
82	PB	0.00027	0.00042
201	OC	0.52397	0.03304
202	EC	0.00000	0.00700
203	SO4	0.00000	0.00001

Table A-17. SOURCE DATA

Type: fried cook emission
Location: U.S.A. Contributor: Lynn Hildemann
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00000	0.00244
14	SI	0.00000	0.00018
15	P	0.00000	0.00075
16	S	0.01638	0.02051
17	CL	0.00354	0.01162
19	K	0.00363	0.00004
20	CA	0.00149	0.00171
22	TI	0.00000	0.00133
23	VA	0.00000	0.00035
24	CR	0.00149	0.00138
25	MN	0.00041	0.00067
26	FE	0.00237	0.00376
27	CO	0.00000	0.00001
28	NI	0.00049	0.00009
29	CU	0.00000	0.01046
30	ZN	0.00000	0.00660
31	GA	0.00000	0.00023
33	AS	0.00000	0.00001
34	SE	0.00006	0.00050
35	BR	0.00084	0.00043
37	RB	0.00090	0.00092
38	SR	0.00006	0.00240
40	ZR	0.00000	0.00001
42	MO	0.00241	0.00341
49	IN	0.00363	0.01213
51	SB	0.00000	0.01156
56	BA	0.00457	0.00042
82	PB	0.00202	0.00321
201	OC	0.44778	0.02164
202	EC	0.00000	0.08788
203	SO4	0.04614	0.06150

Table A-18. SOURCE DATA

Type: coal-fired power station 2
Location: U.S.A. Contributor: KEYSTONE/NEA
Date:
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.02569	0.00228
14	SI	0.08352	0.00996
15	P	0.00305	0.00036
16	S	0.00618	0.00047
17	CL	0.00328	0.00034
19	K	0.01673	0.00240
20	CA	0.02289	0.00130
22	TI	0.00267	0.00015
23	VA	0.00018	0.00004
24	CR	0.00054	0.00024
25	MN	0.00061	0.00006
26	FE	0.02766	0.00361
27	CO	0.00000	0.00001
28	NI	0.00073	0.00062
29	CU	0.02253	0.02393
30	ZN	0.01341	0.01368
31	GA	0.00000	0.00001
33	AS	0.00002	0.00001
34	SE	0.00003	0.00001
35	BR	0.00007	0.00001
37	RB	0.00008	0.00001
38	SR	0.00027	0.00002
40	ZR	0.00000	0.00001
42	MO	0.00010	0.00007
49	IN	0.00021	0.00005
51	SB	0.00032	0.00011
56	BA	0.00313	0.00122
82	PB	0.00185	0.00144
201	OC	0.29406	0.02474
202	EC	0.00945	0.00179
203	SO4	0.01854	0.00102

Table A-19. SOURCE DATA

Type: cigarete emission
Location: U.S.A. Contributor: Lynn M. Hildemann
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00007	0.00002
14	SI	0.00000	0.00002
15	P	0.00006	0.00002
16	S	0.00138	0.00005
17	CL	0.00229	0.00024
19	K	0.00412	0.00017
20	CA	0.00000	0.00001
22	TI	0.00000	0.00001
23	VA	0.00000	0.00001
24	CR	0.00000	0.00001
25	MN	0.00000	0.00001
26	FE	0.00000	0.00001
27	CO	0.00000	0.00001
28	NI	0.00000	0.00001
29	CU	0.00008	0.00006
30	ZN	0.00007	0.00004
31	GA	0.00000	0.00001
33	AS	0.00000	0.00001
34	SE	0.00000	0.00001
35	BR	0.00003	0.00000
37	RB	0.00000	0.00001
38	SR	0.00000	0.00001
40	ZR	0.00002	0.00002
42	MO	0.00000	0.00001
49	IN	0.00000	0.00002
51	SB	0.00000	0.00001
56	BA	0.00000	0.00004
82	PB	0.00000	0.00001
201	OC	0.57648	0.02958
202	EC	0.00486	0.00110
203	SO4	0.00413	0.00016

Table A-20. SOURCE DATA

Type: hog fuel boiler
Location: Univ. of Oregon Contributor: John Core
Date:
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00000	0.00098
14	SI	0.00151	0.00112
15	P	0.00000	0.00320
16	S	0.08995	0.03924
17	CL	0.03703	0.00529
19	K	0.22609	0.06972
20	CA	0.00441	0.00268
22	TI	0.00019	0.00026
23	VA	0.00009	0.00011
24	CR	0.00025	0.00007
25	MN	0.00199	0.00036
26	FE	0.00668	0.00103
27	CO	0.00002	0.00009
28	NI	0.00004	0.00001
29	CU	0.00141	0.00016
30	ZN	0.01490	0.00112
31	GA	0.00000	0.00005
33	AS	0.00049	0.00007
34	SE	0.00003	0.00001
35	BR	0.00087	0.00007
37	RB	0.00078	0.00006
38	SR	0.00009	0.00003
40	ZR	0.00002	0.00003
42	MO	0.00020	0.00004
49	IN	0.00000	0.00015
51	SB	0.00005	0.00022
56	BA	0.00029	0.00078
82	PB	0.00135	0.00016
201	OC	0.02483	0.03105
202	EC	0.01069	0.00666
203	SO4	0.26355	0.04394

*: This source profile was used to represent the residential coal boiler.

Table A-21. SOURCE DATA

Type: vegetative detritus
Location: U.S.A. Contributor: Lynn M. Hildemann
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.02569	0.00228
14	SI	0.08352	0.00996
15	P	0.00305	0.00036
16	S	0.00618	0.00047
17	CL	0.00328	0.00034
19	K	0.01673	0.00240
20	CA	0.02289	0.00130
22	TI	0.00267	0.00015
23	VA	0.00018	0.00004
24	CR	0.00054	0.00024
25	MN	0.00061	0.00006
26	FE	0.02766	0.00361
27	CO	0.00000	0.00001
28	NI	0.00073	0.00062
29	CU	0.02253	0.02393
30	ZN	0.01341	0.01368
31	GA	0.00000	0.00001
33	AS	0.00002	0.00001
34	SE	0.00003	0.00001
35	BR	0.00007	0.00001
37	RB	0.00008	0.00001
38	SR	0.00027	0.00002
40	ZR	0.00000	0.00001
42	MO	0.00010	0.00007
49	IN	0.00021	0.00005
51	SB	0.00032	0.00011
56	BA	0.00313	0.00122
82	PB	0.00185	0.00144
201	OC	0.29406	0.02474
202	EC	0.00945	0.00179
203	SO4	0.01854	0.00102

*: This source profile is used as plant road dust source profile for Beijing's ambient air research.

Table A-22. SOURCE DATA

Type: Leaded gasoline emission
Location: Contributor: DRI
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00640	0.00641
14	SI	0.00786	0.00460
15	P	0.00167	0.00180
16	S	0.00000	0.01208
17	CL	0.00262	0.00262
19	K	0.00051	0.00025
20	CA	0.00092	0.00029
22	TI	0.00040	0.00002
23	VA	0.00002	0.00002
24	CR	0.00001	0.00001
25	MN	0.00987	0.00612
26	FE	0.00111	0.00045
27	CO	0.00000	0.00001
28	NI	0.00012	0.00005
29	CU	0.00026	0.00006
30	ZN	0.00148	0.00040
31	GA	0.00031	0.00041
33	AS	0.00009	0.00698
34	SE	0.00000	0.00006
35	BR	0.06183	0.02113
37	RB	0.00005	0.00045
38	SR	0.00000	0.00005
40	ZR	0.00000	0.00022
42	MO	0.00000	0.00011
49	IN	0.00000	0.00024
51	SB	0.00000	0.00064
56	BA	0.00000	0.00120
82	PB	0.21649	0.07650
201	OC	0.31374	0.19848
202	EC	0.15052	0.02434
203	SO4	0.00000	0.00001

Table A-23. SOURCE DATA

Type: field burning
Location: U.S.A. Contributor: John Hock
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00028	0.00082
14	SI	0.00000	0.00052
15	P	0.00000	0.00042
16	S	0.00644	0.00285
17	CL	0.15399	0.05454
19	K	0.20068	0.07079
20	CA	0.00014	0.00163
22	TI	0.00004	0.00051
23	VA	0.00002	0.00021
24	CR	0.00003	0.00005
25	MN	0.00003	0.00004
26	FE	0.00018	0.00010
27	CO	0.00000	0.00002
28	NI	0.00001	0.00002
29	CU	0.00001	0.00003
30	ZN	0.00007	0.00004
31	GA	0.00000	0.00007
33	AS	0.00000	0.00008
34	SE	0.00001	0.00003
35	BR	0.00040	0.00020
37	RB	0.00006	0.00003
38	SR	0.00001	0.00003
40	ZR	0.00000	0.00006
42	MO	0.00000	0.00010
49	IN	0.00009	0.00030
51	SB	0.00010	0.00046
56	BA	0.00017	0.00016
82	PB	0.00011	0.00021
201	OC	0.34492	0.08029
202	EC	0.10904	0.03259
203	SO4	0.01735	0.00872

Table A-24. SOURCE DATA

Type: calcium carbide furnace
Location: U.S.A.
Contributor: EPA
25201
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.0058	0.0011
14	SI	0.0250	0.0007
15	P	0.0000	0.0001
16	S	0.0160	0.0042
17	CL	0.0105	0.0007
19	K	0.0125	0.0035
20	CA	0.3000	0.0400
22	TI	0.0000	0.0002
23	VA	0.0006	0.0000
24	CR	0.0000	0.0001
25	MN	0.0004	0.0000
26	FE	0.0054	0.0008
27	CO	0.0000	0.0001
28	NI	0.0002	0.0001
29	CU	0.0002	0.0001
30	ZN	0.0002	0.0001
31	GA	0.0000	0.0000
33	AS	0.0000	0.0001
34	SE	0.0000	0.0000
35	BR	0.0000	0.0000
37	RB	0.0000	0.0000
38	SR	0.0000	0.0000
40	ZR	0.0000	0.0000
42	MO	0.0000	0.0000
49	IN	0.0000	0.0000
51	SB	0.0000	0.0000
56	BA	0.0000	0.0000
82	PB	0.0001	0.0000
201	OC	0.0730	0.0130
202	EC	0.0120	0.0028
203	SO4	0.0320	0.0042

Table A-25. SOURCE DATA

Type: secondary sulfate
Location: U.S.A.　　Contributor: DRI
Date:
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00000	0.00000
14	SI	0.00000	0.00000
15	P	0.00000	0.00001
16	S	0.33000	0.03300
17	CL	0.00000	0.00000
19	K	0.00000	0.00000
20	CA	0.00000	0.00000
22	TI	0.00000	0.00000
23	VA	0.00000	0.00000
24	CR	0.00000	0.00000
25	MN	0.00000	0.00000
26	FE	0.00000	0.00000
27	CO	0.00000	0.00001
28	NI	0.00000	0.00000
29	CU	0.00000	0.00000
30	ZN	0.00000	0.00000
31	GA	0.00000	0.00001
33	AS	0.00000	0.00000
34	SE	0.00000	0.00001
35	BR	0.00000	0.00001
37	RB	0.00000	0.00001
38	SR	0.00000	0.00001
40	ZR	0.00000	0.00001
42	MO	0.00000	0.00001
49	IN	0.00000	0.00001
51	SB	0.00000	0.00001
56	BA	0.00000	0.00001
82	PB	0.00000	0.00001
201	OC	0.00000	0.00001
202	EC	0.00000	0.00000
203	SO4	1.00000	0.10000

Table A-26. SOURCE DATA

Type: heavy duty diesel emission
Location: U.S.A. Contributor: John Rau
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00003	0.00026
14	SI	0.00018	0.00018
15	P	0.00042	0.00009
16	S	0.00342	0.00055
17	CL	0.00015	0.00022
19	K	0.00000	0.00009
20	CA	0.00048	0.00008
22	TI	0.00002	0.00004
23	VA	0.00002	0.00003
24	CR	0.00001	0.00003
25	MN	0.00000	0.00003
26	FE	0.00000	0.00008
27	CO	0.00000	0.00001
28	NI	0.00002	0.00003
29	CU	0.00001	0.00003
30	ZN	0.00053	0.00017
31	GA	0.00000	0.00002
33	AS	0.00000	0.00008
34	SE	0.00000	0.00003
35	BR	0.00000	0.00003
37	RB	0.00000	0.00004
38	SR	0.00000	0.00005
40	ZR	0.00000	0.00030
42	MO	0.00000	0.00018
49	IN	0.00000	0.00040
51	SB	0.00000	0.00109
56	BA	0.00000	0.00202
82	PB	0.00000	0.00011
201	OC	0.36046	0.03406
202	EC	0.52058	0.04644
203	SO4	0.00000	0.00001

Table A-27. SOURCE DATA

Type: light duty diesel emission
Location: U.S.A. Contributor: John Rau
Date:
Cut point: 2.5μm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.00009	0.00007
14	SI	0.00053	0.00028
15	P	0.00026	0.00008
16	S	0.00620	0.00239
17	CL	0.00035	0.00012
19	K	0.00013	0.00008
20	CA	0.00023	0.00014
22	TI	0.00000	0.00001
23	VA	0.00000	0.00001
24	CR	0.00000	0.00001
25	MN	0.00000	0.00001
26	FE	0.00002	0.00002
27	CO	0.00000	0.00001
28	NI	0.00000	0.00001
29	CU	0.00002	0.00001
30	ZN	0.00037	0.00011
31	GA	0.00000	0.00001
33	AS	0.00002	0.00002
34	SE	0.00000	0.00001
35	BR	0.00002	0.00001
37	RB	0.00000	0.00001
38	SR	0.00000	0.00001
40	ZR	0.00000	0.00008
42	MO	0.00000	0.00005
49	IN	0.00000	0.00010
51	SB	0.00000	0.00027
56	BA	0.00000	0.00051
82	PB	0.00025	0.00017
201	OC	0.43358	0.02103
202	EC	0.62746	0.07051
203	SO4	0.00000	0.00001

Table A-28. SOURCE DATA

Type: ball coal
Location: Beijing Contributor:
Date: 05/08/90
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.06409	0.00110
14	SI	0.09636	0.00082
15	P	0.00000	0.00062
16	S	0.00329	0.00018
17	CL	0.00000	0.00125
19	K	0.00879	0.00043
20	CA	0.02219	0.00047
22	TI	0.00373	0.00087
23	VA	0.00039	0.00119
24	CR	0.00044	0.00045
25	MN	0.00057	0.00013
26	FE	0.01758	0.00024
27	CO	0.00021	0.00034
28	NI	0.00000	0.00024
29	CU	0.00046	0.00010
30	ZN	0.00035	0.00010
31	GA	0.00000	0.00022
33	AS	0.00000	0.00026
34	SE	0.00000	0.00014
35	BR	0.00000	0.00012
37	RB	0.00001	0.00011
38	SR	0.00057	0.00004
40	ZR	0.00000	0.00018
42	MO	0.00003	0.00028
49	IN	0.00002	0.00158
51	SB	0.00011	0.00217
56	BA	0.00003	0.00631
82	PB	0.00007	0.00033
201	OC	0.14894	0.01043
202	EC	0.82071	0.07386
203	SO4	0.00988	0.00055

Table A-29. SOURCE DATA

Type: industrial coal
Location: Beijing   Contributor:
Date: 07/25/1990
Cut point: 2.5µm
Unit: element/mass

species number	species name	% by WT	uncertain
13	AL	0.05154	0.00063
14	SI	0.07019	0.00042
15	P	0.00000	0.00036
16	S	0.00632	0.00011
17	CL	0.00043	0.00014
19	K	0.00506	0.00017
20	CA	0.00678	0.00016
22	TI	0.00271	0.00032
23	VA	0.00019	0.00043
24	CR	0.00018	0.00005
25	MN	0.00030	0.00005
26	FE	0.01634	0.00013
27	CO	0.00015	0.00024
28	NI	0.00004	0.00009
29	CU	0.00016	0.00003
30	ZN	0.00007	0.00011
31	GA	0.00000	0.00008
33	AS	0.00004	0.00010
34	SE	0.00000	0.00005
35	BR	0.00000	0.00004
37	RB	0.00004	0.00004
38	SR	0.00045	0.00002
40	ZR	0.00016	0.00002
42	MO	0.00000	0.00010
49	IN	0.00000	0.00056
51	SB	0.00000	0.00076
56	BA	0.00048	0.00224
82	PB	0.00003	0.00012
201	OC	0.42371	0.02966
202	EC	0.55883	0.05030
203	SO4	0.01895	0.00033

APPENDIX B. BEIJING'S AMBIENT CONCENTRATIONS

Table B-1. Beijing's ambient data

Type: ambient data
Location: Beijing, west site   Contributor:
Date:
Cut point: 2.5µm
Unit: µg/m3

species number	species name	concentrations				
		5/20/89	5/24/89	5/26/89	5/29/89	5/31/89
1	TOT	64.73	42.97	57.32	56.94	100.64
13	AL	0.94	0.29	0.60	0.64	0.82
14	SI	2.59	1.24	1.99	2.17	2.52
15	P	0.08	0.06	0.03	0.05	0.02
16	S	2.93	1.58	2.32	4.07	7.73
17	CL	0.54	0.15	0.25	0.20	0.44
19	K	1.43	0.46	1.64	1.09	2.97
20	CA	1.39	0.50	1.36	1.04	1.52
22	TI	0.07	0.00	0.03	0.03	0.03
23	VA	0.00	0.00	0.00	0.00	0.00
24	CR	0.00	0.00	0.00	0.00	0.00
25	MN	0.06	0.01	0.06	0.06	0.04
26	FE	0.80	0.43	0.74	0.78	0.79
27	CO	0.00	0.00	0.00	0.00	0.00
28	NI	0.01	0.01	0.00	0.01	0.01
29	CU	0.01	0.00	0.01	0.01	0.02
30	ZN	0.42	0.11	0.21	0.28	0.35
31	GA	0.00	0.00	0.00	0.00	0.00
33	AS	0.01	0.01	0.00	0.01	0.02
34	SE	0.00	0.00	0.00	0.00	0.01
35	BR	0.01	0.01	0.01	0.01	0.03
37	RB	0.01	0.00	0.01	0.00	0.01
38	SR	0.01	0.00	0.01	0.01	0.01
40	ZR	0.01	0.00	0.00	0.00	0.00
42	MO	0.01	0.04	0.00	0.01	0.00
49	IN	0.00	0.00	0.00	0.00	0.00
51	SB	0.00	0.00	0.01	0.00	0.00
56	BA	0.00	0.07	0.00	0.00	0.02
82	PB	0.26	0.12	0.17	0.17	0.33
201	OC	17.93	14.81	18.13	13.41	25.41
202	EC	15.76	12.48	13.24	12.14	21.27
203	SO4	8.85	4.82	7.02	12.28	23.27

Table B-2. Beijing's ambient data

Type: ambient data
Location: Beijing, west site Contributor:
Date:
Cut point: 2.5μm
Unit: μg/m3

species number	species name	concentration				
		6/02/89	6/23/89	7/28/89	9/19/89	9/20/89
1	TOT	116.92	94.10	70.14	18.68	84.53
13	AL	1.33	0.57	0.73	0.27	0.87
14	SI	3.95	2.54	3.35	0.98	2.72
15	P	0.01	0.04	0.08	0.01	0.08
16	S	10.06	8.53	3.61	0.80	3.77
17	CL	0.43	0.40	0.49	0.08	2.71
19	K	1.98	2.35	1.77	0.46	1.98
20	CA	1.89	1.21	1.70	0.60	1.33
22	TI	0.11	0.07	0.05	0.01	0.06
23	VA	0.01	0.00	0.00	0.00	0.00
24	CR	0.01	0.00	0.01	0.00	0.01
25	MN	0.09	0.05	0.10	0.02	0.13
26	FE	0.98	0.88	0.91	0.35	0.83
27	CO	0.00	0.00	0.00	0.00	0.00
28	NI	0.01	0.01	0.01	0.00	0.00
29	CU	0.03	0.02	0.02	0.00	0.02
30	ZN	0.44	0.32	0.72	0.06	0.40
31	GA	0.01	0.00	0.00	0.00	0.01
33	AS	0.07	0.01	0.01	0.00	0.02
34	SE	0.01	0.01	0.00	0.00	0.01
35	BR	0.02	0.04	0.01	0.00	0.03
37	RB	0.01	0.01	0.00	0.00	0.01
38	SR	0.02	0.01	0.01	0.00	0.02
40	ZR	0.00	0.00	0.00	0.00	0.01
42	MO	0.02	0.02	0.01	0.00	0.00
49	IN	0.00	0.00	0.00	0.00	0.00
51	SB	0.00	0.01	0.00	0.00	0.00
56	BA	0.00	0.00	0.00	0.00	0.00
82	PB	0.28	0.23	0.32	0.03	0.28
201	OC	28.07	17.39	17.96	4.13	22.70
202	EC	20.28	23.02	15.35	5.00	23.44
203	SO4	30.27	25.66	10.92	2.41	11.34

Table B-3. Beijing's ambient data

Type: ambient data
Location: Beijing, west site Contributor:
Date:
Cut point: 2.5μm
Unit: μg/m3

species number	species name	concentration				
		9/22/89	9/29/89	10/06/89	10/28/89	10/31/89
1	TOT	113.01	67.78	21.71	110.49	24.01
13	AL	0.20	0.68	0.28	0.90	0.16
14	SI	2.97	2.90	1.11	3.51	2.53
15	P	0.04	0.06	0.01	0.09	0.01
16	S	10.11	4.44	0.94	3.22	0.73
17	CL	3.82	0.59	0.17	4.54	0.20
19	K	1.63	1.31	0.27	1.56	0.36
20	CA	0.74	1.03	0.60	3.62	0.55
22	TI	0.00	0.06	0.03	0.09	0.02
23	VA	0.00	0.00	0.00	0.00	0.00
24	CR	0.00	0.00	0.00	0.00	0.00
25	MN	0.09	0.08	0.04	0.11	0.02
26	FE	0.67	0.88	0.38	0.98	0.28
27	CO	0.00	0.00	0.00	0.00	0.00
28	NI	0.01	0.01	0.00	0.01	0.00
29	CU	0.01	0.01	0.00	0.03	0.00
30	ZN	0.29	0.30	0.11	0.51	0.05
31	GA	0.01	0.01	0.00	0.02	0.00
33	AS	0.03	0.03	0.00	0.06	0.00
34	SE	0.01	0.01	0.00	0.01	0.00
35	BR	0.05	0.02	0.00	0.03	0.00
37	RB	0.00	0.01	0.00	0.01	0.00
38	SR	0.00	0.01	0.00	0.01	0.00
40	ZR	0.00	0.00	0.00	0.00	0.00
42	MO	0.04	0.01	0.00	0.00	0.00
49	IN	0.00	0.00	0.01	0.01	0.00
51	SB	0.01	0.01	0.01	0.00	0.00
56	BA	0.00	0.00	0.00	0.00	0.00
82	PB	0.24	0.18	0.05	0.33	0.03
201	OC	25.81	18.20	6.81	33.18	7.28
202	EC	24.11	13.20	3.85	29.72	3.91
203	SO4	30.35	13.34	2.86	9.70	2.22

Table B-4. Beijing's ambient data

Type: ambient data
Location: Beijing, west site   Contributor:
Date:
Cut point: 2.5μm
Unit: μg/m3

species number	species name	concentration 11/10/89	11/29/89	12/07/89	12/26/89	1/09/90
1	TOT	46.81	67.90	66.50	31.69	174.97
13	AL	0.30	0.92	1.60	0.43	1.87
14	SI	1.13	2.67	4.39	1.44	5.04
15	P	0.08	0.16	0.16	0.05	0.28
16	S	1.53	2.52	2.15	1.25	12.23
17	CL	1.76	2.27	2.10	0.48	7.11
19	K	0.55	0.98	0.91	0.27	3.07
20	CA	0.60	0.86	1.48	0.72	1.40
22	TI	0.00	0.09	0.08	0.06	0.18
23	VA	0.00	0.00	0.00	0.00	0.00
24	CR	0.00	0.00	0.00	0.00	0.00
25	MN	0.03	0.05	0.20	0.02	0.14
26	FE	0.40	0.76	0.93	0.39	1.64
27	CO	0.00	0.00	0.00	0.00	0.00
28	NI	0.00	0.01	0.01	0.00	0.02
29	CU	0.00	0.01	0.01	0.00	0.03
30	ZN	0.17	0.34	0.58	0.09	0.73
31	GA	0.00	0.03	0.03	0.00	0.05
33	AS	0.02	0.02	0.02	0.01	0.06
34	SE	0.01	0.01	0.00	0.00	0.02
35	BR	0.01	0.02	0.02	0.01	0.06
37	RB	0.00	0.00	0.00	0.00	0.01
38	SR	0.00	0.01	0.01	0.00	0.04
40	ZR	0.00	0.00	0.00	0.00	0.02
42	MO	0.00	0.00	0.00	0.00	0.01
49	IN	0.00	0.00	0.00	0.00	0.00
51	SB	0.00	0.00	0.00	0.03	0.00
56	BA	0.10	0.00	0.00	0.00	0.05
82	PB	0.12	0.20	0.26	0.07	0.44
201	OC	14.87	19.68	16.72	9.16	35.93
202	EC	14.67	18.81	15.43	8.15	48.27
203	SO4	4.62	7.55	6.44	3.74	36.70

Table B-5. Beijing's ambient data.

Type: ambient data
Location: Beijing, west site Contributor:
Date:
Cut point: 2.5µm
Unit: µg/m3

species number	species name	concentration			
		1/23/90	3/13/90	5/11/90	5/14/90
1	TOT	21.95	18.64	82.44	61.40
13	AL	0.26	0.36	1.66	1.10
14	SI	0.76	2.40	5.51	3.55
15	P	0.03	0.11	0.22	0.08
16	S	0.64	1.30	2.67	2.99
17	CL	0.26	0.95	1.47	0.69
19	K	0.17	0.49	2.31	1.58
20	CA	0.35	0.23	4.41	1.82
22	TI	0.03	0.03	0.28	0.10
23	VA	0.00	0.00	0.02	0.01
24	CR	0.00	0.00	0.01	0.00
25	MN	0.00	0.06	0.08	0.12
26	FE	0.21	0.31	2.03	1.34
27	CO	0.00	0.00	0.00	0.01
28	NI	0.00	0.01	0.02	0.02
29	CU	0.00	0.00	0.02	0.00
30	ZN	0.06	0.14	0.58	0.40
31	GA	0.00	0.01	0.01	0.02
33	AS	0.00	0.02	0.01	0.03
34	SE	0.00	0.00	0.00	0.00
35	BR	0.01	0.01	0.04	0.03
37	RB	0.00	0.00	0.01	0.01
38	SR	0.00	0.01	0.02	0.01
40	ZR	0.00	0.01	0.01	0.01
42	MO	0.00	0.00	0.07	0.00
49	IN	0.00	0.00	0.00	0.00
51	SB	0.00	0.03	0.00	0.04
56	BA	0.00	0.00	0.00	0.07
82	PB	0.04	0.08	0.45	0.27
201	OC	8.50	0.18	16.06	12.83
202	EC	5.15	4.06	16.97	13.50
203	SO4	1.91	4.02	8.14	9.10

Table B-6. Beijing's ambient data.

Type: ambient data
Location: Beijing, east site Contributor:
Date:
Cut point: 2.5µm
Unit: µg/m3

species number	species name	concentration				
		4/30/89	5/03/89	5/5/89	5/10/89	5/16/89
1	TOT	151.18	106.93	140.12	108.16	140.12
13	AL	1.75	2.17	0.84	1.15	1.33
14	SI	5.77	6.41	3.75	3.96	4.15
15	P	0.12	0.15	0.09	0.12	0.14
16	S	6.48	7.40	7.26	3.05	5.22
17	CL	2.42	1.90	3.24	1.56	2.69
19	K	2.28	2.88	2.07	2.27	2.30
20	CA	4.32	4.48	1.21	2.78	2.35
22	TI	0.20	0.19	0.06	0.12	0.10
23	VA	0.02	0.01	0.01	0.01	0.00
24	CR	0.01	0.03	0.01	0.01	0.01
25	MN	0.14	0.21	0.18	0.11	0.12
26	FE	1.83	2.96	1.04	1.53	1.14
27	CO	0.00	0.00	0.00	0.00	0.00
28	NI	0.01	0.03	0.01	0.01	0.01
29	CU	0.02	0.05	0.01	0.01	0.02
30	ZN	0.80	0.85	0.30	0.31	0.76
31	GA	0.01	0.02	0.01	0.00	0.02
33	AS	0.08	0.05	0.02	0.02	0.04
34	SE	0.02	0.02	0.01	0.01	0.02
35	BR	0.07	0.08	0.07	0.05	0.07
37	RB	0.01	0.01	0.01	0.01	0.01
38	SR	0.03	0.03	0.01	0.02	0.02
40	ZR	0.01	0.01	0.00	0.01	0.00
42	MO	0.11	0.02	0.00	0.08	0.09
49	IN	0.00	0.00	0.00	0.00	0.00
51	SB	0.00	0.00	0.00	0.00	0.00
56	BA	0.01	0.07	0.05	0.00	0.07
82	PB	0.53	0.65	0.31	0.32	0.52
201	OC	25.19	30.93	18.83	10.22	32.85
202	EC	22.45	33.16	18.53	11.05	32.14
203	SO4	19.44	22.19	21.78	9.14	15.66

APPENDIX C. ORGANIC AND ELEMENTAL CARBON CONCENTRATIONS IN BEIJING AT THE WEST SITE.

Table C-1. Organic and elemental carbon concentrations at the west site in Beijing.

ID	OC	EC	TC	OC/EC
QF0520890703	17.93	15.76	33.69	1.14
QF0524890703	14.81	12.48	27.29	1.19
QF0526890703	18.13	13.24	31.37	1.37
QF0529890703	13.41	12.14	25.54	1.10
QF0531890703	25.41	21.27	46.69	1.19
QF0602890703	28.07	20.28	48.35	1.38
QF0616890803	9.02	6.46	15.47	1.40
QF0623890803	17.39	23.02	40.41	0.76
QF0708890803	15.77	15.49	31.27	1.02
QF0714890803	11.47	6.55	18.02	1.75
QF0721890803	9.75	8.63	18.38	1.13
QF0725890803	9.32	6.86	16.18	1.36
QF0728890803	17.96	15.35	33.31	1.17
QF0804890803	18.08	21.6	39.68	0.84
QF0808890803	9.41	12.01	25.43	0.78
QF0811890803	16.55	18.26	34.81	0.91
QF0818890803	27.13	22.51	49.64	1.21
QF0825890803	18.13	25.79	43.92	0.70

*: QF0520890703: A front quartz filter was sampled on 5, 20, 1989 from 7:00 am until 10:00.

Table C-2. Organic and elemental carbon concentrations at the west site in Beijing.

ID	OC	EC	TC	OC/EC
QF0901890803	6.26	5.54	11.79	1.13
QF0919890803	4.13	5.00	9.13	0.83
QF0920890803	22.7	23.44	46.14	0.97
QF0922890803	25.81	24.11	49.92	1.07
QF0929890903	18.20	13.20	31.40	1.38
QF1006890803	6.81	3.85	10.66	1.77
QF1014890803	26.19	27.18	53.34	0.96
QF1028890803	33.18	29.72	62.90	1.12
QF1031890803	7.28	3.91	11.18	1.86
QF1104890803	36.96	46.05	83.01	0.80
QF1110890802	14.87	14.67	34.98	1.01
QF1122890802	36.74	53.41	90.15	0.69
QF1129890902	19.68	18.81	38.49	1.05
QF1207890802	16.72	15.43	32.15	1.08
QF1219890902	11.433	13.68	25.12	0.84
QF1226890803	9.16	8.15	17.31	1.12
QF0103900803	28.91	26.64	55.55	1.09
QF0109900803	35.93	48.27	84.2	0.74

Table C-3. Organic and elemental carbon concentrations at the west site in Beijing.

ID	OC	EC	TC	OC/EC
QF0115900803	26.79	27.48	54.27	0.97
QF0119900803	7.63	6.35	13.98	1.20
QF0123900803	8.50	5.15	13.65	1.65
QF0212900803	36.64	30.27	66.91	1.21
QF0219900903	28.84	25.66	54.50	1.12
QF0224900803	11.41	8.59	20.00	1.33
QF0227900803	24.50	27.38	51.88	0.89
QF0302900802	43.66	37.06	80.71	1.18
QF0306900802	23.00	16.85	39.85	1.36
QF0309900802	21.41	17.34	38.00	1.23
QF0313900702	0.18	4.06	4.24	0.04
QF0316900701	58.21	31.63	89.83	1.84
QF0319900801	16.22	32.11	48.33	0.51
QF0324900801	13.53	11.69	25.23	1.16
QF0330900802	24.50	33.46	57.97	0.73
QF0403900702	5.46	2.54	8.00	2.15
QF0409900802	13.21	11.74	24.95	1.13
QF0416900702	23.38	29.16	52.54	0.80
QF0424900801	20.07	16.99	37.06	1.18
QF0507900801	6.86	11.91	18.77	0.58
QF0511900801	16.06	16.97	33.03	0.95
QF0514900801	12.83	13.5	26.33	0.95

Table C-4. Organic and elemental carbon concentrations at the west site in Beijing.

ID	OC	EC	TC
QF0524890703	14.81	12.48	27.29
QF0524891503	6.29	1.05	7.34
QF0524891903	4.91	4.24	9.15
QF0708890803	15.77	15.49	31.27
QF0708891303	6.66	1.30	7.95
QF0708891703	15.61	16.13	31.74
QF0725890803	9.32	6.86	16.18
QF0725891303	4.52	1.23	5.75
QF0725891703	9.91	3.51	13.42
QF0808890803	9.41	12.01	25.43
QF0808891303	8.94	4.61	13.54
QF0808891703	19.65	4.22	23.86
QF1006890803	6.81	3.85	10.66
QF1006891403	5.14	1.84	6.98
QF1006891703	9.02	6.47	21.11
QF1031890803	7.28	3.91	11.18
QF1031891403	2.87	2.08	4.94
QF1031891703	53.83	24.89	78.71
QF0115900803	26.79	27.48	54.27
QF0115901303	20.03	22.33	42.36
QF0115901703	19.44	27.44	46.88
QF0424900801	20.07	16.99	37.06
QF0424901402	3.14	2.66	5.79
QF0424901702	6.46	1.00	6.46

*: QF0524891503: A quartz filter was sampled from 15:00 until 18:00 on 5, 24, 1989.

APPENDIX D. THE METEOROLOGICAL DATA AND FLOW RATE WHEN SAMPLING AT THE WEST SITE IN BEIJING.

Table D-1. The meteorological data when sampling at the west site in Beijing

ID	H (m)	U (m/s)	T (°C)	AZIMUTH (°)	VISIBILITY (kilometer)
QF0520890703	542	2			10
QF0524890703	1899	2.5		290	35
QF0526890703	174	0.001		280	8
QF0529890703	1239	1			10
QF0531890703	819	0.001			3.5
QF0602890703	651	0.001			6
QF0616890803	2266	0.6	30	30	35
QF0623890803	1666	0.001			8
QF0708890803	1103	0.2	26	35	5
QF0714890803	1001	0.3	25	20	9
QF0721890803	0	0			
QF0725890803	430	0.001	28	0	40
QF0728890803	484	0.001	28	240	8
QF0804890803	807	0.001	28	225	9
QF0808890803	683	0.001	28.3	0	15
QF0811890803	359	0.001	28	210	2
QF0818890803	1200	0.001	25.8	240	8
QF0825890803	622	0.4	25.8	330	3

*: H: the height of inversion lay. U: wind speed. T: temperature.

Table D-2. The meteorological data when sampling at the west site in Beijing

ID	H (m)	U (m/s)	T (°C)	AZIMUTH (°)	VISIBILITY (kilometer)
QF0901890803	1771	0.4	24.9	30	18
QF0919890803	1324	0.001	16.4	0	30
QF0920890803	0	0			
QF0922890803	434	0.001	16.2	320	0.3
QF0929890903	609	0.2	22	330	8
QF1006890803	2142	0.4	15.8	240	30
QF1014890803	444	0.001	17.6	0	4
QF1028890803	0	0	17.8	0	
QF1031890803	1635	1.2	15.8	0	35
QF1104890803	261	0.001	15	0	3
QF1110890802	568	0.2	5.2	0	12
QF1122890802	48	0.8	12	0	5
QF1129890902	238	1	4.6	0	20
QF1207890802	435	0.6	2.4	0	28
QF1219890902	1235	0.4	-3.8	150	6
QF1226890803	796	1.2	0	300	30
QF0103900803		0.6	-3.2	0	5
QF0109900803		0	3	270	2

*: H: the height of inversion lay; U: wind speed.

ID	H (m)	U (m/s)	T (°C)	AZIMUTH (°)	VISIBILIT (kilometer)
QF0115900803		0.4	-3.2	0	4
QF0119900803		1.6	-5.8	0	
QF0123900803		0.5	-6.0	300	
QF0212900803		0	4.0	240	
QF0219900903		0	4.6	30	
QF0224900803		1.4	3.8	300	
QF0227900803		0.2	1.2	30	
QF0302900802		0.4	5.2	0	
QF0306900802		0.4	11.0	0	
QF0309900802		0.4	11.0	0	
QF0313900702		0	10.2	0	10
QF0316900701		0.2	8.0	0	8
QF0319900801		0.2	14.0	0	6
QF0324900801		0.4		110	20
QF0330900802		0	12.2	0	3
QF0403900702		1.4	5.2	0	30
QF0409900802		0.2	17.2	90	7
QF0416900702		0	13.6	0	10
QF0424900801		0	15.0	0	30
QF0507900801		0.2	21.2	300	
QF0511900801		0.4	17.8	180	7
QF0514900801		1.0	24.0	0	10

*: H: the height of inversion lay; U: wind speed.

Table D-4. The meteorological data when sampling

at the west site in Beijing

ID	PRESURE	STABILITY				
	mm	7:00	8:00	9:00	10:00	11:00
QF0520890703	748.4	C	B	B	B	C
QF0524890703	757.6	C	C	C	C	B
QF0526890703	749.4	B	D	B	B	A
QF0529890703		D	D	C	B	B
QF0531890703		C	D	C	B	B
QF0602890703	752.4	B	C	B	B	A
QF0616890803		C	C	C	C	D
QF0623890803		D	D	B	B	C
QF0708890803		D	D	D	B	B
QF0714890803		D	D	B	D	B
QF0721890803						
QF0725890803		D	D	C	D	D
QF0728890803		C	C	B	B	B
QF0804890803		B	B	B	B	D
QF0808890803		B	B	B	B	B
QF0811890803		D	D	B	D	D
QF0818890803	754.5	B	B	B	B	B

Table D-5. The meteorological data when sampling at the west site in Beijing

ID	PRESURE	STABILITY				
	mm	7:00	8:00	9:00	10:00	11:00
QF0825890803	753	B	C	B	B	B
QF0901890803	756.5	E	B	B	C	C
QF0919890803	760.5	E	C	B	B	B
QF0920890803						
QF0922890803	756	D	D	D	D	D
QF0929890903	760.5	E	B	B	B	B
QF1006890803		E	C	C	C	C
QF1014890803		D	D	B	B	B
QF1028890803						
QF1031890803		E	D	D	D	D
QF1104890803		B	D	D	D	D
QF1110890802		E	D	D	D	D
QF1122890802		F	F	E	C	C
QF1129890902		F	F	E	B	B
QF1207890802		F	F	E	B	C
QF1219890902		D	D	D	D	D
QF1226890803	767	E	E	D	C	C

Table D-6. The meteorological data when sampling at the west site in Beijing

ID	PRESURE	STABILITY				
	mm	7:00	8:00	9:00	10:00	11:00
QF0103900803	770.5	F	F	E	B	C
QF0109900803	766.5	F	D	D	D	D
QF0115900803	766	F	F	E	B	B
QF0119900803	776					
QF0123900803	770.5					
QF0212900803						
QF0219900903						
QF0224900803						
QF0227900803						
QF0302900802						
QF0306900802						
QF0309900802						
QF0313900702	760	B	D	D	D	C
QF0316900701	763.5	E	B	C	B	B
QF0319900801	758	D	B	D	C	C
QF0324900801	768	D	D	D	C	C
QF0330900802	758	E	B	D	D	D
QF0403900702	768.5	D	D	D	D	D
QF0409900802	758	E	B	B	B	B
QF0416900702	759.5	E	B	B	B	B
QF0424900801	754.5	B	B	B	B	C
QF0507900801	752	C	B	B	B	B
QF0511900801	750.5	B	D	B	B	B
QF0514900801	757	D	D	C	C	C

Table D-7. the sampling flow rates, time and volumes.

DATA	ID	FLOW LPM	MIN minute	AIR VOL(m^3)
890520	TQF0520890703	20.8	180	3.744
890520	TQB0520890703	20.8	180	3.744
890520	QF0520890703	20.2	180	3.636
890524	TQF0524890703	22.6	180	4.068
	TQB0524890703	22.6	180	4.068
	QF0524890703	21.8	180	3.924
	TQF0524891503	22.6	180	4.068
	TQB0524891503	22.6	180	4.068
	QF0524891503	21.8	180	3.924
	TQF0524891903	21.7	180	3.87
	TQB0524891903	21.7	180	3.87
	QF0524891903	21.8	180	3.924
890526	TQF0526890703	22.6	180	4.068
	TQB0525890703	22.6	180	4.068
	QF0526890703	21.8	180	3.924
890529	TQF0529890703	21.6	180	3.888
	TQB0529890703	21.6	180	3.888
	QF0529890703	21.8	180	3.924
890531	TQF0531890703	22.8	180	4.104
	TQB0531890703	22.8	180	4.104
	QF0531890703	21.7	180	3.87
	TQF0531891504	22.8	240	4.104
	TQB0531891504	22.8	240	4.104
	QF0531891504	21.7	240	3.87
890602	TQF0602890803	22.8	180	4.104
	TQB0602890803	22.8	180	4.104
	QF0602890803	21.7	180	3.87

*: TQF: the Teflon front filter; TQB: the quatz back filter;
QF: the quatz front filter.

Table D-8. The sampling flow rates, time and volumes.

DATA	ID	FLOW LPM	MIN minute	AIR VOL(m^3)
890616	TQF0616890803	22.8	180	4.104
	TQB0616890803	22.8	180	4.104
	QF0616890803	21.8	180	3.924
890623	TQF0623890803	22.8	180	4.104
	TQB0623890803	22.8	180	4.104
	QF0623890803	21.8	180	3.924
890702	TQF0702890803	22.8	180	4.104
	TQB0702890803	22.8	180	4.104
	QF0702890803	21.8	180	3.924
890708	TQF0708890803	22.8	180	4.104
	TQB0708890803	22.8	180	4.104
	QF0708890803	21.8	180	3.924
	TQF0708891303	22.8	180	4.104
	TQB0708891303	22.8	180	4.104
	QF0708891303	21.8	180	3.924
	TQF0708891703	22.8	180	4.104
	TQB0708891703	22.8	180	4.104
	QF0708891703	21.8	180	3.924
890714	TQF0714890803	22.8	180	4.104
	TQB0714890803	22.8	180	4.104
	QF0714890803	21.8	180	3.924
890721	TQF0721890803	22.8	180	4.104
	TQB0721890803	22.8	180	4.104
	QF0721890803	21.8	180	3.924
890725	TQF0725890803	22.8	180	4.104
	TQB0725890803	22.8	180	4.104
	QF0725890803	21.8	180	3.924
	TQF0725891303	22.8	180	4.104
	TQB0725891303	22.8	180	4.104
	QF0725891303	21.8	180	3.924
	TQF0725891703	22.8	180	4.104

Table D-9. The sampling flow rates, time and volumes.

DATA	ID	FLOW LPM	MIN minute	AIR VOL(m^3)
890728	TQF0728890803	22.8	180	4.104
	TQB0728890803	22.8	180	4.104
	QF0728890803	21.8	180	3.924
890804	TQF0804890803	22.8	180	4.104
	TQB0804890803	22.8	180	4.104
	QF0804890803	21.8	180	3.924
891110	TQB1110890802	22.8	120	2.736
	QF1110890802	21.8	120	2.616
891122	TQB1122890802	22.8	120	2.736
	QF1122890802	21.8	120	2.616
891129	TQB1129890902	22.8	120	2.736
	QF1129890902	21.8	120	2.616
891207	TQB1207890802	22.8	120	2.736
	QF1207890802	21.8	120	2.616
891219	TQB1219890902	22.8	120	2.736
	QF1219890902	21.8	120	2.616
900302	TQB0302900802	22.8	120	2.736
	QF0302900802	21.8	120	2.616
900306	TQB0306900802	22.8	120	2.736
	QF0306900802	21.8	120	2.616
900313	TQB0313900702	22.8	120	2.736
	QF0313900702	21.8	120	2.616
900316	TQB0316900701	22.8	60	1.368
	QF0316900701	21.8	60	1.308

Table D-10. The sampling flow rates, time, and volumes.

DATA	ID	FLOW LPM	MIN minute	AIR VOL(m^3)
900319	TQB0319900801	22.8	60	1.368
	QF0319900801	21.8	60	1.308
900324	TQB0324900801	22.8	60	1.368
	QF0324900801	21.8	60	1.308
900309	TQB0330900802	22.8	120	2.736
	QF0330900802	21.8	120	2.616
900403	TQB0403900702	22.8	120	2.736
	QF0403900702	21.8	120	2.616
900409	TQB0409900802	22.8	120	2.736
	QF0409900802	21.8	120	2.616
900416	TQB0416900702	22.8	120	2.736
	QF0416900702	21.8	120	2.616
900424	TQB0424900801	22.8	60	1.368
	QF0424900801	21.8	60	1.308
	TQB0424901402	22.8	120	2.736
	QF0424901402	21.8	120	2.616
	TQB0424901702	22.8	120	2.736
	QF0424901702	21.8	120	2.616
900511	TQB0511900801	22.8	60	1.368
	QF0511900801	21.8	60	1.308
900514	TQB0514900801	22.8	60	1.368
	QF0514900801	21.8	60	1.308

Appendix E. CMB result examples.

Table E-1. CMB results.

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: BEIJING      DATE: 5/20/89     CMB7 33889
SAMPLE DURATION        3       START HOUR        7         SIZE:    FINE
       R SQUARE        .98   PERCENT MASS     117.9
     CHI SQUARE       1.18             DF        24

  SOURCE
     * TYPE     SCE(UG/M3)    STD ERR      TSTAT
---------------------------------------------
5      INDST       14.0854     2.4267     5.8043
14     LIMED        2.7091      .4081     6.6390
20     HOGFU        9.4463     1.9472     4.8512
21     VEGETA      17.2082     2.5847     6.6576
25     SO4          3.8712      .8010     4.8331
26     MVHDDS      28.9795     2.9803     9.7237
---------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE
      64.7+-     6.5

       UNCERTAINTY/SIMILARITY CLUSTERS    CMB7 33889     SUM OF CLUSTER SOURCES
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SPECIES CONCENTRATIONS -  SITE: BEIJING      DATE: 5/20/89     CMB7 33889
SAMPLE DURATION        3       START HOUR        7         SIZE:    FINE
       R SQUARE        .98   PERCENT MASS     117.9
     CHI SQUARE       1.18             DF        24

SPECIES-------I---MEAS------------------CALC-------------RATIO C/M----RATIO R/U
C1     TOT    T  64.73000+-  6.47300  76.29977+-  3.31829 1.18+-    .13     1.6
C13    AL     *    .93800+-   .11240   1.17395+-   .04187 1.25+-    .16     2.0
C14    SI     *   2.59300+-   .07420   2.54694+-   .17294  .98+-    .07     -.2
C15    P      *    .07670<    .14830    .24456<    .03191 3.19<    6.18     1.1
C16    S      *   2.92520+-   .03600   3.05394+-   .39251 1.04+-    .13      .3
C17    CL     *    .53640+-   .09160    .43869+-   .05074  .82+-    .17     -.9
C19    K      *   1.43040+-   .07790   2.58325+-   .65990 1.81+-    .47     1.7
C20    CA     *   1.39120+-   .06610   1.39851+-   .08683 1.01+-    .08      .1
C22    TI     *    .07330<    .24850    .16348<    .00401 2.23<    7.56      .4
C23    VA     *    .00000<    .11020    .01143<    .00198  .00<     .00      .1
C24    CR     *    .00430<    .02870    .01800<    .00428 4.19<   27.96      .5
C25    MN     *    .06210+-   .02200    .03403+-   .00367  .55+-    .20    -1.3
C26    FE     *    .80370+-   .01700    .78200+-   .06299  .97+-    .08     -.3
C27    CO     *    .00000<    .01700    .00258<    .00296  .00<     .00      .1
C28    NI     *    .00920<    .00990    .01873<    .01071 2.04<    2.48      .7
C29    CU          .00660<    .01100    .45245<    .41180 68.55< *****      1.1
C30    ZN     *    .41720+-   .01230    .53815+-   .23570 1.29+-    .57      .5
C31    GA     *    .00000<    .02030    .03775<    .00095  .00<     .00     1.9
C33    AS     *    .01350<    .05550    .01368<    .02155 1.01<    4.46      .0
C34    SE     *    .00460<    .01320    .00277<    .00090  .60<    1.74     -.1
C35    BR     *    .01470+-   .01110    .01114+-   .00124  .76+-    .58     -.3
C37    RB     *    .00590<    .01070    .00987<    .00131 1.67<    3.04      .4
C38    SR     *    .01250+-   .01240    .02234+-   .00152 1.79+-   1.78      .8
C40    ZR     *    .00510<    .02100    .01413<    .00870 2.77<   11.54      .4
C42    MO     *    .01060<    .03430    .00741<    .00537  .70<    2.32     -.1
C49    IN     *    .00000<    .16540    .00418<    .01194  .00<     .00      .0
C51    SB     *    .00000<    .22410    .00908<    .03190  .00<     .00      .0
C56    BA     *    .00000<    .65830    .06181<    .06345  .00<     .00      .1
C82    PB     *    .26160+-   .00800    .17092+-   .02505  .65+-    .10    -3.4
C201   OC     *  17.93000+-  1.25510  17.54396+-  1.12143  .98+-    .09     -.2
```

```
C202   EC     *  15.76000+-   1.41840  16.06713+-   1.34919   1.02+-  .13       .2
C203   SO4    *   8.85190+-    .07490   8.76054+-    .56798    .99+-  .06      -.2
----------------------------------------------------------------------------------
```

Table E-2. CMB results.

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: BEIJING      DATE: 9/19/89     CMB7 33889
SAMPLE DURATION          3       START HOUR        8          SIZE:     FINE
       R SQUARE        .97     PERCENT MASS      112.1
     CHI SQUARE        .75                DF        25

  SOURCE
     * TYPE      SCE(UG/M3)     STD ERR       TSTAT
-------------------------------------------------
14     LIMED        1.3272        .2744      4.8374
20     HOGFU        1.3628        .5375      2.5352
21     VEGETA       9.5235        .9030     10.5468
25     SO4          1.8312        .2109      8.6825
26     MVHDDS       6.8999        .8648      7.9788
-------------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE
     18.7+-       1.9

       UNCERTAINTY/SIMILARITY CLUSTERS    CMB7 33889      SUM OF CLUSTER SOURCES
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SPECIES CONCENTRATIONS -  SITE: BEIJING      DATE: 9/19/89     CMB7 33889
SAMPLE DURATION          3       START HOUR        8          SIZE:     FINE
       R SQUARE        .97     PERCENT MASS      112.1
     CHI SQUARE        .75                DF        25

SPECIES-------I---MEAS-----------------CALC------------RATIO C/M----RATIO R/U
C1      TOT    T  18.68000+-   1.86800  20.94459+-    .99959   1.12+-  .12     1.1
C13     AL     *    .26790+-    .10620    .27287+-    .02201   1.02+-  .41      .0
C14     SI     *    .97570+-    .06590    .88497+-    .09527    .91+-  .12    -.8
C15     P      *    .00530<     .07010    .03362<     .00561   6.34< 83.90      .4
C16     S      *    .79570+-    .02870    .82290+-    .08092   1.03+-  .11      .3
C17     CL     *    .07530<     .08920    .08877<     .00807   1.18<  1.40      .2
C19     K      *    .45920+-    .07530    .46960+-    .09773   1.02+-  .27      .1
C20     CA     *    .59930+-    .06380    .61904+-    .04124   1.03+-  .13      .3
C22     TI     *    .01050<     .25850    .02690<     .00150   2.56< 63.07      .1
C23     VA     *    .00000<     .10960    .00197<     .00046    .00<   .00      .0
C24     CR     *    .00000<     .02850    .00555<     .00230    .00<   .00      .2
C25     MN     *    .02420+-    .02190    .00918+-    .00078    .38+-  .34    -.7
C26     FE     *    .35340+-    .01570    .28637+-    .03444    .81+-  .10   -1.8
C27     CO     *    .00000<     .01310    .00003<     .00017    .00<   .00      .0
C28     NI     *    .00240<     .00970    .00714<     .00591   2.98< 12.28      .4
C29     CU          .00000<     .01170    .21677<     .22790    .00<   .00      .9
C30     ZN     *    .05840+-    .01170    .15305+-    .13030   2.62+- 2.29      .7
C31     GA     *    .00000<     .02160    .00000<     .00018    .00<   .00      .0
C33     AS     *    .00020<     .03050    .00112<     .00059   5.62< *****      .0
C34     SE     *    .00000<     .01400    .00033<     .00023    .00<   .00      .0
C35     BR     *    .00130<     .01100    .00221<     .00025   1.70< 14.39      .1
C37     RB     *    .00090<     .01150    .00182<     .00030   2.03< 25.91      .1
C38     SR     *    .00000<     .01370    .00301<     .00040    .00<   .00      .2
C40     ZR     *    .00000<     .02060    .00003<     .00207    .00<   .00      .0
C42     MO     *    .00000<     .03370    .00122<     .00141    .00<   .00      .0
C49     IN     *    .00000<     .16420    .00200<     .00288    .00<   .00      .0
C51     SB     *    .00000<     .22300    .00312<     .00770    .00<   .00      .0
C56     BA     *    .00000<     .65400    .03020<     .01849    .00<   .00      .0
C82     PB     *    .03300+-    .00540    .02304+-    .01374    .70+-  .43    -.7
C201    OC     *   4.13000+-    .28910   5.32146+-    .33546   1.29+-  .12     2.7
C202    EC     *   5.00000+-    .45000   3.69651+-    .32101    .74+-  .09    -2.4
C203    SO4    *   2.41400+-    .03630   2.36690+-    .19290    .98+-  .08    -.2
-------------------------------------------------------------------------------
```

Table E-3. CMB results

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: BEIJING      DATE: 1/09/90     CMB7 33889
SAMPLE DURATION        3      START HOUR        8          SIZE:    FINE
       R SQUARE      .98    PERCENT MASS    117.0
     CHI SQUARE     3.05              DF       23

  SOURCE
     * TYPE     SCE(UG/M3)    STD ERR      TSTAT
--------------------------------------------
3      HONEYC      16.7460      .8058    20.7823
5      INDST       13.1438     2.2830     5.7574
6      SOIL         8.9949     2.6809     3.3552
13     POWER1      22.7145     4.9357     4.6021
20     HOGFU       33.3370     5.2786     6.3155
25     SO4         23.5538     2.7523     8.5579
26     MVHDDS      86.2045     8.0861    10.6609
--------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE
     175.0+-    17.5

       UNCERTAINTY/SIMILARITY CLUSTERS    CMB7 33889     SUM OF CLUSTER SOURCES
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SPECIES CONCENTRATIONS -  SITE: BEIJING      DATE: 1/09/90     CMB7 33889
SAMPLE DURATION        3      START HOUR        8          SIZE:    FINE
       R SQUARE      .98    PERCENT MASS    117.0
     CHI SQUARE     3.05              DF       23

SPECIES-------I---MEAS------------------CALC-------------RATIO C/M----RATIO R/U
C1     TOT    T 174.97000+- 17.49700 204.69440+-  9.12028  1.17+-  .13     1.5
C13    AL     *   1.86830+-   .12760   2.70857+-   .11818  1.45+-  .12     4.8
C14    SI     *   5.03610+-   .11700   4.19185+-   .16223   .83+-  .04    -4.2
C15    P      *    .28430<    .55850    .30191<    .10983  1.06<  2.12      .0
C16    S      *  12.23300+-   .05490  12.17023+-  1.52317   .99+-  .12     -.0
C17    CL     *   7.11290+-   .11580   7.05672+-   .17777   .99+-  .03     -.3
C19    K      *   3.06960+-   .08120   7.96842+-  2.32429  2.60+-  .76     2.1
C20    CA     *   1.40440+-   .06750   1.66378+-   .10008  1.18+-  .09     2.1
C22    TI     *    .17900<    .24850    .25846<    .01472  1.44<  2.01      .3
C23    VA     *    .00000<    .11050    .01569<    .01254   .00<   .00      .1
C24    CR     *    .00000<    .02760    .02287<    .00368   .00<   .00      .8
C25    MN     *    .14140+-   .02220    .08876+-   .01312   .63+-  .14    -2.0
C26    FE     *   1.64240+-   .01880   1.43822+-   .11151   .88+-  .07    -1.8
C27    CO     *    .00070<    .02700    .00521<    .01135  7.45< *****      .2
C28    NI     *    .02450+-   .01030    .01066+-   .00286   .44+-  .22    -1.3
C29    CU          .03090+-   .01100    .10767+-   .00693  3.48+- 1.26     5.9
C30    ZN     *    .73290+-   .01280    .70379+-   .13885   .96+-  .19     -.2
C31    GA     *    .05130+-   .02040    .03556+-   .00406   .69+-  .29     -.8
C33    AS     *    .05940<    .08590    .02697<    .02192   .45<   .75     -.4
C34    SE     *    .01960+-   .01330    .05299+-   .01303  2.70+- 1.95     1.8
C35    BR     *    .06130+-   .01120    .03834+-   .01459   .63+-  .26    -1.2
C37    RB     *    .01090+-   .01070    .02870+-   .00423  2.63+- 2.61     1.5
C38    SR     *    .03580+-   .01250    .05665+-   .00782  1.58+-  .59     1.4
C40    ZR     *    .01660<    .01880    .02114<    .02591  1.27<  2.13      .1
C42    MO     *    .00850<    .03390    .01072<    .01615  1.26<  5.38      .1
C49    IN     *    .00000<    .16470    .00222<    .03771   .00<   .00      .0
C51    SB     *    .00000<    .22350    .00590<    .09669   .00<   .00      .0
C56    BA     *    .04620<    .65560    .10055<    .18505  2.18< 31.14      .1
C82    PB     *    .44360+-   .00930    .44618+-   .01209  1.01+-  .03      .2
C201   OC     *  35.93000+-  2.51510  35.91127+-  3.25956  1.00+-  .11      .0
C202   EC     *  48.27000+-  4.34430  48.12066+-  4.05182  1.00+-  .12     -.0
C203   SO4    *  36.70320+-   .14510  36.77341+-  2.77663  1.00+-  .08      .0
-------------------------------------------------------------------------------
```

Table E-4. CMB results.

```
SOURCE CONTRIBUTION ESTIMATES -  SITE: BEIJING       DATE: 5/11/90      CMB7 33889
SAMPLE DURATION         1        START HOUR         8          SIZE:     FINE
       R SQUARE        .96     PERCENT MASS      128.1
     CHI SQUARE       1.93                DF        23

  SOURCE
      * TYPE      SCE(UG/M3)    STD ERR      TSTAT
---------------------------------------------------
3       HONEYC        1.8589      .5061     3.6727
5       INDST        11.3420     3.3896     3.3461
14      LIMED        11.3533     1.2610     9.0032
20      HOGFU        17.5394     2.6951     6.5079
21      VEGETA       41.4555     4.4274     9.3635
22      AULEA          .5337      .2117     2.5206
26      MVHODS       21.5571     3.0176     7.1437
---------------------------------------------------

MEASURED CONCENTRATION FOR SIZE: FINE
      82.4+-     8.2

        UNCERTAINTY/SIMILARITY CLUSTERS     CMB7 33889      SUM OF CLUSTER SOURCES
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SPECIES CONCENTRATIONS -  SITE: BEIJING       DATE: 5/11/90      CMB7 33889
SAMPLE DURATION         1        START HOUR         8          SIZE:     FINE
       R SQUARE        .96     PERCENT MASS      128.1
     CHI SQUARE       1.93                DF        23

SPECIES-------I---MEAS-----------------CALC------------RATIO C/M----RATIO R/U
C1      TOT     T  82.44000+-  8.24400 105.64000+-  3.96342   1.28+-  .14      2.5
C13     AL      *   1.66140+-   .12000   1.85169+-   .09935   1.11+-  .10      1.2
C14     SI      *   5.51150+-   .09200   4.97392+-   .41999    .90+-  .08     -1.3
C15     P       *    .21610+-   .06720    .29305+-   .05862   1.36+-  .50       .9
C16     S       *   2.67480+-   .04720   2.61503+-   .68876    .98+-  .26      -.1
C17     CL      *   1.47330+-   .10460   1.49584+-   .09414   1.02+-  .10       .2
C19     K       *   2.31380+-   .09220   4.80707+-  1.22690   2.08+-  .54      2.0
C20     CA      *   4.40740+-   .08530   4.51202+-   .34259   1.02+-  .08       .3
C22     TI      *    .28410+-   .25560    .21540+-   .00789    .76+-  .68      -.3
C23     VA      *    .02290<    .13480    .01513<    .00282    .66<  3.89      -.1
C24     CR      *    .00990<    .02850    .03196<    .01005   3.23<  9.35       .7
C25     MN      *    .08240+-   .02310    .07395+-   .00756    .90+-  .27      -.3
C26     FE      *   2.03390+-   .02610   1.55849+-   .15121    .77+-  .07     -3.1
C27     CO      *    .00160<    .03240    .00232<    .00281   1.45< 29.37       .0
C28     NI      *    .02260+-   .01230    .03569+-   .02571   1.58+- 1.43       .5
C29     CU           .02220+-   .01160   1.00176+-   .99203  45.12+-50.53      1.0
C30     ZN      *    .58480+-   .01450    .96084+-   .56766   1.64+-  .97       .7
C31     GA      *    .00600<    .02660    .03060<    .00118   5.10< 22.61       .9
C33     AS      *    .00760<    .09530    .01866<    .01783   2.45< 30.87       .1
C34     SE      *    .00390<    .01700    .00875<    .00163   2.24<  9.79       .3
C35     BR      *    .04250+-   .01160    .05530+-   .01149   1.30+-  .45       .8
C37     RB      *    .00810<    .01090    .01802<    .00145   2.23<  3.00       .9
C38     SR      *    .02180+-   .01270    .02861+-   .00148   1.31+-  .77       .5
C40     ZR      *    .01490<    .01920    .01160<    .00651    .78<  1.09      -.2
C42     MO      *    .06650+-   .03130    .01077+-   .00490    .16+-  .11     -1.8
C49     IN      *    .00000<    .20020    .00918<    .01080    .00<  .00       .0
C51     SB      *    .00000<    .27270    .01679<    .02660    .00<  .00       .1
C56     BA      *    .00000<    .78630    .13904<    .07432    .00<  .00       .2
C82     PB      *    .45300+-   .01320    .37214+-   .07248    .82+-  .16     -1.1
C201    OC      *  16.06000+-  1.12420  22.03589+-  1.38174   1.37+-  .13      3.4
C202    EC      *  16.97000+-  1.52730  12.51474+-  1.01208    .74+-  .09     -2.4
C203    SO4     *   8.14320+-   .11840   7.28087+-   .77190    .89+-  .10     -1.1
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BIOGRAPHICAL NOTE

The author was born 25 December 1944, in Shan Xi province of China. She graduated from the high school attached to Beijing Normal University in 1962. In 1967, she received her Bachelor of Chemical Engineering at Beijing Chemical Engineering Institute. Then she worked as an assistant engineer and engineer at Mudanjiang Chemical Fiber Factory; the design section of the Research Institute of the Bureau of Light Industry of Mudanjiang city; Yenshan Chemical Corporation in Beijing and the Plastic Institute of the Ministry of the Light Industry from 1968 to 1984. She designed an industrial hygiene system for a CS_2 plant at the Mudanjiang Chemical Fiber Factory. In 1974, she designed one section of Mudanjiang Refinery Factory. From 1976 to 1980, she helped checked the design, construction, process, analysis and did technical training, start up for a 100,000 ton/yr paraxylene factory. In addition she was in charge of waste water treatment for the project. She was an editor of the magazine named "Chinese Plastic" from 1980 to 1984.

The author came to the Oregon Graduate Institute in September 1984, and got her M.S. in Environmental science and Engineering in 1986. She completed the requirement for the degree doctor of Philosophy in July 1992. She cooperated with the Eco-environmental Center of Chinese Academy Sinica to conduct this aerosol and coal burning research project.

She will continue her research after she graduates from OGI.

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