

AN ABSTRACT OF THE THESIS OF

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Title: INDOOR/OUTDOOR ATMOSPHERIC TRACE ELEMENT ABUNDANCES

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The atmospheric trace element abundances associated with "indoor" and "outdoor" air particulate have been measured for university chemistry laboratories, typical homes, modern office buildings, hospital and automobile repair garages in a rural setting (Corvallis, Oregon) and modern office buildings in an urban setting (Portland, Oregon). Samples of atmospheric particulate matter were collected using a high volume sampler, a cascade impactor and a specially designed, quiet sampler. Analysis of the trace elements Al, Fe, Ti, Na, K, Sm, Eu, La, Sc, Cl, Mn, Br, V, Sb, Co, Cr, As, and Zn was done using instrumental neutron activation analysis. I found that "upswept soil" and the "wood products industry contribution" are the main components of Corvallis Oregon rural air. The rural results show the mean indoor concentrations to be ~75% of the outdoor concentrations with preferential loss of larger particles as one moves from outdoors to indoors. The urban results show typical indoor-outdoor ratios of ~18%. By examining any enhancement or chemical fractionation in elemental abundance patterns between indoor and outdoor particulate matter, one can identify

indoor sources. Sources of this type identified in this work include acid vapors in the chemistry laboratory, auto exhaust in the automobile repair garage and unidentified source(s) of atmospheric chromium in the typical homes, potassium in one modern office, antimony and zinc in the other modern office.

Indoor/Outdoor Atmospheric Trace Element Abundances

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Isabella Shiu Wing Cheung

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Typed by Isabella S. W. Cheung

To
My Parents

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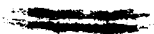
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TABLE OF CONTENTS

INTRODUCTION	1
EXPERIMENTAL METHODS	4
Air Sampling	4
A. Samplers	4
1. High Volume Sampler	4
2. Indoor Air Sampler	6
3. Cascade Impactor	7
B. Collection Medium	9
C. Sampling Location	11
1. University Chemistry Laboratories	11
2. Typical Homes	12
3. Modern Office Buildings	13
4. Hospital	14
5. Automobile Repair Garages	15
D. Sampling Procedures	16
Analysis	17
RESULTS AND DISCUSSION	27
A. Elemental Composition of Oregon Rural Air	27
B. Particle Size Fractions in Oregon Rural Air	34
C. Elemental Composition of Urban (Portland, Oregon) Air Particulates	37
D. Statistical Considerations and Indoor Particulate Composition	41
E. Composition of Indoor Particulate Samples	44
1. University Chemistry Laboratories	44
2. Typical Homes	59
3. Modern Office Buildings (Rural)	68
4. Hospital	76

5. Automobile Repair Garage	76
6. Modern Office Buildings (Urban)	83
CONCLUSIONS	95
BIBLIOGRAPHY	97
APPENDIX I: THE ABSOLUTE INDOOR AND OUTDOOR TRACE ELEMENT CONCENTRATIONS	100
APPENDIX II: ELEMENTAL ABUNDANCES IN AERODYNAMICALLY SIZED ATMOSPHERIC PARTICULATE	116
APPENDIX III: DISTRIBUTION OF INDOOR/OUTDOOR RATIOS	135



LIST OF TABLES

<u>Table</u>	<u>Page</u>
1. Trace Element Content of Filter Paper	10
2. Approximate Limits of Detectability by Several Methods for Various Elements in Aerosols from Urban Atmosphere	18
3. Resolution of 40 cm ³ Lithium Drifted Germanium [Ge(Li)] Gamma Ray Detector (Nuclear Diodes, Model Number LG CC 5.65-1.90)	19
4. Instrumental Neutron Activation Analysis Procedure	21
5. Elemental Concentrations in NBS Coal (SRM 1632)	22
6. Elemental Concentrations in NBS Coal Fly Ash (SRM 1633)	23
7. Elemental Concentrations in NBS Orchard Leaves (SRM 1571)	24
8. Atmospheric Trace Element Concentrations in Rural Air	28
9. Enrichment Factors of Trace Elements in Rural Air	30
10. Trace Element Concentrations in Oregon Soil	31
11. Absolute and Normalized Concentration of Trace Elements in Stack Effluent at the Western Kraft Paper Company	33
12. Trace Element Concentrations and Enrichment Factors of Trace Element in Portland Atmospheric Particulates (Aug. 17, 77)	38
13. Atmospheric Trace Element Abundances in Various Locations (ng/m ³)	40
14. The Variation and Mean of Indoor/Outdoor Elemental Concentration Ratios Observed in Radiation Center (Oregon State University)	42
15. The Variation of <u>Indoor/Outdoor Ratio</u> Mean Value of Indoor/Outdoor Ratios for Each Element	43
16. Concentrations of Chlorine and Bromine in Laboratory III	49

<u>Table</u>	<u>Page</u>
17. Trace Element Concentrations in Solder ($\mu\text{g/g}$)	54
18. Trace Element Concentrations in Solder Vapor	54
19. Elemental Particle Size Distribution of Solder Vapor	55
20. Trace Element Concentrations in Laboratory IV (May 18, 76)	55
21. Trace Element Concentrations in Laboratory IV (May 18, 76)	55
22. Trace Element Concentrations in Laboratory IV (July 23, 77)	56
23. Trace Element Concentrations in Laboratory IV (February 26, 78)	56
24. Trace Element Concentrations in Office I for Various Days	72
25. Ratio of Excess Bromine to Chlorine in Garage I	76
26. Average Indoor/Outdoor Ratios for Several Types of Buildings	95
27. The Percentage of the Penetration of "One in. Throwaway" Filter	96a
28. The Predicted Aluminum Size Distribution in Indoor	96b
29. Aluminum Size Distribution for Different Locations	96b

<u>Appendix Table</u>	<u>Page</u>
I-1. Trace Element Concentrations in Laboratory I (May 4, 76)	100
I-2 Trace Element Concentrations in Laboratory II (May 5, 76)	101
I-3 Trace Element Concentrations in Laboratory III (May 13, 76)	102
I-4 Trace Element Concentrations in Laboratory IV (May 18, 76)	103
I-5 Trace Element Concentrations in Laboratory IV (July 23, 77)	104
I-6 Trace Element Concentrations in Home I-Living Room (June 20, 76)	105
I-7 Trace Element Concentrations in Home I-Bedroom (June 23, 76)	106
I-8 Trace Element Concentrations in Home II-Bedroom (June 29, 76)	107
I-9 Trace Element Concentrations in Office I (July 2, 76)	108
I-10 Trace Element Concentrations in Office II (July 8, 76)	109
I-11 Trace Element Concentrations in the Isolation Station of Hospital (July 13, 76)	110
I-12 Trace Element Concentrations in the General Station of Hospital (July 17, 76)	111
I-13 Trace Element Concentrations in Garage I (July 29, 76)	112
I-14 Trace Element Concentrations in Garage II (Oct. 4, 76)	113
I-15 Trace Element Concentrations in Office III (Aug. 17, 77)	114
I-16 Trace Element Concentrations in Office IV (Aug. 17, 77)	115

<u>Appendix Table</u>	<u>Page</u>
II-1 Elemental Particle Size Distribution in Rural Air	116
II-2 Elemental Particle Size Distribution in Laboratory I (May 4, 76)	117
II-3 Elemental Particle Size Distribution in Laboratory II (May 5, 76)	118
II-4 Elemental Particle Size Distribution in Laboratory III (May 13, 76)	119
II-5 Elemental Particle Size Distribution in Laboratory IV (May 18, 76)	120
II-6 Elemental Particle Size Distribution in Home I-Living Room (June 22, 76)	121
II-7 Elemental Particle Size Distribution in Home I-Bedroom (June 24, 76)	122
II-8 Average Elemental Particle Size Distribution in Home I	123
II-9 Elemental Particle Size Distribution in the Outdoor of Home I (June 26, 76)	124
II-10 Elemental Particle Size Distribution in Home II- Bedroom (June 30, 76)	125
II-11 Elemental Particle Size Distribution in Office I (July 6, 76)	126
II-12 Elemental Particle Size Distribution in Office II (July 9, 76)	127
II-13 Elemental Particle Size Distribution in the Isolation Station of Hospital (July 14, 76)	128
II-14 Elemental Particle Size Distribution in the General Station of Hospital (July 16, 76)	129

<u>Appendix Table</u>	<u>Page</u>
II-15 Elemental Particle Size Distribution in Garage I (July 28, 76)	130
II-16 Elemental Particle Size Distribution in the Outside of Garage I (July 30, 76)	131
II-17 Elemental Particle Size Distribution in Garage II (Oct. 1, 76)	132
II-18 Elemental Particle Size Distribution in the Outside of Garage II (Oct. 6, 76)	133
II-19 Elemental Particle Size Distribution in Office IV (Aug. 17, 77)	134
III-1 Cumulative Percentage of <u>Indoor/Outdoor Ratio</u> Mean Value of Indoor/Outdoor Ratios	135

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. High Volume Sampler with Spacer Ring, Sample Holder and Adaptor	5
2. Indoor Air Sampler	6
3. Eight Stage Andersen Cascade Impactor and the Range of Air Particulate Separated at Each Stage along with Its Relationship to Human Respiratory System	8
4. Andersen Cascade Impactor for the Fractionation of Air Particulates	8a
5. The Photopeak Efficiency of the 40 cm ³ Lithium Drifted Germanium [Ge(Li)] Gamma Ray Detector (Nuclear Diodes, Model Number LG CC 5.65-1.90) at the Distance of 9.5mm from the Detector	20
6. Enrichment Factors (With Respect to Fe) of Elements Present on Particulate Matter Collected in Oregon Rural Air	29
7a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Rural Air (Corvallis, Oregon)	35
7b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Rural Air (Corvallis, Oregon)	36
8. Enrichment Factors (with Respect to Fe) of Elements Present on Particulate Matter Collected in Portland Atmosphere	39
9. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory I (May 4, 1976)	45
10. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory I (May 4, 1976)	46

<u>Figure</u>		<u>Page</u>
11.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory II (May 5, 1976)	47
12.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory II (May 5, 1976)	48
13.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory III (May 13, 1976)	50
14.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory III (May 13, 1976)	51
15.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory IV (May 18, 1976)	52
16.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory IV (May 18, 1976)	57
17.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory IV (July 23, 1977)	58
18.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Home I-Living Room (June 20, 1976)	60
19.	Ratios of Indoor and Outdoor Elemental Concentrations Found in Home I-Bedroom (June 23, 1976)	61
20.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home I-Living Room (June 22, 1976)	62
21.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home I-Bedroom (June 24, 1976)	63
22.	Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home I (Average)	64

<u>Figure</u>	<u>Page</u>
23. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Home I (June 26, 1976)	65
24. Ratios of Indoor and Outdoor Elemental Concentrations Found in Home II (June 29, 1976)	66
25. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home II (June 30, 1976)	67
26. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office I (July 2, 1976)	69
27a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office I (July 6, 1976)	70
27b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office I (July 6, 1976)	71
28. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office II (July 8, 1976)	74
29. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office II (July 9, 1976)	75
30. Ratios of Indoor and Outdoor Elemental Concentrations Found in the Isolation Station of Hospital (July 13, 1976)	77
31. Ratios of Indoor and Outdoor Elemental Concentrations Found in the General Station of Hospital (July 17, 1976)	78
32a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Isolation Station of Hospital (July 14, 1976)	79
32b. Percentage of The Total Elemental Particulate Mass with Given Stage Found in the Isolation Station of Hospital (July 14, 1976)	80

<u>Figure</u>	<u>Page</u>
33. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the General Station of Hospital (July 16, 1976)	81
34. Ratios of Indoor and Outdoor Elemental Concentrations Found in Garage I (July 29, 1976)	82
35a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage I (July 28, 1976)	84
35b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage I (July 28, 1976)	85
36a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage I (July 30, 1976)	86
36b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage I (July 30, 1976)	87
37. Ratios of Indoor and Outdoor Elemental Concentrations Found in Garage II (October 4, 1976)	88
38. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage II (October 1, 1976)	89
39. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage II (October 6, 1976)	90
40. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office III (August 17, 1977)	91
41. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office IV (August 17, 1977)	93
42. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office IV (August 17, 1977)	94

Appendix Figure

Page

1. Cumulative Percentage Plot for the Data in Appendix
III, Table 1 136
2. Cumulative Percentage Plot for the Data in Appendix
III, Table 1 137

Indoor/Outdoor Atmospheric Trace Element Abundances

INTRODUCTION

Most air quality standards and measurements are directed towards outdoor pollutant concentrations but the largest portion (~80%) of most peoples' lives is spent indoors breathing air whose composition may be different from the outdoor air. People who are especially sensitive to atmospheric pollutants such as the elderly, the bedridden or the very young are most likely to spend large amounts of time indoors. Thus an understanding of the mechanisms of pollutant transport from the outdoor to the indoor regime is very important as is the characterization of indoor air pollutant sources. In this work I present the results of a study aimed at characterizing the elemental composition of the indoor atmospheric particulate in a wide variety of locations in rural and urban Oregon communities. By examining any chemical fractionation or enhancement in elemental abundance patterns between indoor and outdoor particulate matter, one can show the presence of indoor pollutant sources. The absolute abundances of the elements present in indoor and outdoor air can be valuable indications of mechanisms for outdoor-indoor pollutant transport.

Several studies (1,2,3,4,5,6) have been made of the relative levels of gaseous components of indoor and outdoor air. The conclusions of these studies may be summarized as follows. Reactive gases, such as ozone, sulfur dioxide, etc. will be absorbed by walls and other interior surfaces, leading to lowered indoor concentrations of these gases. Unreactive gases, such as carbon monoxide, penetrate buildings effectively and thus one expects and observes similar indoor and outdoor

concentrations with some time lag (due to penetration time) between outdoor and indoor diurnal maxima. Some gaseous components, such as carbon dioxide, have significant internal sources and thus one observes higher levels of these gases indoors. Amongst the interior sources of gaseous atmospheric components are such activities as smoking, heating, cooking, etc.. The exact values of the indoor/outdoor ratios for gases have been shown to be complex functions of the time of day, season, location of building, type of building, ventilation system, etc.

A number of studies (2, 5, 6, 7, 8, 9) have been made of the indoor/outdoor ratio for particulate matter and unfortunately, no clear picture emerges for the particulate matter. In general, the particulate levels indoor range from 20-100% of the outdoor levels. Some studies point to a constant indoor/outdoor ratio as the outdoor concentrations increase but other studies have pointed of lowered indoor/outdoor ratios at high ($>300 \mu\text{g}/\text{m}^3$) outdoor concentrations. Most studies have indicated the indoor particulate concentration to be ~60-80% of the outdoor concentration in non-air conditioned buildings, such as homes, etc. Since smaller particles penetrate buildings more effectively than larger particles, the finding that the mean diameter of the particulate matter in interior air is less than the same quantity in outdoor air is not surprising. A few studies have pointed towards indoor sources of particulate matter.

The indoor air particulate has not been chemically characterized except for a few special situations. Yocom et al. (2) measured the lead content of indoor suspended particulate matter and found no statistically significant evidence for any chemical fractionation of the lead in the

particulate matter as it moved from outdoors to indoors. (A similar study of the benzene soluble portion of the suspended particulate showed a factor of ~ 2 enhancement in benzene soluble material relative to total suspended particulate as the particulate went indoors.) Stocks et al. (10) measured the concentrations of thirteen trace elements in particulate matter collected inside English factories, a bus terminal and a garage. The interior air in the steel mills studied showed high trace element content due to the manufacturing processes while the garage air showed elevated lead and vanadium levels compared to the exterior air.

In this work I measured the trace element content of atmospheric particulate matter collected indoors and outdoors for typical homes, college laboratories, modern office buildings, automobile repair garages and a hospital in a rural (Corvallis) Oregon community and modern office buildings in an urban (Portland) Oregon community.

EXPERIMENTAL METHODS

The chemical characterization of typical indoor and outdoor atmospheric particulate matter consists of two equally important operations, the collection of representative samples of atmospheric particulate matter and the analysis of these samples. Sampling of the atmospheric particulate was done using high volume samplers (outdoor samples) and a special quiet, simple home-built sampler (indoor samples). A cascade impactor was used to collect and aerodynamically size the indoor and outdoor atmospheric particulate matter so that representative samples of each particle size fraction were available for elemental analysis. Instrumental neutron activation analysis was used to measure the abundances of the elements Al, Fe, Ti, Na, K, Sm, Eu, La, Sc, Cl, Mn, Br, V, Sb, Co, Cr, As, and Zn in the samples. A detailed description of the procedures used in this study is given below.

AIR SAMPLING

A. SAMPLERS

1. High Volume Sampler. (Shepherd and Associates, Model 8000)

This air sampler (see Figure 1) was used as the outdoor sampler. It is designed to sample a large volume of air within a short time period. It uses a 9/16 horsepower brush type motor and is equipped with independent motor cooling. The sampler was operated using either two 12 volt batteries in series (flow rate was about $0.0085 \text{ m}^3/\text{min}$) or 110 volt A. C. (flow rate ranged from $0.028 \text{ m}^3/\text{min}$ to $0.056 \text{ m}^3/\text{min}$)

as power sources.

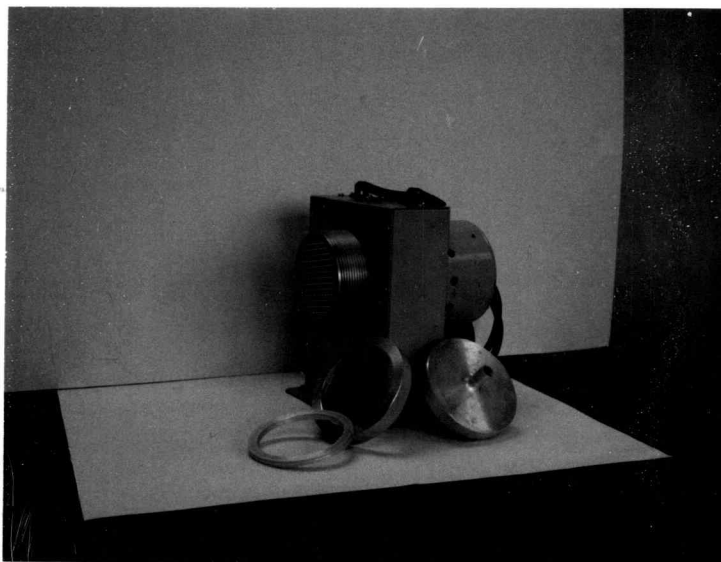


Figure 1. High Volume Sampler with Spacer Ring,
Sample Holder and Adaptor.

2. Indoor Air Sampler

Because of the noise from the high volume air sampler, it is not an acceptable indoor air sampler. A quiet and simple indoor sampler was developed by using small pump (1/3 horsepower) and muffler (see Figure 2). The flow rate using 47 mm sample holder was about 0.023 m³/min.

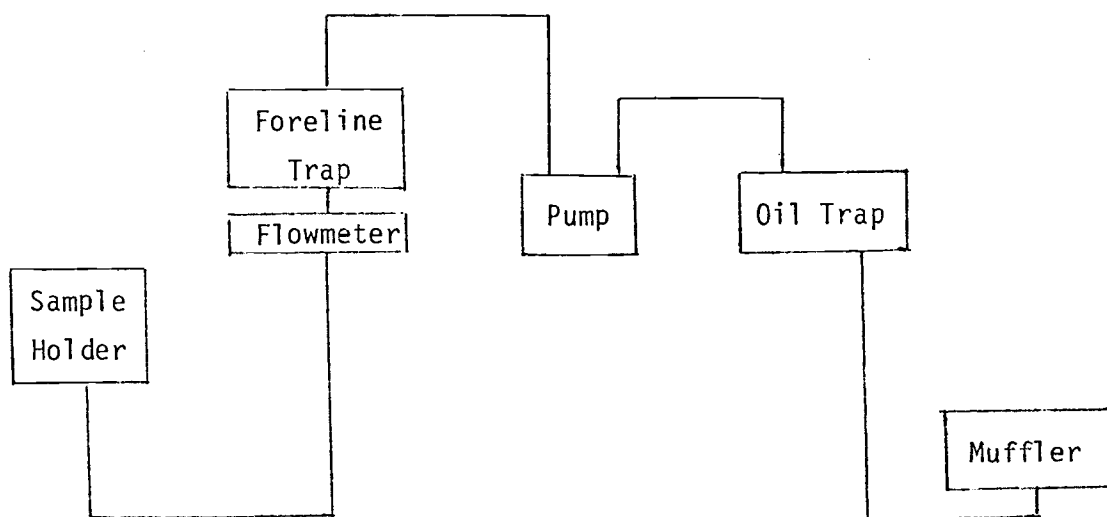


Figure 2. Indoor Air Sampler .

3. Cascade Impactor

To collect representative samples of each particle size range for chemical analysis, a cascade impactor, the Andersen particle fractionating sampler was used. The Andersen particle fractionating sampler (Model Number 23000) collects and aerodynamically sizes all airborne particulate matter in the environment. The Andersen ambient sampler (see Figure 3) is composed of eight aluminum stages that are held together by three spring clamps and gasketed with O-ring seals. Each stage has an integral air inlet section that consists of 400 identical orifices except stage seven with 200 orifices. The orifices are progressively smaller from the top to the bottom stages, ranging from 0.1588 cm diameter in stage zero to 0.0254 cm in stage seven. The air inlet section is about 7.938 cm in diameter. The exhaust section of each stage is about 1.91 cm larger in diameter than the collection plate to allow the unimpacted particles to flow around the plate and into the next stage. A removable glass plate with collection media is placed on each stage. Because the size of the orifices are smaller in each succeeding stage, as the air is drawn through the sampler at constant flow rate, the orifice velocity increases in each succeeding stage. When the velocity imparted to a particle is sufficiently great, its inertia will overcome the aerodynamic drag and the particle will leave the turning stream of air and be impacted on the surface of the collection medium. Otherwise, the particle remains in the air stream and proceeds to the next stage (see Figure 4). The particle size range collected at

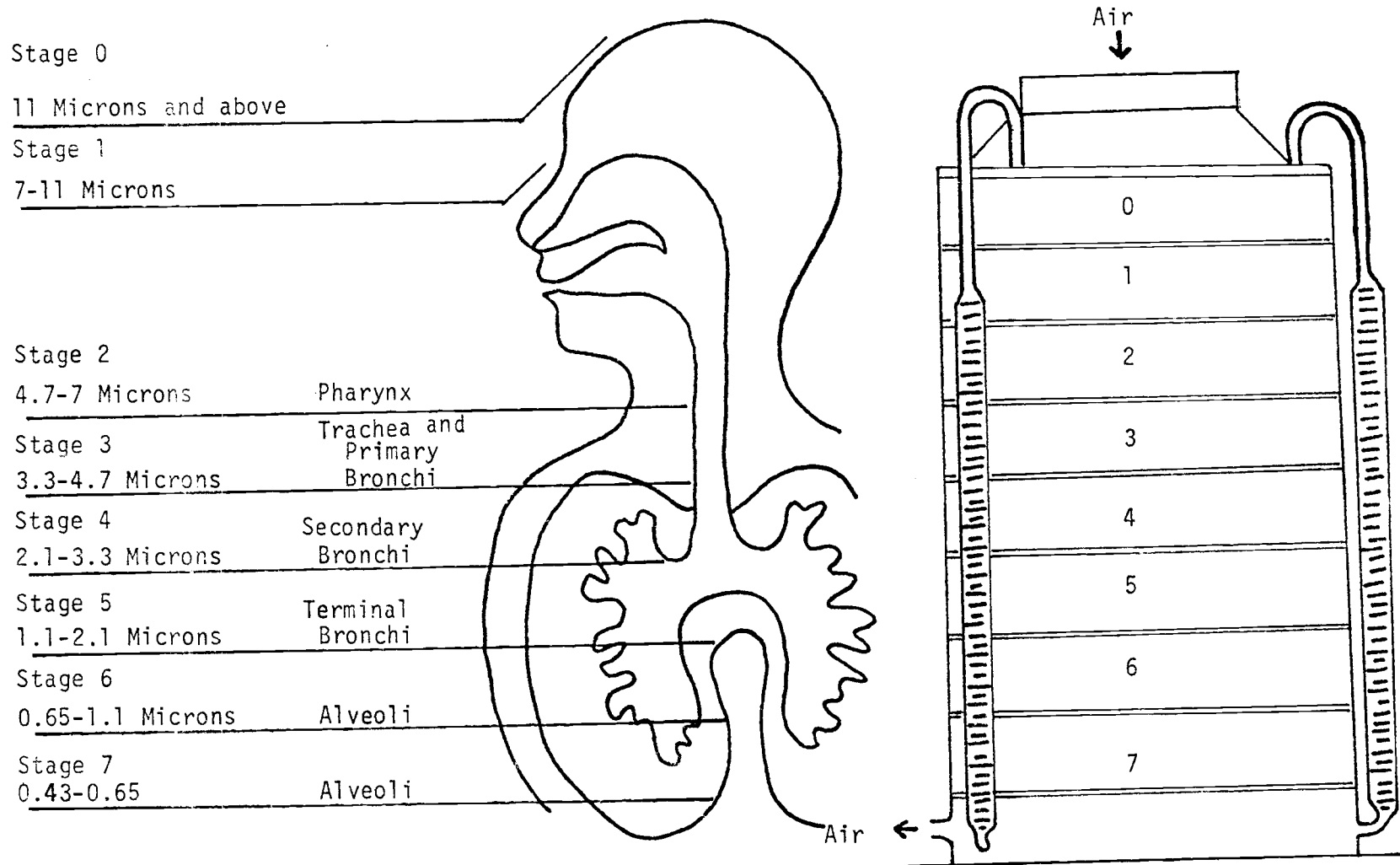


Figure 3. Eight Stage Andersen Cascade Impactor and the Range of Air Particulate Separated at Each Stage along with Its Relationship to Human Respiratory System.

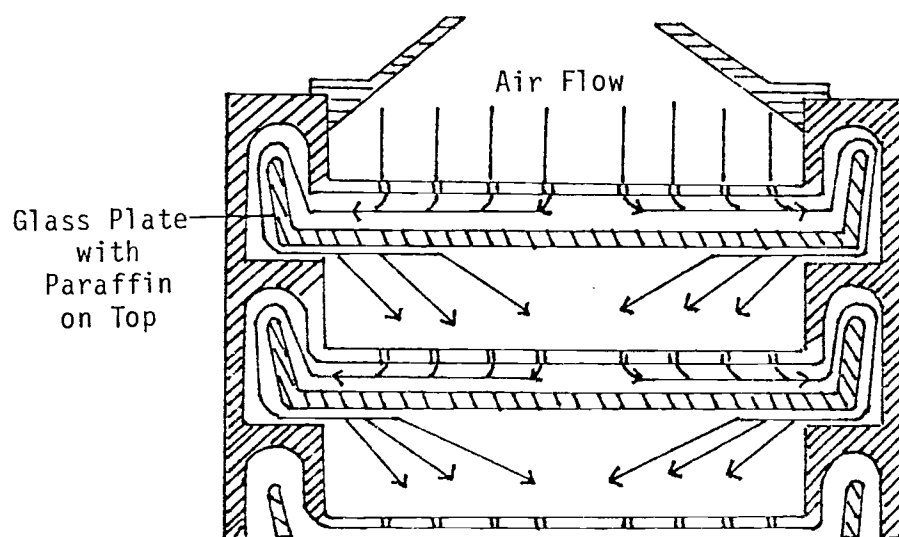


Figure 4. Andersen Cascade Impactor for the Fractionation of Air Particulates.

each of the eight stages depends on the orifice velocity, the distance between the orifice and the collection surface, and the collection characteristics of the preceding stage. In this work, the sampler was operated by connecting to the indoor air sampler with a flow rate of 0.028 m³/min. At this flow rate, the particle fractionation ranges from 11.0 to 0.4 microns diameter. Figure 3 shows the relationship between the range of particle sizes collected on each stage and the human respiratory system.

B. COLLECTION MEDIUM

Nuclepore filter paper with a pore size of 0.2 μ m was used as a collection medium for the high volume sampler and the indoor air sampler. It is non-hygroscopic with uniform pore size and has lower trace element content than Handiwrap, Whatman #1 and Millipore EH (11). In order to retain the particles on the collection surfaces, paraffin was chosen as the collection medium for the Andersen particle fractionating sampler. The abundances of various elements in Nuclepore filter paper and paraffin as measured in this work are listed in Table 1.

Because of the large variability in trace element content of these collection media as shown in Table 1, I was careful to measure the trace element content of filter papers from the same batch as those used in sampling when making "blank" corrections. In most cases, the "blank" corrections were small (<5%) and thus this trace element variability was not a major problem.

Table 1. Trace Element Content of Filter Paper (ng/cm²)

Element	Nuclepore Membrane Filter					This Work		
	Jones (12)	Shum & Loveland (13)	Ricci et al. (14)	Chick (15)	This Work Weighted Average	Range	Weighted Average	Range
Al	5.1	2.7	42.2	---	2.6 ± 0.1	2.3-2.5	212.5 ± 1.6	204.9-241.7
Fe	---	---	---	---	<1.4		50.8 ± 4.9	38.3-55.7
Ti	---	2.1	---	---	<2.3		<21.2	
Na	31	47	34.5	10.4	8.8 ± 0.4	4.9-15.9	18.3 ± 0.9	13.4-23.6
K	---	---	---	8.6	<1.74		<13.3	
Sm	0.0021	<0.0017	---	0.0047	<0.005		<0.0011	
Eu	---	<0.000016	---	0.0004	<0.0026		<0.006	
La	---	---	---	0.10	<0.006		<0.11	
Sc	---	---	---	---	<0.0013		<0.005	
Cl	49	80	39.4	---	57 ± 1	47-77	364 ± 4	348-402
Mn	0.31	0.23	0.10	0.44	0.07 ± 0.01	0.05-0.09	1.8 ± 0.2	1.7-2.3
Br	2.8	1.7	0.92	1.49	0.37 ± 0.06	0.34-0.43	0.35 ± 0.01	0.31-0.39
V	0.015	---	0.33	---	<0.01		<0.2	
Sb	---	---	---	---	<0.002		<0.09	
Co	---	---	---	0.29	0.015 ± 0.008	0.013-0.020	0.11 ± 0.01	0.06 -0.13
Cr	---	---	1.5	---	11.0 ± 0.1	10.4-16.7	2.76 ± 0.08	2.42-2.87
As	---	---	1.3	---	<0.13		<0.47	
Zn	---	---	20.2	1.44	15.4 ± 0.5	15.2-15.5	7.12 ± 0.40	5.54-7.74

C. SAMPLING LOCATIONS

1. University Chemistry Laboratories

Four chemistry laboratories on the Oregon State University campus were used in this study. These laboratories were Weniger 110 (Laboratory II), Weniger 127 (Laboratory IV), Gilbert 125 (Laboratory I) and Gilbert 230 (Laboratory III). The area of each chemistry laboratory is about 1200 square feet. Steam heat for these rooms is supplied by the central heating plant on the campus. Bunsen burners utilizing natural gas operate in each laboratory. Gilbert and Weniger Halls are located at the north part of the Oregon State University campus and face onto a street with moderately heavy traffic. A small parking lot separates the two buildings.

Gilbert Hall is an old four story structure, built of concrete and brick. Its air circulation pattern is very poor and it does not meet current Federal, State or local ventilation standards. The building has been condemned and construction of upgraded facilities is planned. In the basement one finds the main stockroom, offices and physical chemistry laboratories. Lecture rooms, offices, inorganic chemistry research laboratories and general chemistry laboratories occupy the first and second floors. The third floor is the area for organic chemistry laboratories, offices and lecture rooms. Air samples were obtained in one of laboratories on the first floor (Laboratory I) and second floor (Laboratory III). During the sampling, the doors and windows of Laboratory I and III were partly opened. A great deal of

concentrated hydrochloric acid, hydrobromic acid and nitric acid was used in Laboratory III during the sampling period.

Weniger Hall is a six story structure, built of concrete and with brick facing. Air is supplied by a central unit which is located on sixth floor. Filters are checked about every three months, and replaced if necessary. This system gives six to eight air changes per hour in each laboratory. Lecture rooms, offices and laboratories are located in every story. The samples were taken in two different analytical chemistry laboratories in the first floor of this building. Laboratory II is located in the center of this building and does not have any windows. The door to the hallway was opened during the sampling. In Laboratory IV, there are small fume hoods over each bench. All windows were closed and door was open during the sampling period.

2. Typical Homes

Air from two typical homes located southwest of Corvallis, Oregon was sampled. Neither house is air conditioned, both have electric stoves. The occupants of both houses are non-smokers.

Home I is a two story building, built of concrete and wood. Samples were taken in the bedroom and living room. The living room is next to the kitchen, without any door between them. The living room is about 300 square feet in area and the bedroom is about 200 square feet. There is a driveway in front of this house. Outdoor samples were taken on the porch, next to the driveway.

Home II is a single story structure, built of wood. It faces on a

heavily used street, with a big backyard. Oil is used for the heating system in this house. Indoor samples were obtained from the bedroom which is about 280 square feet in area. It is next to the garage and kitchen. The windows between this bedroom and garage were partially open , but the garage was vacant. Outdoor samples were taken in the backyard of this house.

3. Modern Office Buildings

Two pairs of office buildings were studied in this work. One pair is located in the southwest portion of Corvallis, Oregon (offices I, II), while the other pair (office III, IV) is located in downtown Portland, Oregon. All offices sampled are air conditioned and carpeted.

Office I is a public building, the Human Resources Center of the State of Oregon. It is a single story brick building. The air filtration system is placed on the roof of this building and filters are changed twice a year. There are about 0.27 air changes per hour in the building which uses natural gas forced air heat.

Office II is on the third floor of Administration Building of Oregon State University. This building is a seven story structure, built of concrete and with brick facing. Air is supplied by a central unit which is located in the basement. It gives six to eight air changes per hour. Office II is 543 square feet in area and is occupied by ten people. Steam heat for this office is supplied by the central heating plant. Outdoor samples were taken on the fire escape of the same floor as the office under study.

Office III is on the first floor of a new five story building,

the Portland General Electric building. Outdoor samples were taken on a corridor connecting this building to an adjacent structure. Interior air is supplied by a central unit which is located on the roof of this building. It gives four air changes per hour. Filters are checked every week and are changed as necessary. The building is made of graphite shell with steel frame. The inside sampling area was an interior office with an area of about 600 square feet.

Office IV is on the top floor of an older concrete seven story building, the United Good Neighbor building on W. Burnside in Portland. This office is 4720 square feet in area and has an air filtration system with eight air changes per hour. Indoor samples were taken in the corner of the office while outdoor sample was taken on the fire escape of the same floor. This building uses steam heat and fronts on a very heavy traffic street, W. Burnside.

4. Hospital

The hospital sampled, Good Samaritan Hospital is, located in the northeast portion of Corvallis, Oregon. It is a new six story building. The external material of the building is made of concrete and brick. Natural gas is the main fuel for its heating system and it is air conditioned and carpeted. Indoor samples were taken in two different nursing stations on the second floor. One station is located in the south part (Isolation Station), while the other is in the center part (General Station) of the second floor. Basically, there is no difference in the ventilation system and area between these two stations. The area of the entire station is about 4500 square feet, with 3.76 air changes

per hour. The area of each nursing station is about 1000 square feet, with 5.2 air changes per hour. All the air in the second floor is supplied by the penthouse filtration unit which is located on the roof. The outdoor samples were taken from the outside of the cafeteria on the first floor.

5. Automobile Repair Garages

Both garages sampled are single story structures, built of concrete. Natural gas is used for the heating system. They all have exhaust vacuum systems in the garages to remove automotive exhaust directly from the automobile tail pipes.

Garage I is located on a heavy traffic street, in downtown Corvallis, Oregon. The side door of the garage was partly open throughout the sampling period. The other doors were always closed (except during vehicle entry and egress). This garage is about 12500 square feet in area. Indoor samples were taken in the garage in an area which is far away from any mechanical work. Outdoor samples were taken outside of the partly open side door.

Garage II is located at the west part of Oregon State University campus. The area of this garage is about 6000 square feet. All the doors of this garage were open during the sampling period. This garage is surrounded by two gas stations and two parking lots. The indoor samples were taken in one corner of the garage. Outdoor samples were taken on the side of the garage which faced one of the parking lots.

D. SAMPLING PROCEDURES

Because of the strong dependence of indoor concentrations on outdoor concentrations, both indoor and outdoor samples were taken within the same period. The sampling times ranged from two hours to eight hours. Temperature and flow rates were measured at the beginning, midpoint and the end of the sampling period. Average values of the flow rate were used in calculating air volumes. The flow rates of the indoor sampler and Andersen particle fractionating sampler were read directly from a flowmeter (Gilmont Flowmeter Catalog Number F1500) attached to the sample holder. For the high volume sampler, the flowmeter was connected to an adaptor of same size as the sample holder. When the flow rate was measured, the sample holder was replaced by the adaptor.

All air samplers were cleaned with 2.0 N nitric acid, followed by rinses with distilled water, 95% ethanol and acetone prior to sampling and filter paper insertion. Polygloves were worn and plastic forceps were used for handling the air samplers and filter papers. After air sampling, the sample holders and Andersen particle fractionating sampler were wrapped with Handiwrap and transported to the Radiation Center (Oregon State University). Then the samples were pelletized and sealed in clean poly-vials and subjected to irradiation in Oregon State University TRIGA Reactor.

ANALYSIS

Instrumental neutron activation analysis (INAA) was used to determine the trace element (Al, Fe, Ti, Na, K, Sm, Eu, La, Sc, Cl, Mn, Br, V, Sb, Co, Cr, As, Zn) abundances in this study because of its superior sensitivity (see Table 2) and its non-destructive character. This multi-elemental analysis requires no special pretreatment of the sample.

The samples to be analyzed and standards containing known amounts of various trace elements were irradiated for four minutes in the pneumatic terminal of the Oregon State University TRIGA Reactor with neutron flux of 9×10^{12} n/cm-sec. Then the Nuclepore filter paper samples were transferred to new clean polyvials. In the case of the paraffin samples which could not be removed easily from the irradiation containers, the outside of the containers was washed with 2.0 N nitric acid, distilled water and dried. Following this procedure, the samples and standards were counted for seven minutes with a 40 cm³ lithium drifted germanium [Ge(Li)] gamma ray detector (Nuclear Diodes, Model Number LG CC 5.65-1.90) incorporated with a multichannel analyzer.

In this work, all samples were counted at a distance of 9.5 mm from the detector. The resolution and efficiency of this detector are shown in Table 3 and Figure 5. The samples and standards were counted again for sixteen minutes after the first counting was done.

The samples were allowed to decay at least two weeks. They were irradiated again with new standards in the rotating rack of Oregon State University TRIGA Reactor in a flux of 3×10^{12} n/cm-sec for six hours.

Table 2. Approximate Limits of Detectability by Several Methods for Various Elements in Aerosols from Urban Atmospheres. (16)

Element	Limit of Detectability (ng/m ³)		
	Instrumental Neutron Activation Analysis	Emission Spectrography	Atomic Absorption
Na (Sodium)	1	3	1
Al (Aluminum)	1	3	200
Cl (Chlorine)	200	---	---
Ca (Calcium)	1000	3	2
V (Vanadium)	0.5	3	200
Mn (Manganese)	1	11	2
Cu (Copper)	20	10	2
Br (Bromine)	2	---	---
Sc (Scandium)	0.02	0.2	---
Fe (Iron)	1	84	10
Co (Cobalt)	0.001	6.4	1
Ni (Nickel)	10	6.4	6
Zn (Zinc)	0.02	240	1
Se (Selenium)	0.02	---	200
Sb (Antimony)	0.01	40	40
Ba (Barium)	0.1	3	200
La (Lanthanum)	0.05	2	4000
Ce (Cerium)	0.01	20	---
Sm (Samarium)	0.05	10	1000
Eu (Europium)	0.01	1	---
Yb (Ytterbium)	0.01	3	10
Lu (Lutetium)	0.01	100	---
Hf (Hafnium)	0.01	20	---
Th (Thorium)	0.01	10	---
As (Arsenic)	4	---	500
Hg (Mercury)	1	---	10

After "cooling" for eighteen hours, the same precounting treatment of the samples was done. They were either transferred to new polyvial or the outside of polyvial was washed with 2.0 N nitric acid and distilled water. All samples and standards were counted for one hour. Additional counting after twelve to twenty-four hours was done after two to three weeks delay. This procedure is summarized in Table 4.

Standard reference materials with known amounts of various elements were irradiated and counted under identical conditions as the samples being analyzed. The elemental abundances of these standard reference materials (NBS SRM 1632, NBS SRM 1633, NBS SRM 1571) are summarized in Tables 5, 6, 7. The trace element abundances measured in this work agreed within the experimental error with the accepted NBS values. This gives one confidence in the reliability of analysis techniques used.

Table 3. Resolution of 40 cm³ Lithium Drifted Germanium [Ge(Li)] Gamma Ray Detector (Nuclear Diodes, Model Number LG CC 5.65-1.90)

Energy (keV)	FWHM (keV) ^a	Resolution (%) ^b
122	0.97	0.80
662	1.42	0.21
1332	1.90	0.14

^a FWHM: The energy (pulse height) interval for the full width at half the maximum value of the peak.

$$\text{Resolution} = \frac{\text{FWHM}}{\text{Energy}} \times 100\%$$

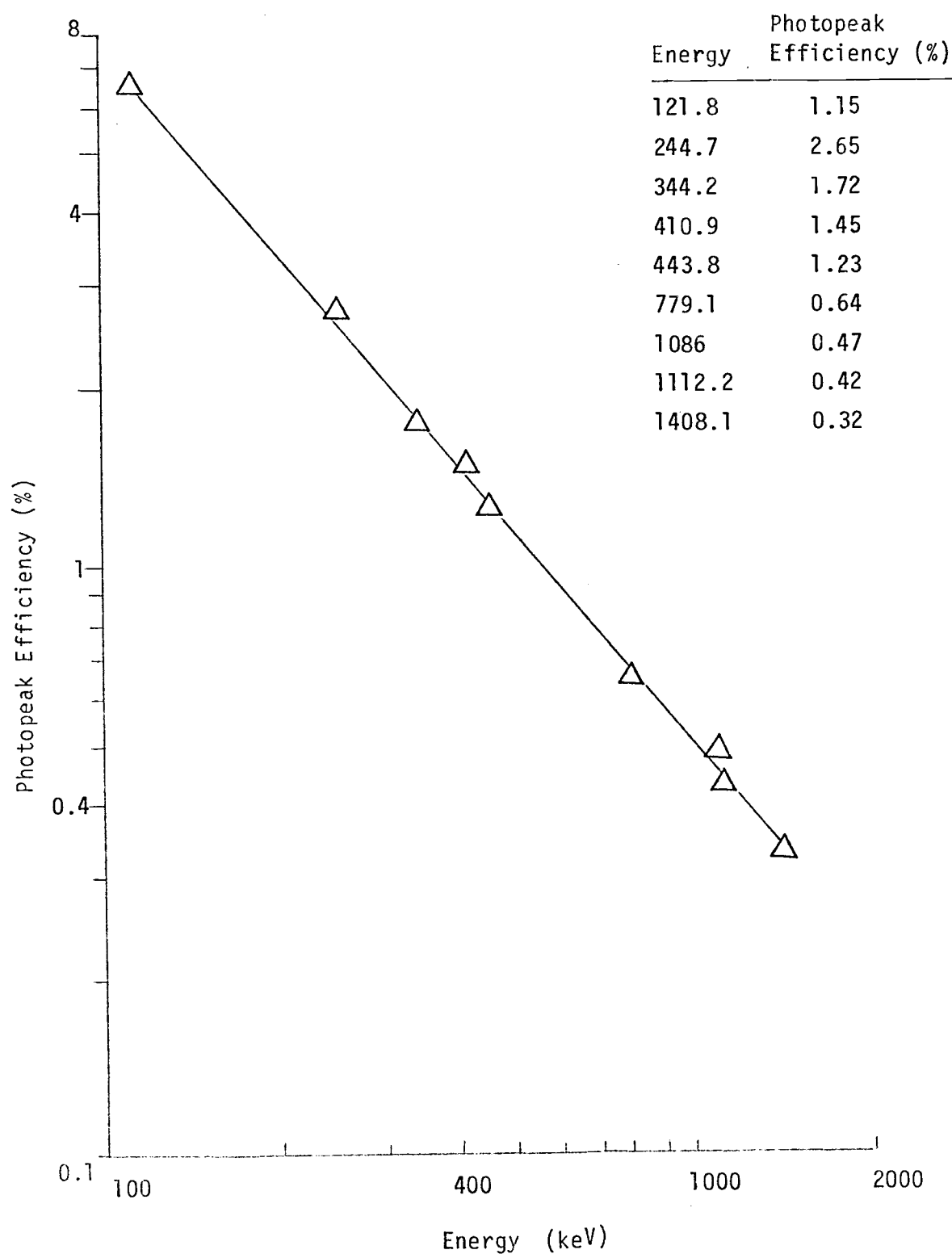


Figure 5. The Photopeak Efficiency of the 40 cm³ Lithium Drifted Germanium [Ge(Li)] Gamma Ray Detector (Nuclear Diodes, Model Number LG CC 5.65-1.90) at the Distance of 9.5 mm from the Detector.

Table 4. Instrumental Neutron Activation Analysis Procedure.

Element	Radionuclide Detected	Half Life (17)	Length of Irradiation	Delay Time	Count Duration	Energy of Gamma Ray Measured (keV) (17)
Al	^{28}Al	2.241 minutes	4 minutes	4 minutes	7 minutes	1778.9
V	^{52}V	3.75 minutes				1434.4
Ti	^{51}Ti	5.80 minutes				319.8
Cl	^{38}Cl	37.094 minutes				1642.4
Na	^{24}Na	15 hours	4 minutes	3 hours	16 minutes	1368.5
Mn	^{56}Mn	2.58 hours				846.6
K	^{42}K	12.401 hours	6 hours	18 hours	1 hour	1524.7
As	^{76}As	1.096 days				657.2
Br	^{82}Br	1.479 days				776.5
La	^{140}La	1.657 days				1596.4
Sm	^{153}Sm	1.933 days				103.2
Sb	^{122}Sb	2.720 days				563.9
Co	^{60}Co	5.260 years	6 hours	21 days	12-24 hours	1173.2
Zn	^{65}Zn	244.0 years				1115.5
Cr	^{51}Cr	27.70 days				320
Fe	^{59}Fe	44.60 days				1099.2
Eu	^{152}Eu	13.20 years				121.8
Sc	^{46}Sc	83.80 days				889.3

Table 5. Elemental Concentrations in NBS Coal (SRM 1632)
($\mu\text{g/g}$ unless % Indicated)

Element	This Work	NBS (18) and Literature (19)	This Work/NBS or Literature
Al (%)	1.8 ± 0.2	1.9 ± 0.1	0.98 ± 0.11
Fe (%)	0.85 ± 0.01	$0.87 \pm 0.03^*$	0.98 ± 0.04
Ti	1000 ± 300	1100 ± 100	0.89 ± 0.31
K (%)	0.29 ± 0.03	0.28 ± 0.03	1.0 ± 0.1
Na	400 ± 10	414 ± 20	0.97 ± 0.05
Sm	1.7 ± 0.1	1.7 ± 0.2	1.0 ± 0.1
Eu	0.32 ± 0.04	0.33 ± 0.04	0.97 ± 0.17
La	10.5 ± 0.3	11 ± 1	0.98 ± 0.11
Sc	3.6 ± 0.2	3.7 ± 0.3	0.97 ± 0.09
Cl	910 ± 60	890 ± 125	1.02 ± 0.16
Mn	47 ± 4	$40 \pm 3^*$	1.2 ± 0.1
Br	19.7 ± 0.5	19 ± 2	1.02 ± 0.09
V	36 ± 5	$35 \pm 3^*$	1.0 ± 0.2
Sb	3.0 ± 0.7	4 ± 1	0.8 ± 0.3
Co	5.7 ± 0.4	5.7 ± 0.4	1.0 ± 0.08
Cr	19 ± 1	$20.2 \pm 0.5^*$	0.96 ± 0.06
As	6.1 ± 0.3	$5.9 \pm 0.6^*$	1.0 ± 0.1
Grand Average			$= 0.99 \pm 0.08$

* Values with asterisk are NBS values

Table 6. Elemental Concentrations in NBS Coal Fly Ash (SRM 1633)
($\mu\text{g/g}$ unless % Indicated)

Element	This Work	NBS (20) and Literature (19)	This Work/NBS or Literature
Al (%)	12 ± 1	12.7 ± 0.5	0.98 ± 0.10
Fe (%)	6.5 ± 0.3	6.2 ± 0.2	1.0 ± 0.1
Na	3119 ± 195	3200 ± 400	0.97 ± 0.14
K (%)	1.74 ± 0.09	1.6 ± 0.2	1.1 ± 0.1
Sm	12.3 ± 0.8	12.4 ± 0.9	1.0 ± 0.1
Eu	2.6 ± 0.5	2.5 ± 0.4	1.0 ± 0.3
La	82 ± 3	82 ± 2	1.0 ± 0.1
Mn	478 ± 18	$493 \pm 7^*$	0.97 ± 0.04
Br	8.4 ± 0.2	12 ± 4	0.7 ± 0.2
V	209 ± 20	$214 \pm 8^*$	0.98 ± 0.04
Sb	6.9 ± 0.2	6.9 ± 0.6	0.99 ± 0.09
Co	42.0 ± 0.8	41.5 ± 1.2	1.01 ± 0.03
Cr	132 ± 4	$131 \pm 2^*$	1.00 ± 0.01
As	58.8 ± 0.3	$61 \pm 6^*$	0.96 ± 0.01
Grand Average			$= 0.98 \pm 0.09$

* Values with asterisk are NBS values.

Table 7. Elemental Concentrations in NBS Orchard Leaves (SRM 1571)
($\mu\text{g/g}$ unless % Indicated)

Element	This Work	NBS (21,22)	This Work/NBS
Fe	271 ± 14	300 ± 20	0.90 ± 0.08
Na	91 ± 10	82 ± 6	1.1 ± 0.1
K (%)	1.38 ± 0.07	1.47 ± 0.03	0.94 ± 0.05
Sm	0.10 ± 0.01	0.14	0.71 ± 0.07
Eu	0.019 ± 0.003	0.021	0.9 ± 0.1
La	1.2 ± 0.1	1.3	0.88 ± 0.08
Sc	0.060 ± 0.005	0.044	1.4 ± 0.1
Cl	627 ± 75	(690)	0.9 ± 0.1
Mn	91 ± 5	91 ± 4	1.0 ± 0.1
Br	10 ± 1	(10)	1.0 ± 0.1
Sb	3.0 ± 0.3	2.9 ± 0.3	1.0 ± 0.1
Co	0.15 ± 0.03	(0.2)	0.8 ± 0.1
Cr	2.4 ± 0.2	2.6 ± 0.3	0.9 ± 0.1
As	11 ± 1	10 ± 2	1.1 ± 0.2
Zn	25 ± 1	25 ± 3	1.0 ± 0.1
Grand Average =			0.97 ± 0.16

Values with parenthesis are NBS uncertified values.

The abundances of the samples were calculated by the following formulas:

$$A_{\text{mid}} = C/t_1 \quad (1)$$

where A_{mid} is the activity at the middle of count time, C is the number of counts obtained in live time t_1 .

$$A_{\text{EOB}} = A_{\text{mid}} e^{-(t_d + t_2/2)} \quad (2)$$

Where t_d is the delay time, t_2 is the length of count time and A_{EOB} is the activity at end of bombardment.

If $t_1 < t_1/2$

for standard,

$$A_1 = (A_{\text{mid}1} e^{-(t_d + t_2/2)}) / \text{wt}(\mu\text{g}) \quad (3)$$

$$\text{Error}(A_1) = A_1 \times \frac{\% E}{100}$$

Where $\text{wt}(\mu\text{g})$ is the weight of the standard in μg and $\% E$ is the counting error in %.

for sample,

$$A_x = A_{\text{mid}x} e^{-(t_d + t_2/2)} \quad (4)$$

$$\text{Error}(A_x) = A_x \times \frac{\% E}{100}$$

$$\text{Abundance}(\mu\text{g}) = A_x/A_1$$

Error in Abundance =

$$((E(A_x)/A_x)^2 + (E(A_1)/A_1)^2)^{1/2} \times \text{Abundance}$$

If $t_1 \geq t_{1/2}$, equation (2) is in error because equation (1) is not a proper estimation of A_{mid} . It should be

$$\begin{aligned} C &= \frac{t_1}{t_2} A_{EOB} e^{-\lambda t_d} \int_0^{t_2} e^{-\lambda t} dt \\ &= \frac{t_1}{t_2} A_{EOB} e^{-\lambda t_d} ((1 - e^{-\lambda t_2})/\lambda) \end{aligned}$$

$$A_{mid}^{corr} = \frac{C}{t_1} = (A_{EOB} e^{-\lambda t_d} (1 - e^{-\lambda t_2})) / \lambda t_2$$

$$\begin{aligned} \frac{A_{mid}^{corr}}{A_{mid}} &= \frac{A_{EOB} e^{-\lambda t_d} (1 - e^{-\lambda t_2})}{A_{EOB} e^{-\lambda t_d} e^{-\lambda t_2/2} \lambda t_2} \\ &= \frac{1 - e^{-\lambda t_2}}{\lambda t_2 e^{-\lambda t_2/2}} \end{aligned}$$

$$\text{Thus } A_{mid}^{corr} = A_{mid} \frac{1 - e^{-\lambda t_2}}{\lambda t_2 e^{-\lambda t_2/2}}$$

In calculation of the abundance, A_{mid}^{corr} replaced A_{mid} in equations (3) and (4).

RESULTS AND DISCUSSION

A. ELEMENTAL COMPOSITION OF OREGON RURAL AIR

Table 8 summarizes the geometric mean of the atmospheric trace element concentrations observed outdoors at fourteen locations in and around Corvallis, Oregon. (All concentrations are normalized to $T=25^{\circ}\text{C}.$) In 1973, Gordon *et al.* (23) showed that one can more easily identify the sources of atmospheric trace elements if one normalizes the trace element concentrations to those of typical crustal elements. They defined the enrichment factor (EF) of an element X by the following equation :

$$EF = (C_X/C)_{\text{air}} / (C_X/C)_{\text{crust.}}$$

C_X : concentration of element X

C : concentration of a typical crustal element, in this case, Fe

Figure 6 and Table 9 show the enrichment factors observed in the rural air, using Ungerer's trace element abundances as representative "Oregon crustal material" (see Table 10). The enrichment factors for Al, Fe, Ti, K, Sm, Eu, La, Sc, Mn, V, and Co are less than five indicating they probably are derived primarily from upswept soil dust. The elevated enrichment factors for the trace elements Na, Cl, Br, Sb, Cr, As, and Zn indicate a non-crustal source(s) for these elements. The neighboring city of Albany has a moderate size industrial sector whose contribution to the atmospheric particulate is dominated by a Kraft

Table 8. Atmospheric Trace Element Concentrations in Rural Air

Element	Absolute Trace Element Concentration (ng/m ³)	Range (ng/m ³)	Relative Trace Element Concentration (Normalized to Fe)
Al	218	71-494	0.88
Fe	248	124-1122	1.00
Ti	83	44-184	0.33
Na	847	368-1856	3.42
K	111	58-628	0.45
Sm	0.010	0.002-0.090	0.00004
Eu	0.007	0.002-0.033	0.0003
La	0.30	0.07-0.77	0.0012
Sc	0.03	0.01-0.27	0.00013
Cl	241	100-1071	0.97
Mn	4.2	1.3-28.7	0.017
Br	64	5-332	0.26
V	1.6	0.6-4.0	0.007
Sb	0.4	0.1-1.7	0.002
Co	0.45	0.05-1.02	0.002
Cr	13.4	2.5-82.3	0.054
As	0.28	0.08-3.07	0.0011
Zn	123	18-626	0.50

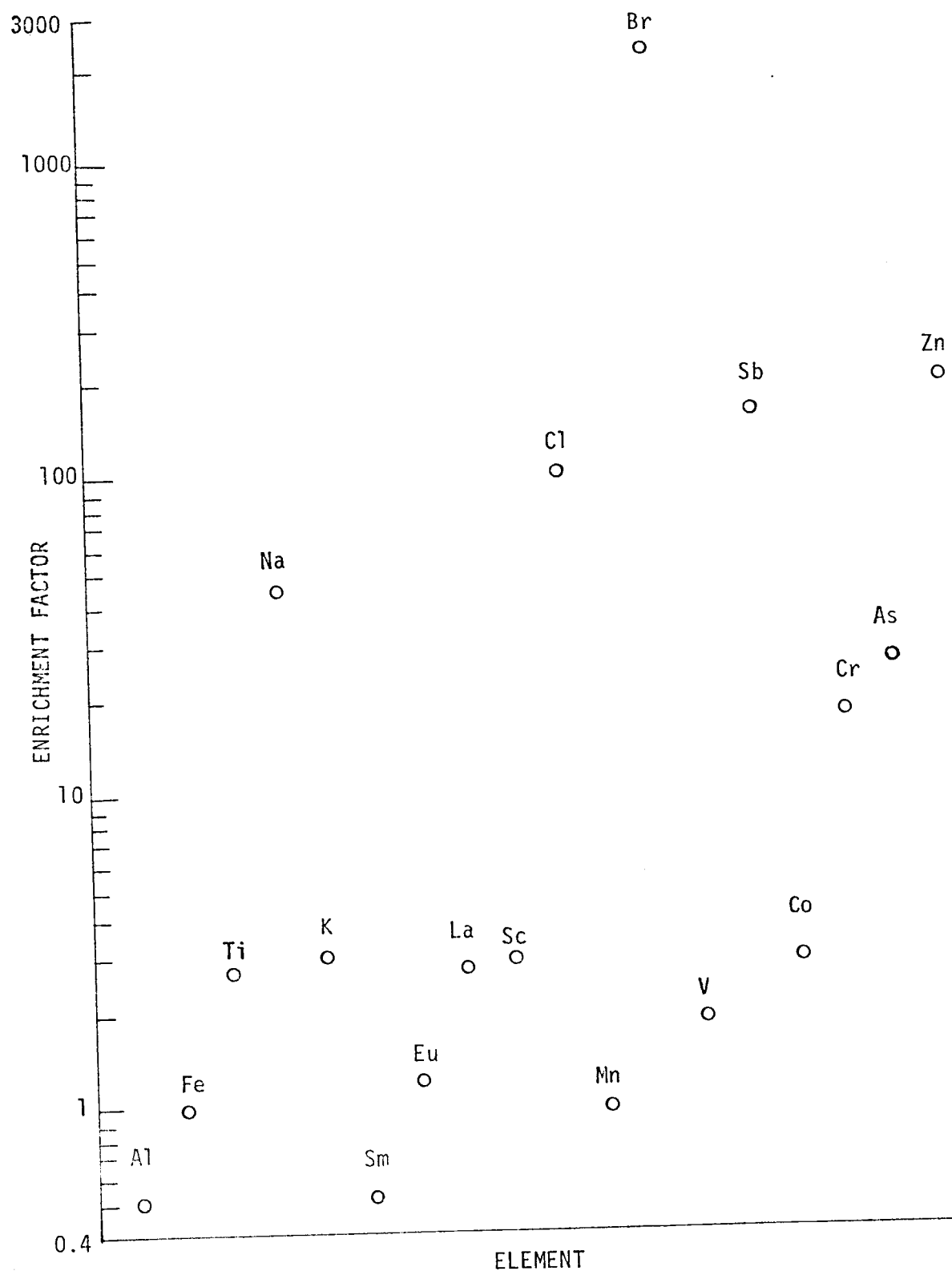


Figure 6. Enrichment Factors (with Respect to Fe) of Elements Present on Particulate Matter Collected in Oregon Rural Air.

Table 9. Enrichment Factors of Trace Elements in Rural Air

Element	Enrichment Factor
Al	0.50
Fe	1.00
Ti	2.59
Na	35.7
K	3.73
Sm	0.50
Eu	1.10
La	3.20
Sc	0.32
Cl	182
Mn	1.42
Br	2178
V	2.10
Sb	170
Co	4.40
Cr	22.5
As	21
Zn	164

Table 10. Trace Element Concentrations in Oregon Soil (24)

Element	Absolute Element Concentration (ppm)	Range (ppm)	Relative Trace Element Concentration (Normalized to Fe)
Al	99500	93200-112700	1.75
Fe	56800	32540-98040	1.00
Ti	7345	4300-12830	0.13
Na	5445	4340-6078	0.096
K	6841	2290-15540	0.12
Sm	4.8	3.6-6.3	0.00008
Eu	1.5	1.4-1.6	0.00003
La	21.9	9.4-44.7	0.0004
Sc	23.3	11.8-48.1	0.0004
Cl	304	280-330	0.005
Mn	667	211-2505	0.012
Br	6.69	3.89-11.4	0.0001
V	178.1	92.9-365.0	0.003
Sb	0.5	0.3-1.2	0.000009
Co	23.4	7.3-70.4	0.0004
Cr	136	55.4-320.7	0.0024
As	3.0	2.2-5.6	0.00005
Zn	172	112-329	0.003

process paper mill, Western Kraft (11). The absolute and normalized concentrations of trace elements present in stack effluent at the Western Kraft Paper Company are summarized in Table 11. (In the Western Kraft Paper Company, wood chips are converted into "pulp" or paper by the Kraft process. The detail of the Kraft process are described in Shum's thesis (11).) To evaluate the role of this effluent in the Corvallis rural air, a linear mixing model was developed in which the composition of Corvallis air was explained as a mixing of upswept soil dust and Western Kraft stack effluent transported from Albany to Corvallis.

The final formal relationship between rural air (Cor), Western Kraft Paper Company effluent (West) and upswept soil dust can be represented as the following equation :

$$\text{Cor} = (3.4 \pm 0.3) (10^{-2}) \text{ West} + (5.3 \pm 1.5) (10^{-1}) \text{ Soil}$$

This linear mixing model gave an excellent, statistically significant fit to the concentrations of the ten trace elements (Al, Fe, Na, K, La, Cl, Mn, Br, Co, Cr) with multiple correlation coefficient $r^2 = 0.94$. As shown by Shum (11), other wood products industries such as the Simpson Timber Company in Albany have stack effluent compositions similar to the Western Kraft effluent. Thus the "Western Kraft contribution" to Corvallis air should more equitably be described as a "wood products industry contribution".

Table 11. Absolute and Normalized Concentration of Trace Elements in
Stack Effluent at the Western Kraft Paper Company

Element	Concentration (11) ($\mu\text{g}/\text{m}^3$)	Relative Concentration (Normalized to Fe)
Al	81.3	6.66
Fe	12.2	1.00
Ti	<3.8	<0.31
Na	1096	89.8
K	47.6	3.90
Sm	<0.003	<0.0002
La	0.017	0.0014
Sc	<0.03	<0.002
Cl	562	46.1
Mn	1.1	0.090
Br	12.5	1.02
V	28.1	2.30
Sb	<0.03	<0.002
Co	1.25	0.10
Cr	1.4	0.12
As	<0.5	<0.04
Zn	<0.9	<0.07

B. PARTICLE SIZE FRACTIONS IN OREGON RURAL AIR

In general, the particle fractionating sampler can be used to determine the aerodynamic particle size weight distribution of suspended particulates, but not the total suspended particulate concentration. Several studies (25, 26) have reported that significant wall losses in these samplers can occur and this loss is a function of atmospheric conditions, such as the humidity and the concentration of particulates in air. In this work, the Andersen particle fractionating sampler was mainly used to obtain representative samples of each air particulate size fraction. These size fractions were then analyzed to determine their elemental composition. The percent total elemental mass of each impactor stage for each sample is summarized in appendix II.

Three sets of samples were used to determine the elemental particle size distribution in rural air. The average elemental particle size distribution curves are shown in Figures 7a and 7b. The stages numbered 0-7 correspond to effective cut-off diameters $\geq 11.0, 7.0, 4.7, 3.3, 2.1, 1.1, 0.7, 0.4$ microns, respectively. As expected, the soil derived elements Al, Fe, Sm, La, Sc, Mn, and V are predominantly associated with large size particulate. Particles bearing the elements Ti, Na, Cl, Br, Co, and Zn show uniform size distributions. The size distribution for Cr shows both small and large particle components. Thus the particle size data adds additional support to the arguments presented in section A as to the major sources of rural atmospheric particulate.

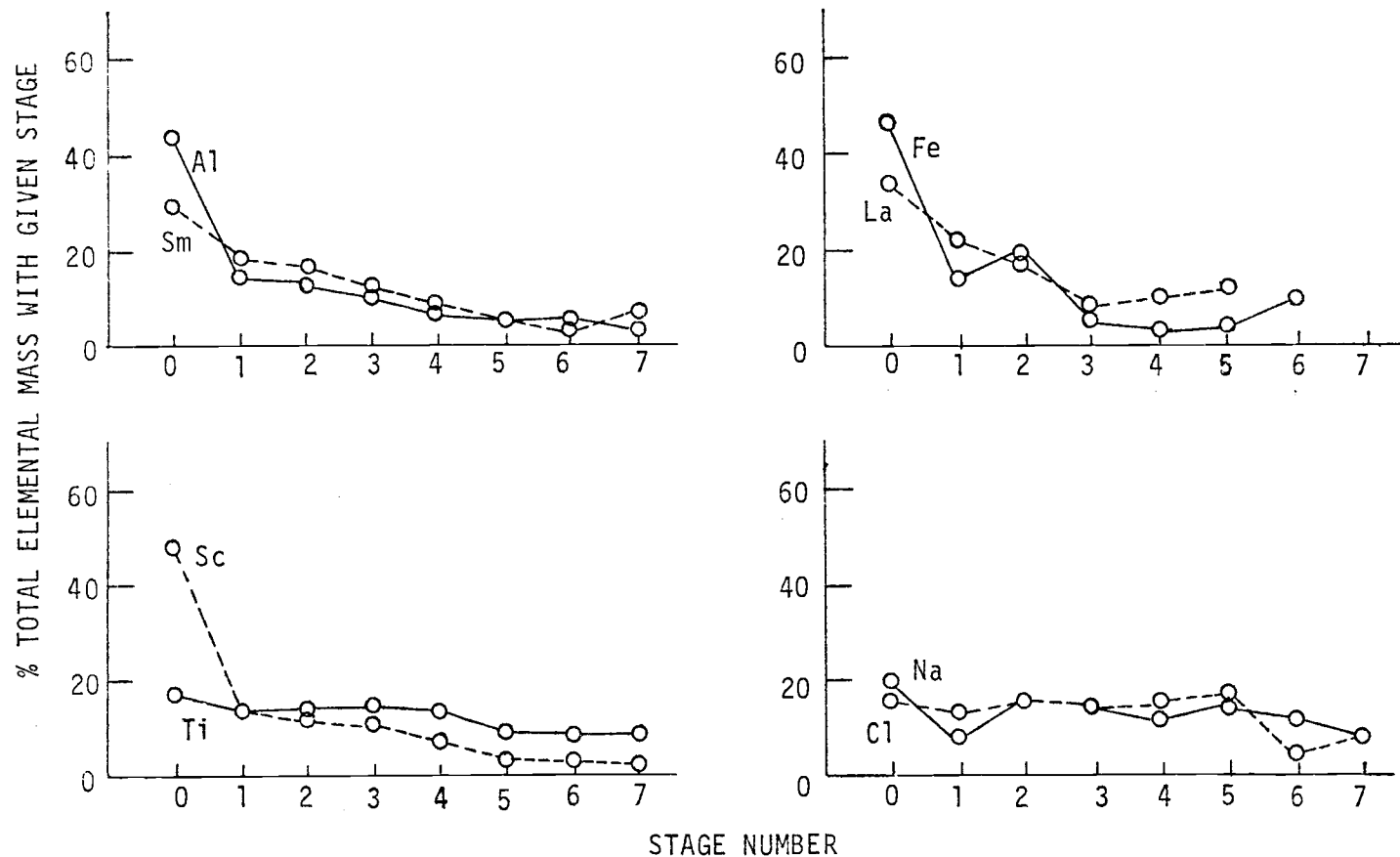


Figure 7a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Rural Air (Corvallis, Oregon).

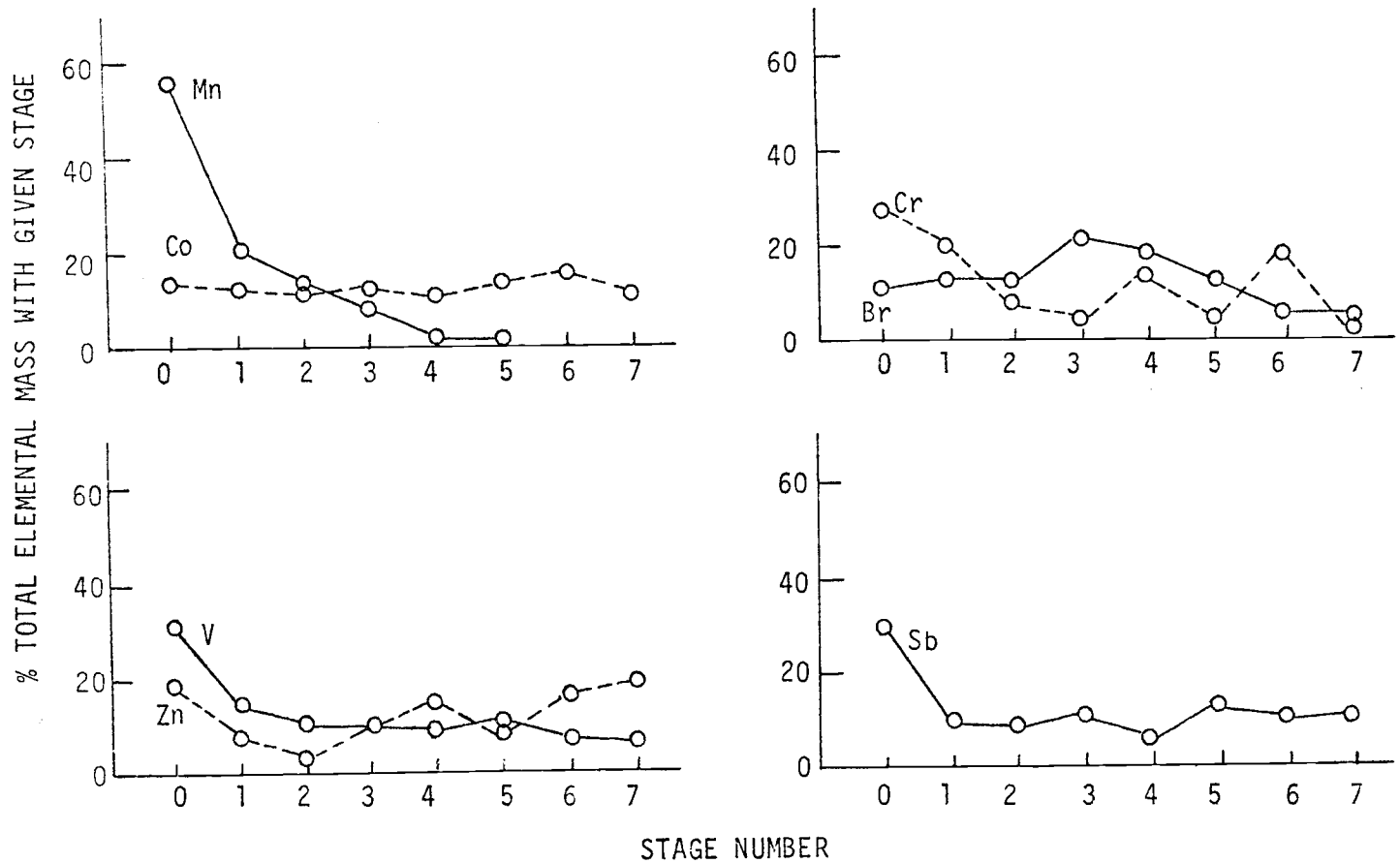


Figure 7b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Rural Air (Corvallis, Oregon).

C ELEMENTAL COMPOSITION OF URBAN (PORTLAND, OREGON) AIR PARTICULATES

The geometric mean of trace element concentrations in atmospheric air particulates and their enrichment factors found in two locations in Portland on August 17, 1977 are summarized in Table 12. The Department of Environmental Quality (27) reported that 49,100 tons of particulates emitted each year in Portland area, 35.1% are due to industrial operations, 19.0% are from combustion of fossil fuels, 12.2% are from agricultural tilling, 11.2% are from gasoline motor vehicle, 10.0% are from slash burning, and 9.1% are from field burning. As shown in Figure 8, most enrichment factors are less than ten except chlorine, bromine, and antimony. The ratio of chlorine/bromine found in Portland (3.2) is similar to the ratio found in Corvallis (3.8). Hopke (28) pointed out that bromine in urban atmospheres is mainly from automobile exhaust. Jones (29) found that the "average" exhaust chlorine/bromine ratio of the vehicles burning leaded fuel is 0.3. In this case, if automobile exhaust is the main source of bromine, there must be some other sources for the particulate chlorine in Portland area. Hopke (28) also suggested that refuse incinerators may be the source of antimony. We suspect, but cannot verify, that the enhancement of antimony results from the burning of refuse in this area. As shown in Table 13, the observed trace element concentrations of Portland atmospheric particulate is higher than the values observed in Corvallis atmosphere and appear to be about in the range found for other cities.

Table 12. Trace Element Concentrations and Enrichment Factors of Trace Elements in Portland Atmospheric Particulates (Aug. 17, 77)

Element	Absolute Trace Element Concentration (ng/m ³)	Range (ng/m ³)	Enrichment Factor
Al	18110	11028-29740	1.78
Fe	5810	5322-6338	1.00
Ti	516	443-601	0.69
Na	3851	3724-3982	6.91
K	1648	1554-1747	2.36
Sm	0.41	0.39-0.42	0.83
Eu	0.102	0.101-0.103	0.65
La	3.1	3.0-3.2	1.39
Sc	1.13	0.97-1.31	0.48
Cl	737	541-1005	23.7
Mn	176.4	153.4-202.8	2.58
Br	234	228-239	340
V	16.7	14.5-19.2	0.92
Sb	2.9	2.8-3.0	52
Co	4.2	3.2-5.5	1.75
Cr	66.8	20.5-217.8	4.79
As	3.4	2.8-4.0	10.9

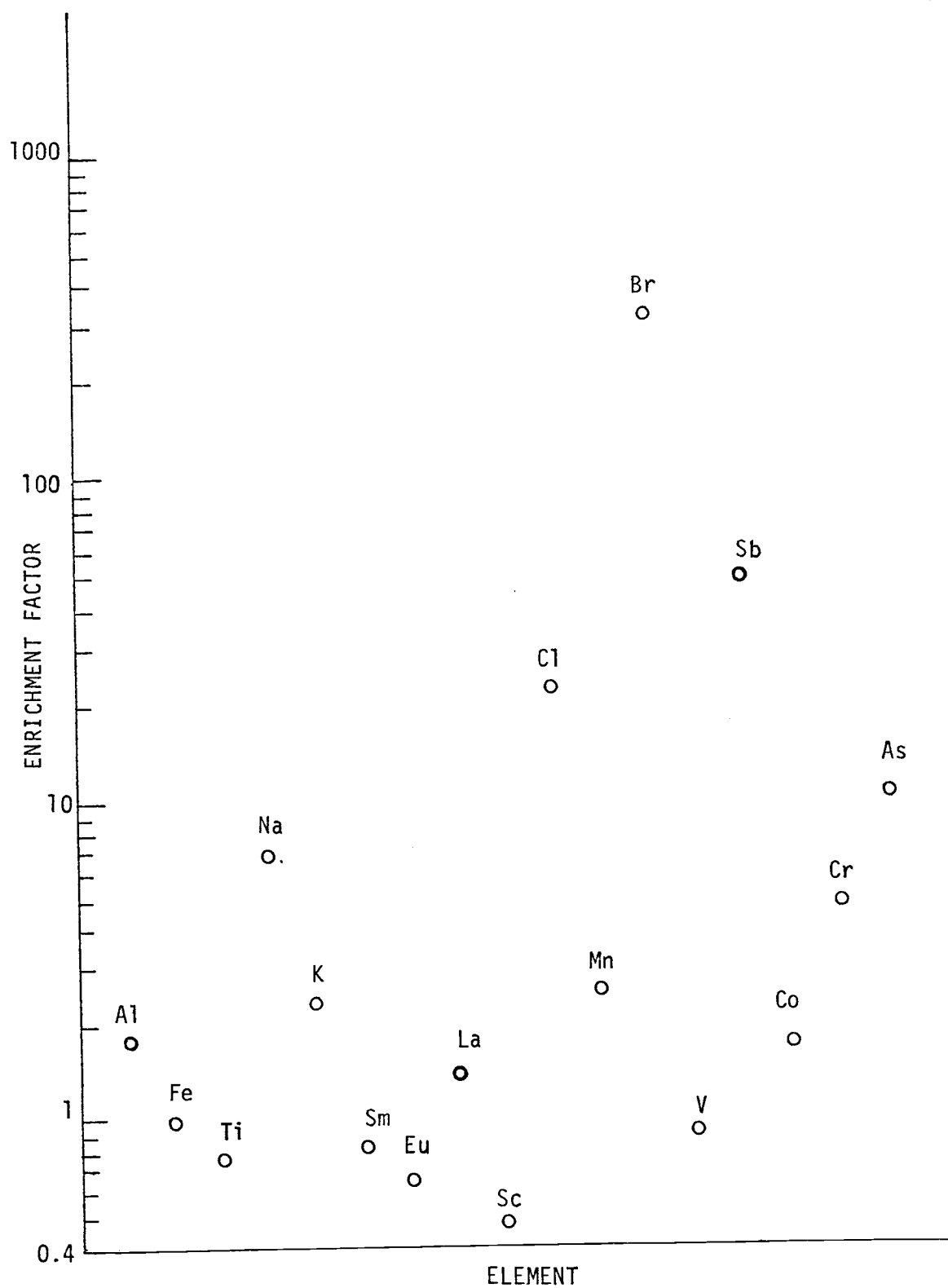


Figure 8. Enrichment Factors (with Respect to Fe) of Elements Present on Particulate Matter Collected in Portland Atmosphere.

Table 13. Atmospheric Trace Element Abundances in Various Locations
(ng/m³)

Element	Corvallis	Portland	Albany, Oregon (11)	Downtown Boston (28)	Chicago, Illinois (30)
	This Work				
Al	218	18110	11822	1540	1900
Fe	248	5810	5105	1120	4800
Ti	83	516	2150	---	---
Na	847	3851	7172	2040	560
K	111	1648	1927	---	---
Sm	0.01	0.41	1.2	0.3	---
Eu	0.007	0.102	---	0.045	0.22
La	0.3	3.1	5.0	2.4	3.7
Sc	0.03	1.13	0.70	0.30	0.90
Cl	241	737	6894	930	5900
Mn	4.2	176.4	122	28.5	700
Br	64	234	256	251	270
V	1.6	16.7	8.9	940	24
Sb	0.4	2.9	20.4	19.4	45
Co	0.4	4.2	3.4	1.2	4.5
Cr	13.4	66.8	168	3.2	25
As	0.3	3.4	20.4	---	---

D. STATISTICAL CONSIDERATIONS AND INDOOR PARTICULATE COMPOSITION

Because of the limited amount of time available to complete this M. S. degree work and because of the desire to make a " broad brush " survey of indoor/outdoor atmospheric trace element abundances, only a limited number of samples (usually one or two) were taken at each indoor sampling location. To evaluate the potential problems associated with this limited sampling program, one indoor location was selected for detailed sampling. In this case, thirty-one different one day samples were taken in the waste disposal room of Radiation Center (Oregon State Universtiy) and the outdoor samples were taken on the roof of Radiation Center to test the variation of the indoor/outdoor elemental concentrations from sample to sample in the same location.

The waste disposal room is used mainly for storage of the radioactive materials. This room is about 650 square feet in area and 7800 cubic feet in volume with 100 cfm air flow inside the room.

The daily variation of indoor/outdoor ratios is summarized in Table 14. In order to have enough data points to determine the distribution of indoor/outdoor ratios, we normalized the indoor/outdoor ratio to its corresponding mean value for each element and then combined the data from all trace elements (believed to originate from a common source) into a single data set. The analysis of this data set shows the indoor/outdoor ratios to be log normally distributed rather than normally distributed (see appendix III). As seen in Table 15, we have taken the position that in order to be statistically significant, an individual indoor/outdoor ratio for a single trace element must deviate from the mean indoor/outdoor ratio for all trace elements by a factor of five.

Table 14. The Variation and Mean of Indoor/Outdoor Elemental Concentration Ratios Observed in Radiation Center (Oregon State University)

Date (1978)	Element					
	Al	Na	V	Ti	Cl	Mn
Jan. 16	0.97	0.49	0.64	1.13	1.03	0.52
17	2.56	0.72	0.47	<1.19	2.01	0.51
18	4.15	0.63	1.58	1.39	0.30	0.52
19	2.42	0.68	0.56	0.91	1.67	0.54
20	0.59	0.49	0.33	<0.66	0.90	0.29
21	0.98	0.47	<0.12	0.84	1.06	0.15
22	0.98	0.84	<0.13	0.86	2.31	0.15
23	3.49	0.53	0.30	<1.25	2.81	0.48
24	3.57	1.22	0.52	1.84	3.46	0.54
25	2.31	0.78	0.27	<0.91	1.94	0.35
26	2.76	0.44	0.26	0.98	0.25	0.36
27	2.65	0.54	0.92	0.90	0.43	0.50
28	1.51	0.54	0.42	<0.87	0.54	0.25
29	3.31	0.29	0.30	<1.30	---	0.26
30	4.00	0.60	0.56	1.18	0.17	0.48
31	2.15	0.69	0.32	2.47	1.39	0.49
Feb. 1	3.08	0.70	<0.22	1.40	---	0.27
2	3.26	0.09	0.36	<1.09	---	0.34
3	1.45	0.12	0.32	1.20	0.03	0.26
4	4.32	0.16	0.31	<1.44	---	0.37
5	2.73	0.03	0.28	<1.08	---	0.20
6	4.45	0.15	0.71	1.46	---	0.49
7	4.06	0.21	<0.26	2.81	---	0.38
8	2.28	0.06	0.30	0.67	---	0.26
9	2.48	0.28	2.22	3.01	---	1.28
10	4.68	0.42	0.37	1.50	0.70	0.70

Table 14. Continued

Date (1978)	Element					
	Al	Na	V	Ti	Cl	Mn
Feb. 11	1.25	0.07	0.14	<0.64	---	0.22
12	2.29	0.56	0.45	0.63	5.45	0.30
13	0.46	0.61	0.15	0.28	0.77	0.14
14	1.33	0.19	0.36	<0.34	---	0.12
15	9.18	0.67	1.18	0.56	---	2.22
Mean ($\bar{X}$)	2.76	0.44	0.54	1.33	1.43	0.45
Geometric Mean ($\bar{X}_g$)	2.30	0.35	0.43	1.22	0.86	0.36
Geometric Standard Deviation (Sg)	+2.07	+0.50	+0.36	+0.97	+2.02	+0.32
	-1.10	-0.21	-0.20	-0.53	-0.61	-0.17

Table 15. The Variation of Indoor/Outdoor Ratio
Mean Value of Indoor/Outdoor Ratios
for Each Element

Date (1978)	Element					
	Al	Na	V	Ti	Cl	Mn
Jan. 16	0.35	1.11	1.19	0.85	0.72	1.16
17	0.93	1.64	0.87	<0.89	1.40	1.13
18	0.05	1.43	2.93	1.04	0.21	1.16
19	0.88	1.54	1.04	0.68	1.17	1.20
20	0.21	1.11	0.61	<0.50	0.63	0.64
21	0.36	1.07	<0.22	0.64	0.74	0.33
22	0.36	1.91	<0.24	0.65	1.62	0.33

Table 15. Continued

Date (1978)	Element					
	Al	Na	V	Ti	Cl	Mn
Jan 23	1.26	1.20	0.56	<0.94	1.96	1.07
24	1.29	2.78	0.96	1.38	2.42	1.20
25	0.84	1.77	0.50	<0.68	1.25	0.78
26	1.00	1.00	0.48	0.74	0.17	0.80
27	0.96	1.23	1.70	0.68	0.30	1.11
28	0.55	1.23	0.78	<0.65	0.38	0.56
29	1.20	0.66	0.56	<0.98	---	0.58
30	1.45	1.36	1.04	0.89	0.12	1.07
31	0.78	1.57	0.59	1.86	0.97	1.09
Feb 1	1.11	1.59	<0.41	1.05	---	0.60
2	1.18	0.20	0.67	<8.20	---	0.76
3	0.53	0.27	0.59	0.90	0.02	0.58
4	1.56	0.36	0.57	<1.08	---	0.82
5	0.99	0.07	0.52	<0.81	---	0.44
6	1.61	0.34	1.32	0.56	---	1.09
7	1.47	0.48	<0.48	2.11	---	0.85
8	0.83	0.14	0.56	0.50	---	0.58
9	0.90	0.64	4.10	2.26	---	2.84
10	1.70	0.95	0.69	1.13	0.49	1.56
11	0.45	0.16	0.26	<0.48	---	0.49
12	0.83	1.27	0.83	0.47	3.81	0.67
13	0.17	1.39	0.28	0.21	0.54	0.31
14	0.48	0.43	0.67	<0.26	---	0.27
15	3.33	1.52	2.19	0.42	---	4.93
Geometric Mean ($\bar{X}_g$)			= 0.75			
Geometric Standard Deviation ($\bar{S}_g$)			= 2.23			
Upper Limit*			= 4.97			
$\bar{X}_g$						

$$* \text{ Upper Limit} = \text{antilog} (\log \bar{X}_g + 2 \log \bar{S}_g) = \bar{X}_g \bar{S}_g^2$$

E. COMPOSITION OF INDOOR PARTICULATE SAMPLES

The absolute indoor and outdoor trace element concentrations, their ratios and geometric mean values found in each location are summarized in appendix I.

1. University Chemistry Laboratories

For chemistry laboratory I, the indoor/outdoor ratios are less than one (Figure 9). The soil derived elements iron and aluminum concentrated on the medium sized particles instead of the larger particles (Figure 10). This can be explained as due to selective removal of the larger particles as the particulate penetrates indoors. Based upon the same argument, it is not surprising that chlorine distributions favor smaller particles which are different from its uniform size distribution found in rural air. For the other non-soil derived trace elements cobalt, zinc, and sodium show uniform size distributions which are similar to their distributions found in rural air.

For chemistry laboratory II, the indoor/outdoor ratios are near unity except for antimony (Figure 11). Based upon the criterion established in section D, the antimony abundance does not significantly exceed the geometric mean indoor/outdoor ratio for all trace elements. As shown in Figure 12, the elemental particle size distribution curves are somewhat similar to the rural air pattern (Figures 7a, 7b). One concludes that outdoor air is the main component of the indoor air for chemistry laboratory II.

Students were working on a variety of individual, independent

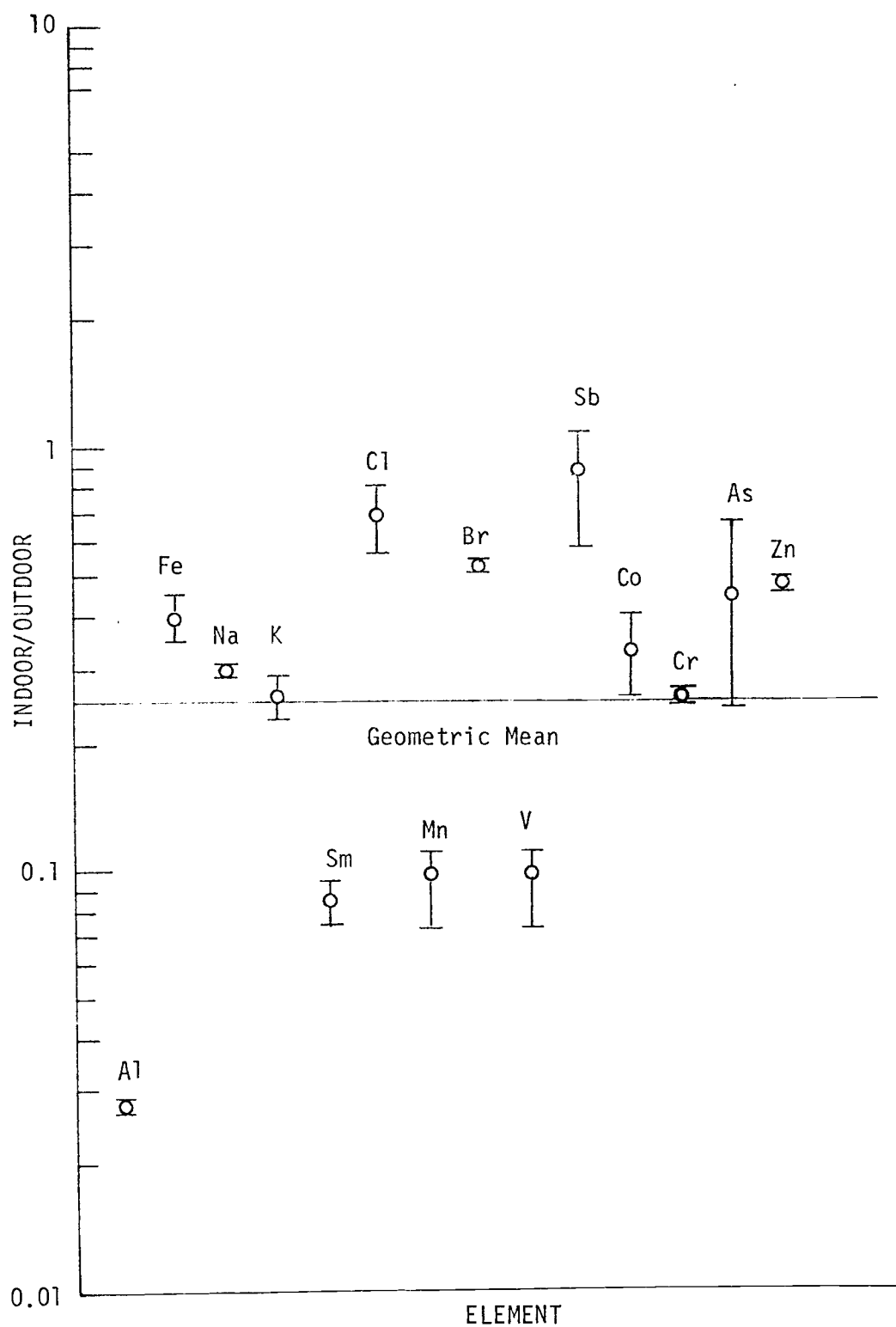


Figure 9. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory I (May 4, 1976).

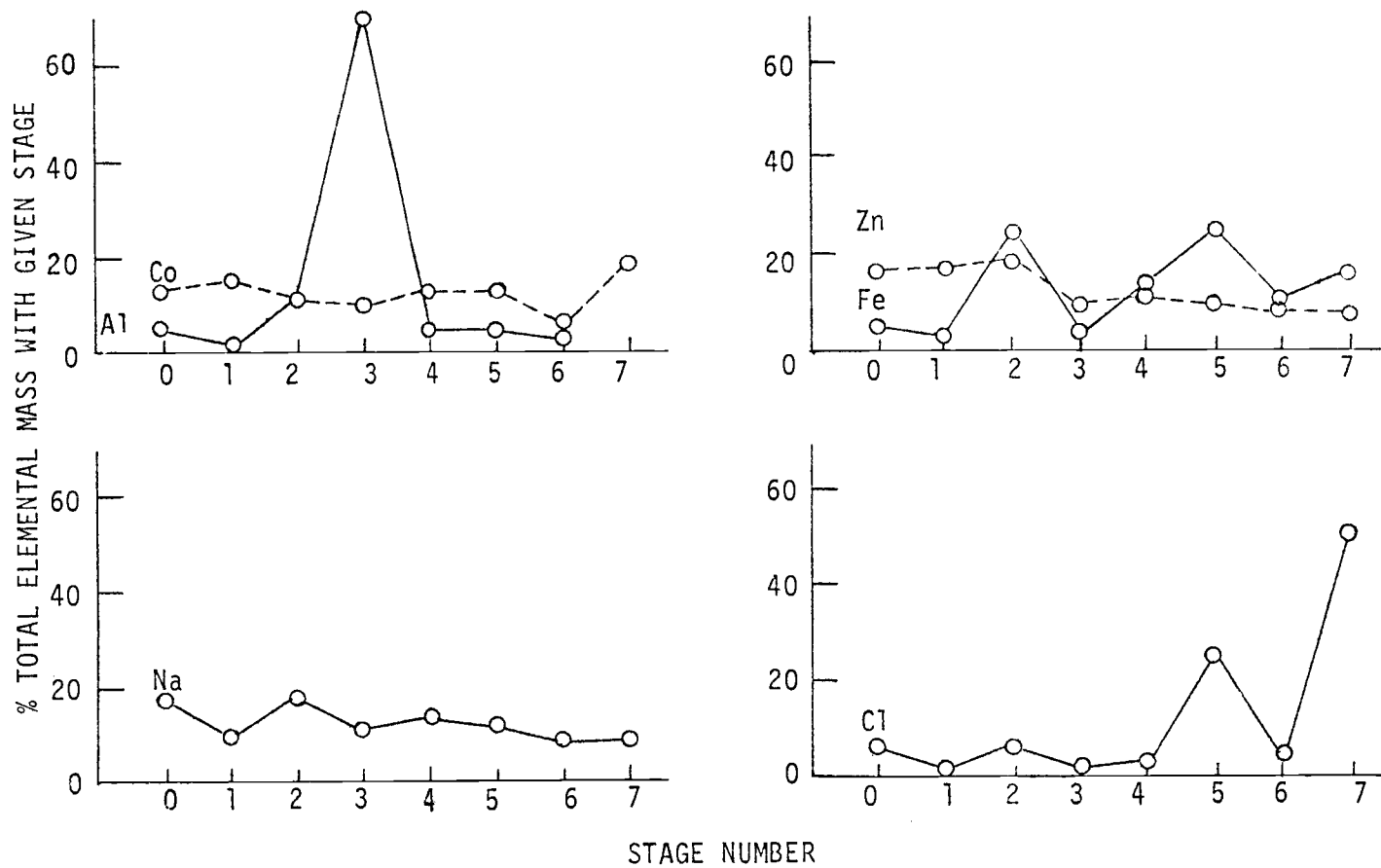


Figure 10. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory I (May 4, 1976).

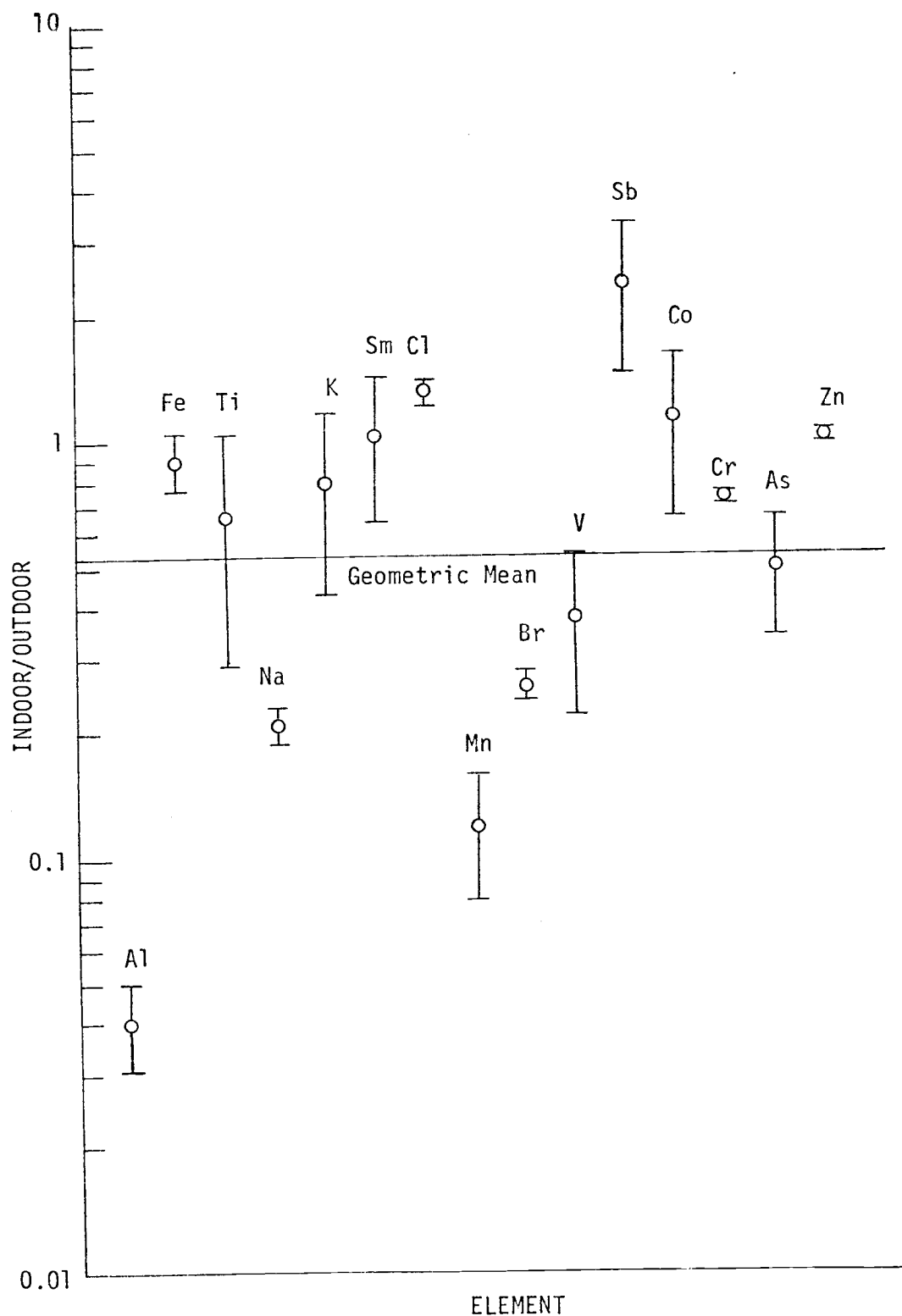


Figure 11. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory II (May 5, 1976).

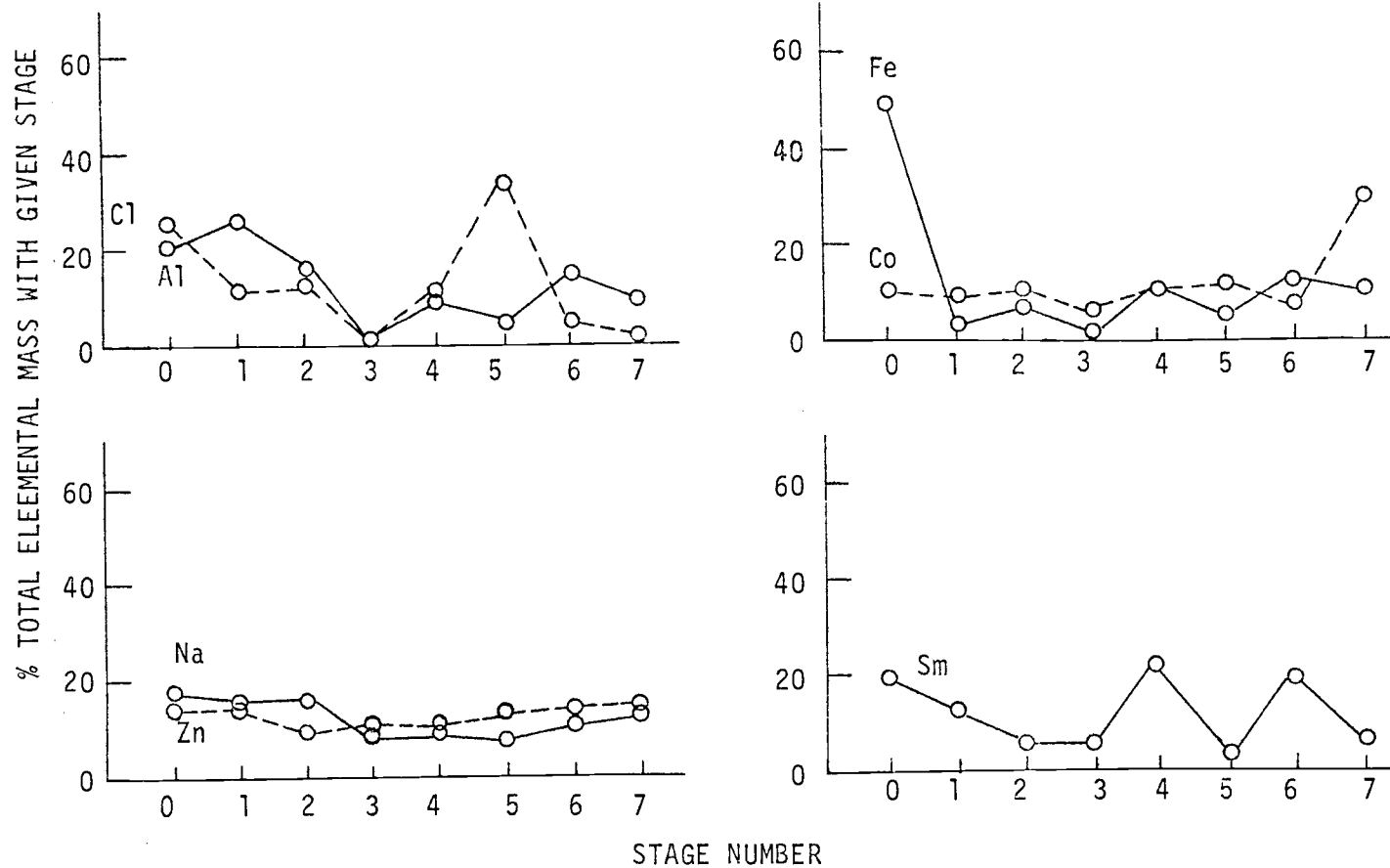


Figure 12. Percentage of Total Elemental Particulate Mass with Given Stage Found in Laboratory II (May 5, 1976).

experiments during the sampling period in chemistry laboratory III. Unknown amounts of concentrated hydrochloric acid and hydrobromic acid were used. The expected enhancement in particulate phase chlorine and bromine is obtained (Figure 13).

The quantity and the exact concentration of hydrochloric acid and hydrobromic acid used are not known. One can, however, do a simple calculation that shows that the ratio of "excess" chlorine to "excess" bromine (see Table 16) lies within the same order as the ratio of the partial pressure of 38% HCl to 48% HBr. Particles bearing the element chlorine and bromine have small sizes (Figure 14). One concludes that chemical reagents are mainly the sources of chlorine and bromine in the atmosphere of chemistry laboratory III. The indoor/outdoor ratios (Figure 13) and size distribution curves (Figure 14) for the other elements, indicate that the outdoor air is the main source of the other elements inside the laboratory III.

Table 16. Concentrations of Chlorine and Bromine in Laboratory III
(ng/m^3)

Element	Indoor Concentration	Outdoor Concentration	Excess Concentration	Ratio
Cl	70758 ± 2201	9579 ± 541	61179 ± 2266	<u>104</u>
Br	774 ± 18	185 ± 4	589 ± 18	1

In chemistry laboratory IV, the indoor/outdoor ratios (Figure 15) of all the trace elements, except antimony and samarium are close or less than one. Soldering has been done in this room frequently, and so

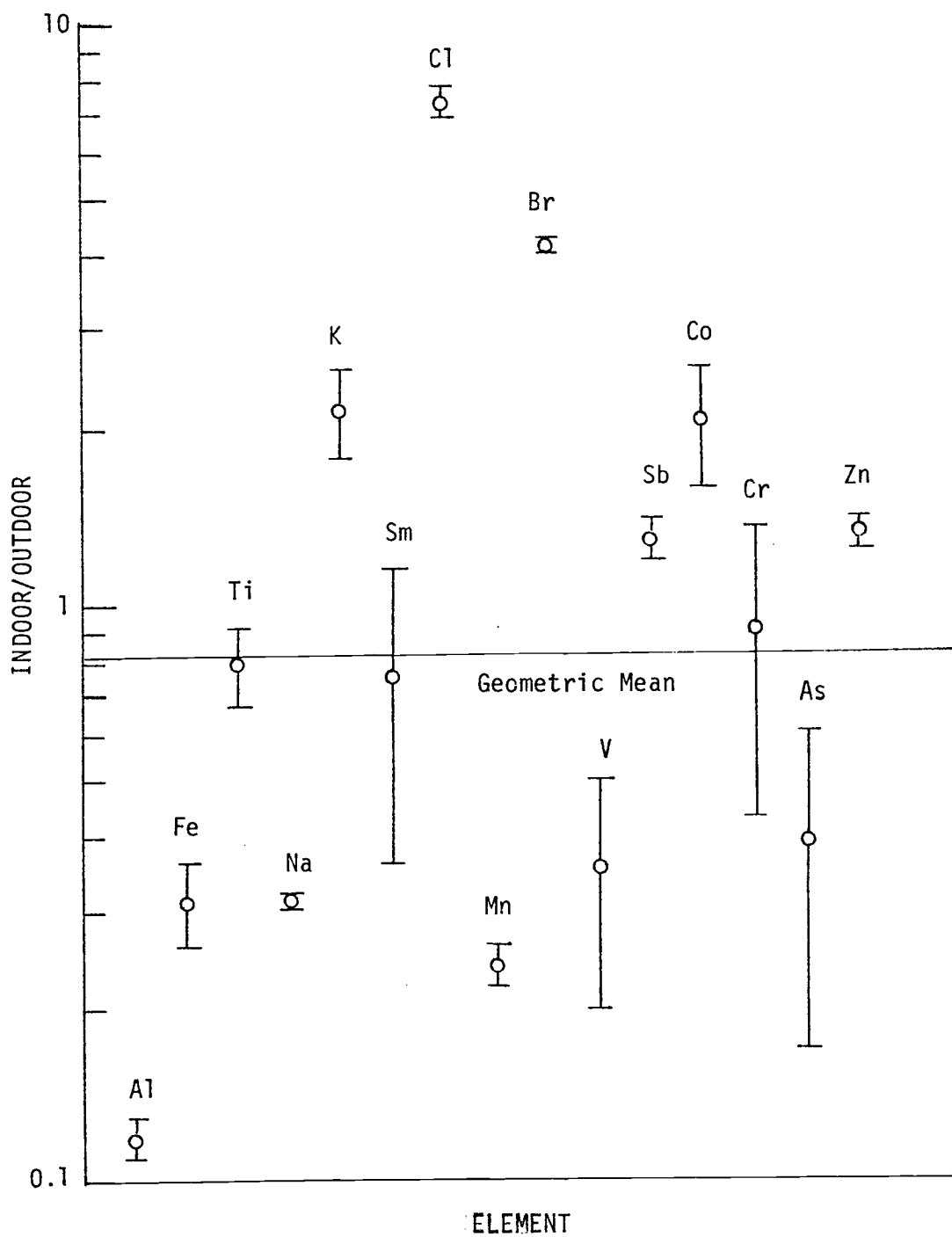


Figure 13. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory III (May 13, 1976).

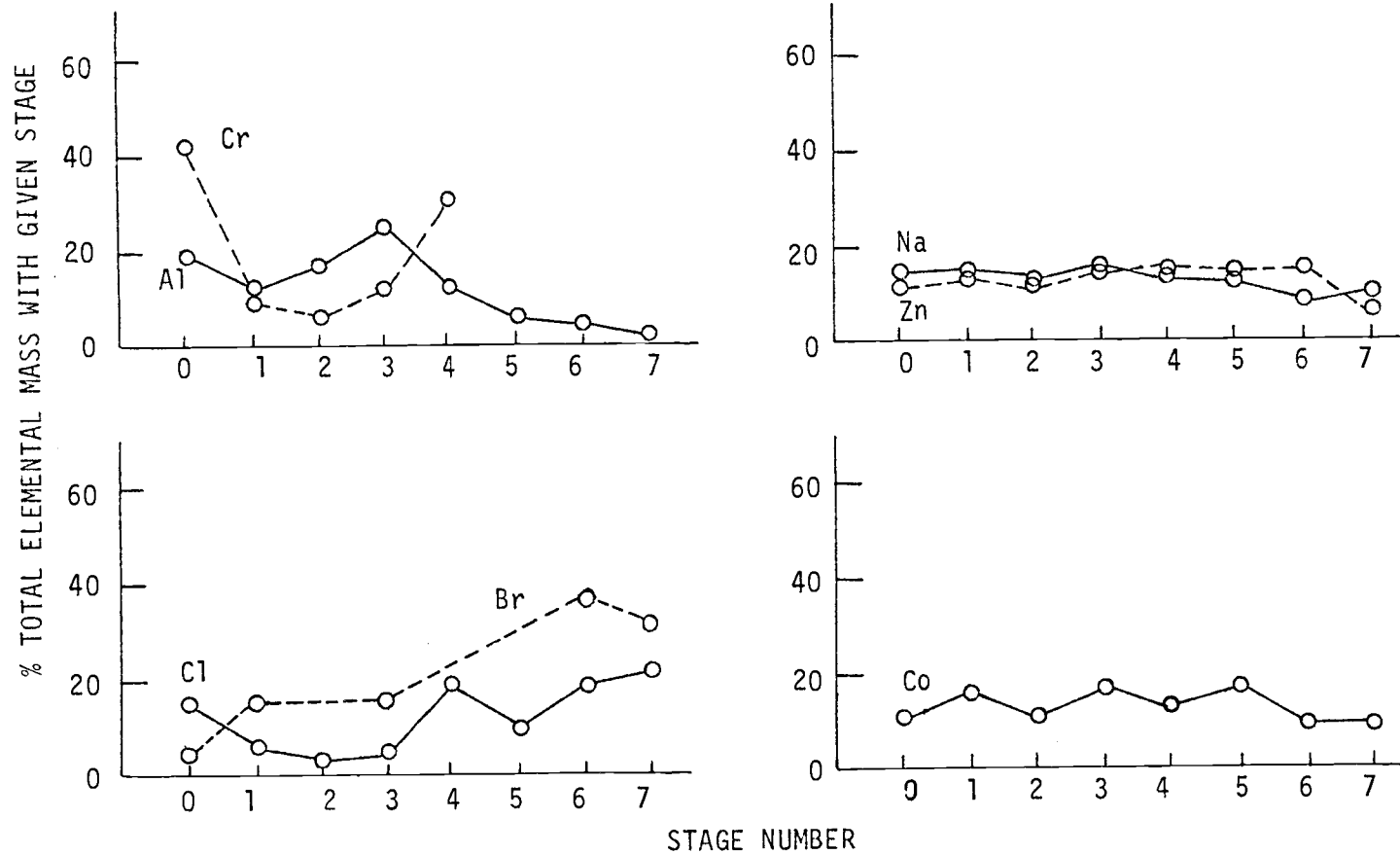


Figure 14. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory III (May 13, 1976).

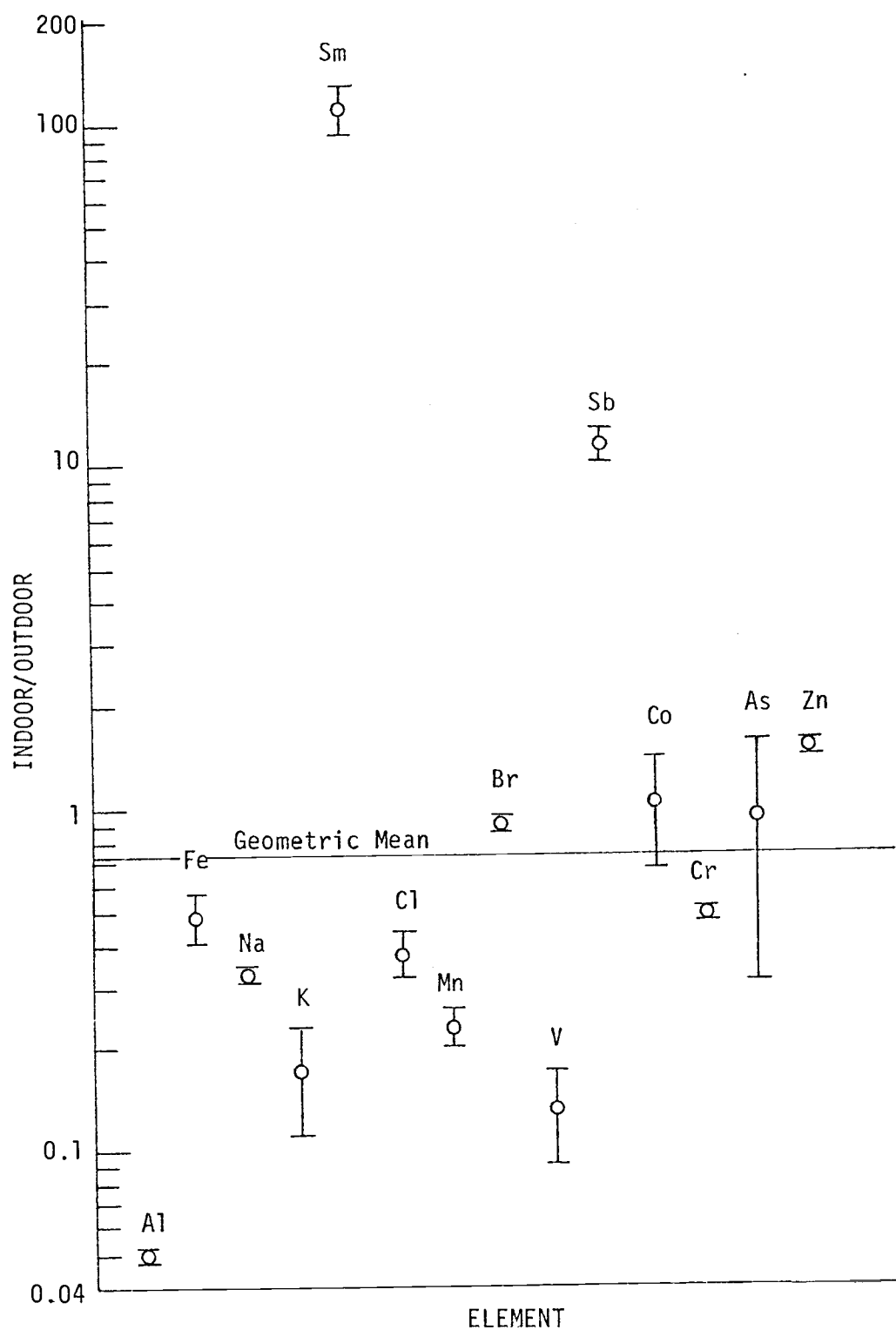


Figure 15. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory IV (May 18, 1976).

one thought that solder may be the source of the particulate antimony. Different procedures were done to test this possibility. First, solid solder was analyzed. Table 17 indicates that solder contains about 3.5 mg/g of antimony. Then high volume samples and Andersen particle fractionating samples were taken in the hood (average face velocity was 172.5 feet/min) while the solder vapor was being formed. Solder vapor was made by adding solder to a red hot crucible continuously. The sampling time was one hour and 0.8470 g solder was vaporized. Tables 18 and 19 show the results. By comparing the composition of solder vapor and the data found in chemistry laboratory IV (Table 20), one sees the ratios of As/Sb and K/Sb in solder vapor and the indoor air particulate do not agree. The level of particulate antimony in chemistry laboratory IV was 141 ng/m^3 . If solder vapor was the source of this antimony, one would need to vaporize about 46 g solder to reach this level. This does not sound plausible. The samarium also shows an incredible enrichment, and it is predominantly of large size (Figure 16).

In this case, we decided to repeat the sampling two more times. A reasonable result for the particulate samarium and antimony was observed (Tables 21, 22, 23, Figure 17). No evidence was found for any elemental enrichments in the air of chemistry laboratory IV. The inside air is mainly controlled by the outdoor air.

Table 17. Trace Element Concentrations in Solder ($\mu\text{g/g}$)

Element	Concentration
Na	1400 ± 200
La	<1.1
K	105 ± 43
Sm	<0.2
As	129 ± 15
Sb	3420 ± 30
Br	<4.6
Co	<2.3
Zn	<60
Cr	23 ± 6
Fe	<140
Sc	<0.01
Eu	<0.2

Table 18. Trace Element Concentrations in Solder Vapor

Element	Concentration (ng/g-m^3)
Sb	3.1 ± 0.3
As	1.0 ± 0.2
K	121 ± 13
$\text{As/Sb} = 0.3$	
$\text{K /Sb} = 40$	

Table 19. Elemental Particle Size Distribution of Solder Vapor

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Sb	8.5	4.8	4.8	5.7	25.7	41.7	4.4	4.3
As	9.9	9.6	7.5	12.4	5.5	11.8	15.9	39.0
K	10.9	13.4	16.1	6.4	11.6	19.0	9.8	12.8

Table 20. Trace Element Concentrations in Laboratory IV (May 18, 76)

Element	Concentration (ng/m ³)
Sb	141 ± 8
As	13 ± 6
K	166 ± 52
As/Sb = 0.09	
K /Sb = 1.2	

Table 21. Trace Element Concentrations in Laboratory IV
(May 18, 76)

Element	Absolute Concentration in indoor (ng/m ³)	Absolute Concentration in outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Sm	15.2 ± 0.1	0.14 ± 0.02	111 ± 18
Sb	141 ± 8	12 ± 1	12 ± 1
K	166 ± 52	958 ± 76	0.17 ± 0.06

Table 22. Trace Element Concentrations in Laboratory IV
(July 23, 77)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Sm	0.009 $\pm$ 0.002	0.160 $\pm$ 0.004	0.05 $\pm$ 0.01
Sb	0.86 $\pm$ 0.02	1.18 $\pm$ 0.05	0.72 $\pm$ 0.03
K	124 $\pm$ 23	643 $\pm$ 53	0.19 $\pm$ 0.04

Table 23. Trace Element Concentrations in Laboratory IV
(February 26, 78)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Sm	0.002 $\pm$ 0.001	0.100 $\pm$ 0.004	0.020 $\pm$ 0.001
Sb	0.18 $\pm$ 0.01	0.700 $\pm$ 0.004	0.26 $\pm$ 0.02
K	44 $\pm$ 5	363 $\pm$ 37	0.12 $\pm$ 0.02

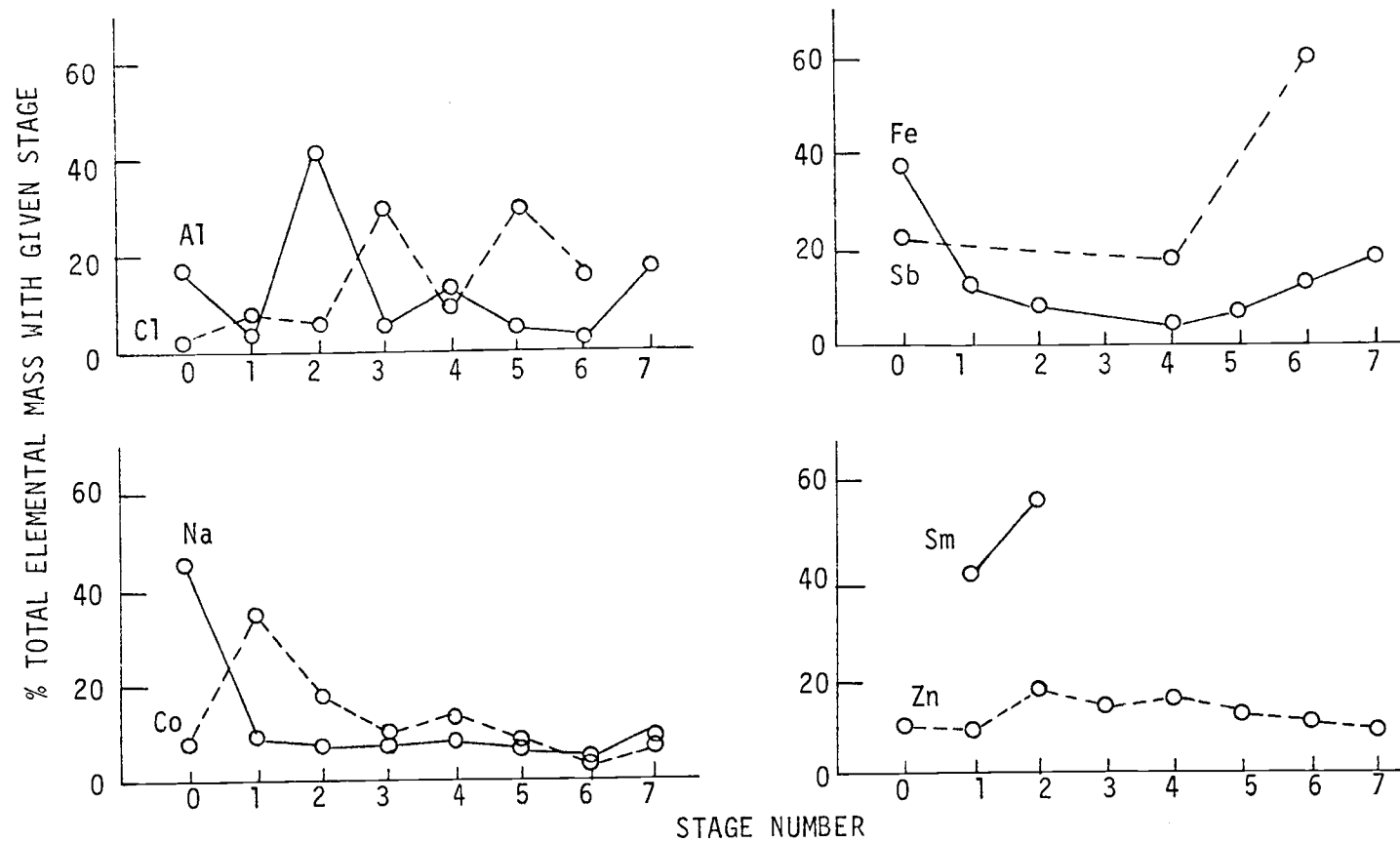


Figure 16. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Laboratory IV (May 18, 1976).

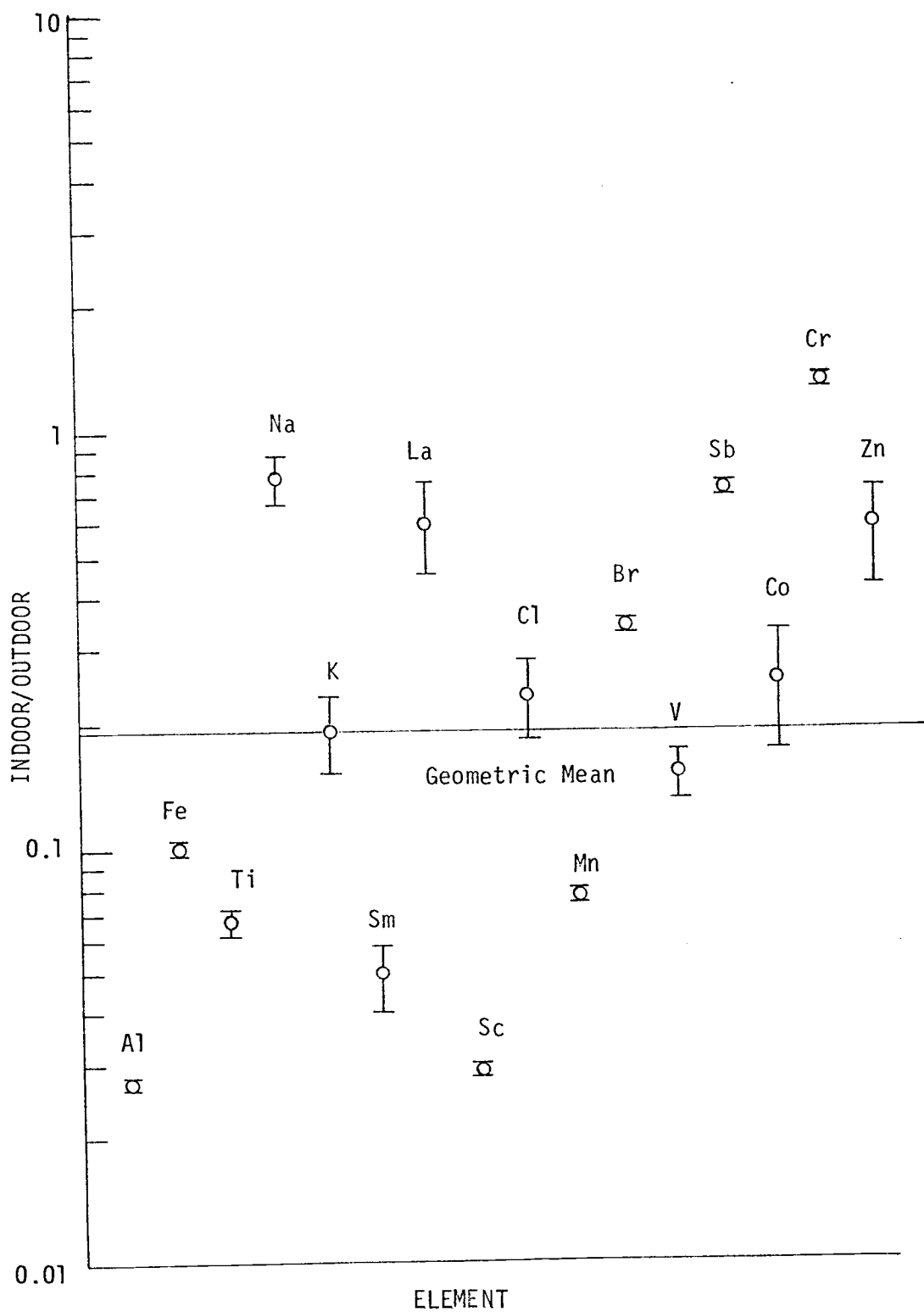


Figure 17. Ratios of Indoor and Outdoor Elemental Concentrations Found in Laboratory IV (July 23, 1977).

2. Typical Homes

In home I, samples were taken in the living room and bedroom. In general, the ratio of indoor and outdoor elemental concentrations (Figure 18) found in living room are higher than the values observed in bedroom (Figure 19). This is probably due to increased "people traffic" in the living room as compared to the bedroom.

It is interesting to note (see Figures 20, 21, and 23) that chlorine and aluminum are both concentrated on the large particles (6 microns) in both rooms. The particle size distribution curve for chlorine is different than the outside air pattern for home I (Figure 23). The mechanism(s) producing this effect is not understood.

The ratios of indoor and outdoor trace element concentrations found in home II are about or less than one except chromium (Figure 24). Higher indoor/outdoor chromium ratios are also obtained in both rooms of home I (Figures 18, 19), although the chromium particle size distributions (Figures 20, 21, 25) are quite dissimilar for these different locations. While the lack of an extensive sampling regime handicaps interpretation of the data, consideration of the results presented in section D would indicate a significant interior source of chromium exists for these two homes. Overall, the interior suspended particulates are mainly controlled by outdoor air for both homes.

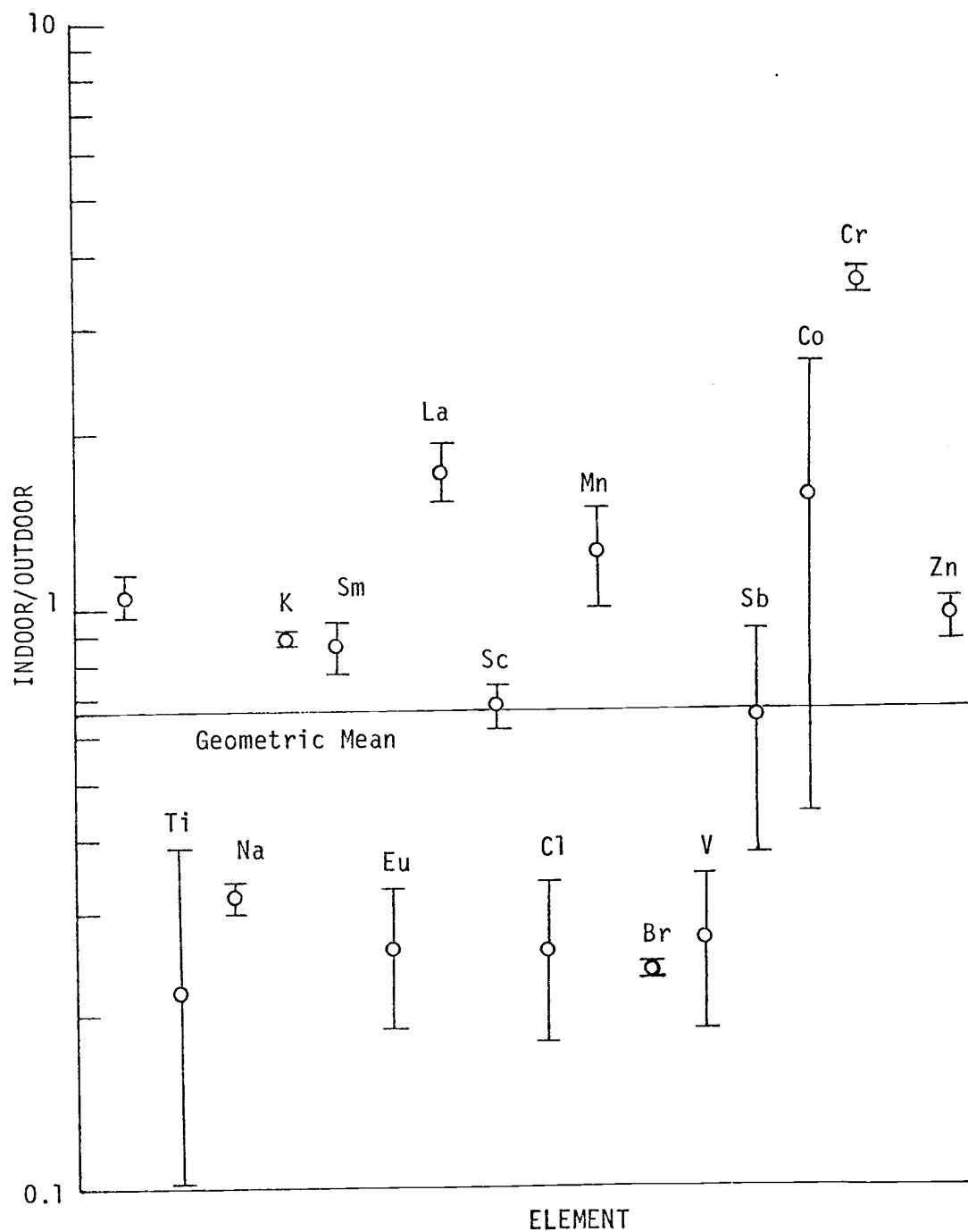


Figure 18. Ratios of Indoor and Outdoor Elemental Concentrations Found in Home I-Living Room (June 20, 1976).

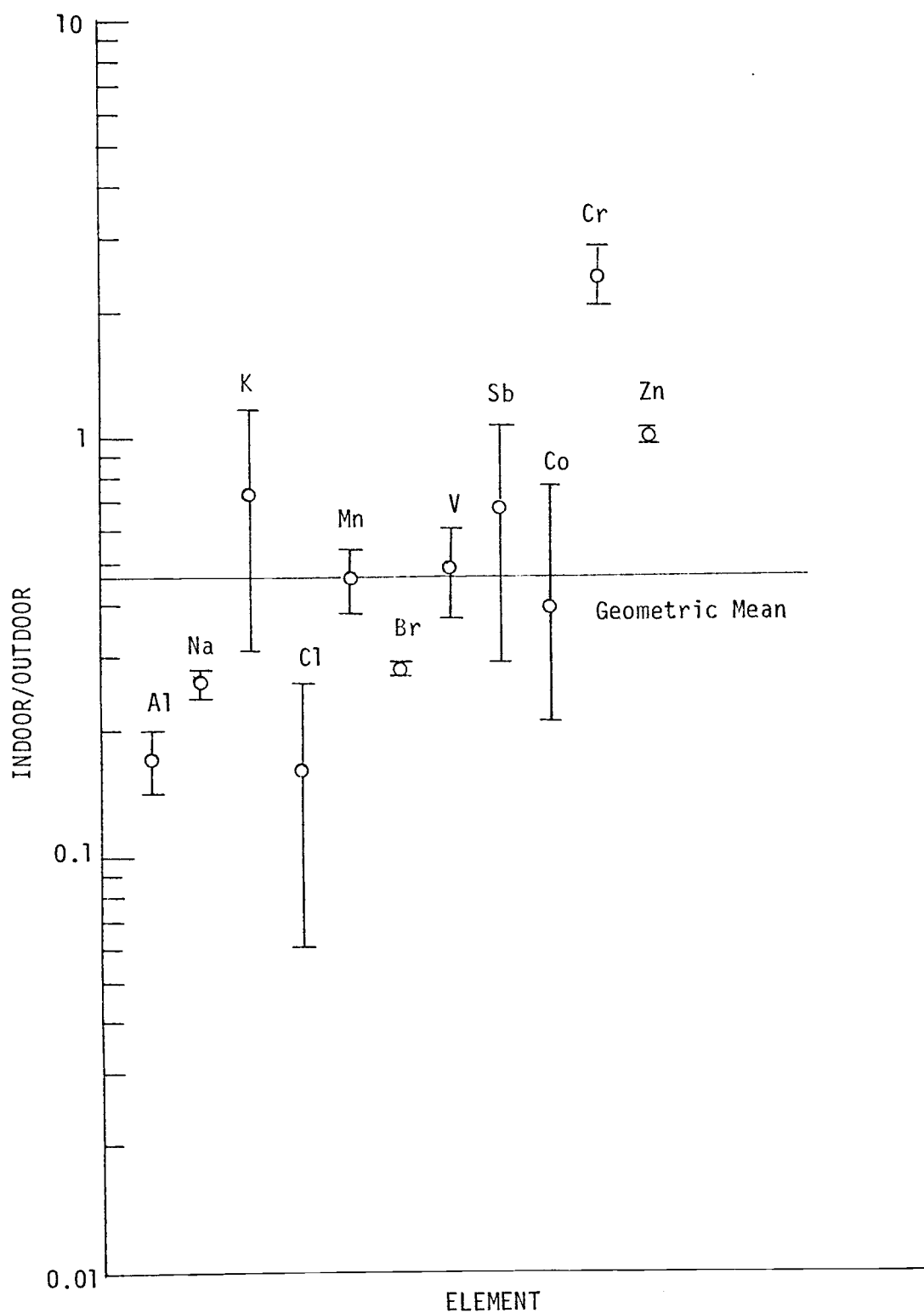


Figure 19. Ratios of Indoor and Outdoor Elemental Concentrations Found in Home I-Bedroom (June 23, 1976).

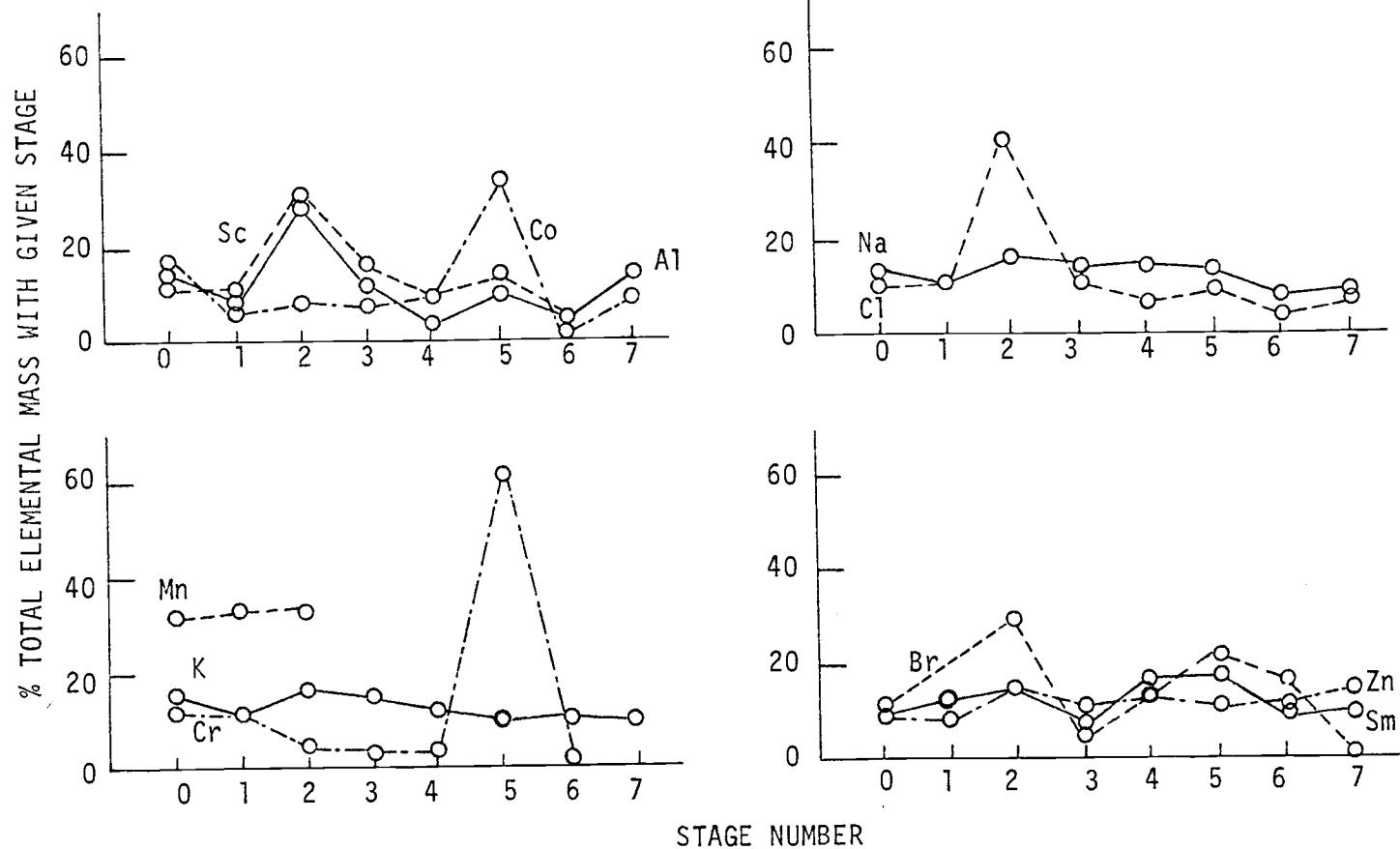


Figure 20. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home I-Living Room (June 22, 1976).

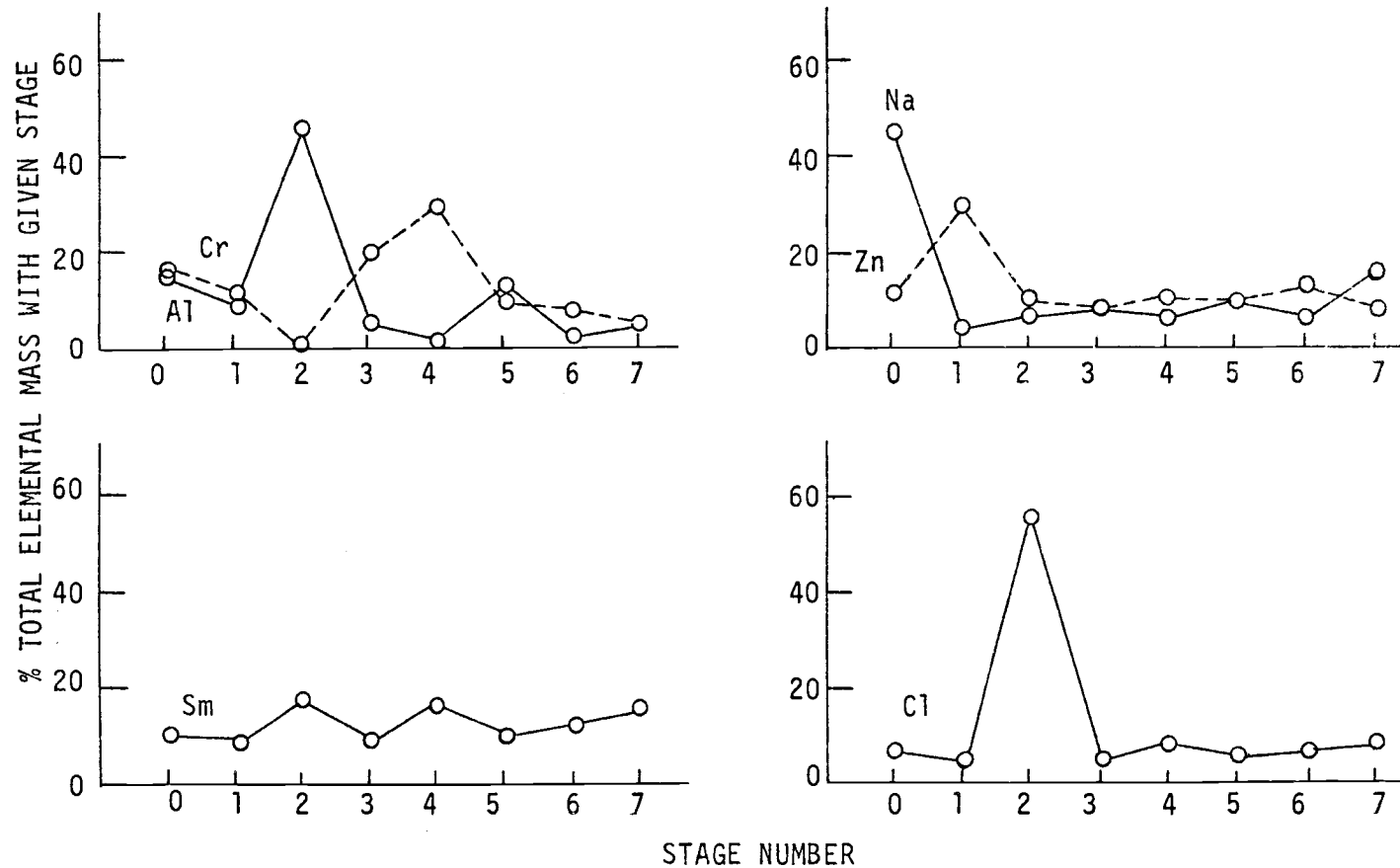


Figure 21. Percentage of total Total Elemental Particulate Mass with Given Stage Found in Home I-Bedroom (June 24, 1976).

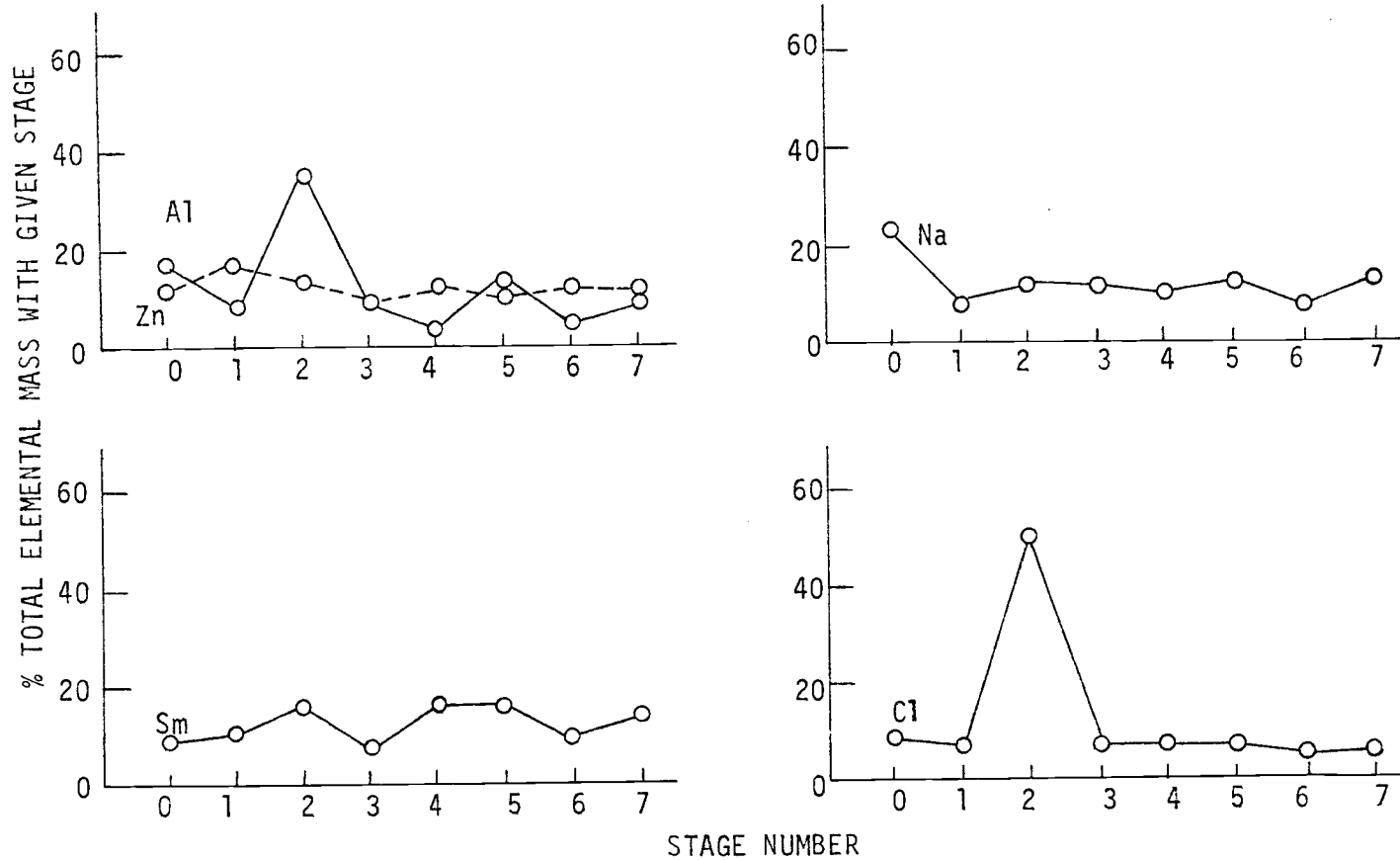


Figure 22. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home I (Average).

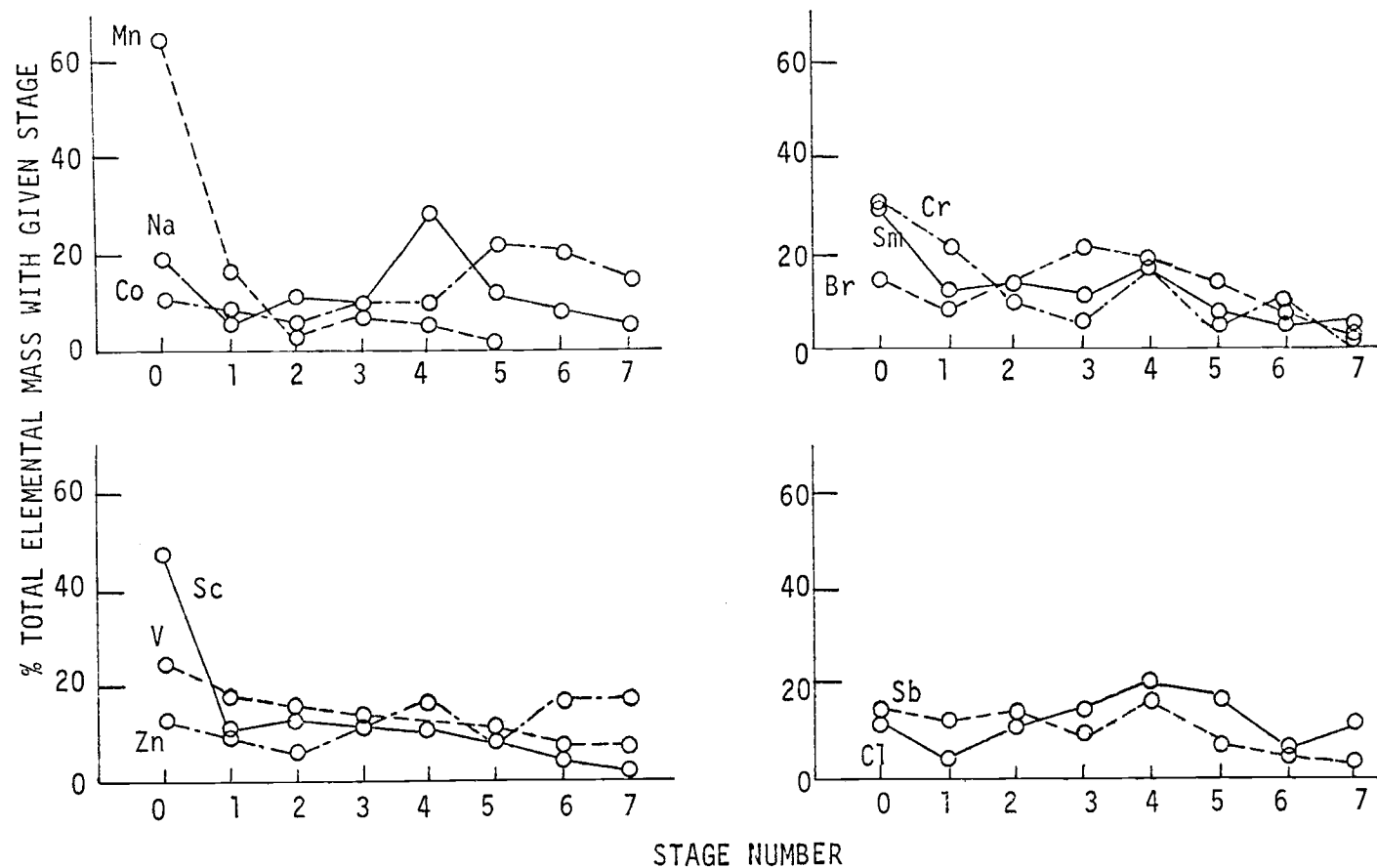


Figure 23. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Home I (June 26, 1976).

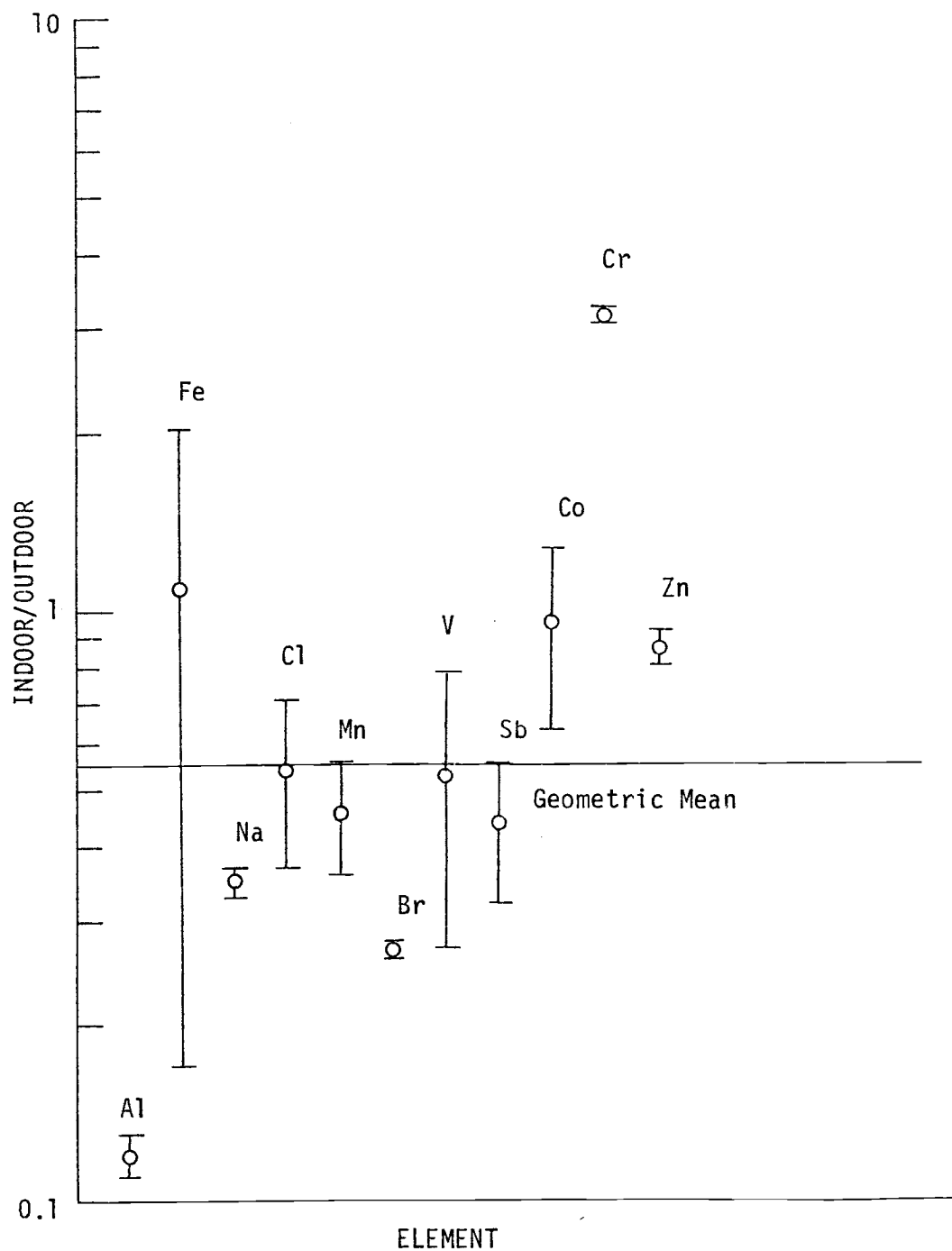


Figure 24. Ratios of Indoor and Outdoor Elemental Concentrations Found in Home II (June 29, 1976).

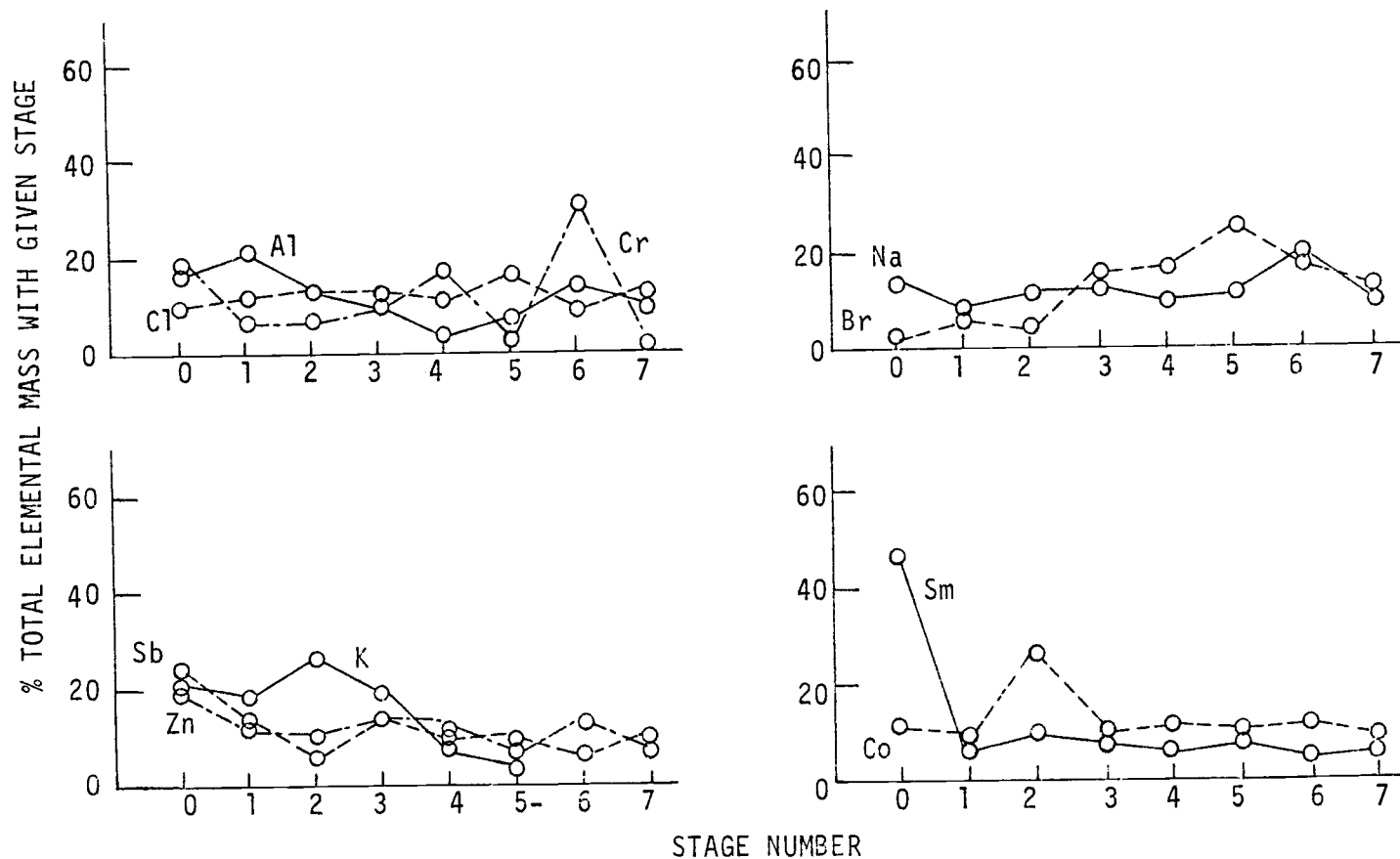


Figure 25. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Home II (June 30, 1976).

3. Modern Office Buildings (Rural)

Some of the trace element levels, such as Fe, K, Sm, La, Sc, Cl, Mn, Co, Cr inside office I are higher than outside (Figure 26).

Particle bearing the elements Fe, Sm, La, Sc, Mn, Cr are preferentially of large size (Figures 27a, 27b). The size distribution for Cl and Co are uniform. Their distribution curves are similar to rural air pattern.

The remaining question is the origin of the enhancement of potassium in the interior particulate. The potassium-bearing particles are primarily larger in size with some hint of a small size component indicating that they may originate from two or more processes of comparable magnitude. To further investigate this question, five days sampling was done at office I. The results are shown in Table 24. The mean indoor/outdoor ratios are less than one for all trace elements except potassium. The potassium mean indoor/outdoor ratio is 3.8 times the mean of all the other indoor/outdoor ratios. All the inside potassium levels lie within the same range and they are higher than the outside level. There is no doubt that the potassium level is elevated in office I, but the source of this potassium is not well known.

As shown in Figure 28, no enriched elements are found in office II and the size distributions for Sb, Al, Co, Na, Cl, and Br (Figure 29) are consistent with the ones found in rural air. It is suggested that the indoor trace element levels are primarily controlled by outdoor levels.

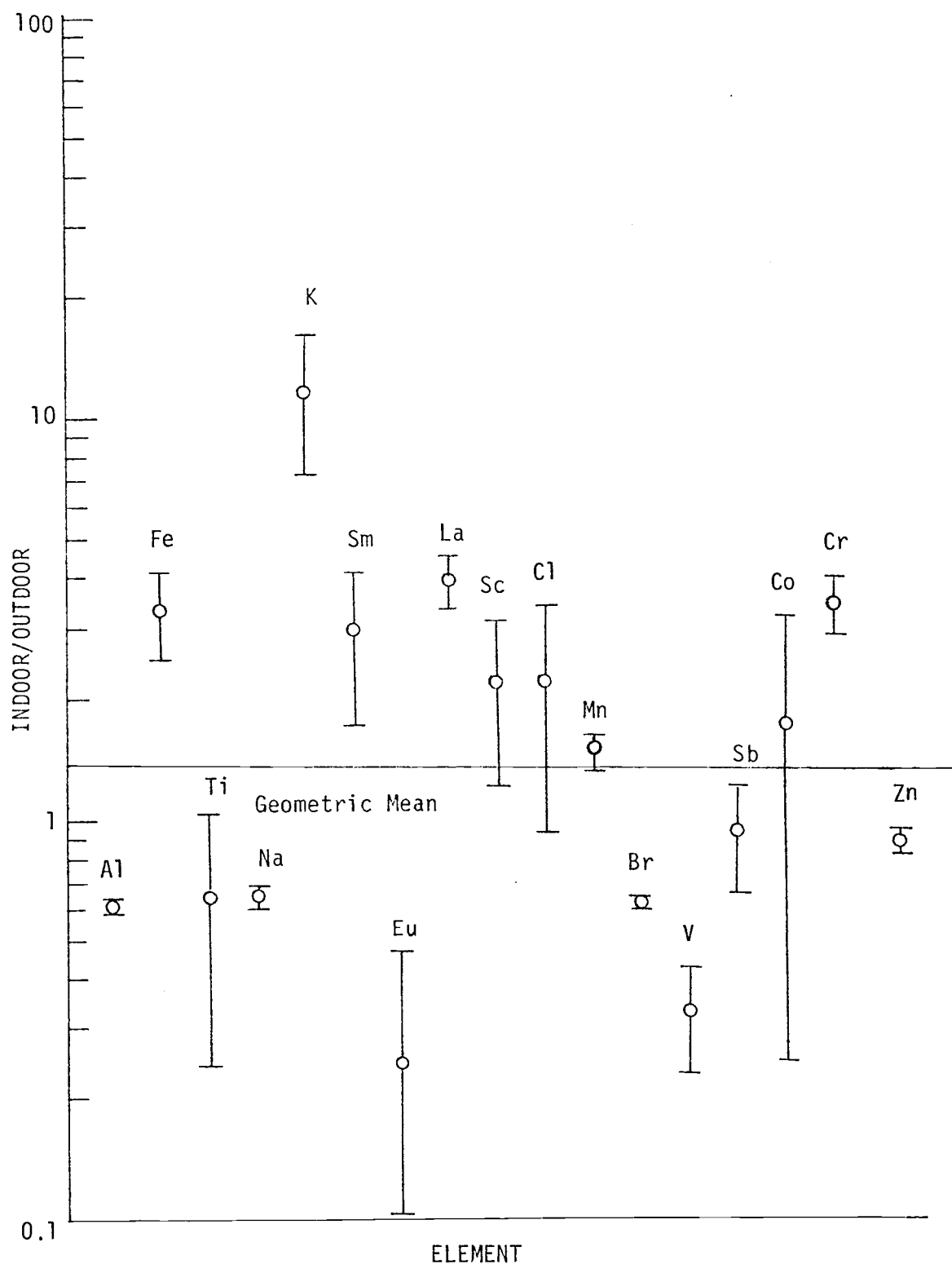


Figure 26. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office I (July 2, 1976).

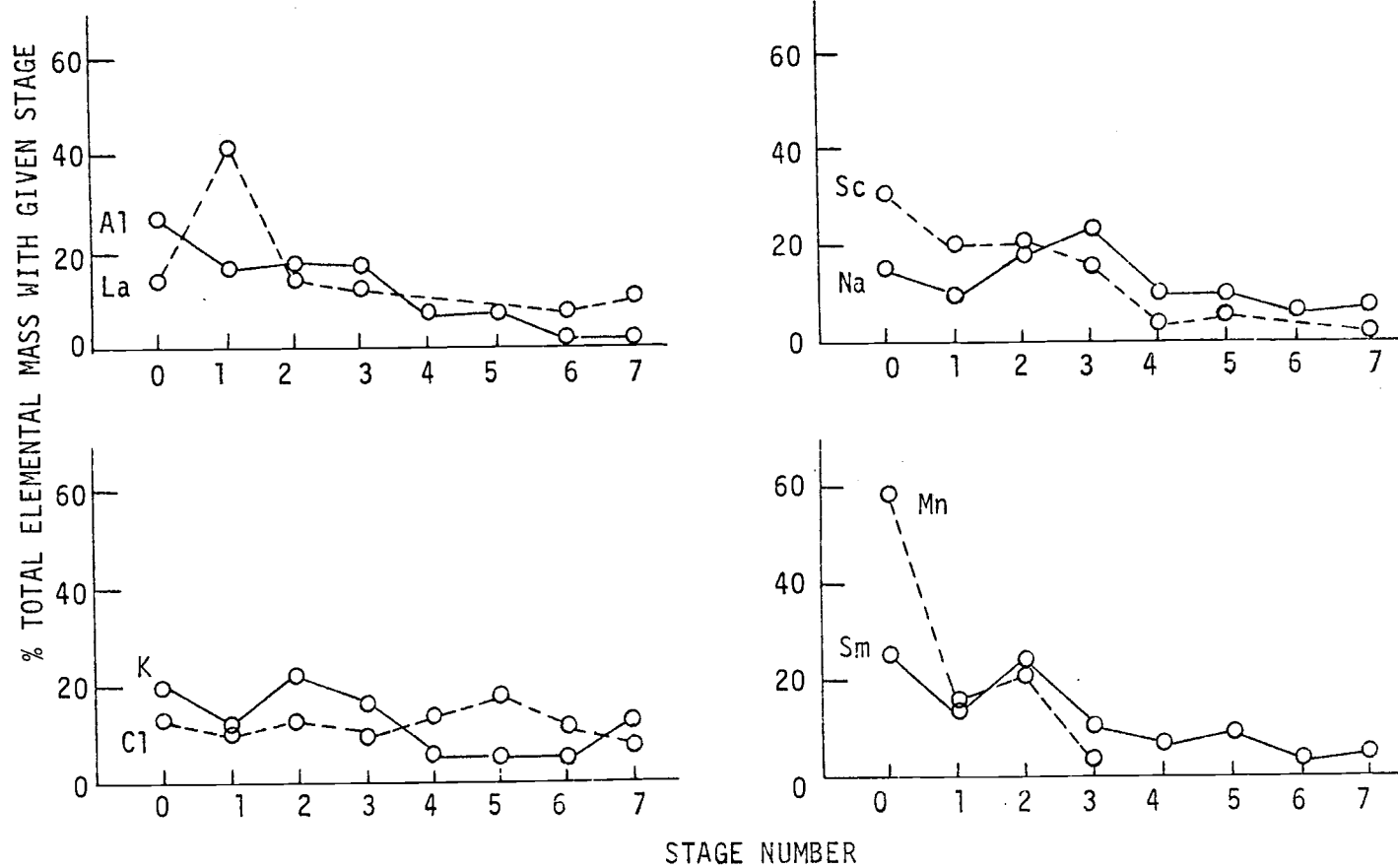


Figure 27a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office I (July 6, 1976).

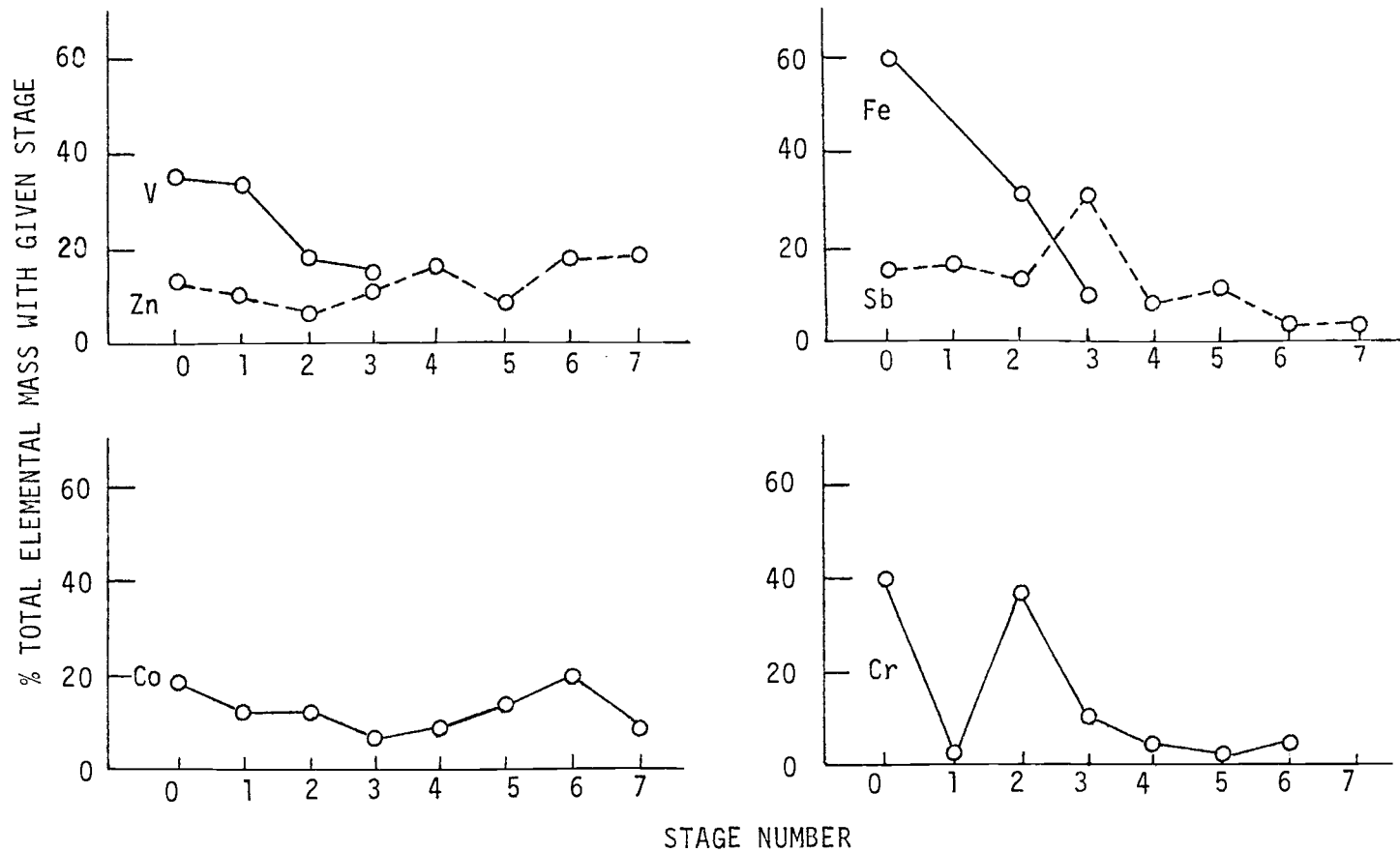


Figure 27b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office I (July 6, 1976).

Table 24. Trace Element Concentrations in Office I for Various Days

Date	Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
July 2, 76	K	967 $\pm$ 32	83 $\pm$ 32	12 $\pm$ 5
Feb. 27, 78		787 $\pm$ 23	486 $\pm$ 26	1.6 $\pm$ 0.1
Feb. 28, 78		841 $\pm$ 25	620 $\pm$ 29	1.36 $\pm$ 0.07
March 27, 78		685 $\pm$ 26	307 $\pm$ 23	2.2 $\pm$ 0.2
March 28, 78		1002 $\pm$ 28	467 $\pm$ 26	2.1 $\pm$ 0.1
March 29, 78		682 $\pm$ 23	516 $\pm$ 25	1.32 $\pm$ 0.08
July 2, 76	Sb	0.8 $\pm$ 0.1	0.8 $\pm$ 0.2	1.0 $\pm$ 0.3
Feb. 27, 78		0.23 $\pm$ 0.07	0.49 $\pm$ 0.09	0.5 $\pm$ 0.2
Feb. 28, 78		0.27 $\pm$ 0.07	0.6 $\pm$ 0.1	0.5 $\pm$ 0.2
March 27, 78		<0.44	0.3 $\pm$ 0.2	---
March 28, 78		0.7 $\pm$ 0.2	0.9 $\pm$ 0.2	0.8 $\pm$ 0.2
March 29, 78		0.6 $\pm$ 0.1	1.2 $\pm$ 0.2	0.5 $\pm$ 0.1
July 2, 76	Sm	0.057 $\pm$ 0.006	0.020 $\pm$ 0.008	2.9 $\pm$ 1.2
Feb. 27, 78		0.054 $\pm$ 0.005	0.156 $\pm$ 0.007	0.35 $\pm$ 0.04
Feb. 28, 78		0.072 $\pm$ 0.005	0.168 $\pm$ 0.009	0.43 $\pm$ 0.04
March 27, 78		0.07 $\pm$ 0.01	0.090 $\pm$ 0.006	0.7 $\pm$ 0.1
March 28, 78		0.13 $\pm$ 0.01	0.19 $\pm$ 0.01	0.67 $\pm$ 0.06
March 29, 78		0.047 $\pm$ 0.008	0.160 $\pm$ 0.006	0.30 $\pm$ 0.05
July 2, 76	Sc	0.14 $\pm$ 0.04	0.06 $\pm$ 0.02	2.2 $\pm$ 0.9
Feb. 27, 78		0.13 $\pm$ 0.01	0.51 $\pm$ 0.01	0.26 $\pm$ 0.02
Feb. 28, 78		0.25 $\pm$ 0.01	0.56 $\pm$ 0.01	0.45 $\pm$ 0.02
July 2, 76	Fe	821 $\pm$ 203	<530	3.3 $\pm$ 0.8
Feb. 27, 78		598 $\pm$ 98	1356 $\pm$ 95	0.44 $\pm$ 0.08
Feb. 28, 78		637 $\pm$ 109	1586 $\pm$ 115	0.40 $\pm$ 0.07

Table 24. Continued

Date	Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
July 2, 76	Cr	82 $\pm$ 3	24 $\pm$ 4	3.5 $\pm$ 0.6
Feb. 27, 78		13 $\pm$ 1	29 $\pm$ 2	0.33 $\pm$ 0.04
Feb 28, 78		32 $\pm$ 2	54 $\pm$ 4	0.60 $\pm$ 0.06
July 2, 76	Mn	13.8 $\pm$ 0.7	9.2 $\pm$ 0.7	1.5 $\pm$ 0.1
March 27, 78		20.8 $\pm$ 0.5	37.6 $\pm$ 0.9	0.55 $\pm$ 0.02
March 28, 78		42 $\pm$ 1	66 $\pm$ 1	0.64 $\pm$ 0.02
March 29, 78		24.4 $\pm$ 0.6	74 $\pm$ 2	0.33 $\pm$ 0.01
July 2, 76	Br	38.4 $\pm$ 0.7	62 $\pm$ 1	0.62 $\pm$ 0.02
March 27, 78		22.0 $\pm$ 0.4	77 $\pm$ 2	0.29 $\pm$ 0.01
March 28, 78		44.0 $\pm$ 0.9	138 $\pm$ 3	0.32 $\pm$ 0.01
March 29, 78		34.4 $\pm$ 0.8	143 $\pm$ 3	0.24 $\pm$ 0.01

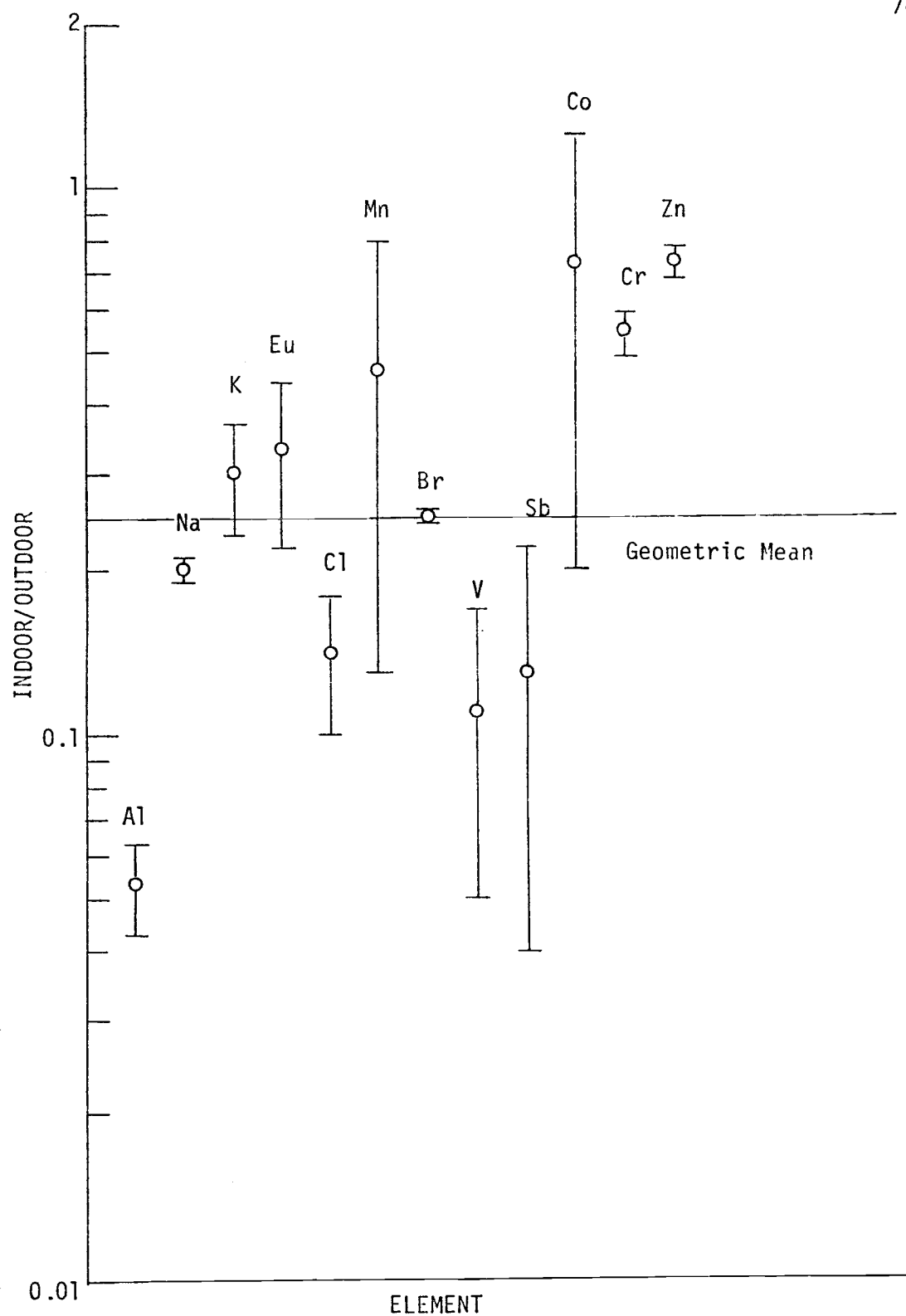


Figure 28. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office II (July 8, 1976).

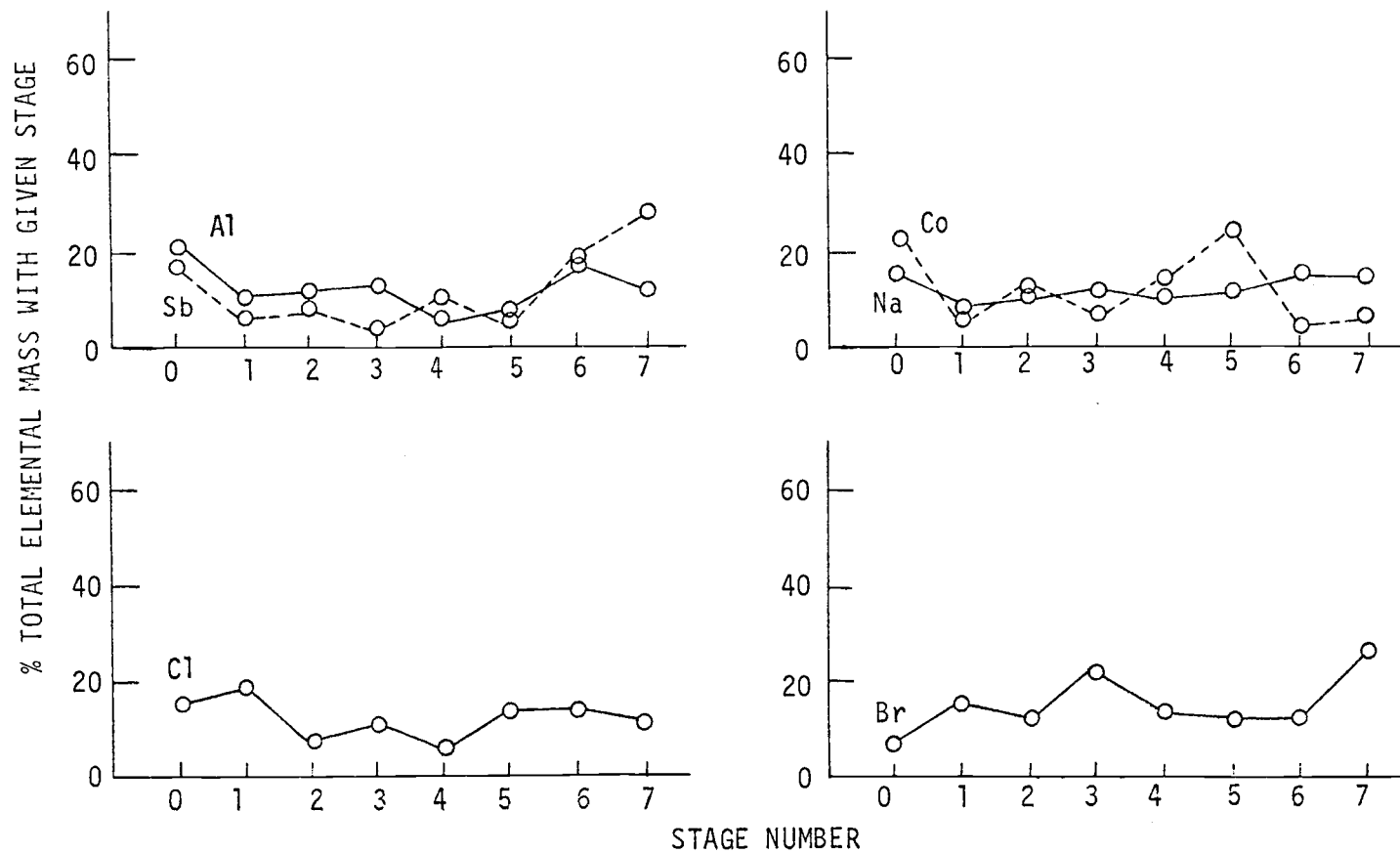


Figure 29. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office II (July 9, 1976).

4. Hospital

It is not surprising that comparable indoor/outdoor ratios and elemental particle size distribution (Figures 30, 31, 32a, 32b, 33) are observed in the nursing stations of general station and isolation station in the hospital because they receive their air from the same air supply system. No enriched elements are found inside these two stations. It is believed that the indoor trace element levels are directly controlled by outdoor trace element levels. Perhaps somewhat surprising in the result that the mean particulate indoor/outdoor ratios in the hospital where a clean air supply would seem important are greater than the indoor/outdoor ratios seen in some office buildings.

5. Automobile Repair Garages

In garage I, enhancement in bromine (Figure 34) is observed and the ratio of excess bromine to chlorine is 3.36 (Table 25).

Table 25. Ratio of Excess Bromine to Chlorine in Garage I

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Excess Concentration (ng/m ³)	Ratio
Br	347 $\pm$ 3	27.5 $\pm$ 0.3	319.5	3.36
Cl	199 $\pm$ 42	104 $\pm$ 5	95	

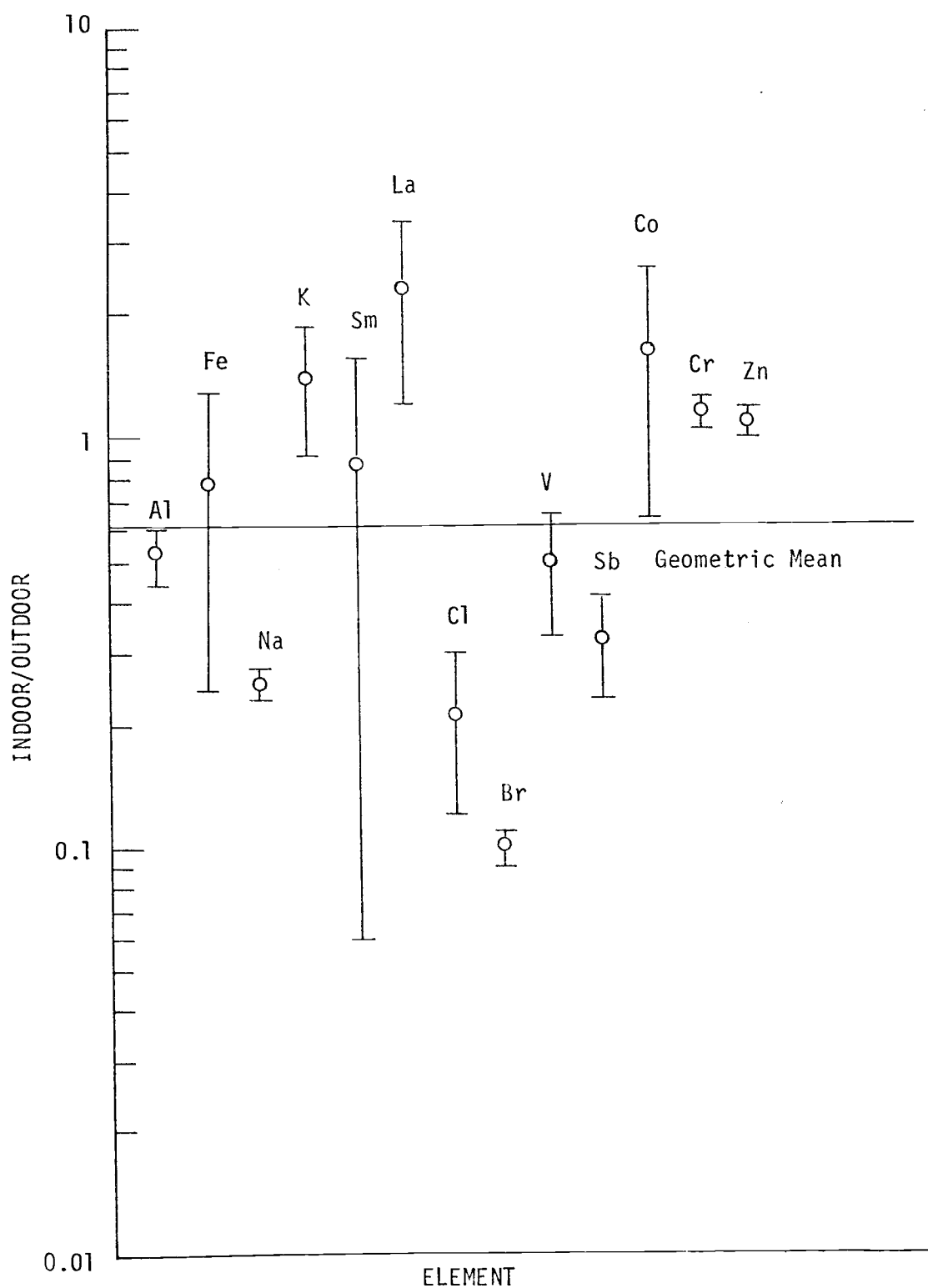


Figure 30. Ratios of Indoor and Outdoor Elemental Concentrations Found in the Isolation Station of Hospital (July 13, 76).

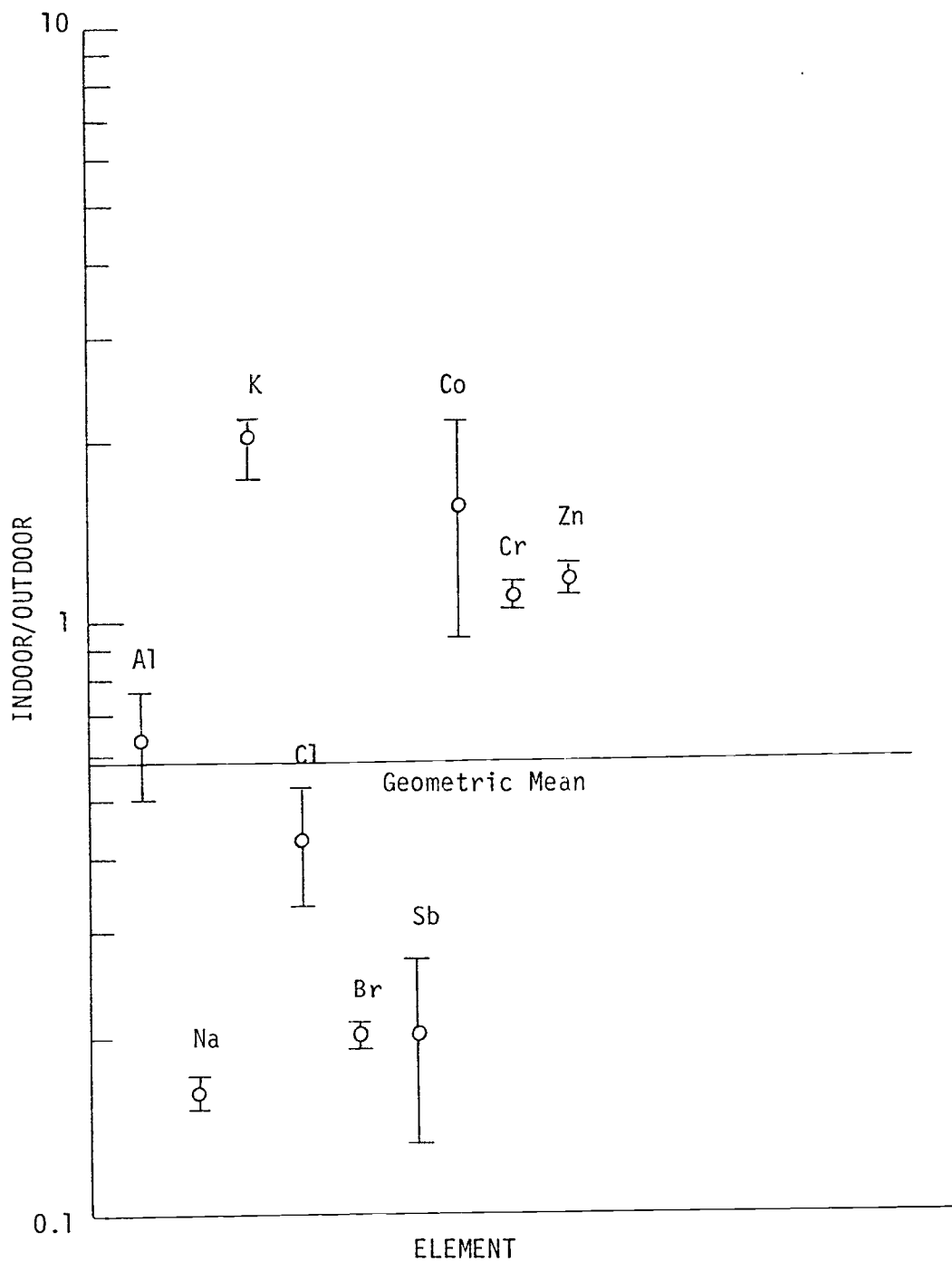


Figure 31. Ratios of Indoor and Outdoor Elemental Concentrations Found in the General Station of Hospital (July 17, 76).

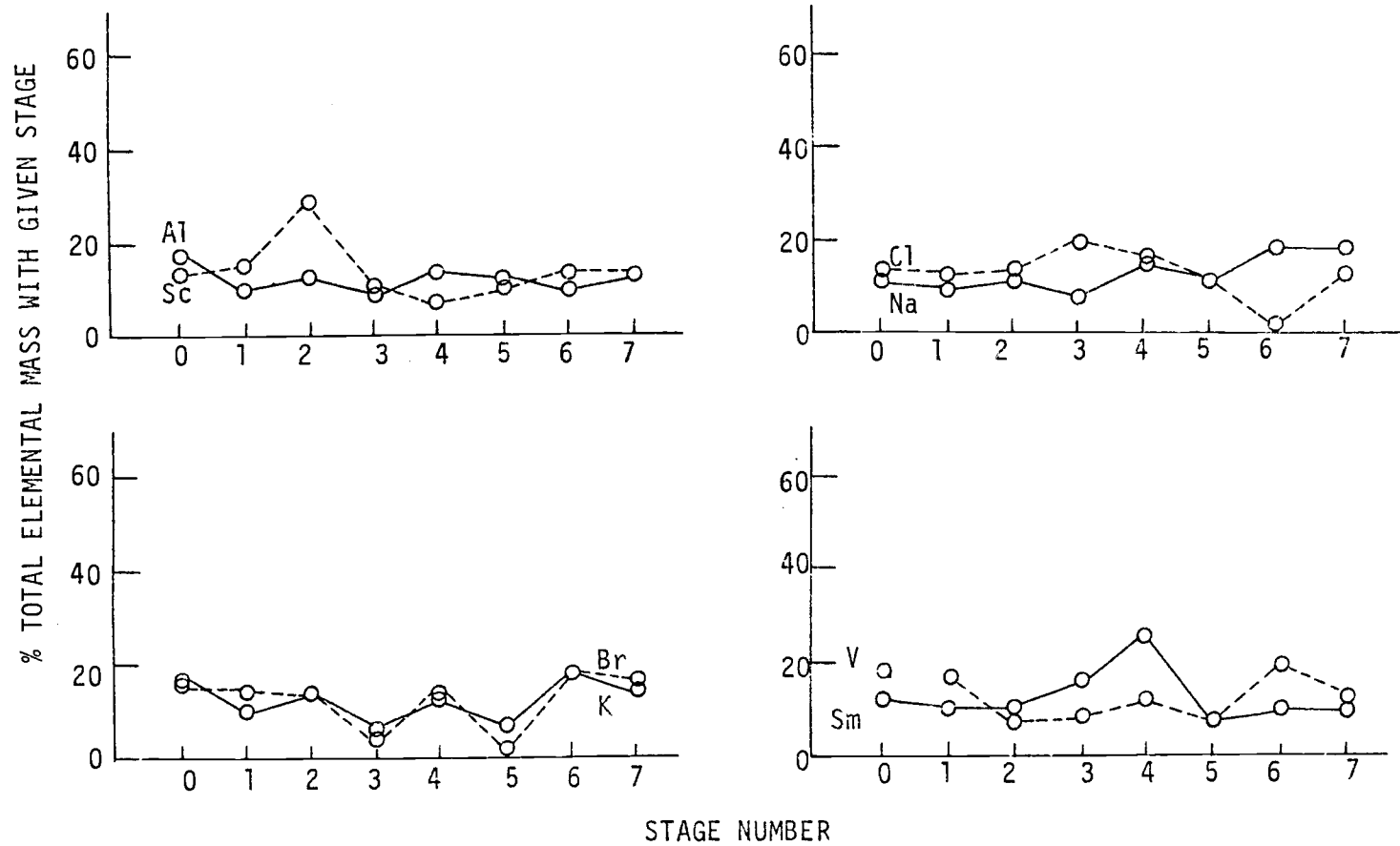


Figure 32a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Isolation Station of Hospital (July 14, 1976).

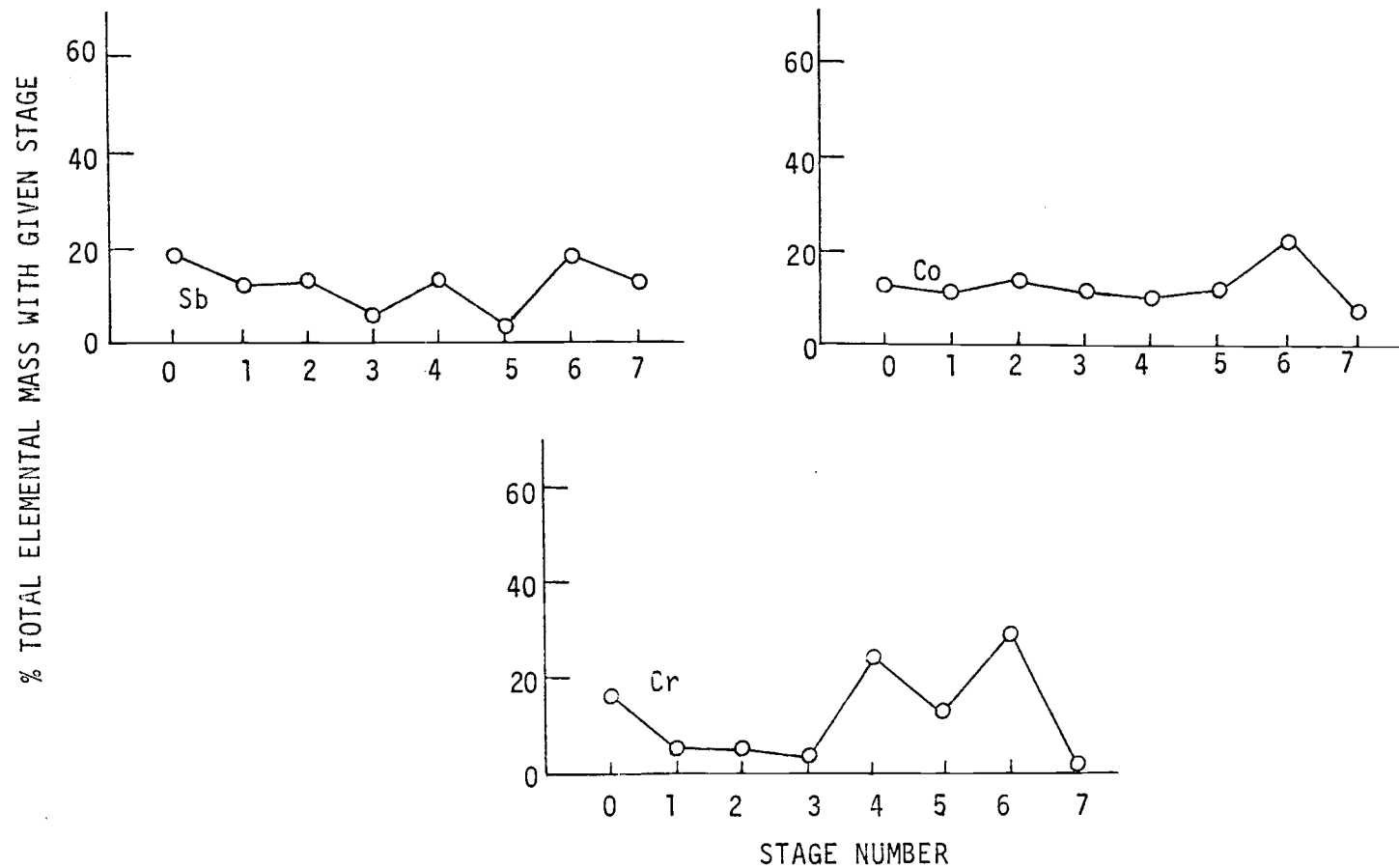


Figure 32b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Isolation Station of Hospital (July 14, 1976).

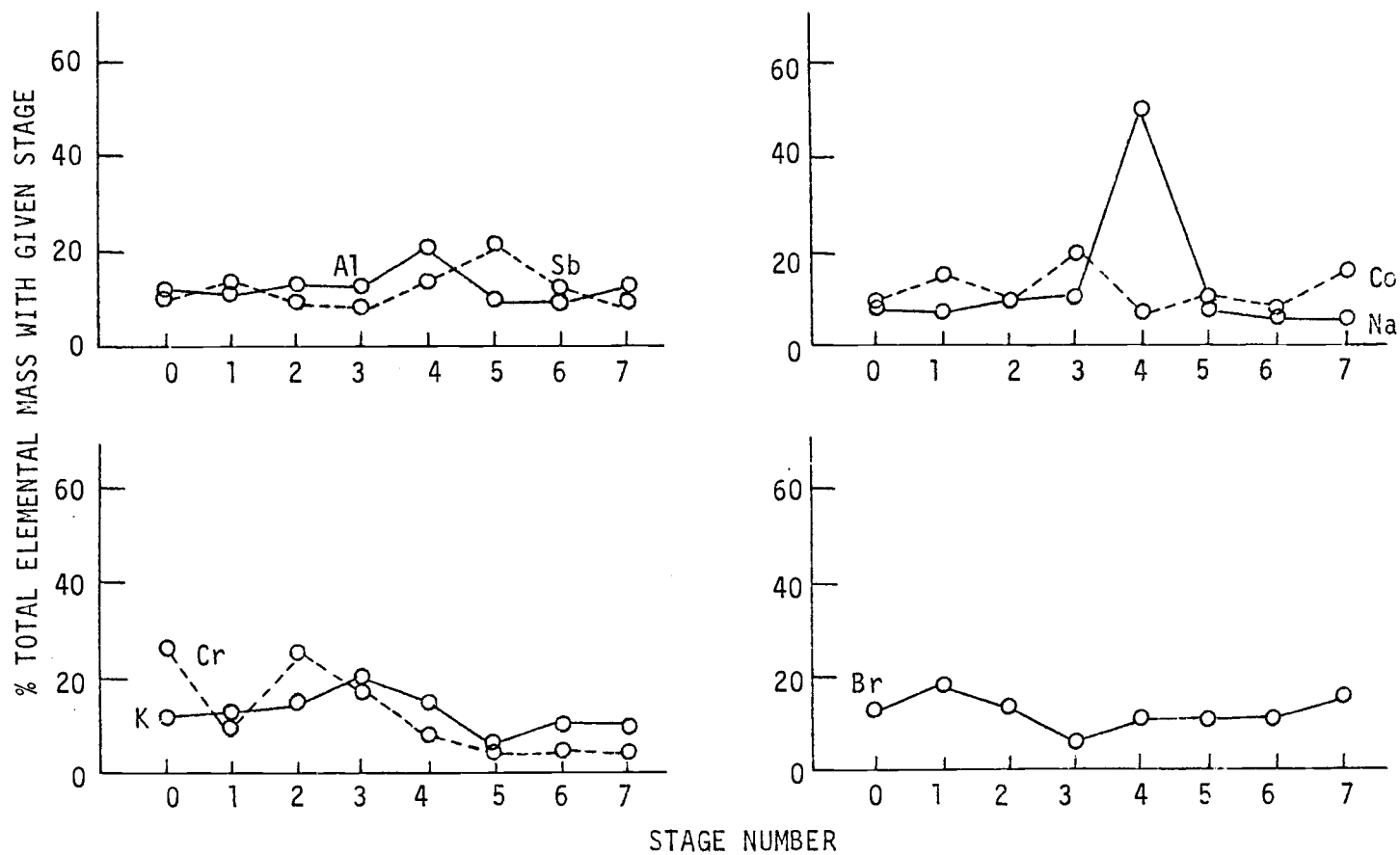


Figure 33. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the General Station of Hospital (July 16, 1976).

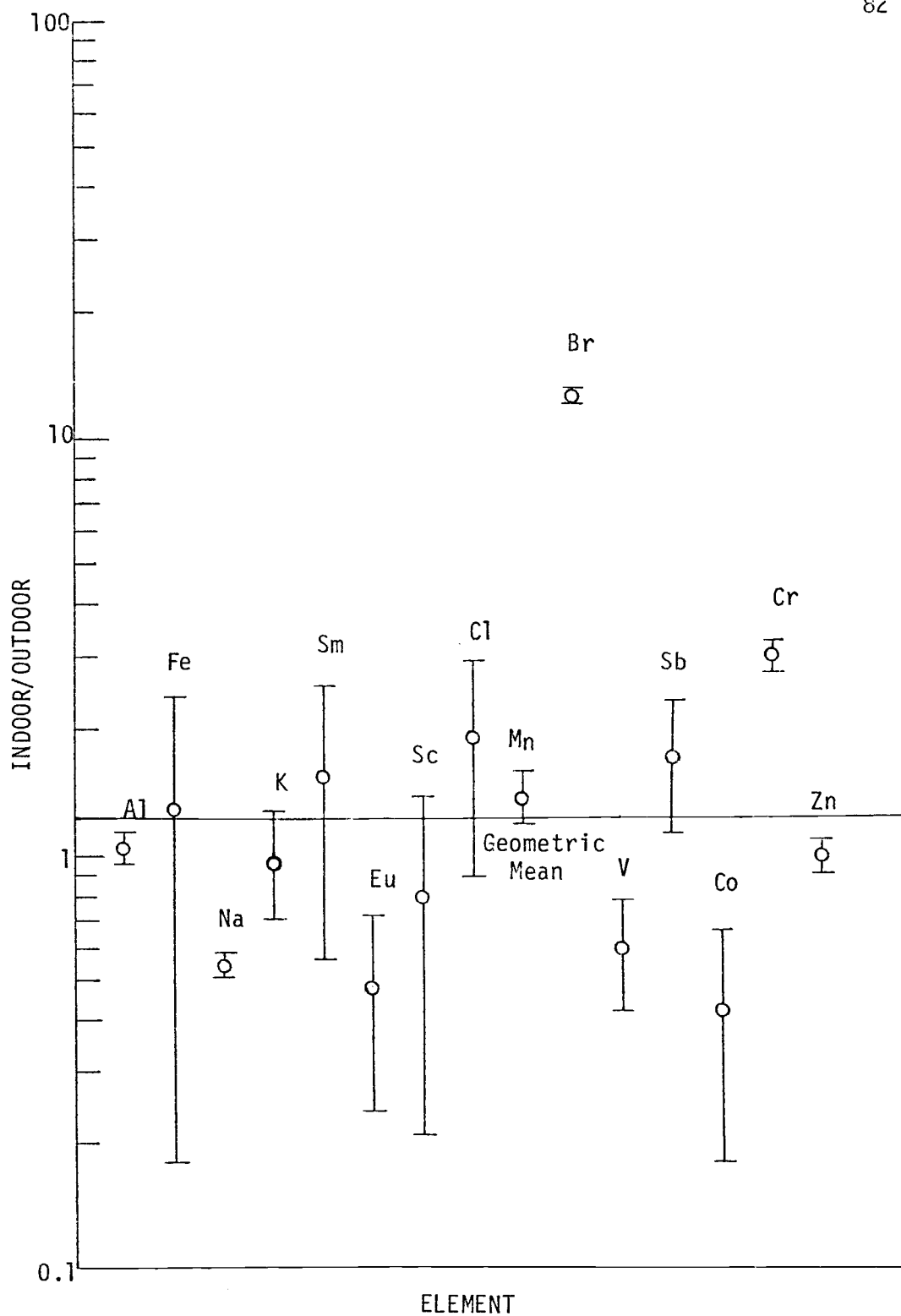


Figure 34. Ratios of Indoor and Outdoor Elemental Concentrations Found in Garage I (July 29, 1976).

The ratio of the "average" exhaust bromine to chlorine of the vehicles burning leaded fuel is 3.38 found by Jones (29), 3.83 found by Gordon, et al. (31) and 2.25 found by Cahill and Feeney (32).

Figure 35a shows that bromine and chlorine are more predominantly associated with small particles. It appears that most bromine and chlorine in garage I originates from automobile exhaust. As seen in Figures 35a, 35b, 36a, 36b, the particle size data indicates that outdoor air is the most likely source of the indoor air. It appears that a portion of the bigger particles are filtered out as they penetrate the building.

The concentration of bromine is elevated in garage II (Figure 37). But the expected automobile exhaust ratio of bromine/chlorine is not found. As shown in Figures 38 and 39, the size distribution for elements such as aluminum, iron, potassium, scandium, bromine found inside the garage II is similar to the one found in outdoor air. Because the doors of garage II were wide open during the sampling period, no further conclusion is drawn from the above data.

6. Modern Office Buildings (Urban)

The two urban offices studies in this work were located in Portland, Oregon.

For office III, all the ratios of indoor and outdoor elemental concentrations scatter around the geometric mean value (Figure 40).

Because of time limitation, no outdoor cascade impactor samples were involved in the Portland area. In office IV, the elemental

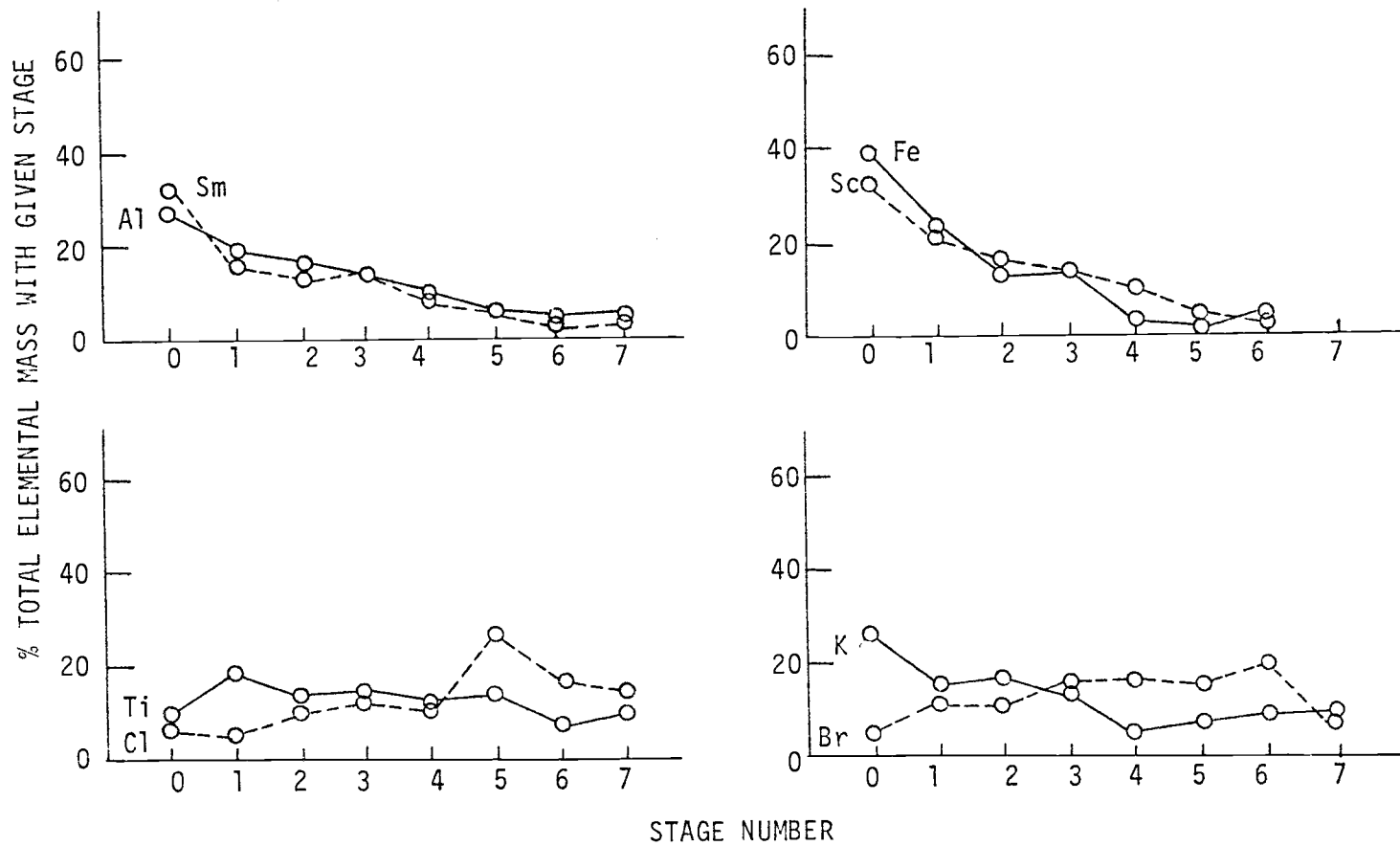


Figure 35a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage I (July 28, 1976).

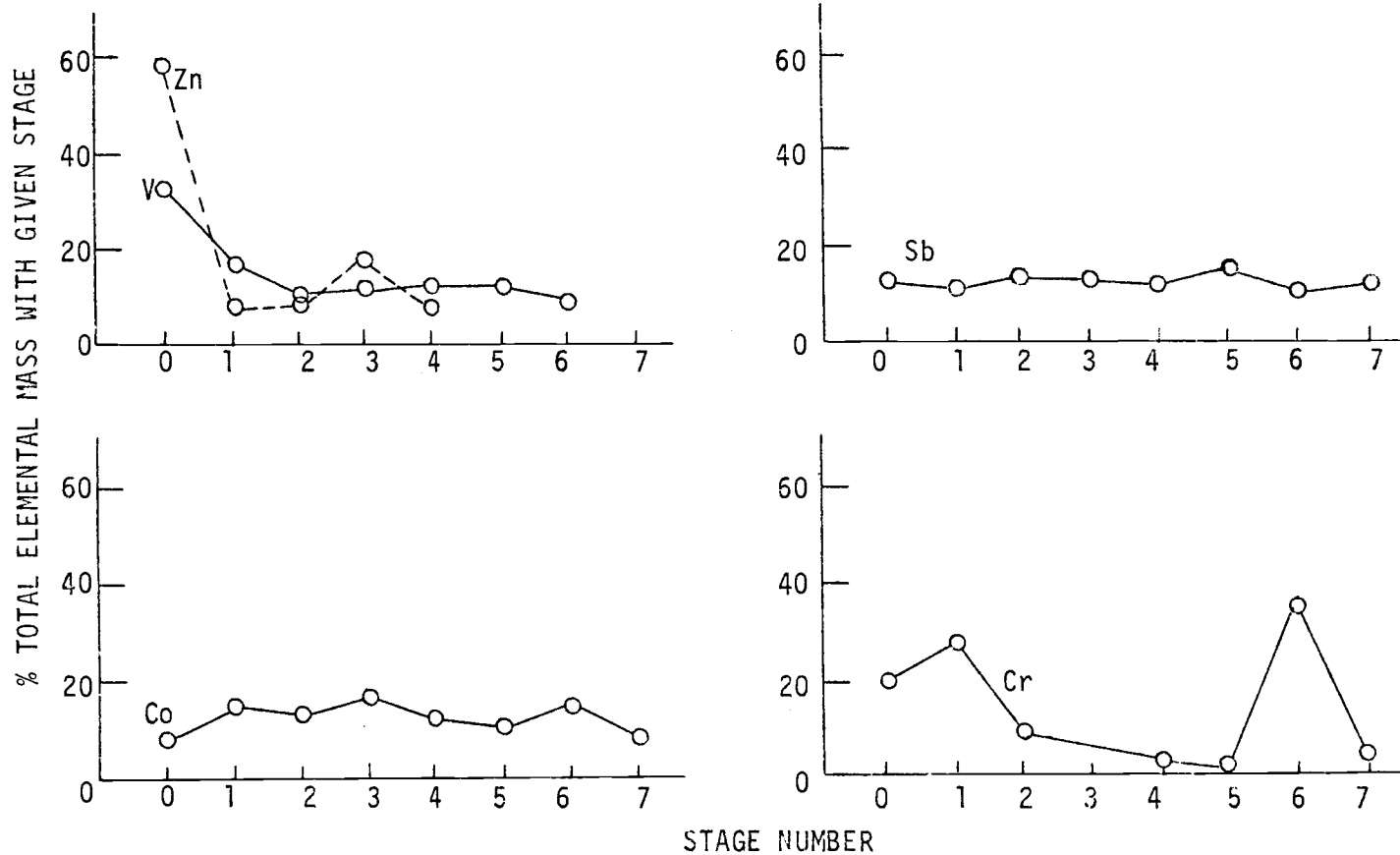


Figure 35b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage I (July 28, 1976).

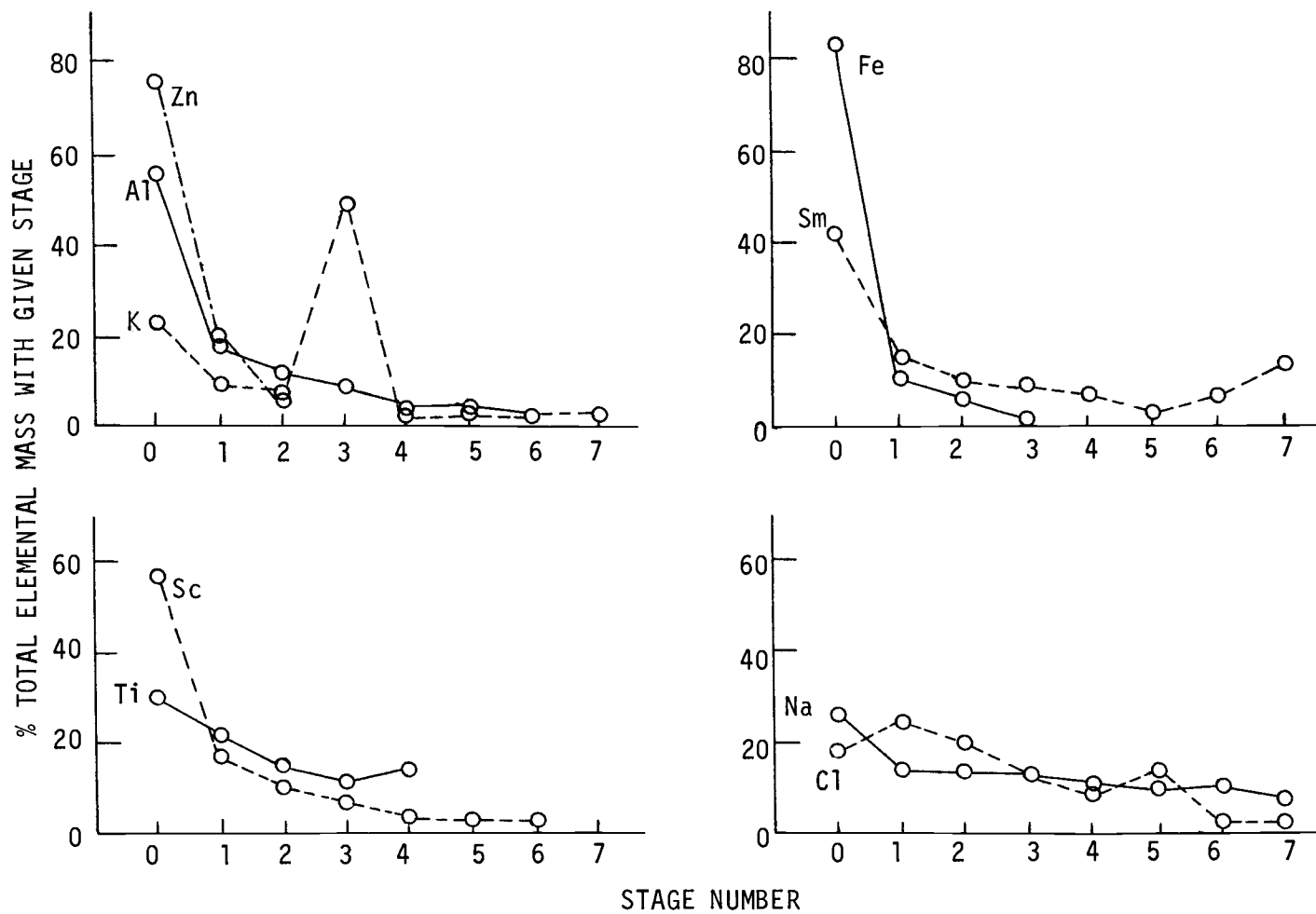


Figure 36a. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage I (July 30, 1976).

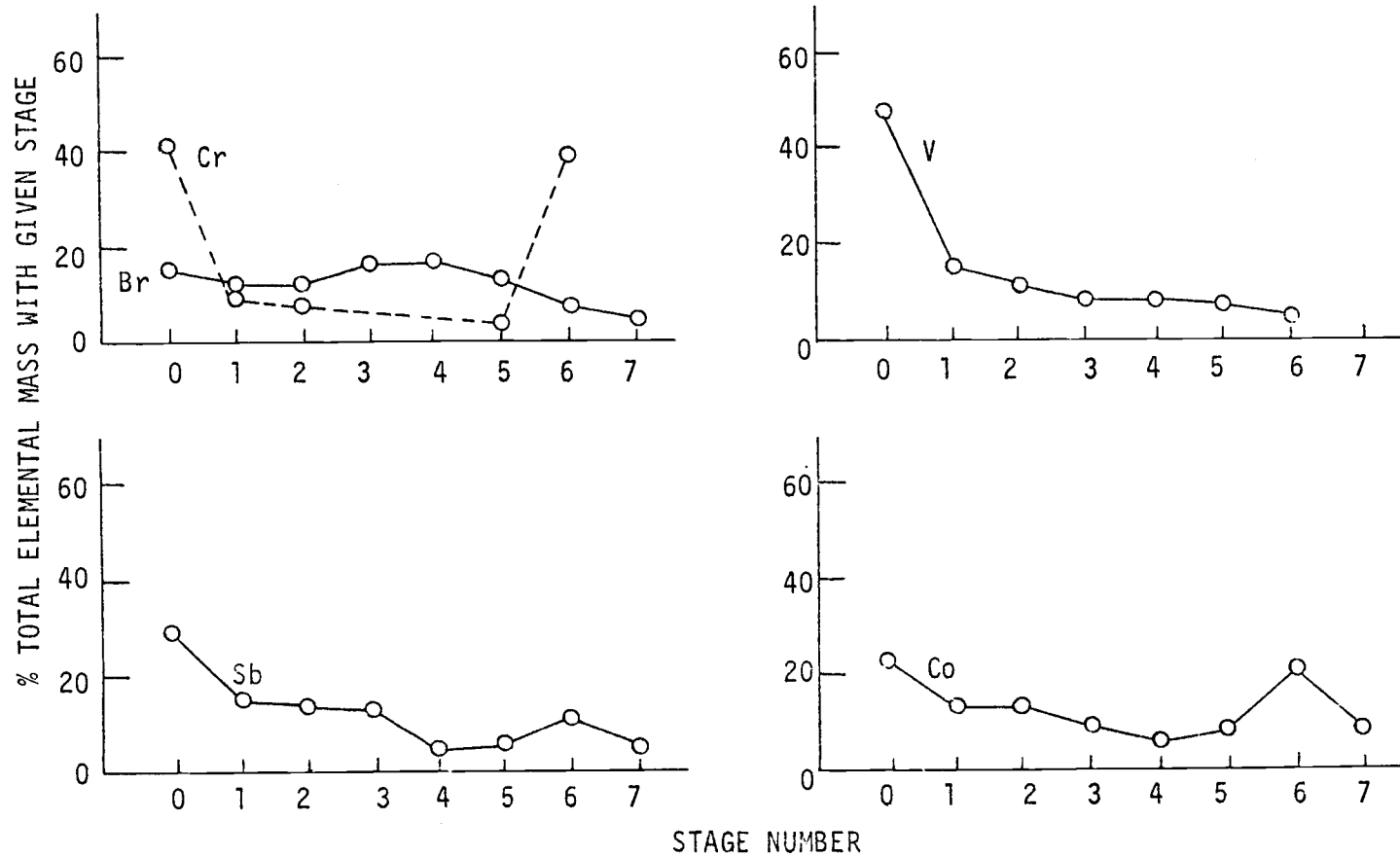


Figure 36b. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage I (July 30, 1976).

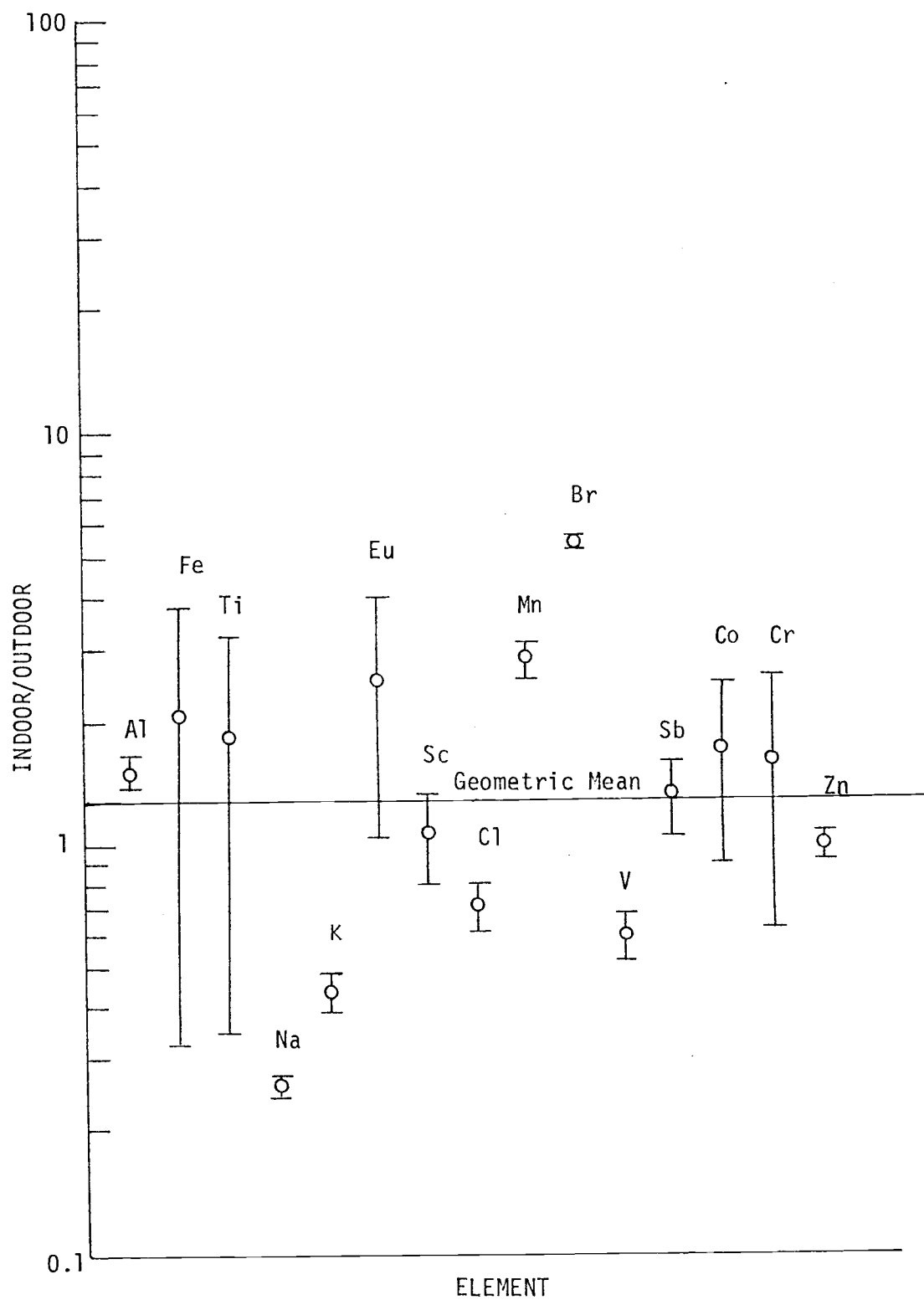


Figure 37. Ratios of Indoor and Outdoor Elemental Concentrations Found in Garage II (October 4, 1976).

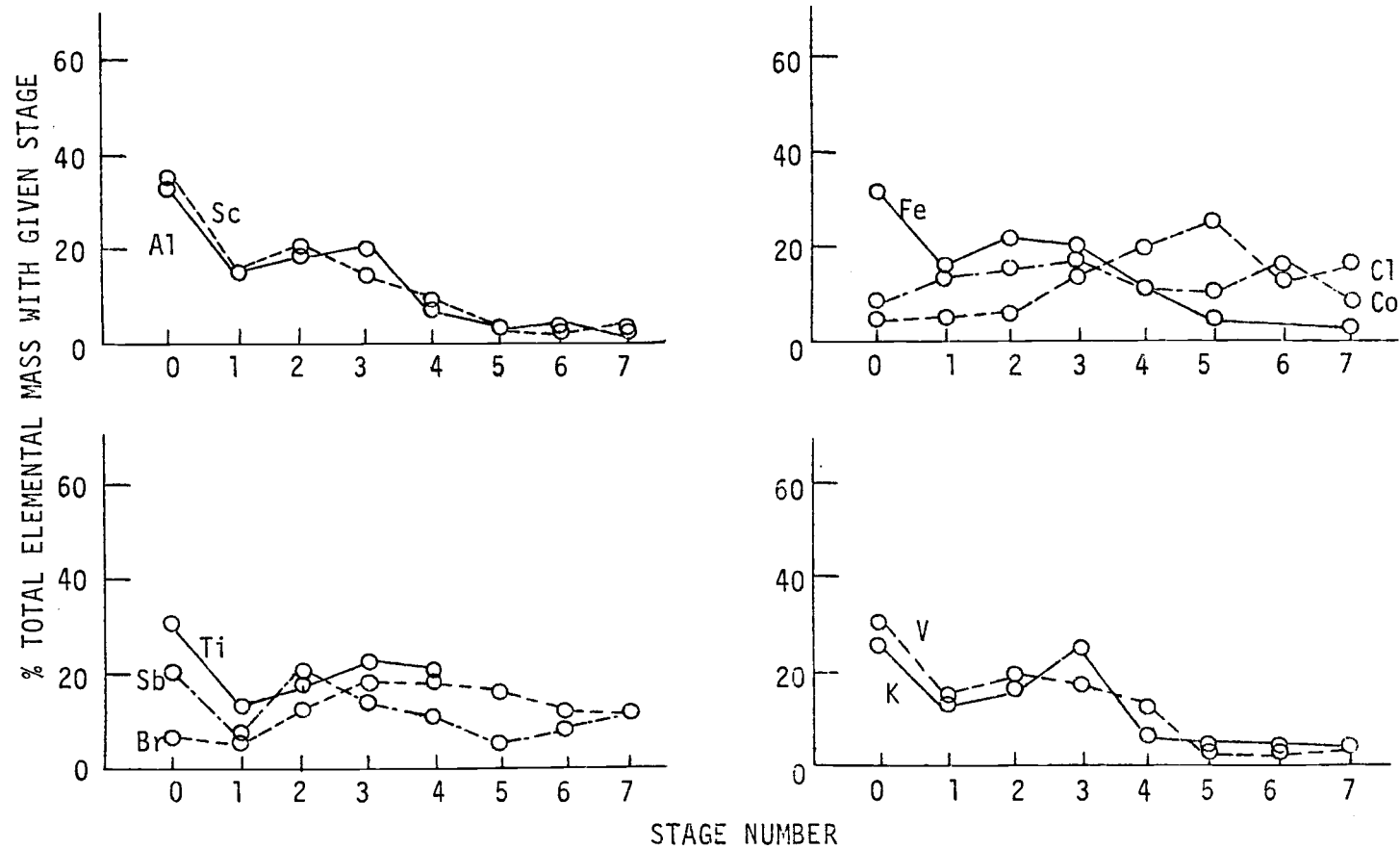


Figure 38. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Garage II (October 1, 1976).

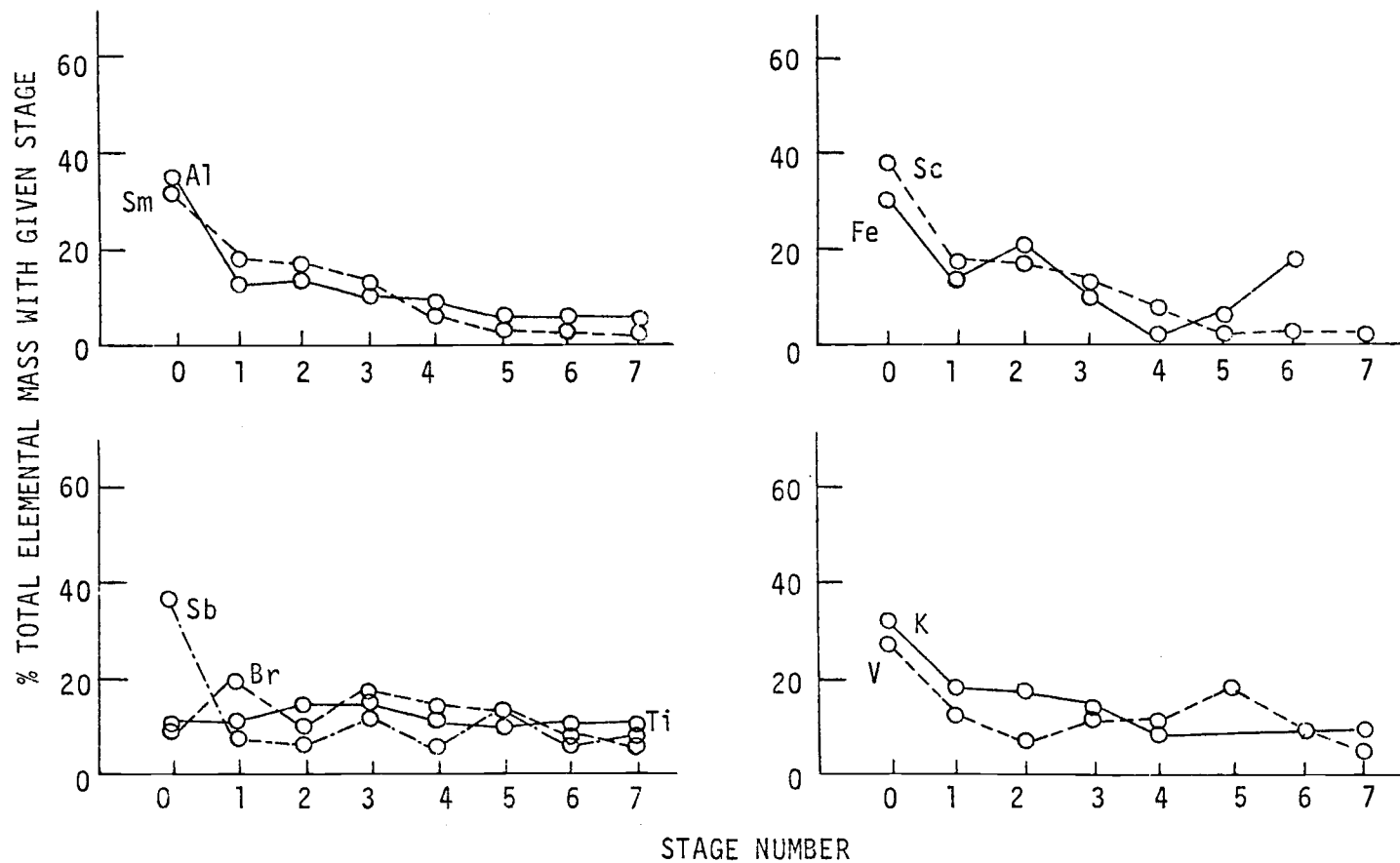


Figure 39. Percentage of the Total Elemental Particulate Mass with Given Stage Found in the Outside of Garage II (October 6, 1976).

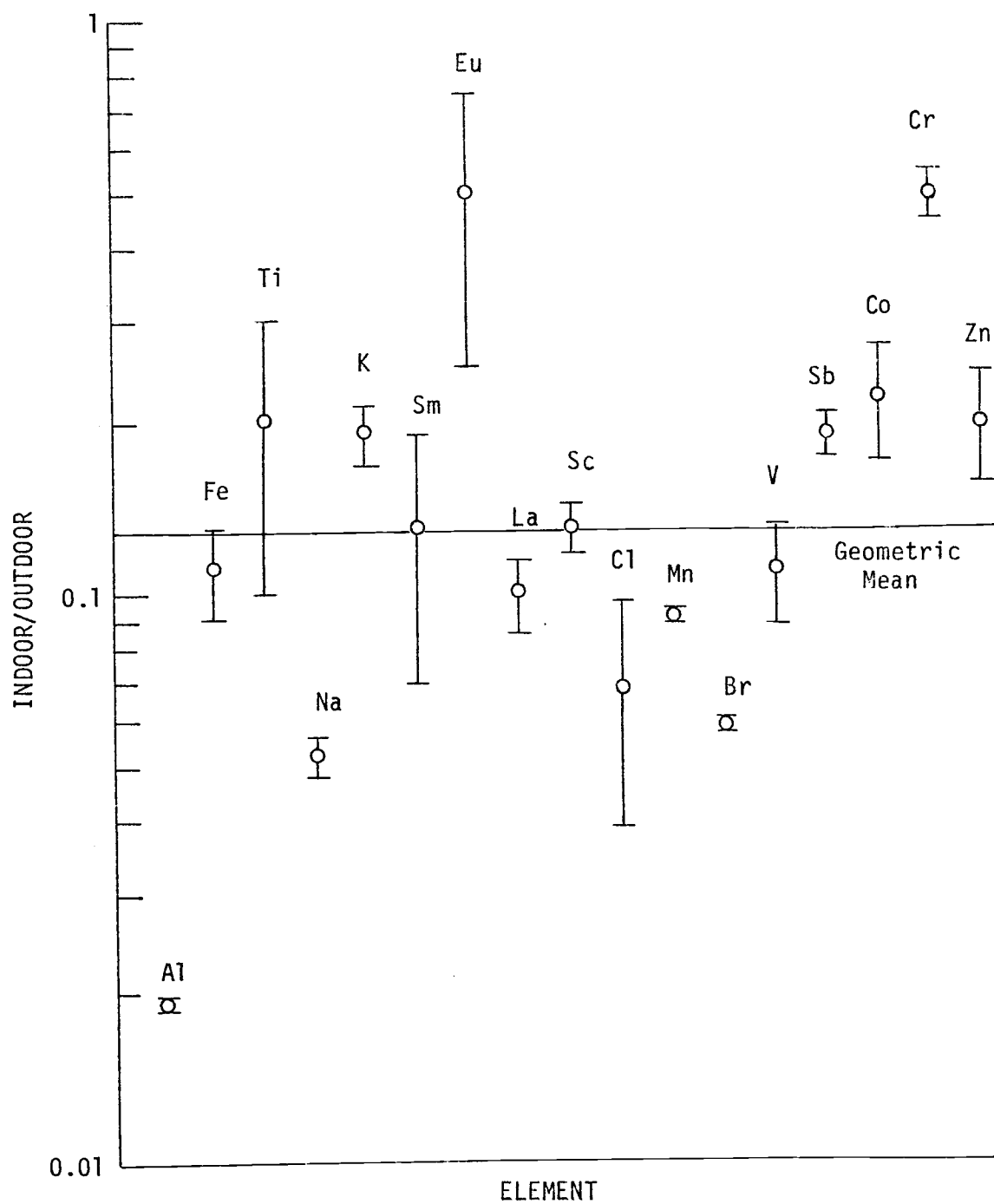


Figure 40. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office III (August 17, 1977).

particles are predominantly of medium and small sizes (Figure 42). By comparing this data to the rural air pattern, it indicates most of the larger particles are filtered out when the particulates penetrate into this office. By considering the statistical criteria described in section D, the existence of interior sources for the particulate antimony and zinc in office IV (Figure 41) is indicated.

In both offices, the indoor and outdoor elemental levels are higher than the ones found in Corvallis area but the indoor/outdoor ratios generally are lower than the data observed in Corvallis. It is because of higher concentration of larger (non-penetrating) particulates outdoors.

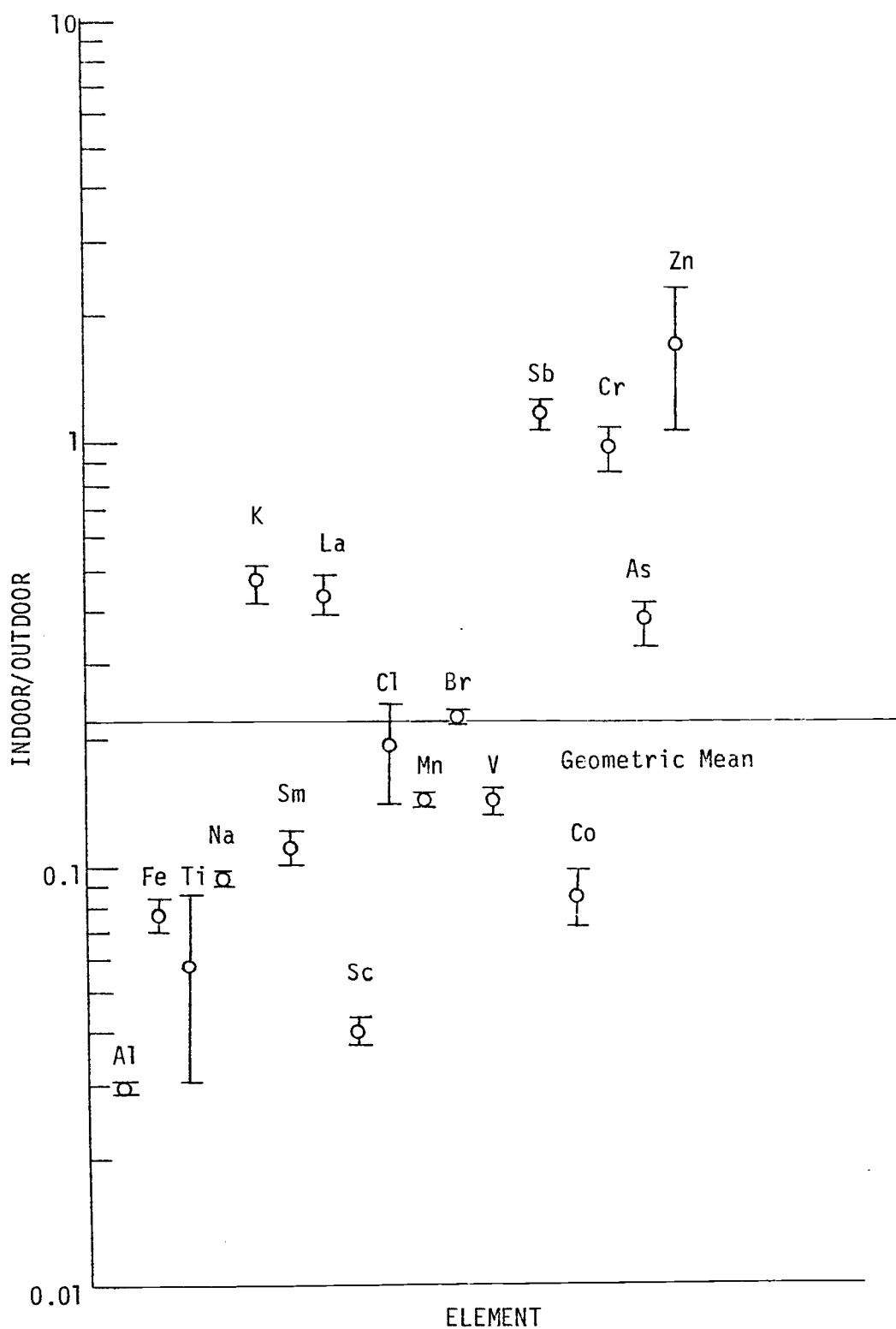


Figure 41. Ratios of Indoor and Outdoor Elemental Concentrations Found in Office IV (August 17, 1977).

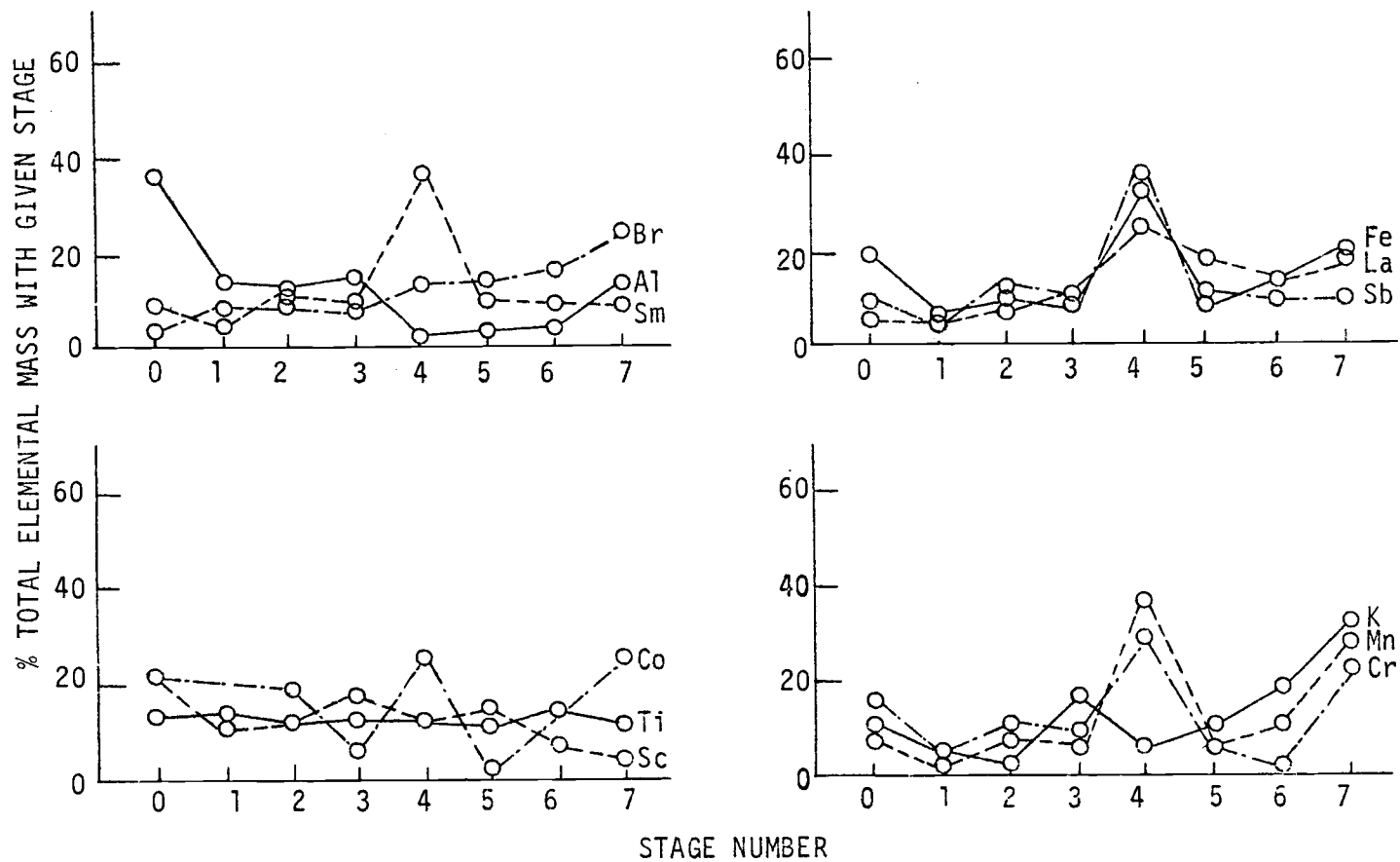


Figure 42. Percentage of the Total Elemental Particulate Mass with Given Stage Found in Office IV (August 17, 1977).

CONCLUSION

It is obvious that the indoor trace element levels are completely under the influence of outdoor changes. Indoor trace element concentrations appear to be generally lower than the outdoor concentrations, especially at high outdoor levels.

The rural results show average indoor/outdoor ratios of ~ 0.75 . The urban results show the indoor concentrations to be ~ 0.18 of the outdoor concentrations. The average indoor/outdoor ratios for several types of buildings are summarized in Table 26.

Table 26. Average Indoor/Outdoor Ratios for Several Types of Buildings

Building	Average Indoor/Outdoor Ratio
Laboratory	0.59
Home	0.56
Hospital	0.60
Garage	1.26
Office (Rural)	0.81
Office (urban)	0.18

The mechanisms for particle removal from the air are sedimentation, impaction, cloud processes, diffusion and coagulation. Larger particles have low mobility, high Stokes's number (33) and high settling velocity (34). For the smallest particles (radius $< 0.1 \mu\text{m}$), diffusion and coagulation are more dominant (33).

The degree of penetration of aerosols through buildings is mainly dependent on the filtration system of the building and the radii of the

particles.

Some experiments on the efficiency of commercial filters made of cloth, felt, paper or glass fiber, were conducted by Whitby (35), who shows plot of efficiency against particle size at a constant face velocity for each filter. These filters were of the type used in air conditioned buildings. Whitby showed that the filtration efficiencies increase as the filter fiber radius decreases, with a rise in resistance for a given volume fraction when the fibers become very fine. Whitby stated that three mechanisms, inertial impaction, interception and diffusion, normally contribute to the collection efficiency of filters. The percentage of the penetration of "one in. throwaway" filters at different radius was calculated from the efficiency curve reported by Whitby (see Table 27). By using this data, one can predict the elemental size distribution in indoor particulate matter from the known elemental size distribution found in outdoor particulate matter. The predicted and experimental size distributions for particulate containing a typical crustal element, Al are shown in Tables 28 and 29. The ratios of "% particles $>7\text{ }\mu\text{m}$ " to "% particles $<2.1\text{ }\mu\text{m}$ " found in indoor air generally are lower than the ratio found in rural outdoor air and higher than the predicted ratio. It is obvious that smaller particles penetrate the buildings more readily than the larger particles. We do not have detail informations about the filtration system of the buildings where we sampled. No further conclusion can be drawn.

There is no doubt that "activity" inside the buildings raises up the indoor trace element levels such as acid in chemistry laboratory, auto exhaust in the auto repair shop.

Although there are some unresolvable problems such as the source of potassium in office I, the source of chromium in the typical modern homes, etc., this work presents one step into the "indoor/outdoor atmospheric trace element abundances" field.

Table 27. The Percentage of the Penetration of "One in. Throwaway" Filter

Particle Diameter (μm)	% Efficiency (n)	% Penetration(P)*
11	0.75	0.10
7	0.85	0.07
4.7	0.82	0.08
3.3	0.65	0.13
2.1	0.29	0.41
1.1	0.08	0.78
0.7	0.07	0.80
0.4	0.10	0.73

* $p = e^{-ns}$ $S(\text{Solidarity}) = (4w)/(D D_f)$
 where w : weight per unit mat area, g/cm^2
 D : true density of fibers, g/cm^3
 D_f : fiber diameter, cm
 $S = 3.10$ (This value was calculated by Whitby for the "one in. Throwaway" filter used in his experiment)

Table 28. The Predicted Aluminum Size Distribution in Indoor

Particle Diameter (μm)	Size Distribution Found in Outdoor (% Total Element Mass)	% Total Element Mass (The Predicted Value Found in Indoor)
11	43.5	21
7	14.5	5
4.7	12.6	5
3.3	9.5	6
2.1	6.9	13
1.1	4.9	18
0.7	4.9	18
0.4	3.3	14

Table 29. Aluminum Size Distribution for Different Locations

Location	% Particles			% Particles > 7 μm
	< 1.1 μm	< 2.1 μm	> 7 μm	% Particles < 2.1 μm
Rural Air	8.2	13.1	58.0	4.43
Predicted Rural Air	32.0	50.0	26.0	0.52
Laboratory I	2.3	7.9	6.2	0.78
Laboratory II	24.3	29.1	47.0	1.62
Laboratory III	7.4	13.1	32.0	2.44
Laboratory IV	20.6	25.4	19.9	0.78
Home I-Living Room	20.1	31.1	23.3	0.75
Home I-Bedroom	8.3	20.9	25.4	1.22
Home II	25.2	32.9	38.4	1.17
Office I	4.6	12.2	44.4	3.64
Office II	29.8	38.0	31.7	0.83
Isolation Station of Hospital	23.0	35.8	27.7	0.77
General Station of Hospital	22.1	31.8	22.9	0.72
Garage I	9.4	15.3	45.9	3.00
Garage II	3.9	7.0	47.5	6.80

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APPENDIX I

THE ABSOLUTE INDOOR AND OUTDOOR TRACE ELEMENT CONCENTRATIONS

Table 1. Trace Element Concentrations in Laboratory I (May 4,76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	558.03±25.84	20116.75±276.24	0.028±0.001
Fe	2349.75±195.00	5846.98±462.19	0.40 ±0.05
Ti	<266.27	1191.00±254.94	---
Na	1059.11±55.23	3534.05±82.02	0.30 ±0.01
K	330.59±33.63	1303.56±112.06	0.26 ±0.03
Sm	0.05±0.01	0.60±0.02	0.09 ±0.01
Eu	<0.08	0.14±0.03	---
Sc	<0.06	1.54±0.08	---
Cl	1904.57±241.93	2772.76±387.52	0.69 ±0.13
Mn	9.34±1.46	103.78±2.09	0.09 ±0.02
Br	65.40±1.52	125.05±3.19	0.53 ±0.02
V	1.91±0.37	20.11±2.28	0.09 ±0.02
Sb	1.25±0.38	1.41±0.24	0.88 ±0.30
Co	1.15±0.24	3.44±0.80	0.33 ±0.07
Cr	129.60±4.44	506.31±6.14	0.26 ±0.01
As	10.24±4.69	<14.31	0.45 ±0.21
Zn	740.96±11.87	1567.68±355.57	0.47 ±0.01
Gross Concentration	7161.95	37095.11	0.19
Geometric Mean Ratio of Indoor and Outdoor Concentrations = 0.25			

*The upper limit is taken as 3σ where σ is the square root of the sum of the number of counts in the channels as the standard. The definition applies to all the upper limit values in this work.

Table 2. Trace Element Concentrations in Laboratory II (May 5, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	240.84±56.87	6012.62±106.86	0.04±0.01
Fe	1793.07±186.24	1992.82±288.11	0.90±0.14
Ti	387.25±162.69	580.05±202.93	0.66±0.37
Na	664.73±50.10	3088.64±83.66	0.21±0.02
K	260.72±87.16	322.55±103.82	0.80±0.37
Sm	0.07±0.01	0.068±0.02	1.03±0.39
Eu	<0.09	<0.09	---
Sc	<0.07	<0.08	---
Cl	13979.85±626.30	10708.93±568.17	1.31±0.09
Mn	2.58±0.88	21.48±1.52	0.12±0.04
Br	32.35±2.20	127.19±4.12	0.26±0.02
V	1.43±0.49	3.77±0.95	0.38±0.16
Sb	1.59±0.62	<1.25	2.39±0.93
Co	1.10±0.27	0.96±0.33	1.15±0.49
Cr	189.49±5.15	260.07±2.18	0.73±0.02
As	6.64±1.76	13.26±2.63	0.50±0.16
Zn	677.79±27.15	660.15±1.98	1.03±0.04
Gross Concentration	18239.02	23792.56	0.77
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentration =			0.53

Table 3. Trace Element Concentrations in Laboratory III (May 13, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	671.65±41.93	5668.97±93.67	0.12±0.01
Fe	1479.79±208.28	4741.74±300.33	0.31±0.05
Ti	966.45±27.43	1232.41±189.78	0.79±0.12
Na	1921.35±76.03	6115.36±113.04	0.31±0.01
K	2028.96±133.56	931.25±113.34	2.18±0.38
Sm	0.07±0.04	0.10±0.03	0.75±0.40
Eu	<0.11	<0.10	---
Sc	<0.10	0.58±0.08	---
Cl	70757.98±2200.75	9578.76±541.58	7.38±0.47
Mn	15.39±1.44	64.44±1.72	0.24±0.02
Br	774.41±41.93	184.95±4.29	4.19±0.12
V	4.18±1.79	11.94±1.24	0.35±0.15
Sb	62.57±3.69	47.88±2.94	1.30±0.11
Co	4.79±0.60	2.30±0.46	2.09±0.49
Cr	186.90±6.77	208.61±7.90	0.90±0.47
As	16.38±7.32	41.59±13.48	0.39±0.22
Zn	859.45±37.65	646.83±43.40	1.33±0.10
Gross Concentration	79750.30	29477.71	2.71
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations =			0.82

Table 4. Trace Element Concentrations in Laboratory IV (May 18, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	383.65±20.23	7565.23±109.81	0.05±0.003
Fe	1952.03±327.04	4030.30±229.0	0.49±0.08
Ti	<280.42	840.29±160.34	---
Na	1093.74±54.40	3314.24±77.10	0.33±0.02
K	165.98±52.20	957.36±76.19	0.17±0.06
Sm	15.20±0.10	0.14±0.02	111.47±17.74
Eu	<0.125	<0.07	---
Sc	<0.11	0.89±0.06	---
Cl	1754.34±215.52	4613.88±420.49	0.38±0.06
Mn	10.74±1.46	47.19±1.59	0.23±0.03
Br	434.25±9.95	475.16±7.59	0.92±0.02
V	1.26±0.35	10.18±0.96	0.13±0.04
Sb	140.52±7.94	12.22±1.22	11.50±1.31
Co	2.28±0.70	2.19±0.39	1.04±0.37
Cr	221.71±8.13	456.22±7.63	0.49±0.02
As	12.90±5.69	13.53±6.82	0.95±0.64
Zn	969.50±47.90	638.38±30.48	1.51±0.10
Gross Concentration	7158.10	22977.40	0.31
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations =			0.74

Table 5. Trace Element Concentrations in Laboratory IV (July 23, 77)

Element	Absolute Concentrations in Indoor (ng/m ³)	Absolute Concentrations in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	78.84±3.0	2887.8±24.29	0.027±0.001
Fe	185.15±82.15	1817.62±75.74	0.10 ±0.04
Ti	13.67±10.47	208.45±31.45	0.06 ±0.05
Na	100.73±1.23	130.15±16.10	0.77 ±0.10
K	124.43±22.63	643.06±53.28	0.19 ±0.04
Sm	0.009±0.002	0.160±0.004	0.05 ±0.01
Eu	<0.027	<0.048	---
La	0.052±0.019	0.088±0.055	0.60 ±0.15
Sc	0.014±0.006	0.49±0.01	0.03 ±0.01
Cl	66.47±12.56	283.91±32.26	0.23 ±0.05
Mn	2.63±0.13	34.03±0.41	0.077±0.004
Br	27.48±0.27	81.23±0.70	0.34 ±0.01
V	0.71±0.10	4.74±0.33	0.15 ±0.02
Sb	0.86±0.019	1.18±0.046	0.72 ±0.03
Co	0.38±0.11	1.52±0.10	0.25 ±0.08
Cr	47.60±1.78	36.67±1.51	1.30 ±0.07
As	<0.26	1.17±0.29	---
Zn	60.37±16.31	101.78±9.06	0.59 ±0.17
Gross Concentration	709.40	6229.04	0.11
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations =			0.19

Table 6. Trace Element Concentrations in Home I - Living Room
(June 20, 1976)

Element	Absolute Concentration in Indoor (ng/m^3)	Absolute Concentration in Outdoor (ng/m^3)	Indoor Outdoor
Al	133.96 $\pm$ 7.40	126.32 $\pm$ 7.23	1.06 $\pm$ 0.09
Fe	<200.21	<237.57	---
Ti	47.23 $\pm$ 36.35	<62.52	0.22 $\pm$ 0.17
Na	314.46 $\pm$ 15.16	900.90 $\pm$ 32.61	0.32 $\pm$ 0.02
K	138.82 $\pm$ 2.61	<59.71	0.88 $\pm$ 0.01
Sm	0.014 $\pm$ 0.001	<0.010	0.86 $\pm$ 0.09
Eu	0.003 $\pm$ 0.001	<0.004	0.26 $\pm$ 0.07
La	0.37 $\pm$ 0.04	<0.35	1.71 $\pm$ 0.20
Sc	0.030 $\pm$ 0.002	<0.023	0.68 $\pm$ 0.06
Cl	92.98 $\pm$ 24.81	360.63 $\pm$ 59.55	0.26 $\pm$ 0.08
Mn	2.77 $\pm$ 0.32	2.23 $\pm$ 0.36	1.24 $\pm$ 0.24
Br	13.56 $\pm$ 0.18	56.36 $\pm$ 0.62	0.24 $\pm$ 0.01
V	0.59 $\pm$ 0.16	2.22 $\pm$ 0.21	0.27 $\pm$ 0.08
Sb	0.18 $\pm$ 0.02	0.27 $\pm$ 0.11	0.65 $\pm$ 0.27
Co	0.53 $\pm$ 0.19	0.35 $\pm$ 0.21	1.54 $\pm$ 1.09
Cr	47.79 $\pm$ 1.56	---	3.57 $\pm$ 0.12
As	<1.28	<3.25	---
Zn	244.43 $\pm$ 11.53	254.59 $\pm$ 14.23	0.96 $\pm$ 0.07
Gross Concentration	1037.82	1703.87	0.61
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentration =			0.66

Table 7. Trace Element Concentrations in Home I - Bedroom (June 23, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	15.71±2.44	93.84±7.49	0.17±0.03
Fe	<181.38	<245.91	---
Ti	< 39.48	< 57.37	---
Na	152.14±11.04	584.15±24.08	0.26±0.02
K	52.51±13.76	70.80±35.20	0.74±0.43
Sm	< 0.07	0.009±0.004	---
Eu	< 0.018	0.014±0.009	---
La	< 0.15	< 0.24	---
Sc	< 0.02	0.014±0.009	---
Cl	28.90±16.94	177.46±46.59	0.16±0.10
Mn	1.58±0.25	3.43±0.36	0.46±0.08
Br	18.48±0.29	67.09±7.03	0.28±0.01
V	0.42±0.09	0.86±0.14	0.49±0.12
Sb	0.13±0.05	0.19±0.08	0.68±0.39
Co	0.35±0.17	0.72±0.23	0.49±0.28
Cr	74.16±1.86	29.93±4.95	2.48±0.41
As	< 1.23	< 2.68	---
Zn	238.39±10.69	238.07±113.86	1.00±0.07
Gross Concentration	582.77	1849.35	0.32
Geometric Mean Ratio of Indoor and Outdoor Elemental Concentration =			0.47

Table 8. Trace Element Concentrations in Home II - Bedroom
(June 29, 1976)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	40.73±3.27	351.11±11.19	0.12±0.01
Fe	240.35±100.34	219.40±163.71	1.10±0.93
Ti	<43.04	82.36±48.24	---
Na	287.14±14.91	820.04±32.61	0.35±0.02
K	<16.45	<72.16	---
Sm	<0.006	<0.013	---
Eu	<0.003	0.006±0.003	---
La	<0.13	<0.31	---
Sc	<0.02	<0.03	---
Cl	123.42±26.31	230.40±58.75	0.54±0.17
Mn	1.57±0.28	3.45±0.47	0.46±0.10
Br	15.97±0.27	59.11±0.74	0.27±0.01
V	0.32±0.09	0.59±0.24	0.53±0.26
Sb	0.14±0.04	0.32±0.01	0.44±0.12
Co	0.54±0.18	---	0.95±0.32
Cr	41.87±1.60	---	3.13±0.12
As	<1.56	<3.31	---
Zn	256.26±11.71	294.96±18.04	0.87±0.06
Gross Concentration	1008.31	2061.75	0.49
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentration =			
			0.56

Table 9. Trace Element Concentrations in Office I (July 2, 76)

Element	Absolute Concentration ₃ in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	300.04±9.38	493.62±14.19	0.61±0.03
Fe	820.85±203.33	<529.51	3.31±0.82
Ti	53.22±33.53	< 89.69	0.64±0.40
Na	607.13±26.41	944.24±37.70	0.64±0.04
K	967.16±32.08	82.68±32.17	11.69±4.57
Sm	0.057±0.006	0.02±0.01	2.94±1.22
Eu	0.015±0.0014	0.006±0.002	0.24±0.23
La	1.19±0.18	< 0.56	3.94±0.60
Sc	0.14±0.038	0.064±0.021	2.19±0.94
Cl	262.81±44.64	118.53±64.48	2.22±1.27
Mn	13.79±0.72	9.18±0.71	1.50±0.14
Br	38.37±0.70	61.52±1.02	0.62±0.015
V	0.74±0.20	2.24±0.29	0.33±0.10
Sb	0.76±0.12	0.81±0.20	0.94±0.28
Co	1.05±0.36	0.60±0.47	1.47±1.48
Cr	82.24±3.09	23.73±3.83	3.47±0.58
As	<5.53	< 6.95	---
Zn	473.80±21.67	528.76±25.97	0.89±0.06
Gross Concentration	3623.36	22.62	1.60
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentration =			1.37

Table 10. Trace Element Concentrations in Office II (July 8, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	18.30±3.45	347.31±13.68	0.05±0.010
Fe	<416.46	<642.72	---
Ti	< 61.87	<107.21	---
Na	247.38±16.22	1218.41±47.88	0.20±0.01
K	80.20±15.17	269.96±39.81	0.30±0.07
Sm	<0.009	<0.021	---
Eu	0.0025±0.0001	<0.0055	0.33±0.11
La	< 0.16	< 0.69	---
Sc	< 0.035	< 0.055	---
Cl	141.11±34.06	983.49±118.84	0.14±0.04
Mn	0.86±0.51	1.89±0.81	0.46±0.33
Br	9.05±0.33	37.19±1.07	0.25±0.01
V	0.18±0.09	< 0.59	0.11±0.06
Sb	0.11±0.06	0.82±0.27	0.13±0.09
Co	0.79±0.35	1.02±0.53	0.73±0.53
Cr	44.08±2.91	82.29±5.99	0.54±0.05
As	< 2.96	< 8.21	---
Zn	454.79±207.20	625.79±31.13	0.73±0.05
Gross Concentration	996.85	3568.17	0.28
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations =			0.25

Table 11. Trace Element Concentrations in the Isolation Station of Hospital (July 13, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	25.38±3.17	48.70±4.32	0.52±0.08
Fe	175.88±120.67	<211.65	0.76±0.52
Ti	< 39.15	< 35.79	---
Na	106.75±9.48	431.06±16.14	0.25±0.024
K	90.90±11.62	66.09±21.79	1.38±0.48
Sm	0.0020±0.0016	0.0024±0.0012	0.85±0.79
Eu	<0.00104	<0.0022	---
La	0.23±0.05	0.10±0.04	2.29±1.08
Sc	<0.00017	<0.00018	---
Cl	46.92±20.36	---	0.21±0.09
Mn	---	2.24±0.24	---
Br	1.35±0.12	13.53±0.40	0.10±0.01
V	0.20±0.05	0.40±0.084	0.49±0.16
Sb	0.12±0.033	0.36±0.030	0.32±0.09
Co	0.55±0.18	0.34±0.17	1.60±0.96
Cr	41.10±1.86	35.00±3.01	1.17±0.11
As	< 1.32	< 2.45	---
Zn	286.6 ± 12.86	267.95±11.55	1.07±0.07
Gross Concentration	775.98	865.77	0.90
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			0.61

Table 12. Trace Element Concentrations in the General Station of Hospital (July 17, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	19.45±3.15	30.69±4.04	0.63±0.13
Fe	<2785.22	< 263.21	---
Ti	< 44.31	< 44.44	---
Na	145.73±11.26	877.11±26.57	0.16±0.01
K	347.42±13.08	167.51±25.98	2.07±0.33
Sm	< 0.006	0.002±0.001	---
Eu	< 0.00088	< 0.0039	---
La	< 0.17	< 0.17	---
Sc	< 0.00017	<0.00019	---
Cl	172.90±30.88	401.37±53.0	0.43±0.10
Mn	---	0.70±0.34	---
Br	2.34±0.15	11.78±0.25	0.20±0.01
V	< 0.16	0.19±0.10	---
Sb	0.14±0.047	0.71±0.02	0.20±0.07
Co	0.51±0.20	0.33±0.20	1.57±0.63
Cr	59.69±2.28	54.49±2.05	1.10±0.06
As	< 0.97	< 3.81	---
Zn	314.68±14.27	267.14±13.48	1.18±0.08
Gross Concentration	1062.86	1812.02	0.59
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			0.58

Table 13. Trace Element Concentrations in Garage I (July 29, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	193.84±12.19	183.48±12.65	1.05±0.09
Fe	318.36±272.97	< 586.82	1.29±1.11
Ti	<78.78	< 88.11	---
Na	436.17±21.51	782.71±31.28	0.55±0.035
K	115.34±21.64	115.79±26.16	0.99±0.29
Sm	0.016±0.010	< 0.023	1.54±1.01
Eu	0.0032±0.0014	0.0068±0.0018	0.48±0.24
La	< 0.42	< 0.55	---
Sc	0.026±0.019	< 0.05	0.80±0.59
Cl	199.03±41.75	104.05±51.43	1.91±1.02
Mn	8.41±0.62	6.08±0.77	1.38±0.20
Br	347.09±3.22	27.50±0.27	12.62±0.17
V	0.69±0.18	1.16±0.20	0.60±0.18
Sb	0.69±0.24	< 5.97	1.72±0.60
Co	0.77±0.41	1.85±0.46	0.42±0.24
Cr	41.71±3.62	---	3.01±0.26
As	< 5.54	< 6.32	---
Zn	511.80±32.80	515.62±35.91	0.99±0.09
Gross Concentration	2173.95	1738.25	1.25
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			1.22

Table 14. Trace Element Concentrations in Garage II (Oct. 4, 76)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	Indoor Outdoor
Al	329.80±18.98	215.96±14.40	1.53±0.14
Fe	679.85±247.85	326.52±249.61	2.08±1.76
Ti	159.48±77.95	87.76±57.04	1.82±1.47
Na	478.45±21.81	1856.32±50.78	0.26±0.014
K	273.9±26.65	627.64±33.85	0.44±0.05
Sm	<0.034	0.023±0.010	---
Eu	0.0086±0.0025	0.0034±0.0017	2.54±1.49
La	< 0.48	<0.65	---
Sc	0.054±0.013	0.050±0.0002	1.07±0.26
Cl	768.38±75.74	1071.54±112.49	0.72±0.10
Mn	21.01±1.0	7.30±0.86	2.88±0.86
Br	1234.74±10.58	226.22±2.34	5.46±0.07
V	2.42±0.24	3.96±0.31	0.61±0.08
Sb	2.12±0.38	1.60±0.16	1.33±0.27
Co	1.30±0.38	0.76±0.28	1.71±0.79
Cr	9.45±3.11	5.82±2.93	1.62±0.98
As	< 7.47	<6.70	---
Zn	498.93±30.28	493.20±23.33	1.02±0.08
Gross Concentration	4459.89	4924.68	0.91
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			1.29

Table 15. Trace Element Concentrations in Office III (Aug. 17, 77)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	575.42+19.29	29740.46+867.73	0.019+0.001
Fe	582.42+103.5	5322+252.1	0.11+0.02
Ti	86.93+23.08	442.68+180.94	0.20+0.10
Na	194.29+12.80	3724.16+72.53	0.052+0.004
K	301.50+19.15	1553.89+158.66	0.19+0.02
Sm	0.051+0.022	0.39+0.02	0.13+0.06
Eu	0.051+0.020	0.10+0.032	0.50+0.25
La	0.32+0.02	3.05+0.36	0.10+0.015
Sc	0.12+0.11	0.97+0.30	0.13+0.013
Cl	68.29+28.12	1005.27+114.60	0.068+0.029
Mn	13.95+0.60	153.38+2.53	0.091+0.004
Br	14.11+0.14	239.28+1.66	0.059+0.001
V	1.63+0.22	14.54+2.07	0.11+0.02
Sb	0.56+0.02	3.00+0.23	0.19+0.01
Co	0.71+0.14	3.17+0.30	0.22+0.05
Cr	108.79+5.13	217.83+21.78	0.50+0.05
As	0.56+0.05	2.84+0.57	0.20+0.04
Zn	159.18+10.86	---	---
Gross Concentration	2107.88	42427	0.05
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			0.13

Table 16. Trace Element Concentrations in Office IV (Aug. 17, 77)

Element	Absolute Concentration in Indoor (ng/m ³)	Absolute Concentration in Outdoor (ng/m ³)	<u>Indoor</u> <u>Outdoor</u>
Al	314.61 $\pm$ 10.29	11027.40 $\pm$ 321.82	0.029 $\pm$ 0.001
Fe	483.04 $\pm$ 43.98	6337.59 $\pm$ 185.40	0.076 $\pm$ 0.007
Ti	34.54 $\pm$ 15.52	601.15 $\pm$ 105.02	0.057 $\pm$ 0.027
Na	365.50 $\pm$ 11.19	3981.96 $\pm$ 64.65	0.092 $\pm$ 0.003
K	814.48 $\pm$ 23.33	1746.53 $\pm$ 134.61	0.47 $\pm$ 0.03
Sm	0.047 $\pm$ 0.004	0.42 $\pm$ 0.015	0.11 $\pm$ 0.01
Eu	<0.014	0.10 $\pm$ 0.02	
La	1.36 $\pm$ 0.06	3.20 $\pm$ 0.30	0.43 $\pm$ 0.04
Sc	0.055 $\pm$ 0.004	1.31 $\pm$ 0.023	0.04 $\pm$ 0.01
Cl	102.20 $\pm$ 16.61	540.69 $\pm$ 110.59	0.19 $\pm$ 0.05
Mn	28.59 $\pm$ 0.54	202.79 $\pm$ 2.51	0.14 $\pm$ 0.01
Br	49.91 $\pm$ 0.34	227.89 $\pm$ 1.48	0.22 $\pm$ 0.01
V	2.77 $\pm$ 0.14	19.21 $\pm$ 1.03	0.14 $\pm$ 0.01
Sb	3.26 $\pm$ 0.055	2.82 $\pm$ 0.21	1.16 $\pm$ 0.08
Co	0.46 $\pm$ 0.066	5.50 $\pm$ 0.29	0.084 $\pm$ 0.013
Cr	19.65 $\pm$ 1.70	20.51 $\pm$ 1.71	0.96 $\pm$ 0.12
As	1.53 $\pm$ 0.10	4.04 $\pm$ 0.47	0.38 $\pm$ 0.05
Zn	93.37 $\pm$ 5.48	55.80 $\pm$ 20.11	1.67 $\pm$ 0.61
Gross Concentration	2315.37	24778.91	0.09
Geometric Mean Ratio of Indoor & Outdoor Elemental Concentrations=			0.22

APPENDIX II

ELEMENTAL ABUNDANCES IN AERODYNAMICALLY SIZED ATMOSPHERIC PARTICULATE

Table 1. Elemental Particle Size Distribution in Rural Air

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	43.5	14.5	12.6	9.5	6.9	4.9	4.9	3.3
Fe	45.8	14.4	18.9	4.1	3.1	3.6	9.7	---
Ti	17.0	14.0	14.3	15.4	13.1	8.8	8.6	8.6
Na	19.9	8.1	15.2	14.3	11.3	12.3	11.1	7.4
Sm	28.8	17.9	16.4	12.8	8.4	4.7	3.4	7.3
La	33.0	21.3	17.0	7.9	9.0	11.6	---	---
Sc	47.2	14.3	13.7	9.9	6.6	3.2	3.0	1.8
Cl	15.1	12.7	14.5	14.4	14.7	16.2	4.0	7.9
Mn	56.2	20.2	12.6	7.5	2.5	0.7	---	---
Br	11.2	13.2	12.6	21.7	18.4	12.5	5.7	4.3
V	31.7	14.6	10.7	10.7	9.2	9.9	6.9	6.1
Sb	29.9	9.6	9.4	11.1	5.9	13.6	10.2	9.9
Co	13.8	12.5	11.3	12.1	10.9	13.6	15.0	11.1
Cr	28.8	20.0	8.9	4.8	13.2	4.8	17.9	1.6
Zn	18.0	7.6	3.9	10.6	15.7	8.1	16.6	19.2

'---' signifies the concentration is lower than the detection limit.

Table 2. Elemental Particle Size Distribution in Laboratory I
(May 4, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	5.5	0.7	10.6	69.9	5.4	5.6	2.3	---
Fe	4.6	2.9	24.2	4.1	13.4	25.8	9.5	15.5
Na	17.9	9.8	18.0	11.2	13.5	12.0	8.5	9.0
Cl	6.8	1.2	6.1	2.1	3.6	26.0	2.7	51.4
Co	13.2	15.6	11.1	9.2	12.9	13.1	5.9	19.2
Zn	11.4	17.0	18.7	9.8	12.1	9.9	8.9	7.3

Table 3. Elemental Particle Size Distribution in Laboratory II
(May 5, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	21.0	26.0	13.4	1.0	9.6	4.8	14.5	9.8
Fe	49.6	3.3	7.9	0.4	11.4	6.1	12.8	11.9
Na	17.1	15.5	15.8	9.2	9.8	8.0	11.1	13.4
Sm	19.6	13.2	6.4	6.4	22.6	4.1	19.9	7.8
Cl	25.5	11.2	10.5	0.7	11.2	34.2	5.3	1.4
Co	11.3	9.9	10.4	6.1	11.9	12.1	8.0	30.3
Zn	13.6	14.0	9.7	10.1	10.8	13.1	14.1	14.5

Table 4. Elemental Particle Size Distribution in Laboratory III
(May 13, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	19.1	12.9	17.7	25.0	12.2	5.7	3.9	3.5
Na	14.3	14.6	12.4	15.7	12.5	12.2	8.5	9.8
Cl	15.1	6.0	2.9	6.9	19.0	9.9	18.8	21.2
Br	2.2	15.4	---	15.2	---	---	35.7	31.5
Co	10.4	16.3	11.7	17.0	13.1	17.0	7.4	7.4
Cr	42.3	9.0	6.2	11.8	30.9	---	---	---
Zn	11.2	12.5	11.1	14.1	14.6	14.8	15.1	6.7

Table 5. Elemental Particle Size Distribution in Laboratory IV
(May 18, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	16.6	3.3	41.8	5.2	7.7	4.8	2.7	17.9
Fe	37.2	12.2	8.1	---	4.4	7.0	13.0	18.2
Na	45.6	9.8	7.5	7.8	8.4	6.6	5.6	8.7
Sm	---	42.5	57.5	---	---	---	---	---
Cl	2.1	7.4	5.9	29.5	9.2	29.8	16.0	---
Sb	22.7	---	---	---	17.9	---	59.4	---
Co	8.5	35.2	18.2	4.8	13.3	8.2	4.8	7.0
Zn	10.2	10.0	18.0	14.3	15.9	12.3	10.4	8.9

Table 6. Elemental Particle Size Distribution in Home I - Living Room
(June 22, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	14.7	8.6	28.9	12.3	4.4	11.0	5.3	14.8
Na	13.7	10.8	16.2	15.1	14.0	13.4	7.8	8.9
K	15.0	11.8	16.2	14.8	12.4	9.3	10.3	10.2
Sm	9.3	13.1	14.8	7.7	16.9	18.0	10.4	9.8
Sc	11.8	11.8	31.3	15.7	9.4	14.1	6.0	---
Cl	10.6	10.9	41.0	10.9	6.8	8.6	3.5	7.7
Mn	32.6	33.7	33.7	---	---	---	---	---
Br	10.1	---	29.4	5.2	15.2	21.6	16.5	2.0
Co	17.3	7.6	9.1	8.6	10.3	34.6	3.2	9.3
Cr	13.2	11.2	5.2	3.6	4.0	62.2	0.5	---
Zn	11.9	9.7	15.1	11.9	13.8	10.9	11.7	14.9

Table 7. Elemental Particle Size Distribution in Home I - Bedroom
(June 24, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	16.9	8.5	45.2	6.2	2.3	12.6	3.2	5.1
Na	44.2	4.4	6.4	8.0	6.0	9.3	6.1	15.5
Sm	10.2	8.1	17.2	9.1	16.7	10.2	12.9	15.6
Cl	6.6	3.9	55.2	5.2	8.4	5.8	6.5	8.4
Cr	15.6	12.6	0.5	19.9	29.3	9.3	8.8	4.1
Zn	10.6	28.8	10.2	8.2	10.7	10.2	13.2	8.0

Table 8. Average Elemental Particle Size Distribution in Home I

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	16.9	8.2	34.7	9.5	3.4	13.0	4.3	9.1
Na	23.0	8.0	11.7	12.5	10.6	12.7	7.8	13.3
Sm	8.8	10.3	16.1	7.5	16.1	16.1	10.9	14.0
Cl	8.5	7.1	49.7	7.7	7.7	7.2	5.2	6.6
Zn	11.6	17.2	13.0	10.3	12.5	11.0	12.8	11.3

Table 9. Elemental Particle Size Distribution Found in the Outdoor of Home I (June 26, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Na	18.4	5.7	11.9	9.9	28.4	12.3	8.4	5.0
Sm	28.8	12.8	14.4	10.1	16.5	8.0	5.1	4.3
Sc	47.2	10.3	13.1	11.9	10.6	---	4.3	2.7
Cl	12.2	4.8	10.5	15.4	20.9	17.8	6.8	11.7
Mn	64.6	16.4	3.7	8.0	5.4	1.8	---	---
Br	14.6	8.8	14.8	20.7	18.4	12.0	7.1	3.5
V	25.0	17.9	15.7	13.5	---	11.2	8.2	8.5
Sb	15.0	7.3	12.8	9.8	9.3	25.7	5.7	14.4
Co	11.2	8.1	4.7	9.9	10.3	21.1	20.1	14.6
Cr	29.1	21.2	10.8	5.1	16.6	4.9	11.1	1.3
Zn	13.0	9.4	6.2	11.2	16.5	8.5	17.4	17.3

Table 10. Elemental Particle Size Distribution in Home II - Bedroom
(June 30, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	17.0	21.4	13.9	10.2	4.7	7.7	14.9	10.3
Na	14.6	8.6	11.2	12.2	10.5	12.3	20.2	10.4
K	21.8	18.8	27.4	19.6	8.0	4.5	---	---
Sm	47.1	7.2	11.1	7.9	6.2	8.5	5.5	6.5
Cl	9.4	12.6	13.6	13.6	11.5	16.0	9.4	12.9
Br	2.7	5.7	4.0	15.8	17.3	25.2	17.5	11.8
Sb	25.6	14.6	6.1	14.6	10.4	11.0	6.7	11.0
Co	11.2	9.0	27.0	9.9	11.4	10.8	11.6	9.2
Cr	19.6	6.7	7.8	11.2	17.9	3.7	31.2	2.0
Zn	20.3	12.9	11.4	13.8	12.6	7.5	13.3	8.1

Table 11. Particle Size Distribution in Office I (July 6, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	27.2	17.2	18.7	17.2	7.5	7.6	1.9	2.7
Fe	59.9	---	30.9	9.2	---	---	---	---
Na	15.7	9.10	17.9	23.6	10.2	10.2	6.2	7.2
K	20.0	9.9	23.2	16.1	5.8	6.0	5.0	14.0
Sm	25.6	14.7	24.1	10.9	7.6	9.0	3.6	4.5
La	14.1	41.1	14.7	12.6	---	---	7.4	10.1
Sc	31.0	20.5	21.5	16.0	3.9	4.7	---	2.6
Cl	13.4	11.4	13.4	9.3	14.2	18.7	11.7	7.9
Mn	58.1	16.1	21.1	4.6	---	---	---	---
V	34.7	33.0	17.8	14.5	---	---	---	---
Sb	14.8	16.1	12.4	30.8	8.4	10.2	3.7	3.6
Co	18.7	12.8	11.4	6.8	9.0	13.4	19.7	8.1
Cr	39.4	2.8	37.4	10.3	4.6	0.9	4.6	---
Zn	13.0	9.4	6.2	11.2	16.5	8.5	17.4	17.8

Table 12. Elemental Particle Size Distribution in Office II
(July 9, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	21.3	10.4	12.1	12.5	5.6	8.2	17.1	12.7
Na	16.4	8.5	10.5	11.9	10.1	12.5	15.2	14.9
Cl	16.0	18.8	7.6	11.6	6.5	13.8	14.4	11.4
Br	6.5	15.1	12.4	21.0	12.7	11.9	11.9	27.1
Sb	17.0	6.2	9.6	4.6	10.3	5.8	18.0	28.1
Co	22.1	5.6	12.8	7.8	14.0	24.5	5.5	7.3

Table 13. Elemental Particle Size Distribution in the Isolation
Station of Hospital (July 14, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	17.3	10.4	12.6	9.9	13.9	12.8	9.4	13.6
Na	11.8	8.7	11.2	7.9	14.4	11.1	17.4	17.6
K	16.8	10.5	13.5	5.9	12.7	7.8	18.2	14.6
Sm	12.4	10.5	9.6	16.3	24.9	7.4	9.5	9.5
Sc	13.2	15.1	28.3	11.3	7.5	10.4	14.2	---
Cl	12.7	13.5	13.9	19.5	15.6	11.4	1.6	11.7
Br	16.0	14.8	13.8	3.8	13.8	2.9	18.7	16.2
V	18.2	16.5	7.4	8.0	12.3	7.2	18.7	11.7
Sb	18.6	12.6	13.6	5.5	13.1	4.0	18.4	14.1
Co	12.3	11.6	13.5	12.6	9.5	12.1	21.5	6.9
Cr	16.8	5.2	5.5	4.4	24.2	13.2	28.6	2.0

Table 14. Elemental Particle Size Distribution in the General Station of Hospital (July 16, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	11.8	11.1	12.9	12.1	20.3	9.7	9.2	12.9
Na	7.7	7.4	9.4	9.7	50.0	6.1	4.9	4.9
K	11.8	12.2	15.4	20.7	14.6	6.2	10.3	9.0
Br	12.7	18.3	13.8	6.6	10.9	10.9	11.2	15.6
Sb	10.4	13.7	9.9	8.9	14.1	21.2	12.4	9.5
Co	8.9	14.8	10.9	19.2	6.9	9.9	7.3	16.1
Cr	26.3	7.5	24.9	18.0	8.1	5.2	5.3	4.6

Table 15. Elemental Particle Size Distribution in Garage I
(July 28, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	26.9	18.8	15.7	13.8	9.6	5.9	4.4	5.0
Fe	39.4	23.3	13.6	14.4	3.9	1.0	4.5	---
Ti	9.4	18.9	14.1	15.1	11.8	13.8	7.4	9.6
K	25.7	14.8	15.4	13.3	5.6	7.0	8.6	9.7
Sm	32.9	16.5	14.2	14.2	8.6	5.3	3.2	2.2
Sc	32.3	21.1	15.5	13.9	10.3	4.4	2.5	---
Cl	6.4	4.4	9.9	12.4	10.2	26.6	16.0	13.9
Br	4.1	11.0	11.3	15.5	16.6	15.6	19.5	6.5
V	32.3	16.6	9.5	11.0	11.3	11.1	8.2	---
Sb	12.6	11.5	14.8	13.1	11.7	14.0	10.9	11.5
Co	8.3	15.4	14.1	16.7	11.9	10.3	15.6	7.8
Cr	20.4	28.3	7.3	---	3.2	1.8	35.2	3.9
Zn	58.9	7.5	8.4	17.1	8.1	---	---	---

Table 16. Elemental Particle Size Distribution in the Outside of Garage I (July 30, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	55.1	16.8	11.9	8.9	2.7	3.7	1.0	---
Fe	83.3	9.8	6.2	0.7	---	---	---	---
Ti	35.7	22.8	15.0	11.8	14.7	---	---	---
Na	25.9	13.9	12.9	12.7	9.6	8.6	9.6	6.6
K	22.3	10.0	8.0	49.3	3.9	2.8	1.3	2.6
Sm	42.3	15.2	9.2	8.8	6.3	2.7	6.5	13.0
Sc	57.8	16.7	10.7	6.7	2.6	2.9	2.6	---
Cl	18.4	24.4	19.1	12.5	7.9	13.4	1.5	2.9
Mn	55.0	16.9	9.4	6.4	---	---	12.4	---
Br	15.9	12.4	12.8	16.4	16.4	13.4	7.3	5.4
V	48.0	14.8	10.6	8.2	8.3	6.5	3.7	---
Sb	29.6	15.0	13.5	13.5	5.4	6.0	11.4	5.7
Co	22.5	12.4	13.2	8.5	5.6	8.3	20.9	8.5
Cr	41.1	9.0	8.0	---	---	3.3	38.7	---
Zn	75.1	18.4	6.5	---	---	---	---	---

Table 17. Elemental Particle Size Distribution in Garage II
(Oct. 1, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	32.9	14.6	18.9	20.1	6.3	3.1	2.2	1.7
Fe	30.4	13.4	21.8	18.3	11.0	3.9	---	1.2
Ti	29.8	12.2	17.9	20.6	19.5	---	---	---
K	26.0	14.0	16.4	25.4	6.1	4.1	5.3	3.0
Sc	34.1	15.5	19.7	15.5	8.5	2.9	1.3	2.5
Cl	4.2	5.8	5.3	13.5	18.8	24.8	11.8	15.8
Br	7.1	5.5	12.3	18.2	18.0	16.3	10.8	11.8
V	31.9	14.7	19.3	17.6	6.4	3.2	3.3	3.5
Sb	21.7	6.6	19.2	14.5	11.3	5.3	9.4	11.9
Co	8.3	15.4	14.1	16.7	11.9	10.3	15.9	7.8

Table 18. Elemental Particle Distribution in the Outdoor of Garage II
(Oct. 6, 76)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	35.2	13.4	14.3	10.7	8.2	5.9	6.6	5.8
Fe	30.3	13.6	20.7	9.5	2.1	6.5	17.4	---
Ti	11.3	11.5	15.3	15.5	12.1	11.6	11.3	11.4
Na	32.6	4.8	---	---	19.7	42.8	---	---
K	31.7	18.5	17.3	14.1	8.7	---	---	9.7
Sm	33.8	18.6	18.3	12.1	6.8	4.2	3.1	3.1
Sc	38.5	17.7	17.7	12.5	7.4	1.8	2.9	1.6
Mn	36.1	24.7	20.9	8.0	2.7	---	7.7	---
Br	9.3	20.3	9.9	16.6	14.4	14.0	9.4	6.1
V	21.4	12.7	6.7	11.5	9.5	17.7	9.6	4.9
Sb	36.9	7.9	6.6	12.1	6.2	14.1	8.6	7.6
Co	20.7	---	52.1	---	---	5.0	13.2	9.1
Cr	---	44.0	---	2.0	5.3	10.6	38.1	---

Table 19. Elemental Particle Distribution in Office IV (Aug. 17,77)

Element	Stage Number (% Total Elemental Mass)							
	0	1	2	3	4	5	6	7
Al	35.9	14.0	12.5	14.7	0.4	4.4	4.6	13.6
Fe	18.3	5.7	9.5	7.6	31.8	8.4	---	18.7
Ti	13.0	13.9	12.2	12.2	12.1	11.3	14.6	10.9
K	10.1	4.6	2.7	17.1	5.3	10.0	18.1	32.1
Sm	8.4	4.9	11.2	10.6	36.3	9.3	9.8	9.5
La	4.7	4.5	6.2	9.3	25.3	17.9	14.0	18.1
Sc	21.2	11.3	12.0	17.6	11.3	15.3	7.1	4.4
Mn	7.6	1.3	7.0	6.1	36.3	5.5	9.7	26.5
Br	4.1	8.0	9.3	9.1	13.7	14.8	16.5	24.5
Sb	14.8	7.1	6.6	5.0	4.9	9.8	25.5	26.3
Co	20.7	---	18.6	6.9	25.7	2.8	---	25.5
Cr	15.1	4.6	10.9	8.9	29.4	7.2	1.3	22.9

APPENDIX III
DISTRIBUTION OF INDOOR/OUTDOOR RATIOS

Table 1. Cumulative Percentage of $\frac{\text{Indoor/Outdoor Ratio}}{\text{Mean Value of Indoor/Outdoor Ratios}}$

Range of the Ratio	Number of Observation	Cumulative Percentage
0 - 0.1	3	1.8
0.1 - 0.2	6	5.5
0.2 - 0.3	11	12.3
0.3 - 0.4	10	18.4
0.4 - 0.5	14	27.0
0.5 - 0.6	15	36.2
0.6 - 0.7	14	44.8
0.7 - 0.8	8	50.0
0.8 - 0.9	12	57.1
0.9 - 1.0	9	62.6
1.0 - 1.1	9	68.1
1.1 - 1.2	11	74.8
1.2 - 1.3	9	80.4
1.3 - 1.4	5	83.4
1.4 - 1.5	3	85.3
1.5 - 1.6	6	89.0
1.6 - 1.7	5	92.0
1.7 - 1.8	1	92.6
1.8 - 1.9	1	93.3
1.9 - 2.0	1	93.9
2.1 - 2.2	2	95.1
2.2 - 2.3	1	95.7
2.4 - 2.5	1	96.3
2.7 - 2.8	1	97.0
2.8 - 2.9	1	97.5
2.9 - 3.0	1	98.1
3.3 - 3.4	1	98.8
4.0 - 4.1	1	99.4
4.9 - 5.0	1	100.0

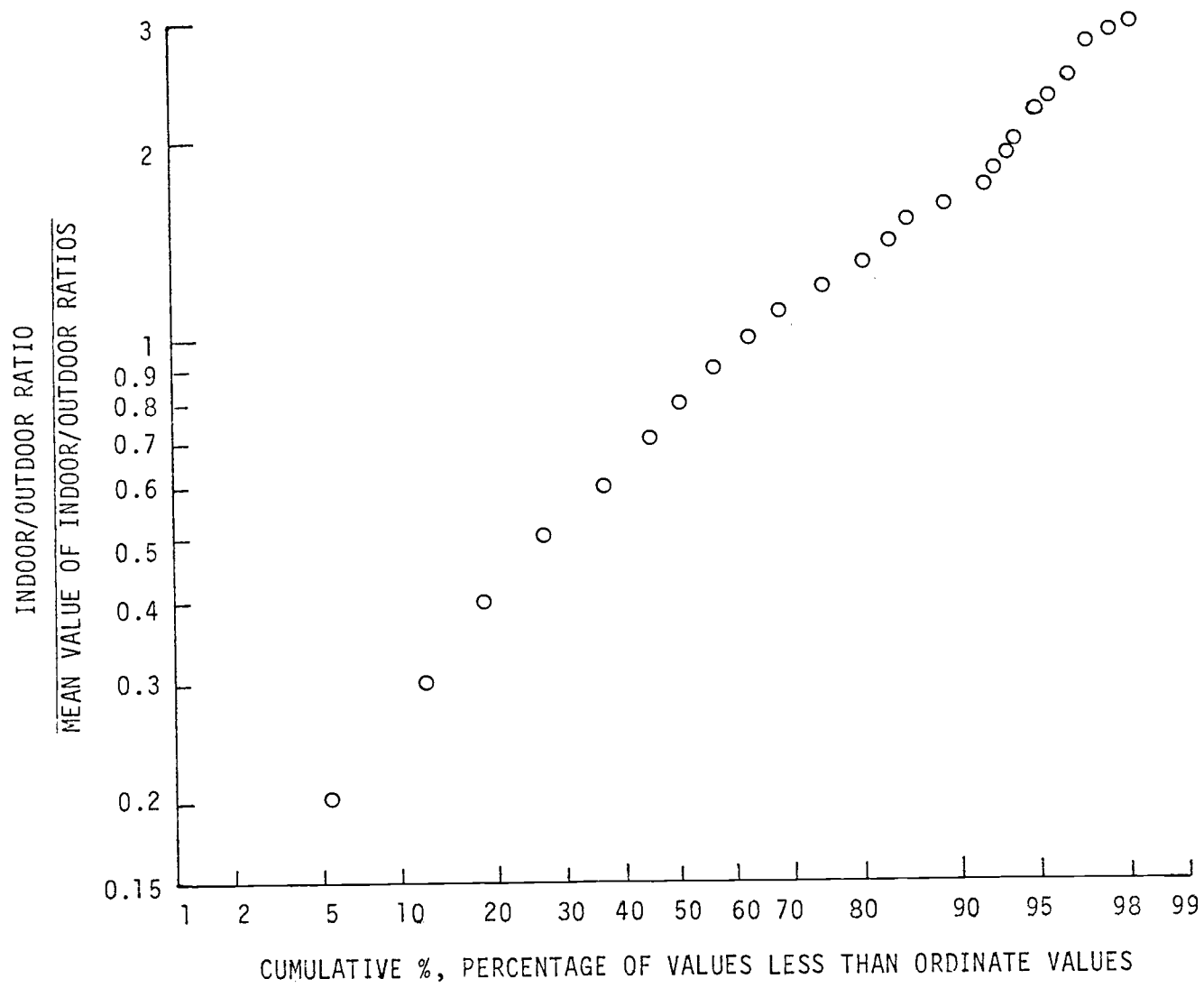


Figure 1. Cumulative Percentage Plot for the Data in Appendix III, Table 1.

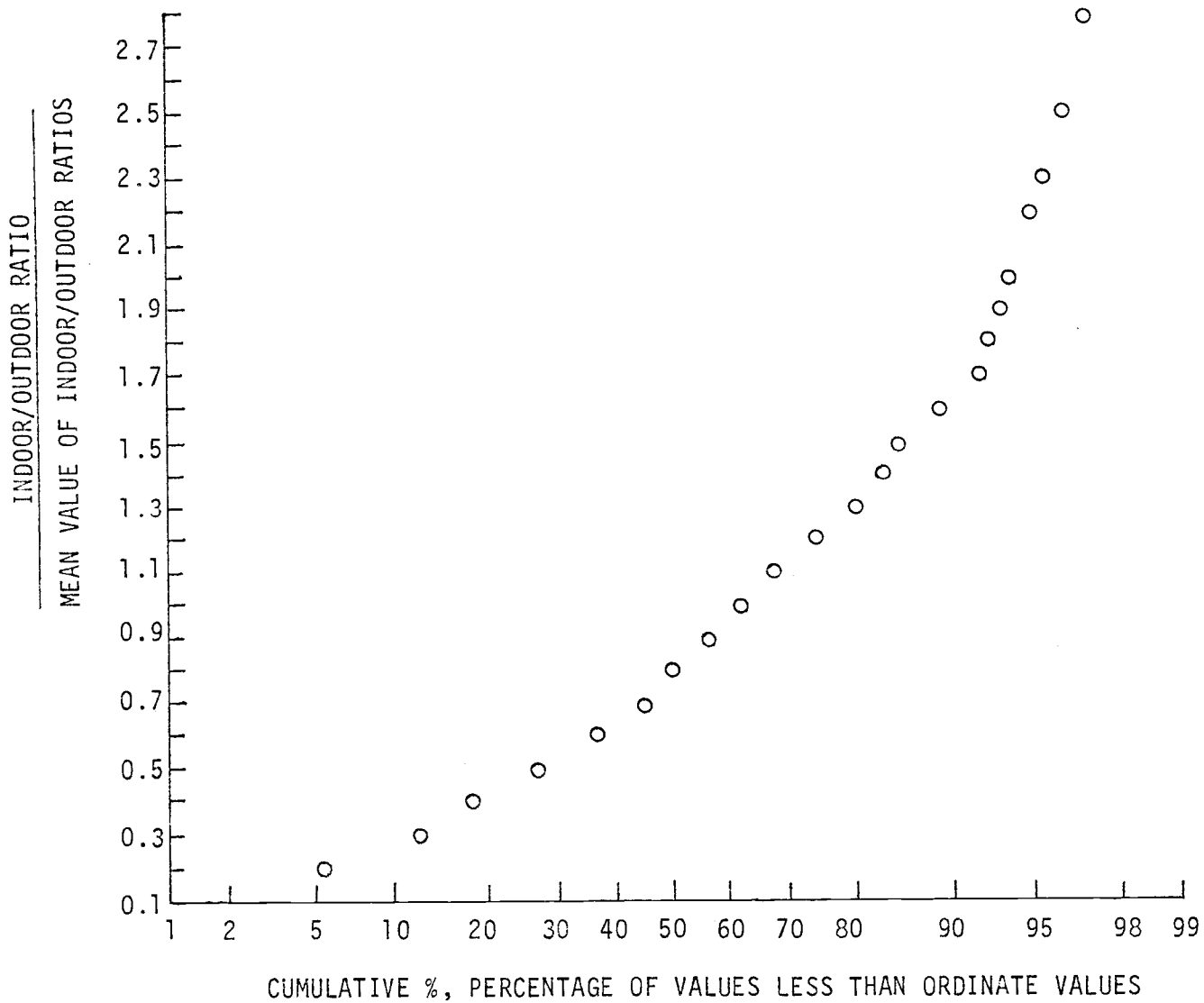


Figure 2. Cumulative Percentage Plot for the Data in Appendix III, Table 1.