Appendix E-3

Air Resources Board
Research Contract Road Study

CONTRACT NO. A032-147
FINAL REPORT
AUGUST 1992

Development of a Technique to Estimate Ambient Asbestos Downwind from Serpentine Covered Roadways

CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

AIR RESOURCES BOARD
Research Division

E-3-1

DEVELOPMENT OF A TECHNIQUE TO ESTIMATE AMBIENT ASBESTOS DOWNWIND FROM SERPENTINE COVERED ROADWAYS

Final Report
Contract No. A032-147

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DISCLAIMER

ABSTRACT

In the foothills of the Sierra Nevada Mountains, serpentine rock has been mined extensively and widely used as a material for many types of unpaved surfaces, including parking lots, driveways, roads, and apparently even some school playgrounds. When vehicles are driven over unpaved roads surfaced with asbestos-containing serpentine material, asbestos fibers are released into the atmosphere as part of the resultant dust cloud. Thus persons near the roadway, especially on the downwind side, are exposed to elevated ambient concentration of asbestos. The goal of the present study was to quantify asbestos concentrations downwind of these roadways and relate the concentrations to vehicle traffic, road surface materials, and meteorological and climatological conditions.

After reviewing the occurrence of serpentine-covered unpaved roads in various parts of California and visiting roads throughout the State, it was found that the locale most suitable for study was in the vicinity of Oakdale in eastern Stanislaus County. After gaining permission from landowners, four sites were selected for field experiments. At each site, a network of four to five asbestos monitoring stations was established as well as a meteorological station for measuring wind speed and direction. During 5 to 8 one-hour test runs at each site, traffic was simulated on the road by repeated van trips while air samples were taken and meteorological conditions were monitored. Bulk samples of the road surface material were also taken for analysis of bulk asbestos content, silt content, and moisture content. Air samples were analyzed for asbestos using both optical and electron microscopes for two size ranges: all structures and structures $\geq 5\ \mu m$.

The EPA model that consists of the Copeland road dust emission model and Gaussian line source equation was evaluated by comparing measured asbestos concentrations with concentrations predicted by the model for the test conditions. The EPA model was found to be good only to estimate an order of magnitude of downwind concentrations. The structure of the model was found to be generally adequate, but the inclusion of both short temporal and long-term average parameters in the model appeared to decrease the accuracy of model estimates. Residual analysis of model-predicted concentrations less measured concentrations revealed that the model tends to overestimate asbestos concentrations at lower vehicle speeds and the model's performance is skewed with respect to model's site parameters such as moisture, silt, and asbestos contents.

A modified roadside asbestos model called CALSCRAM was developed by rectifying some of the defects found in the EPA model. The new model, which was calibrated over the range of 14% to 18% bulk asbestos content, was found to reduce the EPA model prediction errors by 76%. It is capable of predicting both short-term and long-term average asbestos concentrations and has a feature that accounts for the effect of a finite road segment on downwind concentrations.

ACKNOWLEDGMENTS

This roadway asbestos study could not have been completed without help from numerous individuals. Dr. Susanne Hering of Aerosol Dynamics, Inc., provided expert advice and assistance in designing the field experiments. Arthur Shrope of VRC and Dr. Wayne Harrington of ATC Environmental, Inc., contributed additional ideas and planning assistance early on in the project. For assistance during our site identification and selection effort we thank Tim Moore of the BLM in San Benito County, Scott Adams of the BLM in Lake County, the APCDs and Public Works Departments of northern and central California, the U.S. Forest Service staff in Stanislaus, El Dorado, and Shasta National Forests, and several cooperative private landowners. Arvid Severson of Severson Company, Inc., provided assistance with instrumentation. Larry Bregman and Dr. Charles Pyke of Continental Weather Service provided invaluable climatological assessments and weather forecasts for the field sites.

For their indefatigable assistance in asbestos sampling and analysis, the staff of ATC is gratefully acknowledged . Don Beck of ATC directed the field sampling effort with skill and dedication, and also contributed to many other facets of the project. Brian Urbaszewski of VRC and Dan Gawrys of ATC provided additional field assistance. Samples were analyzed by the staff of ATC's laboratory in Sioux Falls, SD.

The authors also thank the ARB staff for their valued input and guidance throughout the project: the Contract Manager Dr. Robert Grant of the Research Division; Victor Douglas, Ann Eli, and Todd Wong of the Stationary Source Division; and James McCormack of the Monitoring & Laboratory Division.

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ABBREVIATIONS AND ACRONYMS

AACES-RS	Airborne Asbestos Concentration Estimator System-Roadway Screening, a computer code for the EPA model which was developed by Battelle Northwest Lab.
APCD	Air Pollution Control District
ARB	Air Resources Board
ATC	ATC Environmental Inc., subcontractor for asbestos sampling and analysis
ASTM	American Standards for Testing and Materials
CALSCRAM	California Serpentine-Covered Roadway Asbestos Model, the model developed under the present study
EDS	Energy Dispersive Spectroscopy
EPA	Environmental Protection Agency
ft	Feet
g	Gram
km/h	Kilometers per hour
m	Meter
mph	Miles per hour
m/s	Meters per second
NIOSH	National Institute for Occupational Safety and Health
NWS	National Weather Service
OSHA	Occupational Safety and Health Administration
PCM	Phase Contrast Microscopy
PLM	Polarized Light Microscopy
SAED	Selected Area Electron Diffraction
struc/cc	Structures per cubic centimeter
struc/g	Structures per gram
TEM	Transmission Electron Microscopy
TEM0	TEM-measured asbestos concentration for all structures having ≥ 3 to 1 aspect ratio regardless of size
TEM5	TEM-measured asbestos concentration for structures ≥5 μm and having ≥ 3 to 1 aspect ratio
μg	Microgram (10^{-6} gram)
vph	Vehicles per hour
VRC	Valley Research Corporation

1.0 INTRODUCTION

1.1 BACKGROUND AND OBJECTIVES

Serpentine rock is widespread in California. In the foothills of the Sierra Nevada mountains, serpentine rock has been mined extensively and has also been widely used as a material for many types of unpaved surfaces, including parking lots, driveways, roads, and apparently even some school playgrounds. It has an attractive blue-gray or greenish appearance, and it can be locally inexpensive and readily available. These factors, along with its superior compaction properties contribute to its frequent use in certain areas of the Sierra foothills.

Serpentine rock in many parts of California can also have a significant content of the chrysotile form of asbestos. Since 1986, when the California Air Resources Board (ARB) first identified asbestos as a toxic air contaminant, a number of bulk samples of serpentine material have been taken in California and analyzed for asbestos content. ARB has identified serpentine deposits with asbestos contents ranging from trace amounts to as high as 90 percent, with typical contents in the Sierra Nevada falling between 2 and 20 percent. Asbestos is a known human and animal carcinogen, and exposure to asbestos has been linked to a number of serious illnesses including lung cancer, mesothelioma, and asbestosis.

When vehicles are driven over unpaved roads surfaced with asbestos-containing serpentine material, asbestos fibers are released into the atmosphere as part of the resultant dust cloud. Thus persons near the roadway, especially on the downwind side, are exposed to elevated ambient concentration of asbestos. In response to these health concerns, many serpentine-covered roads in California have already been paved over, and regulations have been enacted to prevent further road surfacing with serpentine material having more than a 5% asbestos content. However, according to ARB (1990), there are still hundreds of miles of serpentine-covered roads in the State, and some of these roads are near residences or human activity.

1.1.1 BRIEF SUMMARY OF PREVIOUS RESEARCH

A number of studies conducted over the past 15 years along serpentine-covered roads have revealed high ambient levels of asbestos fibers generated by the mechanical action of vehicle traffic. The most ambitious of these was a 1987 study done by Ecology and Environment, Inc., for the U.S. Environmental Protection Agency (EPA), in which airborne asbestos concentrations downwind from a single roadway in Amador County were related to the asbestos content of the road surface material and simulated vehicle traffic on the roadway (EPA 1987, 1988). Several other investigations have looked at asbestos emissions from unpaved roads or off-road vehicle trails over native serpentine soil.

In the above EPA project, two different serpentine-covered roadways were originally selected for study, both on private property in the foothills east of Stockton and Sacramento. EPA personnel reached agreement with property owners at these two sites, and scheduled field work at both. However, work at one site was ultimately scrubbed due to unfavorable topography and wind conditions. Therefore, one road only, in western Amador County, was subjected to field experiments (EPA 1988).

To determine the effects of vehicle traffic on downwind concentrations of airborne asbestos, the EPA-sponsored study team erected meteorological monitoring and air sampling equipment downwind of the subject roadway (a single air sampling station was also placed upwind to determine background concentrations). The most distant downwind station was located at 100 ft. from the roadway. Experiments consisted of a series of one hour sampling runs, and some 8 hour sampling runs, during which a van was driven over a 100 ft. study section of the roadway at intervals of 15 minutes at a constant speed of 30 mph. No variations in these traffic conditions were attempted. Several bulk samples of the road surface material were also taken for analysis of asbestos content, silt content, and road moisture content. All bulk and air samples were forwarded to independent laboratories for phase contrast microscopy (PCM) or transmission electron microscopy (TEM) analysis. Laboratory results were entered into databases in conjunction with traffic and meteorological data specific to each sampling run.

As part of this EPA-sponsored work, a computer code was developed by Battelle Memorial Institute's Pacific Northwest Laboratory (Stenner et al. 1990). The code, named AACES-RS, uses a modified form of the Copeland Model (EPA 1985) to estimate downwind concentrations from a contaminated roadway. Among the improvements to the standard Copeland model found in the AACES-RS are the ability to analyze variable downwind distances instead of a fixed "within 50 feet" and consideration of wind speed and stability variables as model inputs. The primary input variables for the AACES-RS code are site specific silt content and asbestos content. For other input variables, AACES-RS contains default values but allows user input of the following variables:

1. Particle-Size Multiplier (k-factor)
2. Vehicle Speed
3. Vehicle Weight
4. Number of Wheels
5. Vehicle Frequency (number of vehicles per hour)
6. Vertical Dispersion Parameter (σ_z)
7. Distance from Road
8. Precipitation Days (number of days per year with precipitation)
9. Stability Class
10. Average Wind Speed
11. Initial Vertical Dispersion of Vehicle Wake (H)

The AACES-RS code (hereafter referred to as the "EPA model") was calibrated using the results of the EPA field work in Amador County. However, owing to the limited amount of field data and the narrow range of experimental conditions investigated, little improvement to the modified version of the Copeland Model was possible. Thus the model is believed to be accurate to an order of magnitude at best. Prior to the current study, the model has never been adequately validated or field tested.

1.1.2 OBJECTIVES

In California, there are at least hundreds of miles of existing roads that either traverse native serpentine soils or are surfaced with hauled-in serpentine material. Many of the health-related issues regarding these roads are still a subject of debate. However, a need has been recognized to evaluate existing roads and prioritize them as to their potential for contributing to public exposure to airborne asbestos. Since it would be prohibitively difficult to conduct individual field tests on all existing serpentine-covered roadways, a better approach would be to develop a predictive model which takes a few site specific parameters as model input and yields, as output, the ambient asbestos concentration as a function of distance from the roadway. Such a model can provide a cost effective way of evaluating a large number of roadways. The EPA has developed a model for such a purpose, but it has not been validated or field tested.

The primary objectives of this study, therefore, were to conduct field experiments at multiple sites in California under a wider range of conditions than had previously been investigated, and to use these results to validate and improve the existing EPA model or to replace it with an improved model.

1.2 SUMMARY AND CONCLUSIONS

After an extensive search for roadways suitable for study, several candidate serpentine-covered roadways were identified in the Sierra Nevada foothills. All were on private property. Permission to use them for study was sought and granted by most property owners. Field work was conducted during August and September, 1991, by Valley Research Corporation (VRC) and its subcontractor ATC Environmental, Inc.

Field work was completed at four sites, all of which were in the general vicinity of Oakdale in Stanislaus County. At each site, a 500 ft. section of the road was chosen for study. One air sampling station was set up upwind of the roadway and 3 to 4 stations were set up downwind. Two meteorological stations were also established, one to measure wind speed and direction; and the other to measure temperature and relative humidity. Several bulk samples of the road surface material were taken at each site, for analysis of silt content, asbestos content (by ARB Test Method 435), and moisture content. To make the study results usable for dispersion modeling, atmospheric stability variables were also recorded.

Field testing consisted of about six 1-hour experimental runs at each site. During the runs, traffic was simulated on the roadway by driving a van back and forth across the study section at designated speeds and time intervals. In total, four vehicle frequency conditions -- 5 vehicles per hour, 15 vehicles per hour, 45 vehicles per hour, and no traffic -- and two vehicle speeds -- 10 mph and 25 mph -- were investigated.

Air and road surface samples collected in the field were subjected to laboratory analyses. For bulk samples, these analyses were to determine asbestos content, silt content, and moisture content; for air samples, asbestos content by TEM and PCM analyses.

Results of the field experiments were compared to ambient asbestos concentrations predicted for the field conditions by the EPA model. Based on discrepancies between measured and model-predicted concentrations, a modified model, named CALSCRAM (California Serpentine-Covered Roadway Asbestos Model), was developed.

This study has yielded the following findings and conclusions:

- Although serpentine-covered unpaved roads indeed exist in many parts of California, nearly all unpaved roads covered with serpentine material on public land are either unsurfaced roads or off-road vehicle trails over native serpentine soil, or logging roads in mountainous, forested and often remote areas.

- Serpentine-covered unpaved roads in the vicinity of residences and centers of human activity suitable for field tests are common only in the Sierra Nevada foothills of California from approximately Mariposa County in the south to Placer County in the north.

- Traffic over serpentine-covered unpaved roads was found to generate measurably elevated levels of airborne asbestos at downwind distances to at least 250 feet.

- The EPA model for estimating airborne asbestos concentrations downwind of serpentine-covered roadways was found to predict concentrations accurately to an order of magnitude, but it performed poorly for low vehicle speeds and certain ranges of other input parameters.

- A modified model, called CALSCRAM, was developed based on the field data collected under the present study. This model not only out-performs the EPA model for estimating downwind asbestos concentrations but also possesses capabilities of predicting both short-term and long-term average concentrations. The model can also account for the effect of shorter road segments on downwind concentrations.

The model developed under this study provides a cost-effective tool for determining whether identified serpentine-covered unpaved roads pose risks of public exposure to elevated ambient levels of asbestos.

Although the model is capable of predicting asbestos concentrations downwind of unpaved roads surfaced with imported mined serpentine rock, it has not been tested on unsurfaced roads with native serpentine material. Therefore, recommendations for future research in the subject area are as follows:

(1) Design and implement a similar experiment to evaluate the model's applicability to unpaved roadways consisting of native serpentine material. These roadways appear to be far more prevalent in California than roadways surfaced with imported serpentine material.

(2) Develop a comprehensive compilation of unpaved roads in California covered by mined serpentine and native serpentine and determine their spatial distribution and vehicle activity levels.

(3) Identify regions in California where these roads occur in conjunction with human activity. Employ the model on roads in these regions to make first-order estimates of public exposure levels and develop priorities for further efforts on assessing health risks from such exposure.

2.0 EXPERIMENTAL METHODS

2.1 SELECTION OF STUDY SITES

Prior to this study, ARB staff estimated that in California there are at least 700 miles and possibly thousands of miles of publicly-owned serpentine-covered unpaved roads and possibly hundreds more miles that are privately-owned (ARB 1990). These estimates were based on conversations with several Air Pollution Control Districts (APCDs) in California counties with unpaved roads. However, no systematic compilation of either exact road mileage or road locations has yet been attempted. Thus there was no existing database to aid in the process of site selection for this study.

To aid in the identification of potential sites, we contacted knowledgeable officials at local APCDs, county public works departments, national forests and national parks, Bureau of Land Management, Caltrans, EPA, and ARB. Based on these conversations, we identified specific regions in California with potential study roads. A site reconnaissance tour of these regions was conducted for the purpose of identifying candidate sites and recording preliminary information on road characteristics, site topography, and meteorology, as well as for taking road surface samples for asbestos analysis.

Based on the results of the reconnaissance tour, it was concluded that although serpentine-covered unpaved roads indeed exist in many parts of California, the overwhelming majority do not meet basic experimental requirements, such as having a straight road segment, level terrain, and an absence of major obstructions such as trees or buildings. Moreover, nearly all unpaved roads covered with serpentine material on public land are either unsurfaced roads or offroad vehicle trails over native serpentine soil, or logging roads in mountainous, forested and often remote areas. These roads were not suited for the experimental approach.

Each candidate site was subjected to independent review first by meteorologists of Continental Weather Service and then by ARB staff. Based on this review, the pool of suitable candidate sites was reduced to several sites located in the vicinity of Oakdale in eastern Stanislaus County. The Oakdale region is distinct from other parts of the Sierra Nevada foothills in that most serpentine-covered roads are on open and level terrain. Outside of the Sierra Nevada, we were unable to locate <u>any</u> serpentine-covered roads other than unpaved roads over native serpentine material or roads with an unacceptably low serpentine content. One unpaved road over native serpentine material (in Lake County) was originally included in this study and subjected to preliminary field work, but results were ultimately excluded from the study by the ARB contract manager based on its native serpentine content and roadside slope.

The region north to northeast of Oakdale is characterized by flat and gently sloping open rangeland. Houses in this region are typically set far back in ranch-type parcels and connected to the paved public roads by straight driveways several hundred feet in length. A majority of these driveways are unpaved, and many of the unpaved driveways are surfaced with serpentine material. We identified an initial pool of about 10 straight, flat, serpentine road segments, which were primarily driveways. The property owners at each road segment were identified and contacted, and based on their receptiveness to our initial inquiries about use of their roads for the study, we reduced the number of candidate sites to 7. One liter bulk samples of the road surface material were taken and analyzed for asbestos content according to ARB Test Method 435, and each of the sites was found to have a chrysotile asbestos content within the range of 5 to 20 percent. Selection of final study sites was left until within a few days of each study period in order to incorporate the latest wind forecasts for selecting the road segments with optimal orientations.

The four study roads that were finally selected each had the distinctive "green" appearance of roadways covered with hauled-in serpentine, and each functioned as a driveway used for access between a public road and a private ranch. Three of the four had residences near or at the terminus of the roadway. All were on relatively flat and open rangeland, and three of the four had cattle or horses grazing in adjacent fields. Following is a more exact description of each study site:

Site 1: VRC Code: P5
Road Orientation: 165° (from magnetic north)
Roadside Terrain: Flat and open pasture, short grass.
Roadside Obstructions: Some small trees along the downwind roadside, barbed wire fences on either side.

Site 2: VRC Code: 7-3
Road Orientation: 167°
Roadside Terrain: Flat and open pasture, short grass.
Roadside Obstructions: Barbed wire fence on west side.

Site 3: VRC Code: P8
Road Orientation: 168°
Roadside Terrain: Flat and open pasture, somewhat marshy, vegetation about 2 to 3 ft. high.
Roadside Obstructions: None

Site 4: VRC Code: P9
Road Orientation: 73°
Roadside Terrain: Flat and open pasture, short grass.
Roadside Obstructions: Barbed wire-like fence to the south, chain-link fence to the north.

Figure 2-1 shows a map of the Oakdale region and the approximate locations of the four study sites.

2.2 EXECUTION OF FIELD EXPERIMENTS

The field experiments were conducted over 9 days during the months of August and September, 1991. Study personnel consisted of two VRC staff members and one ATC asbestos sampling technician. Each study day consisted of 2 to 4 one hour test runs during which samples of airborne asbestos were taken. The test runs were generally begun during a time when the wind was approximately perpendicular to the road segment under study. On most study days, such winds occurred during the afternoon hours.

2.2.1 PROTOCOL DEVELOPMENT AND STUDY DAY SELECTION

A detailed study protocol was developed specifying the methodologies to be employed in taking bulk samples, air samples, meteorological data, and in simulating traffic. A matrix specifying the traffic conditions designated for each experimental run was developed. Comprehensive equipment checklists were also prepared and thoroughly reviewed. Data sheets were prepared to be used by the field team to monitor the progress of the field tests.

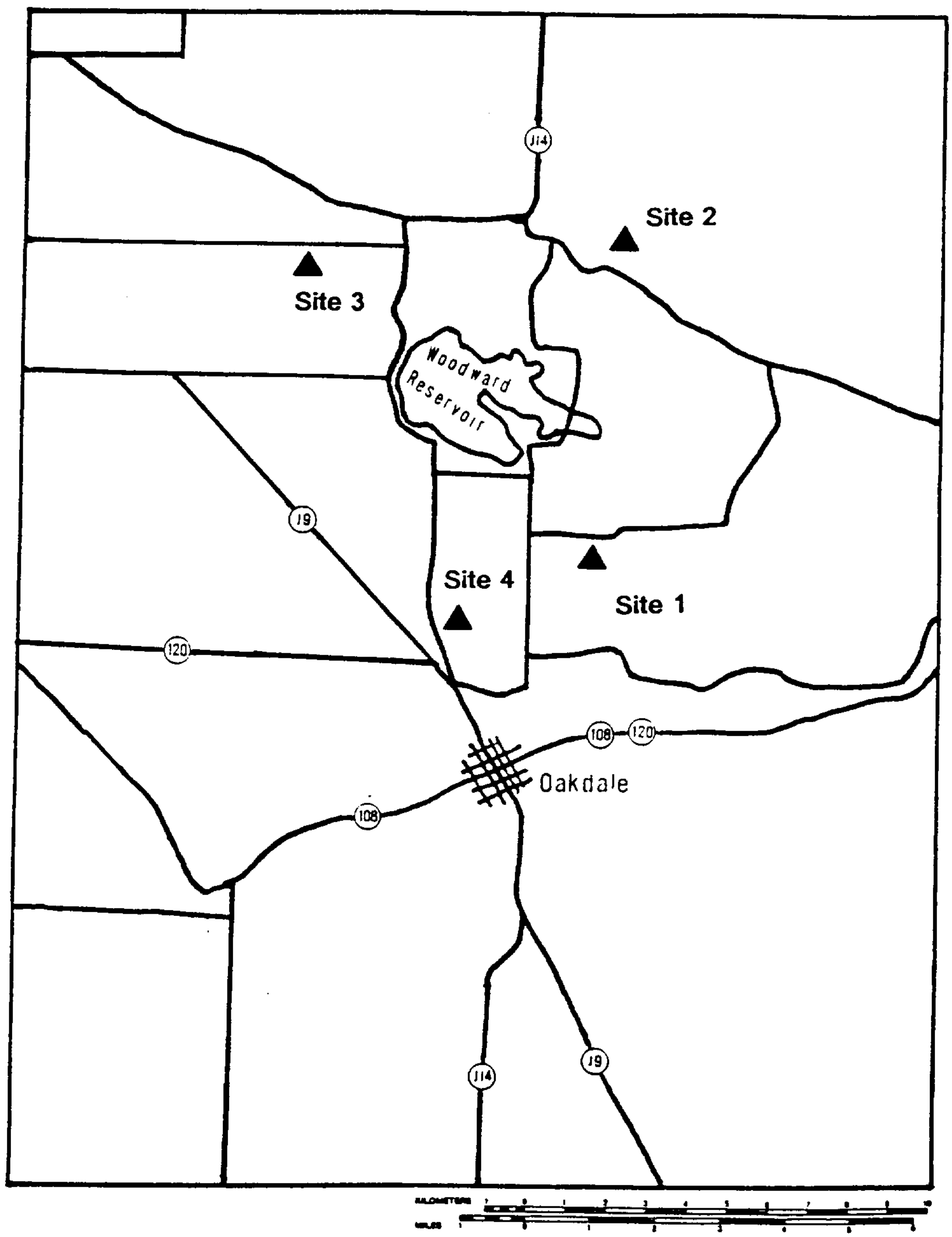

Figure 2-1. Map of the Oakdale Region Showing Locations of the Four Study Sites.

VRC made arrangements with meteorologists at Continental Weather Service to monitor weather conditions in the Oakdale region and provide detailed daily 4 day forecasts on wind speed and direction and rain probability beginning 3 to 4 days prior to any planned mobilization of the field team. Also, before visiting the first site studied, a VRC field assistant was dispatched to Oakdale 2 days in advance of the scheduled experiments to monitor winds with a handheld anemometer and verify the forecasts. Use of forecasts combined with advance site visits proved quite useful for selecting road segments with optimal orientations, and in one case for averting the mobilization of the entire field crew when rain was forecasted and confirmed prior to a scheduled field visit.

2.2.2 FIELD EXPERIMENT SETUP

Figure 2-2 depicts the arrangement of air sampling and meteorological monitoring stations in relation to the test road segment. The test segment has a 250 ft constant speed zone in each direction from the midpoint.

Each road segment's midpoint was chosen at a point relatively free of downwind obstruction with good roadside access, and where there was an adequate road length on either side. The study zone on the road segment, including the segment's midpoint and constant speed zone, was marked using a combination of traffic cones and stake wire flags.

The bearing of the test segment of the road was first measured with a compass, and all air samplers, at 4 to 5 air sampling stations, were then set up along a line perpendicular to the road segment's orientation. The first station was located at 50 ft. upwind from the road. The remaining stations were established downwind from the road at 25 ft., 75 ft., and 250 ft. A fifth station, termed the "distant sampler", was established at 1100 ft. at one site only. At the 25 ft. downwind station, samplers were mounted at heights of 1.5 m and 3 m, while at all other stations samplers were mounted at 1.5 m only. A floating replicate sampler was randomly placed at one of the stations prior to each test run.

At each site, a wind monitoring station was established 25 ft. upwind from the roadway so not to be affected by passing vehicles. A temperature and relative humidity station was established at the immediate roadside to measure conditions just above the road surface. The command station provided a central location for traffic and meteorological monitoring by the VRC field manager as well as for maintaining refreshments and miscellaneous research supplies.

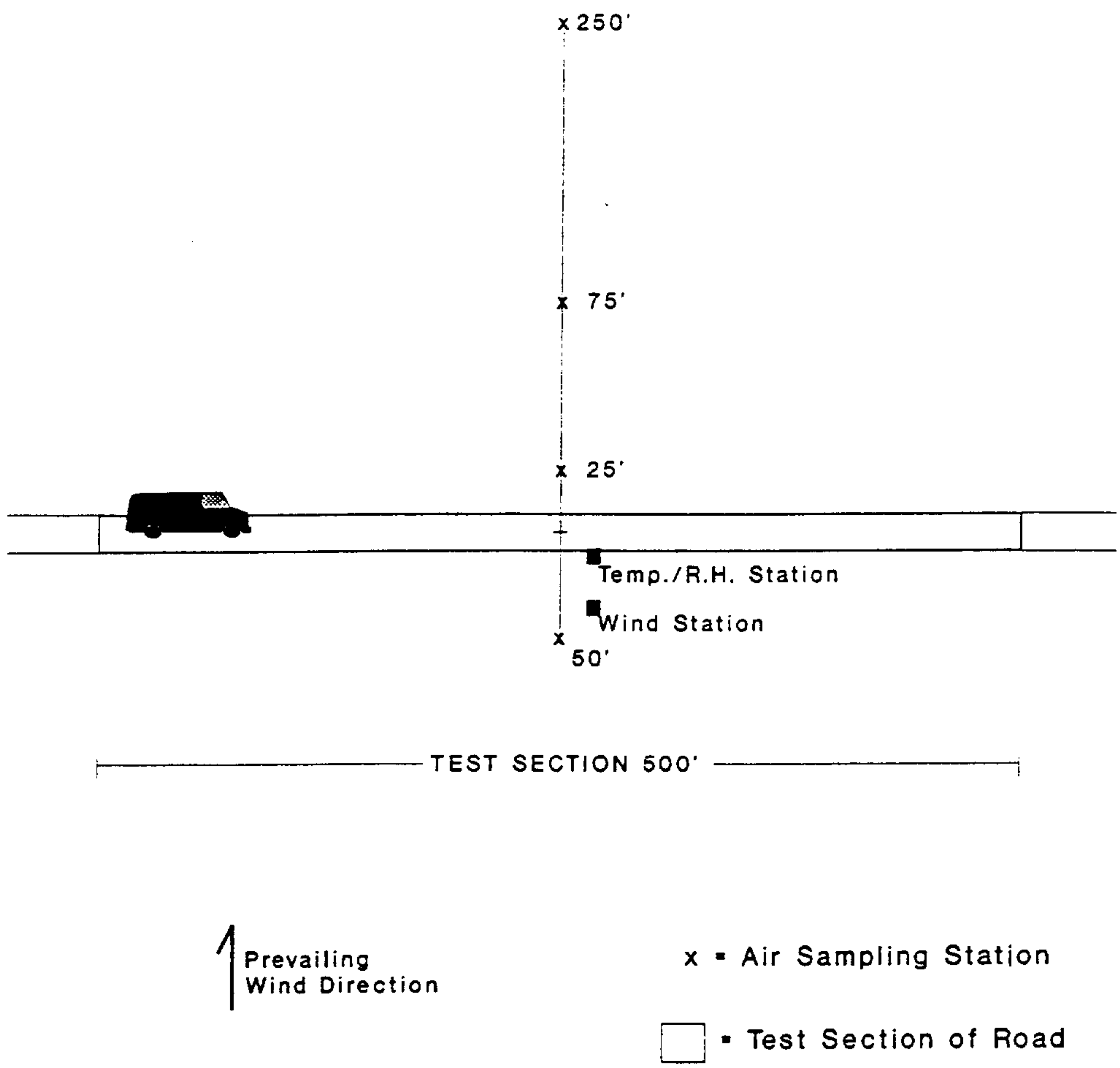

Figure 2-2. Setup Diagram for Study Sites.

2.2.3 TRAFFIC SIMULATION

For the purposes of eventual model development, the field tests were designed to focus on repeating similar traffic conditions rather than testing a multitude of traffic conditions without repeats. After considering issues such as expected dust generation per vehicle pass, real-world traffic conditions, and safety, traffic conditions were designated for 27 test runs as shown in Table 2-1. It was also decided that rather than trying to vary the vehicle type and weight, only one vehicle of "typical" size and weight would be used.

Table 2-1. DESIGNATED TRAFFIC CONDITIONS

Vehicle Speed (mph)	Vehicle Freq. (vph)	Number of Test Runs				
		Site 1	Site 2	Site 3	Site 4	Total
0	0	1	1	1	1	4
10	5	0	1	1	1	3
10	15	2	1	1	0	4
10	45	2	1	2	0	5
25	5	1	1	1	1	4
25	15	1	1	1	1	4
25	45	1	1	0	1	3

The vehicle speeds designated, 10 and 25 mph, are lower than the assumed average vehicle speed of 30 mph in the EPA study. The AACES-RS code uses a default value of 30 mph based on a survey of drivers on unpaved roads in the St. Louis area by Cowherd and Guenther (1976). Serpentine covered roads in California, however, are typically found as winding roads in the foothills or as rural driveways, where vehicle speeds are likely to be slower, for reasons of safety (in the case of winding roads) and to minimize dust generation (especially when near residences). Although typical vehicle frequencies on these serpentine-covered roads are likely to be less than 1 or 2 vehicles per hour, higher frequencies of 5, 15 and 45 vehicles per hour were employed for this study in order to ensure that the traffic would generate a measurable range of airborne asbestos concentrations.

At each study site, the first test run was conducted to determine the "background" asbestos level, namely, concentrations present prior to the experiment. This involved completion of a one hour sampling period with no traffic on the road segment. On subsequent runs, traffic was "simulated" by a single unloaded cargo van (Ford Econoline 150, unladen weight 1.8 tons) driven by a VRC staff member. The van was driven over the study segment at constant speed and at regular intervals both specified in advance. The driver and field manager maintained constant audio contact via two-way radios. Each time the study vehicle passed the midpoint of the road segment, the field manager noted on the traffic data sheet the exact time, vehicle direction, and vehicle type.

Occasionally, during the course of the experiments, access to the road was requested by non-study vehicles which were stopped and informed of the study and asked either to drive through at 2 mph (to minimize disturbance) or to pass at the designated time and speed as a substitute for the study van. The vehicle type (e.g., auto, pickup, van), speed, direction, and the time were noted for all non-study vehicles.

2.2.4 METEOROLOGICAL MONITORING

Wind speed and direction were measured continuously during each entire study day with a Young wind sensor Model 05103 (combination vane and anemometer) mounted on a 10' tripod. The following data items were automatically recorded in a Campbell Scientific, Inc., datalogger once each minute: time, mean absolute wind speed, vector wind speed, mean wind direction, and standard deviation of the wind direction. At the end of each study day, all data were downloaded to a laptop computer for quality checks and backup to hard and floppy disks.

Temperature and relative humidity readings were recorded manually each 30 minutes from an Oakton hygrometer/thermometer placed in a well-ventilated shaded area approximately 6 feet above ground level at the edge of the study road. Percent cloud cover was also recorded for each experimental run and solar angle was calculated based on the time of the run. These cloud cover and solar angle data in conjunction with wind data were later used to determine the atmospheric stability class for each test run.

2.2.5 BULK SAMPLING

In addition to the previously noted screening samples, at each site three "composite" bulk samples of the road surface material were taken and analyzed for asbestos content according to ARB Test Method 435. Composite samples were also taken prior to each test run and analyzed for moisture and silt content.

All bulk samples were taken using a clean round-tipped shovel. Each sample was taken from approximately the top 1/2 inch of the road surface at three longitudinal distances on the road segment: at the midpoint and at points 150' from the midpoint in either direction along the roadway. Samples were sealed in sterile 1 liter containers.

2.2.6 AIR SAMPLING

As mentioned earlier, four air sampling stations were established along a line perpendicular to the roadway -- one upwind (50 ft.) and 3 downwind (25 ft., 75 ft., and 250 ft.). A fifth station, the distant sampler, was established at one site only. All but the 25 ft. downwind station consisted of a single air collection pump with a filter sampler mounted at 1.5 m. The 25 ft. station consisted of two air collection pumps with one sampler mounted at 1.5 m from the ground and another at 3 m. Additionally, one "floating" sampler was collocated to acquire a replicate sample for each of the test runs . Because no other power source was available, portable generators were used to power all air pumps.

Before each one hour test run, each sampler was loaded with a labeled mixed-cellulose ester filter cassette with a .45 micron pore size. At the signal of the field manager, the pumps were turned on at the start of the run. Flow rates for each of the samplers were measured, using "The Gilibrator" primary flow electronic calibrator (Gilian Instrument Corp.) near the beginning and end of the run. At the end of the run, power to the air pumps was turned off and the filter cassettes were collected and sealed. The distant sampler, used 2 days at a single study site, was turned on at the beginning of the study day and turned off at the end. For the "background" test runs, which occurred once per site, only 3 samplers were used: upwind 50 ft., downwind 25 ft. at 1.5 m, and downwind 75 ft.

As a routine quality assurance measure, "field blanks" and "lab blanks" were collected once per site. The purpose was to establish the integrity of the sampling cassettes in the handling process both at the site and in the laboratory.

2.3 LABORATORY METHODS

All field samples were clearly labeled, packaged, and transported according to ATC's chain-of-custody procedures. The following paragraphs briefly describe the laboratory procedures that were used for silt/moisture content analysis, bulk sample analysis, and PCM and TEM analyses of air samples.

2.3.1 SILT AND MOISTURE CONTENT ANALYSIS

Moisture content for the bulk samples was determined according to ASTM Method D2216 which is a standard test method for laboratory determination of water (moisture) content of soil and rock. The method consists of oven drying the samples at 110°C to a constant mass. Moisture content is then calculated from the difference in sample weight before and after drying.

Silt content determination was based on ASTM Method D1140 which is a standard test method for quantifying the amount of material in soils finer than a No. 200 sieve. The method consists of washing and dry-sieving samples through nested sieves (upper sieve is a No. 40 and lower sieve is a No. 200). Silt content, or percentage of material finer than a No. 200 sieve, is based on the dry weight of the sample after washing and dry-sieving divided by the original sample dry weight.

2.3.2 BULK SAMPLE ASBESTOS ANALYSIS

Bulk sample preparation was accomplished by crushing the material to a nominal size of less than 0.375 inch. The sample volume was reduced to one pint as per ASTM Method C-702-80. The one pint sample was further reduced in particle size to produce a material of which the majority passed a 200 mesh Tyler screen.

The one pint sample was first examined macroscopically for color, texture, homogeneity, and visible fibers. A portion of the sample was placed on a watchglass and its fibrous content was examined under a stereomicroscope. An aliquot of the sample was removed and spread out on a glass slide. Two drops of 1.55 refractive index solution was added to the aliquot and a coverslip was placed on top of the slide. Three slides were prepared for each sample.

The slides were then examined under polarized light microscopy where fibrous structures were analyzed noting color and pleochroism, morphology, index of refraction, extinction, sign of elongation, and dispersion staining colors. Once the fibrous content was identified, a visual percentage estimate was recorded based on macroscopic and microscopic observations.

Asbestos content was then quantified according to ARB Test Method 435.

2.3.3 AIR SAMPLE ASBESTOS ANALYSIS

All air samples were subjected to TEM and PCM analyses in ATC's laboratory in Sioux Falls, SD. TEM analysis followed the microscopic methods according to EPA's AHERA Method. A set number of 200-mesh electron microscopy grid openings were analyzed as governed by the grid opening and the analytical sensitivity. Structure counting criteria were based on being greater than 0.25 microns in length with a length-to-width ratio of 3:1 or greater. Structures meeting the counting criteria were analyzed by selected area electron diffraction (SAED) and Energy-Dispersive Spectroscopy (EDS) for asbestos identification. It should be pointed out that although most of the fibers can be identified as asbestos or non-asbestos, there are still some cases where a fiber will have borderline data and thus cannot be ruled out as non-asbestos. These "borderline" fibers were labeled ambiguous, but were included in the asbestos calculations.

A portion of each sample was analyzed by PCM according to NIOSH Method 7400. The samples were prepared by removing a pie-shaped wedged portion from each sample cassette filter. The samples were then mounted by the acetone/triacetin on individual sample slides. The microscope was set up and its optics were adjusted according to the 7400 Method. The slide was examined under the microscope where the 7400 Method counting rules were implemented. Only fibers equal to or greater than 5 micrometers in length with an aspect ratio of 3:1 or greater were counted. Slides were examined until a fiber count of 100 or a field count of 100 is yielded with a minimum of at least 20 fields examined. The fiber concentration was then calculated based on the microscope graticule field area, filter cassette field area, sample volume, fiber count, and field count. All air sampling results were examined for consistency and anomalies before and after being entered into VRC's computer system.

3.0 RESULTS OF FIELD EXPERIMENTS

3.1 ACTUAL TRAFFIC CONDITIONS AND AIR SAMPLING CONFIGURATIONS

Both the traffic conditions (i.e., vehicle speed and frequency) and the configuration for active air samplers for each test run were designated prior to execution of the field experiments. In general, the field team was able to conform to these designations. On 3 occasions, however, a predesignated test run was completed but later discarded after review of the wind conditions. Table 3-1 summarizes the number of bulk and air samples analyzed for each traffic condition. Table 3-2 shows in detail for each test run the actual traffic conditions and active air sampler configuration. A symbol indicates that TEM and PCM analyses were performed for a particular sample. Test runs containing no symbols are those that were discarded due to poor wind conditions.

3.2 AIR AND BULK ASBESTOS SAMPLES

Table 3-3 summarizes the TEM-measured asbestos concentrations (i.e., TEM0 for total structures having ≥ 3-to-1 aspect ratios regardless of size) at each study site, according to the traffic conditions for the test runs. The table shows measured ambient asbestos concentrations both upwind and downwind of each roadway. For all test runs with simulated traffic, concentrations were higher downwind (note: upwind samples are all at 50 ft). Concentrations were generally higher on test runs with higher vehicle speed and frequency. Table 3-4 presents a more detailed summary of the TEM, PCM, and bulk sample analyses results for each test run at each site. The table corresponds to the actual traffic conditions and air sampling configuration shown in Table 3-2. Note that the bulk asbestos content of the road surface material is the mean of three composite samples. Also, note that the last sample listed under each test run is a collocated sample, included to test the variability observed between two samplers at similar locations.

Of the 128 air samples analyzed by TEM, about 93% were positive for chrysotile asbestos. Amphibole and "Ambiguous" were the other designated forms of asbestos and occurred in trace amounts in 15.6% and 4.7% of the samples respectively. Non-asbestos fibers identified were grouped into Antigorite and "Other" and occurred in trace amounts in 9.4% and 18.8%

Table 3-1. SUMMARY OF TEST CONDITIONS AND BULK AND AIR SAMPLES ANALYZED

Vehicle Speed (mph)	Vehicle Freq. (vph)	Bulk Samples		Air Samples Analyzed				
		Asbestos	Moisture & Silt[a]	Blank[b]	Back-ground[c]	Upwind	Down-wind	All Day Sample[d]
0	0	4	4	0	12	4	8	1
10	5	0	2	0	0	2	10	0
10	15	0	4	0	0	3	15	1
10	45	3	5	4	0	4	20	0
25	5	0	3	0	0	3	15	0
25	15	3	4	0	0	4	20	0
25	45	2	3	4	0	3	15	0
Total		12	25	8	12	19	95	2

[a] Some moisture and silt analyses were performed on the same sample as used for bulk asbestos content analysis.
[b] Both field and laboratory blanks.
[c] For background asbestos concentrations present prior to road tests.
[d] Two all day samples were analyzed. They were each collected on days with 3 to 4 test runs.

Table 3-2. ACTUAL TRAFFIC CONDITIONS AND AIR SAMPLING CONFIGURATION FOR EACH TEST RUN

Site No.	Test Run	Veh. Speed (mph)	Veh. Freq. (vph)	Type and Location of Air Samples Analyzed									Total No. of Samples
				1	2	3	4	5	6	7	8	9	
1	1	0	0			■	■		■				3
1	2	10	45	■	■								2
1	3	25	15			■	■	■	■	■		■	6
1	4	10	15										0*
1	5	25	5			■	■	■	■	■		■	6
1	6	25	45			■	■	■	■	■		■	6
1	7	10	15			■	■	■	■	■		■	6
1	8	10	45			■	■	■	■	■		■	6
2	1	0	0			■	■		■		♦		4
2	2	25	45	■	■	■	■	■	■	■		■	8
2	3	10	45			■	■	■	■	■		■	6
2	4	25	15			■	■	■	■	■		■	6
2	5	10	15			■	■	■	■	■	♦	■	7
2	6	25	5			■	■	■	■	■		■	6
2	7	10	5			■	■	■	■	■		■	6
3	1	0	0			■	■		■				3
3	2	10	45	■	■	■	■	■	■	■		■	8
3	3	25	15			■	■	■	■	■		■	6
3	4	10	15			■	■	■	■	■		■	6
3	5	25	5			■	■	■	■	■		■	6
3	6	10	5			■	■	■	■	■		■	6
3	7	10	45			■	■	■	■	■		■	6
4	1	0	0			■	■		■				3
4	2	25	45	■	■	■	■	■	■	■		■	8
4	3	25	15			■	■	■	■	■		■	6
4	4	25	5										0*
4	5	10	5										0*

Samplers:

1. Field Blank
2. Lab Blank
3. Upwind 50'/1.5m
4. Downwind 25'/1.5m
5. Downwind 25'/3m
6. Downwind 75'/1.5m
7. Downwind 250'/1.5m
8. Downwind 1100'/1.5m
9. Replicate (floating)

■ One hour sample
♦ Continuous sample (all day)
*Due to poor wind conditions

Table 3-3. SUMMARY OF TEST CONDITIONS AND TEM-MEASURED ASBESTOS CONCENTRATIONS AT EACH STUDY SITE

Study Site	Test Run	Veh. Speed (mph)	Veh. Freq. (vph)	TEM0 (struc./cc)	
				Upwind	Downwind
1	1	0	0	.02	.01 - .08
1	4, 7	10	15	.01	.15 - .44
1	2, 8	10	45	.14	.59 - 1.87
1	5	25	5	.01	.25 - 7.25
1	3	25	15	.02	.94 - 3.23
1	6	25	45	.02	3.83 - 10.04
2	1	0	0	.01	.01
2	7	10	5	.01	.00* - .21
2	5	10	15	.01	.00* - 1.34
2	3	10	45	.01	.03* - 2.07
2	6	25	5	.02	.00* - 3.99
2	4	25	15	.05	.04* - 4.10
2	2	25	45	.01	.00 - 9.57
3	1	0	0	.02	.04 - .11
3	6	10	5	.01	.04 - .17
3	4	10	15	.02	.10 - .56
3	2, 7	10	45	.01 - .02	.05 - 4.01
3	5	25	5	.01	.47 - 1.66
3	3	25	15	.04	.55 - 7.59
4	1	0	0	.02	.02 - .05
4	3	25	15	.01	1.05 - 5.28
4	2	25	45	.01	2.65 - 14.20

* At 1100 ft downwind

Table 3-4. SUMMARY OF AIR AND BULK SAMPLE ANALYSIS RESULTS

	DATE	RUN	TIME START	VEH. SPEED (MPH)	VEH. FREQ. (VPH)	STAB. CLASS	SAMPLER DIST. (FT)	SAMPLER HEIGHT (M)	BULK ASB. CONT.[a]	MOIS-TURE CONT.[b]	SILT CONT.[b]	PCM CONC.[c] (F/CC)	TEM-MEASURED CONC. >=5u (STRUC/CC)	ALL (STRUC/CC)
SITE 1														
	8/19/91	1	13:55	0	0	B	50	1.5	14.0	.3	4.8	.01	0.00	.02
	8/19/91	1	13:55	0	0	B	25	1.5	14.0	.3	4.8	.01	.02	.08
	8/19/91	1	13:55	0	0	B	75	1.5	14.0	.3	4.8	.01	.01	.01
	8/19/91	3	17:40	25	15	B	50	1.5	14.0	.1	8.0	.01	0.00	.02
	8/19/91	3	17:40	25	15	B	25	1.5	14.0	.1	8.0	.02	.24	3.23
	8/19/91	3	17:40	25	15	B	25	3.0	14.0	.1	8.0	.02	.06	1.38
	8/19/91	3	17:40	25	15	B	75	1.5	14.0	.1	8.0	.02	.02	.94
	8/19/91	3	17:40	25	15	B	250	1.5	14.0	.1	8.0	.01	.04	1.42
	8/19/91	3	17:40	25	15	B	75	1.5	14.0	.1	8.0	.01	.10	2.56
	8/20/91	5	14:28	25	5	C	50	1.5	14.0	.4	9.3	.01	0.00	.01
	8/20/91	5	14:28	25	5	C	25	1.5	14.0	.4	9.3	.05	.32	7.25
	8/20/91	5	14:28	25	5	C	25	3.0	14.0	.4	9.3	.01	.07	1.67
	8/20/91	5	14:28	25	5	C	75	1.5	14.0	.4	9.3	.02	.14	3.59
	8/20/91	5	14:28	25	5	C	250	1.5	14.0	.4	9.3	.01	.01	.25
	8/20/91	5	14:28	25	5	C	25	1.5	14.0	.4	9.3	.06	.27	5.47
	8/20/91	6	17:08	25	45	C	50	1.5	14.0	.6	6.9	.01	0.00	.02
	8/20/91	6	17:08	25	45	C	25	1.5	14.0	.6	6.9	.15	.94	9.12
	8/20/91	6	17:08	25	45	C	25	3.0	14.0	.6	6.9	.10	.47	4.67
	8/20/91	6	17:08	25	45	C	75	1.5	14.0	.6	6.9	.08	.48	5.41
	8/20/91	6	17:08	25	45	C	250	1.5	14.0	.6	6.9	.05	.34	3.83
	8/20/91	6	17:08	25	45	C	75	1.5	14.0	.6	6.9	.07	.65	10.04
	8/23/91	7	12:35	10	15	B	50	1.5	14.0	.8	9.9	.01	0.00	.01
	8/23/91	7	12:35	10	15	B	25	1.5	14.0	.8	9.9	.01	.02	.44
	8/23/91	7	12:35	10	15	B	25	3.0	14.0	.8	9.9	.01	.32	.37
	8/23/91	7	12:35	10	15	B	75	1.5	14.0	.8	9.9	.01	.03	.26
	8/23/91	7	12:35	10	15	B	250	1.5	14.0	.8	9.9	.01	0.00	.15
	8/23/91	7	12:35	10	15	B	25	1.5	14.0	.8	9.9	.01	0.00	.06
	8/23/91	8	14:00	10	45	B	50	1.5	14.0	.7	9.9	.01	.01	.14
	8/23/91	8	14:00	10	45	B	25	1.5	14.0	.7	9.9	.02	.18	1.87
	8/23/91	8	14:00	10	45	B	25	3.0	14.0	.7	9.9	.02	.05	1.27
	8/23/91	8	14:00	10	45	B	75	1.5	14.0	.7	9.9	.01	.07	.77
	8/23/91	8	14:00	10	45	B	250	1.5	14.0	.7	9.9	.01	.03	.59
	8/23/91	8	14:00	10	45	B	25	1.5	14.0	.7	9.9	.01	.17	1.76
SITE 2														
	8/21/91	1	13:35	0	0	B	50	1.5	14.0	.3	4.9	.01	0.00	.01
	8/21/91	1	13:35	0	0	B	25	1.5	14.0	.3	4.9	.01	0.00	.01
	8/21/91	1	13:35	0	0	B	75	1.5	14.0	.3	4.9	.01	0.00	.01
	8/21/91	2	14:40	25	45	B	50	1.5	14.0	.5	4.8	.01	0.00	.01
	8/21/91	2	14:40	25	45	B	25	1.5	14.0	.5	4.8	.09	1.57	9.57
	8/21/91	2	14:40	25	45	B	25	3.0	14.0	.5	4.8	.07	.41	5.00
	8/21/91	2	14:40	25	45	B	75	1.5	14.0	.5	4.8	.06	.32	5.78
	8/21/91	2	14:40	25	45	B	250	1.5	14.0	.5	4.8	.02	.05	1.66
	8/21/91	2	14:40	25	45	B	1100	1.5	14.0	.5	4.8	.00	.01	.04
	8/21/91	2	14:40	25	45	B	25	1.5	14.0	.5	4.8	.10	.81	6.15
	8/21/91	3	15:52	10	45	C	50	1.5	14.0	.2	4.5	.01	0.00	.01
	8/21/91	3	15:52	10	45	C	25	1.5	14.0	.2	4.5	.02	.17	1.74
	8/21/91	3	15:52	10	45	C	25	3.0	14.0	.2	4.5	.01	.18	2.11
	8/21/91	3	15:52	10	45	C	75	1.5	14.0	.2	4.5	.02	.15	2.07
	8/21/91	3	15:52	10	45	C	250	1.5	14.0	.2	4.5	.01	.04	.46
	8/21/91	3	15:52	10	45	C	1100	1.5	14.0	.2	4.5	.00	.01	.04

Table 3-4 (continued) - 2

DATE	RUN	TIME START	VEH. SPEED (MPH)	VEH. FREQ. (VPH)	STAB. CLASS	SAMPLER DIST. (FT)	SAMPLER HEIGHT (M)	BULK ASB. CONT.[a]	MOIS-TURE CONT.[b]	SILT CONT.[b]	PCM CONC.[c] (F/CC)	TEM-MEASURED CONC. >=5u (STRUC/CC)	ALL (STRUC/CC)
8/21/91	3	15:52	10	45	C	75	1.5	14.0	.2	4.5	.01	.22	2.04
8/21/91	4	17:10	25	15	C	50	1.5	14.0	.2	5.9	.01	0.00	.05
8/21/91	4	17:10	25	15	C	25	1.5	14.0	.2	5.9	.03	.42	4.35
8/21/91	4	17:10	25	15	C	25	3.0	14.0	.2	5.9	.02	.29	4.10
8/21/91	4	17:10	25	15	C	75	1.5	14.0	.2	5.9	.04	.22	2.41
8/21/91	4	17:10	25	15	C	250	1.5	14.0	.2	5.9	.01	.06	1.31
8/21/91	4	17:10	25	15	C	1100	1.5	14.0	.2	5.9	.00	.01	.04
8/21/91	4	17:10	25	15	C	250	1.5	14.0	.2	5.9	.01	.19	1.17
8/22/91	5	13:05	10	15	B	50	1.5	14.0	.3	5.5	.01	0.00	.01
8/22/91	5	13:05	10	15	B	25	1.5	14.0	.3	5.5	.01	.03	.77
8/22/91	5	13:05	10	15	B	25	3.0	14.0	.3	5.5	.01	.02	1.34
8/22/91	5	13:05	10	15	B	75	1.5	14.0	.3	5.5	.01	.04	.56
8/22/91	5	13:05	10	15	B	250	1.5	14.0	.3	5.5	.01	.01	.09
8/22/91	5	13:05	10	15	B	1100	1.5	14.0	.3	5.5	.01	.01	.01
8/22/91	5	13:05	10	15	B	50	1.5	14.0	.3	5.5	.01	0.00	.01
8/22/91	6	14:35	25	5	B	50	1.5	14.0	.3	6.1	.01	0.00	.02
8/22/91	6	14:35	25	5	B	25	1.5	14.0	.3	6.1	.03	.25	3.90
8/22/91	6	14:35	25	5	B	25	3.0	14.0	.3	6.1	.01	.21	2.52
8/22/91	6	14:35	25	5	B	75	1.5	14.0	.3	6.1	.01	.08	1.32
8/22/91	6	14:35	25	5	B	250	1.5	14.0	.3	6.1	.01	.05	.46
8/22/91	6	14:35	25	5	B	1100	1.5	14.0	.3	6.1	.01	.01	.01
8/22/91	6	14:35	25	5	B	25	1.5	14.0	.3	6.1	.02	.38	3.99
8/22/91	7	15:55	10	5	B	50	1.5	14.0	.3	5.6	.01	0.00	.01
8/22/91	7	15:55	10	5	B	25	1.5	14.0	.3	5.6	.01	.03	.21
8/22/91	7	15:55	10	5	B	25	3.0	14.0	.3	5.6	.01	.01	.11
8/22/91	7	15:55	10	5	B	75	1.5	14.0	.3	5.6	.01	0.00	.08
8/22/91	7	15:55	10	5	B	250	1.5	14.0	.3	5.6	.01	0.00	.01
8/22/91	7	15:55	10	5	B	1100	1.5	14.0	.3	5.6	.01	.01	.01
8/22/91	7	15:55	10	5	B	75	1.5	14.0	.3	5.6	.01	0.00	.06
SITE 3													
9/12/91	1	11:50	0	0	B	50	1.5	18.3	.8	6.9	.01	0.00	.02
9/12/91	1	11:50	0	0	B	25	1.5	18.3	.8	6.9	.01	.01	.11
9/12/91	1	11:50	0	0	B	75	1.5	18.3	.8	6.9	.01	0.00	.04
9/12/91	2	14:50	10	45	B	50	1.5	18.3	1.9	5.6	.01	0.00	.03
9/12/91	2	14:50	10	45	B	25	1.5	18.3	1.9	5.6	.01	.08	1.22
9/12/91	2	14:50	10	45	B	25	3.0	18.3	1.9	5.6	.01	.02	.88
9/12/91	2	14:50	10	45	B	75	1.5	18.3	1.9	5.6	.01	.06	.84
9/12/91	2	14:50	10	45	B	250	1.5	18.3	1.9	5.6	.01	.01	.21
9/12/91	2	14:50	10	45	B	50	1.5	18.3	1.9	5.6	.01	0.00	.05
9/12/91	3	15:52	25	15	B	50	1.5	18.3	1.5	10.3	.01	0.00	.05
9/12/91	3	15:52	25	15	B	25	1.5	18.3	1.5	10.3	.05	.09	8.32
9/12/91	3	15:52	25	15	B	25	3.0	18.3	1.5	10.3	.02	.28	3.43
9/12/91	3	15:52	25	15	B	75	1.5	18.3	1.5	10.3	.05	.29	2.42
9/12/91	3	15:52	25	15	B	250	1.5	18.3	1.5	10.3	.01	.03	.55
9/12/91	3	15:52	25	15	B	25	1.5	18.3	1.5	10.3	.05	.35	5.33
9/13/91	4	12:12	10	15	A	50	1.5	18.3	1.2	6.4	.01	0.00	.02
9/13/91	4	12:12	10	15	A	25	1.5	18.3	1.2	6.4	.01	.02	.56
9/13/91	4	12:12	10	15	A	25	3.0	18.3	1.2	6.4	.01	0.00	.39
9/13/91	4	12:12	10	15	A	75	1.5	18.3	1.2	6.4	.01	.02	.11
9/13/91	4	12:12	10	15	A	250	1.5	18.3	1.2	6.4	.01	0.00	.10
9/13/91	4	12:12	10	15	A	75	1.5	18.3	1.2	6.4	.01	.01	.14

Table 3-4 (continued) - 3

DATE	RUN	TIME START	VEH. SPEED (MPH)	VEH. FREQ. (VPH)	STAB. CLASS	SAMPLER DIST. (FT)	SAMPLER HEIGHT (M)	BULK ASB. CONT.[a]	MOIS-TURE CONT.[b]	SILT CONT.[b]	PCM CONC.[c] (F/CC)	TEM-MEASURED CONC. >=5u (STRUC/CC)	ALL (STRUC/CC)
9/13/91	5	13:21	25	5	B	50	1.5	18.3	1.4	7.4	.01	0.00	.01
9/13/91	5	13:21	25	5	B	25	1.5	18.3	1.4	7.4	.02	.12	1.66
9/13/91	5	13:21	25	5	B	25	3.0	18.3	1.4	7.4	.02	.09	1.05
9/13/91	5	13:21	25	5	B	75	1.5	18.3	1.4	7.4	.01	.03	.74
9/13/91	5	13:21	25	5	B	250	1.5	18.3	1.4	7.4	.01	.03	.47
9/13/91	5	13:21	25	5	B	250	1.5	18.3	1.4	7.4	.01	.04	.51
9/13/91	6	14:28	10	5	B	50	1.5	18.3	1.2	6.4	.01	0.00	.01
9/13/91	6	14:28	10	5	B	25	1.5	18.3	1.2	6.4	.01	.01	.17
9/13/91	6	14:28	10	5	B	25	3.0	18.3	1.2	6.4	.01	0.00	.05
9/13/91	6	14:28	10	5	B	75	1.5	18.3	1.2	6.4	.01	.02	.15
9/13/91	6	14:28	10	5	B	250	1.5	18.3	1.2	6.4	.01	0.00	.04
9/13/91	6	14:28	10	5	B	25	3.0	18.3	1.2	6.4	.01	0.00	.04
9/13/91	7	15:40	10	45	C	50	1.5	18.3	.4	7.4	.01	0.00	.01
9/13/91	7	15:40	10	45	C	25	1.5	18.3	.4	7.4	.03	.24	4.01
9/13/91	7	15:40	10	45	C	25	3.0	18.3	.4	7.4	.01	.03	.77
9/13/91	7	15:40	10	45	C	75	1.5	18.3	.4	7.4	.01	.12	1.16
9/13/91	7	15:40	10	45	C	250	1.5	18.3	.4	7.4	.01	.01	.39
SITE 4													
9/14/91	1	11:48	0	0	B	50	1.5	16.7	.7	7.8	.01	0.00	.02
9/14/91	1	11:48	0	0	B	25	1.5	16.7	.7	7.8	.01	0.00	.02
9/14/91	1	11:48	0	0	B	75	1.5	16.7	.7	7.8	.01	0.00	.05
9/14/91	2	13:47	25	45	B	50	1.5	16.7	.7	7.1	.01	0.00	.01
9/14/91	2	13:47	25	45	B	25	1.5	16.7	.7	7.1	.14	1.10	14.20
9/14/91	2	13:47	25	45	B	25	3.0	16.7	.7	7.1	.09	.52	6.64
9/14/91	2	13:47	25	45	B	75	1.5	16.7	.7	7.1	.12	.24	6.72
9/14/91	2	13:47	25	45	B	250	1.5	16.7	.7	7.1	.02	.22	3.86
9/14/91	2	13:47	25	45	B	250	1.5	16.7	.7	7.1	.03	.12	2.66
9/14/91	3	15:45	25	15	B	50	1.5	16.7	.5	8.4	.01	0.00	.01
9/14/91	3	15:45	25	15	B	25	1.5	16.7	.5	8.4	.07	.07	5.28
9/14/91	3	15:45	25	15	B	25	3.0	16.7	.5	8.4	.03	.04	2.64
9/14/91	3	15:45	25	15	B	75	1.5	16.7	.5	8.4	.03	.12	2.34
9/14/91	3	15:45	25	15	B	250	1.5	16.7	.5	8.4	.01	.10	1.05
9/14/91	3	15:45	25	15	B	75	1.5	16.7	.5	8.4	.03	.07	2.18

[a] Bulk asbestos content in percent, determined by the mean of three composite samples of the road surface material.

[b] In percent

[c] Phase contrast microscopy measured asbestos concentration

of the samples respectively. Non-chrysotile structures including Antigorite generally occurred at a rate of about 1% of chrysotile structures.

3.3 METEOROLOGICAL CONDITIONS

Table 3-5 summarizes the meteorological conditions experienced each day of testing at each study site. Note that data recording for each day began upon site arrival, usually 9 to 11 A.M., and ended upon site departure, usually 5 to 7 P.M. Therefore these values represent highs, lows, and means of the meteorological parameters during this period, not true daily highs, lows, and means.

Table 3-6 summarizes the wind conditions experienced for each testing run at each study site. Items included are mean wind speed, mean wind direction, and standard deviation of wind direction.

Table 3-5. SUMMARY OF METEOROLOGICAL CONDITIONS MEASURED ON EACH STUDY DAY

Site No.	Date	Relative Humidity		Temperature		Avg. Wind Speed (m/s)	Avg. Wind Direction
		Low	High	Low	High		
1	8/19/91	38%	51%	81.4	89.3	4.0	298°
1	8/20/91	24%	49%	73.3	91.6	4.3	297°
1	8/23/91	37%	47%	80.7	92.9	3.4	275°
2	8/21/91	20%	44%	79.5	93.0	3.8	286°
2	8/22/91	29%	44%	82.1	91.5	3.9	295°
3	9/12/91	37%	53%	78.7	93.5	2.5	265°
3	9/13/91	41%	61%	74.0	91.1	2.4	273°
4	9/14/91	40%	53%	77.8	86.4	3.1	289°
4	9/15/91	51%	63%	74.1	85.7	2.4	283°

Table 3-6. SUMMARY OF WIND CONDITIONS MEASURED FOR EACH TEST RUN

Site No.	Test Run	Mean Wind Speed (m/s)	Mean Wind Direction	Standard Dev. of Wind Dir.
1	1	4.0	301	10.4
1	3	4.1	293	6.3
1	5	4.2	297	11.7
1	6	4.5	294	7.2
1	7	3.4	288	21.1
1	8	3.1	260	12.4
2	1	3.6	280	13.4
2	2	3.3	285	16.8
2	3	3.8	280	10.8
2	4	4.3	283	7.5
2	5	4.0	296	11.1
2	6	3.7	292	11.7
2	7	3.9	290	12.3
3	1	2.2	255	19.6
3	2	2.5	268	17.4
3	3	2.9	288	11.7
3	4	1.2	263	45.6
3	5	2.3	249	15.7
3	6	3.1	269	14.1
3	7	3.5	282	9.8
4	1	3.1	293	13.1
4	2	3.2	303	16.2
4	3	3.3	306	12.9

3.4 QUALITY ASSURANCE FOR AIR SAMPLES

To ensure that the field experiments would yield scientifically valid air samples, the following types of quality assurance data samples were taken:

(1) Four laboratory blanks and four field blanks to ensure that all filter cassettes used for air sampling were neither contaminated nor mishandled.

(2) A total of 12 air samples with no traffic on the test road segments (2 air samples at downwind distances of 25' and 75' and 1 at an upwind distance of 50', for each of the 4 study sites) to determine the spatial distribution of background asbestos concentrations.

(3) A total of 21 upwind air samples with traffic on the test road segments to determine the asbestos concentrations in in-coming wind.

(4) A total of 18 replicate air samples taken by a floating sampler that was collocated with one of the primary samplers at 1.5 m or 3.0 m above the ground in order to determine the reproducibility of ambient asbestos concentration measurements. Collocated sampler results are provided in Appendix A.

(5) Two distant air samplers at 1100 feet downwind at Site 2 for two 5-hour periods to determine the downwind extent of traffic-induced road dust.

As to the laboratory and field blanks, none of the blank samples were found to contain any structures above the detection limit of transmission electron microscopy. This provided assurance that the filter cassettes used in the field experiments were indeed not contaminated.

In addition to the quality assurance measures listed above, all results were further verified by checking the consistency of data and examining all anomalous values. Although some values were identified that did not meet expected patterns (e.g., run 3 at site 3 where the TEM0 concentration at 3m was higher than at 1.5m), none were judged to be outside the range of plausibility.

Table 3-7 provides comparisons of ambient asbestos concentrations under three background conditions and two test conditions:

Background Condition

- No traffic
- Upwind receptors with traffic
- Remote receptors with traffic

Test Condition

- Downwind receptors at 1.5 m with traffic
- Downwind receptors at 3.0 m with traffic

The table shows that mean concentrations under the three background conditions (0.022 - 0.032 struc/cc) are only about a hundredth of those under the two test conditions (2.11 and 2.43). Because of this extremely low asbestos concentration level, the three background conditions (i.e., no traffic, upwind and 1100 ft downwind with traffic) indeed were judged to provide background asbestos concentrations.

Concentration values listed in Table 3-7 are for TEM0 -- all structures having ≥ 3-to-1 aspect ratio regardless of size. More conventional TEM5 (structures greater than 5 micrometers with ≥ 3-to-1 aspect ratio) concentrations were an order of magnitude lower than TEM0 concentrations. Since TEM5 concentrations under the three background conditions were below or around the TEM detection limit, the background asbestos levels exemplified by those under the three background conditions were judged to be negligible as compared to asbestos concentrations of the two test conditions -- in immediate downwind area with considerable traffic.

Asbestos concentrations of each pair of two collocated air samples (i.e., "replicate" vs "primary") are compared in Figures 3-1 and 3-2. Figure 3-1 shows TEM0 concentrations of 18 replicate samples taken by the floating sampler and those of the corresponding primary samples taken at upwind (2 samples) and downwind (16 samples) locations. The near symmetric scatter around the 1-to-1 line in the figure indicates a good reproducibility of ambient asbestos measurement by our sampling and TEM analysis methods. Although there is moderate scatter (indicating some random error), no particular trend is present (indicating negligible systematic error). Figure 3-2 shows the same pairs of data for TEM5 concentrations. This figure also exhibits a symmetric scatter around the 1-to-1 line, indicating no biases in either the sampling method or the analysis method used.

Table 3-7. COMPARISON OF BACKGROUND ASBESTOS CONCENTRATIONS WITH DOWNWIND ASBESTOS CONCENTRATIONS.

Background (B)/ Test (T) Conditions	Sample Size	TEM0, struc/cc				
		min	max	median	mean	s.d.
B: No traffic (both upwind & downwind)	12	.009	.114	.019	.032	.033
B: Upwind w/ traffic	21	.009	.139	.010	.024	.030
B: Remote Sample (at 1100 ft) w/ traffic	2	.009	.035	n/a	.022	.019
T: Downwind at 1.5m above the ground w/ traffic	72	.009	14.200	1.314	2.434	2.864
T: Downwind at 3.0m above the ground w/ traffic	19	.047	6.642	1.380	2.109	1.850

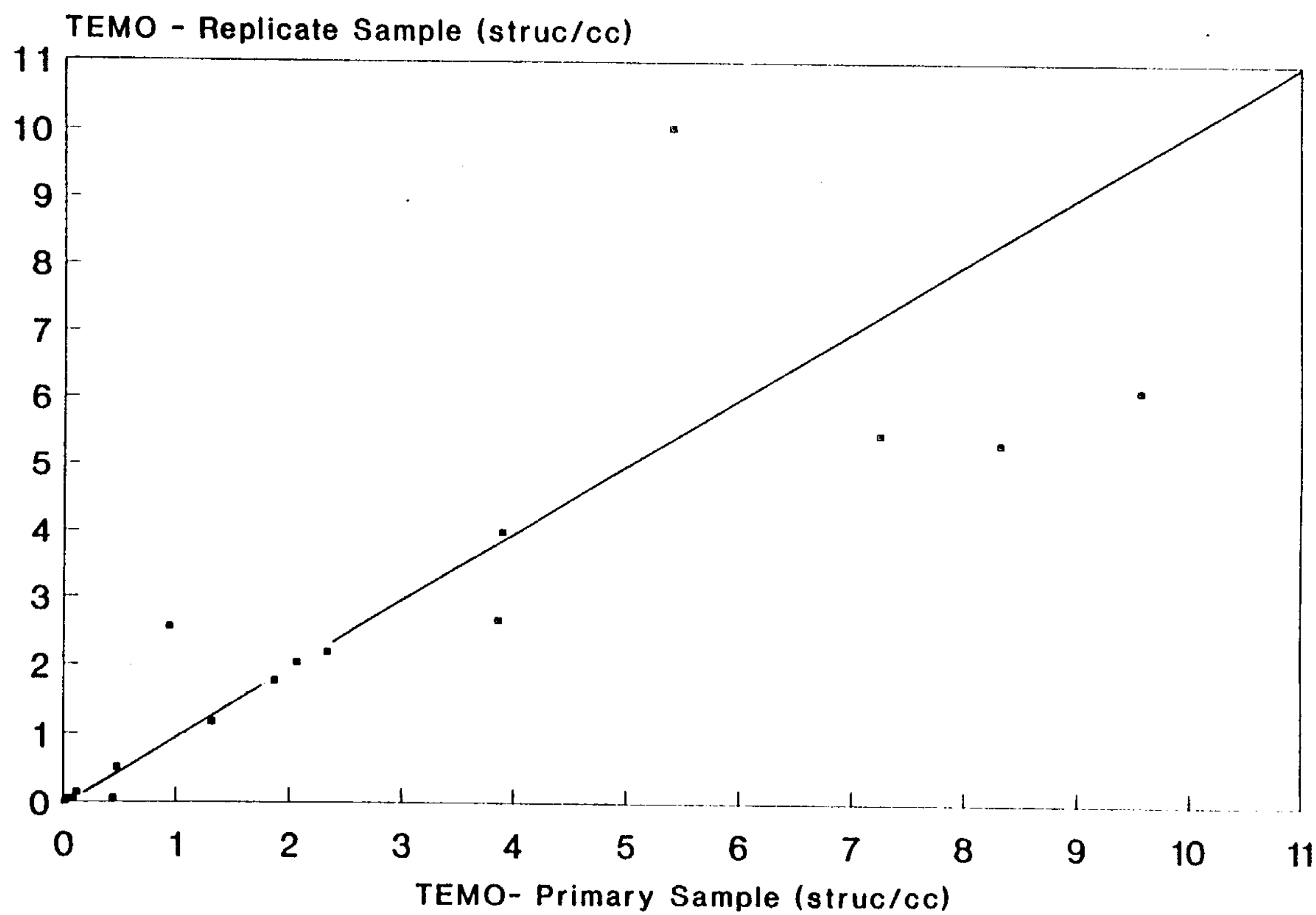

Figure 3-1. Comparison of TEM0 Asbestos Concentrations of Replicate Samples with those of Primary Samples (n = 18).

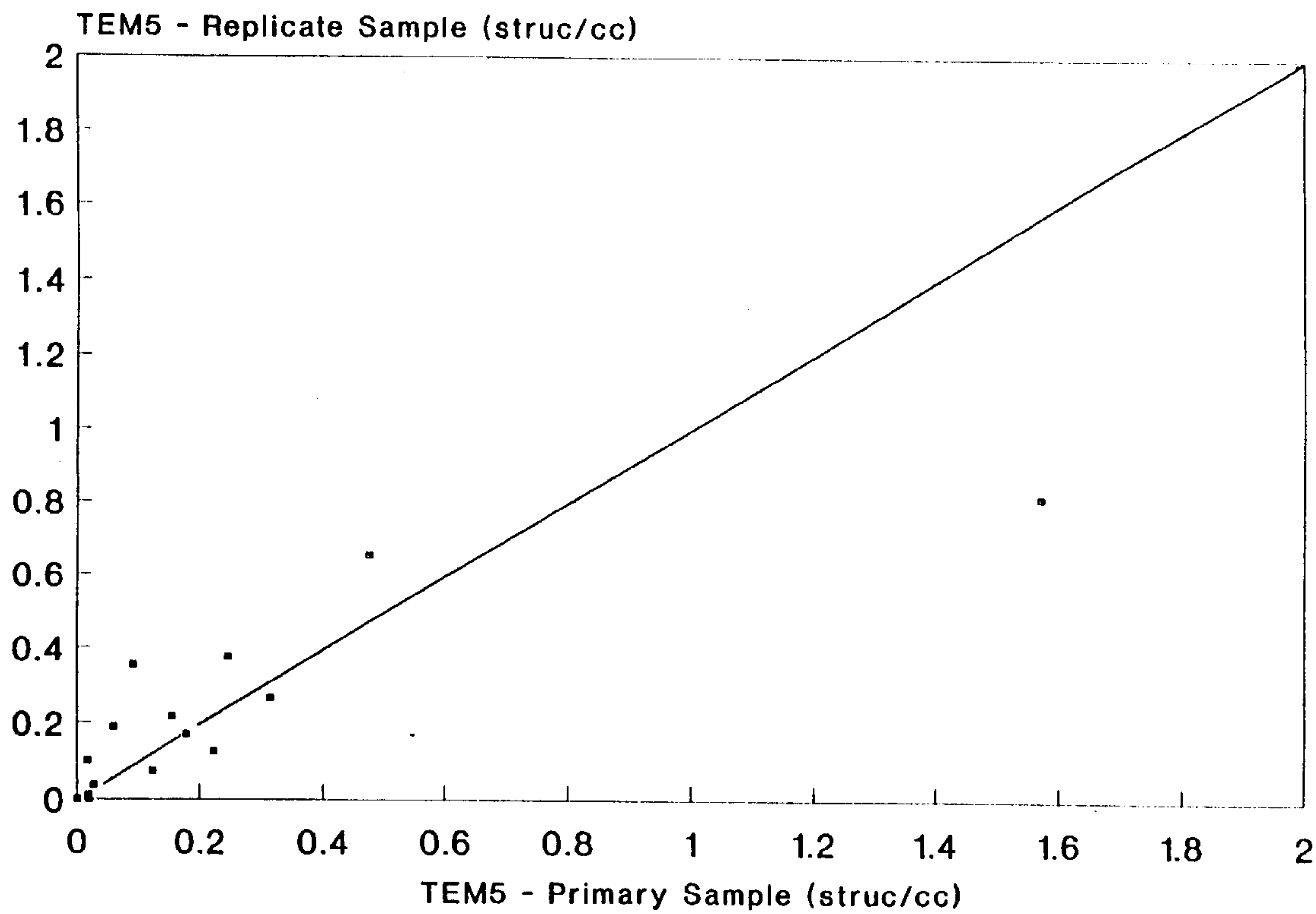

Figure 3-2. Comparison of TEM5 Asbestos Concentrations of Replicate Samples with those of Primary Samples (n = 18).

Figure 3-3 shows a scattergram of downwind (at 25 feet) asbestos concentrations at two different heights: 1.5 m and 3.0 m above the ground. It exhibits fairly high correlation between concentrations at 1.5 m and 3.0 m. To check whether the correlation exhibited in measured concentrations at 1.5 m and 3.0 m is reasonable, a theoretical ratio of concentrations at the two heights was computed according to the following equation:

$$\frac{A_{1.5}}{A_0} = \exp\left[-\frac{1}{2}\left(\frac{1.5}{\sigma_z}\right)^2\right] \quad (3\text{-}1)$$

where $A_{1.5}$ is a theoretical concentration at 1.5 m above the ground, A_0 is a theoretical concentration on the ground, and σ_z is a vertical dispersions parameter. The reason for using 1.5 m and 0 m in the equation is that samplers at 1.5 m in the field experiment were presumed to represent virtual ground-level concentrations to which people are exposed.

Theoretical concentration ratios were computed using actual wind and stability conditions that existed at the 19 data points. Then, the theoretical ratios were compared with ratios of measured asbestos concentrations at 1.5 m and 3.0 m. Table 3-8 shows such comparisons. In general, the theoretical ratios of concentrations at the two heights are in good agreement with those calculated from measured asbestos concentrations. One noticeable difference between the theoretical and measured ratios is that the latter exhibit much wider variation in the ratio values than the theoretical ones.

Judging from the quality assurance data samples described hitherto, the field experiments seem to have generated reasonable scientific data of ambient asbestos concentrations around a serpentine-covered unpaved roadway.

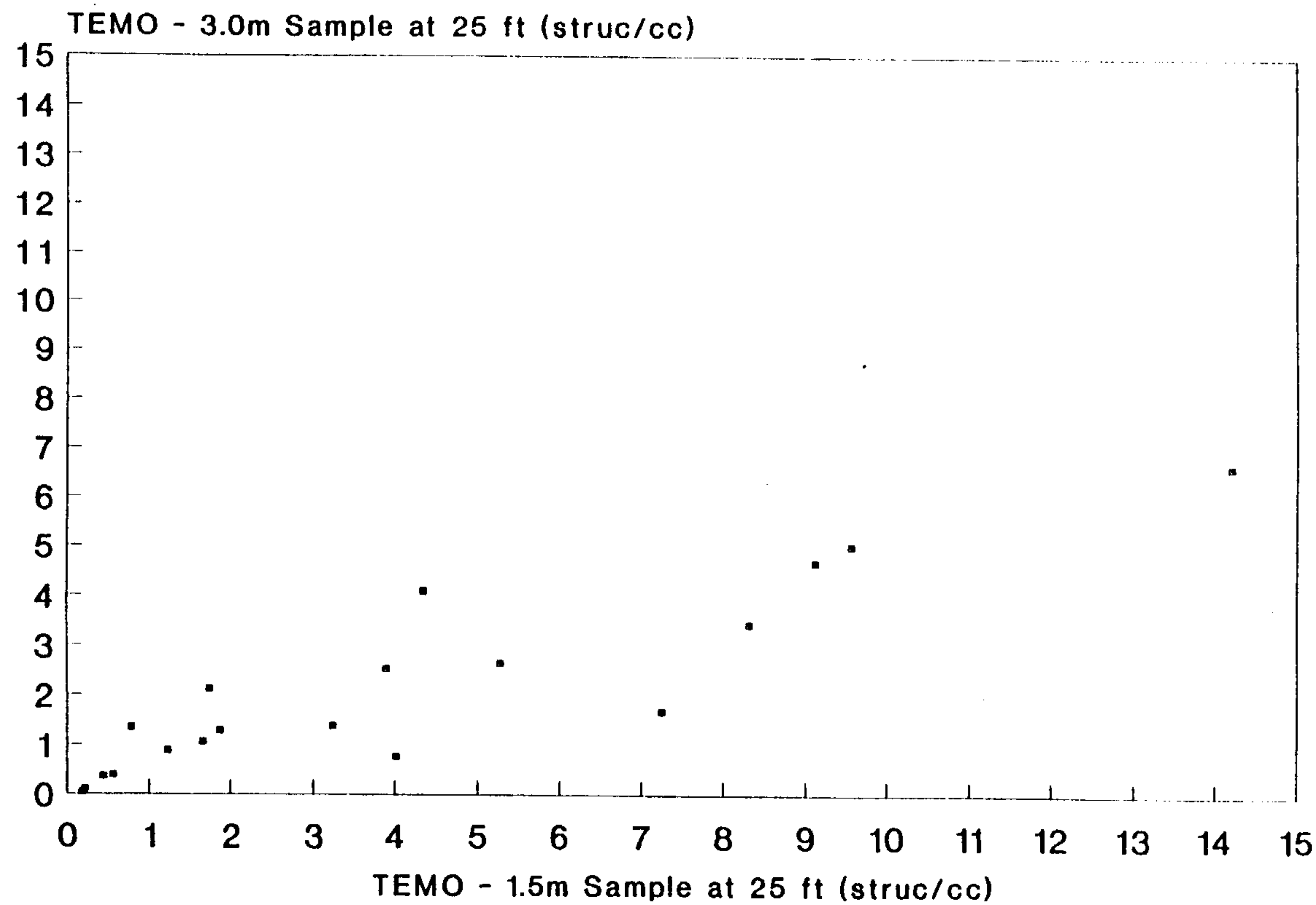

Figure 3-3. Downwind Asbestos Concentrations at 3.0 m and 1.0 m (n = 19).

Table 3-8. COMPARISON OF MEASURED RATIOS AND THEORETICAL RATIOS OF ASBESTOS CONCENTRATIONS AT 3.0 M TO THOSE AT 1.5 M ABOVE THE GROUND.

	Theoretical Ratio	Measured Ratio	
		TEM0	TEM5
Number of Cases	19	19	19
Minimum	0.34	0.19	0.00
Maximum	0.66	1.73	16.03
Median	0.61	0.52	0.47
Mean	0.57	0.64	1.39

4.0 EVALUATION OF EPA MODEL PERFORMANCE

4.1 COMPARISON OF MEASURED vs PREDICTED CONCENTRATIONS

As a preliminary step for evaluating and improving EPA's roadway asbestos concentration model, we compared asbestos concentrations observed in the field experiments with concentrations predicted by the model. The comparisons were made for two types of TEM-measured concentrations: TEM0 (total structures having ≥ 3-to-1 aspect ratios regardless of size) and TEM5 (structures ≥ 5 µm in length). These two number concentrations are reported as number of structures per cubic centimeter of air (struc/cc). The EPA model predicts number concentrations for structures ≥ 5 µm only, namely TEM5, which are considered to be PCM equivalent concentrations. PCM-based airborne asbestos exposure standards are given in Appendix B.

4.1.1 DESCRIPTION OF DATA SET USED FOR EVALUATION

Table 4-1 summarizes the number of TEM-analyzed air samples collected during the field experiments. The complete data set consists of 125 asbestos concentrations and corresponding sampler locations and traffic and weather conditions. This data set comes from test runs at all four study sites near Oakdale and excludes three test runs with unfavorable wind conditions.

Table 4-1. NUMBER OF ANALYZED ASBESTOS SAMPLES BY LOCATION[1]

Sample Location	Background	With Traffic
Downwind, 1.5m height	8	72[2]
Upwind, 1.5m height	4	21
Downwind, 3m height	0	20
Total	12	113

[1]Excluding field blanks, lab blanks, and distant samples.
[2]64 of these above detection limit for TEM5.

Of the 125 data points, 12 are background samples and the other 113 represent samples taken during traffic simulation. Since the model does not predict concentrations in the absence of traffic, background samples were excluded from preliminary analyses. Of the 113 with-traffic samples, only the 72 samples located downwind at 1.5 m height were used for this analysis. This excludes 21 upwind samples and 20 downwind samples at the 3 m sampling height.

The final set of 72 samples includes samples collected at downwind distances of 25 ft., 75 ft., and 250 ft. from the center line of the test roadways. For use as model inputs, the actual distance travelled by the plume was calculated by dividing the sampler distance from the roadway by the cosine of the wind direction's deviation from the perpendicular path to the roadway using:

$$x = \frac{x'}{\cos(DEV)} \qquad (4\text{-}1)$$

Here x = distance travelled by the plume

x' = sampler distance from roadway

DEV = wind direction's deviation from perpendicular path

All 72 samples in the data set were used in TEM0 model analyses. However, 8 data points were excluded from the TEM5 model analyses because of concentrations below detection limits. The complete set including these 72 data points is given in Table 3-4.

4.1.2 COMPARISON OF RESULTS WITH EPA MODEL PREDICTIONS

Model calculations were performed using the EPA model, which is an expanded version of the Copeland Model that incorporates elements of a Gaussian line-source dispersion model and the original Copeland Model for dust emissions from unpaved roads:

$$A = 1.7\,k\,\frac{2}{(2\pi)^{0.5}}\,\frac{S}{12}\,\frac{V}{48}\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{WH}{4}\right)^{0.5}\frac{AC}{100}\,\frac{n}{\sigma_z}\,\frac{CF}{U}\,\frac{365-p}{365} \qquad (4\text{-}2)$$

where A = TEM5 airborne asbestos concentration (struc/cc)

k = aerodynamic particle size multiplier

S = silt content of road surface (%)

V = vehicle speed (km/h)

W = vehicle weight (Mg=megagrams)

WH = number of wheels

AC = asbestos content of road surface (%)

n = vehicle frequency (no. of vehicle passes/s)

σ_z = vertical dispersion parameter (m)

CF = conversion factor (assumes 3×10^{10} struc/g of asbestos)

U = wind speed (m/s)

p = average number of days per year with ≥0.01 inches of precipitation

The vertical dispersion parameter σ_z was calculated using the equation:

$$\sigma_z = (\sigma_z'^2 + H^2)^{0.5} \quad (4\text{-}3)$$

where H is an estimate of the initial vertical dispersion of the vehicle wake (in this case it was set to 1 m, or about half the vehicle height) and where σ_z' is calculated as:

$$\sigma_z' = A\,x^B + C \quad (4\text{-}4)$$

where A, B, and C are constants as defined in Table 4-2.

Four model parameters were kept constant for all model runs. The average number of days per year with greater than 0.01 inches of precipitation was not known for Oakdale, so the value for Stockton (51 days) was used. The particle-size multiplier (k) was kept at the default value of 0.36, which is for particles ≤10 μm in accordance with AP-42. Vehicle weight was kept at 1.8 tons, which is the unladen weight of the test van. The number of wheels was kept at 4.

Table 4-2. CONSTANTS FOR VERTICAL DISPERSION PARAMETER

Stability Class	Distance ≤ 100 m			Distance > 100 m and < 153 m		
	A	B	C	A	B	C
A	0.192	0.936	0.0	0.00066	1.941	9.3
B	0.156	0.922	0.0	0.0382	1.149	3.3
C	0.116	0.905	0.0	0.113	0.911	0.0
D	0.079	0.881	0.0	0.222	0.725	-1.7
E	0.063	0.871	0.0	0.211	0.678	-1.3
F	0.053	0.814	0.0	0.086	0.740	-0.35

4.1.3 RESULTS OF THE COMPARISON

Figure 4-1 shows a comparison of model-predicted TEM5 concentrations vs measured TEM0 concentrations (all structures). The predicted concentrations are short of the measured concentrations by about an order of magnitude. Figure 4-2 shows the comparison using TEM5 data. This shows a better agreement in magnitude between predicted and measured concentrations, but exhibits a weaker association than that shown in Figure 4-1.

Figure 4-3 shows the comparison between model-predicted TEM5 concentrations and measured TEM5 concentrations at the two vehicle speeds used in the test runs. At 10 mph, the model overpredicts concentrations by about 300%, while at 25 mph the model-predicted and measured concentrations show reasonable agreement. Linear regressions were determined for the data shown in figures 4-1 through 4-3 in two ways: (1) with a non-zero intercept and (2) with a zero intercept. Regression statistics are given in Table 4-3. It should be noted that regressions with no intercept consistently perform better than those including an intercept. This implies that measured asbestos concentrations would be better explained by a multiplicative correction term to the EPA model rather than by an additive correction term.

Figure 4-4a shows the concentration profile of measured TEM5 airborne asbestos along downwind distance. Figure 4-4b shows the same profile for model-predicted TEM5

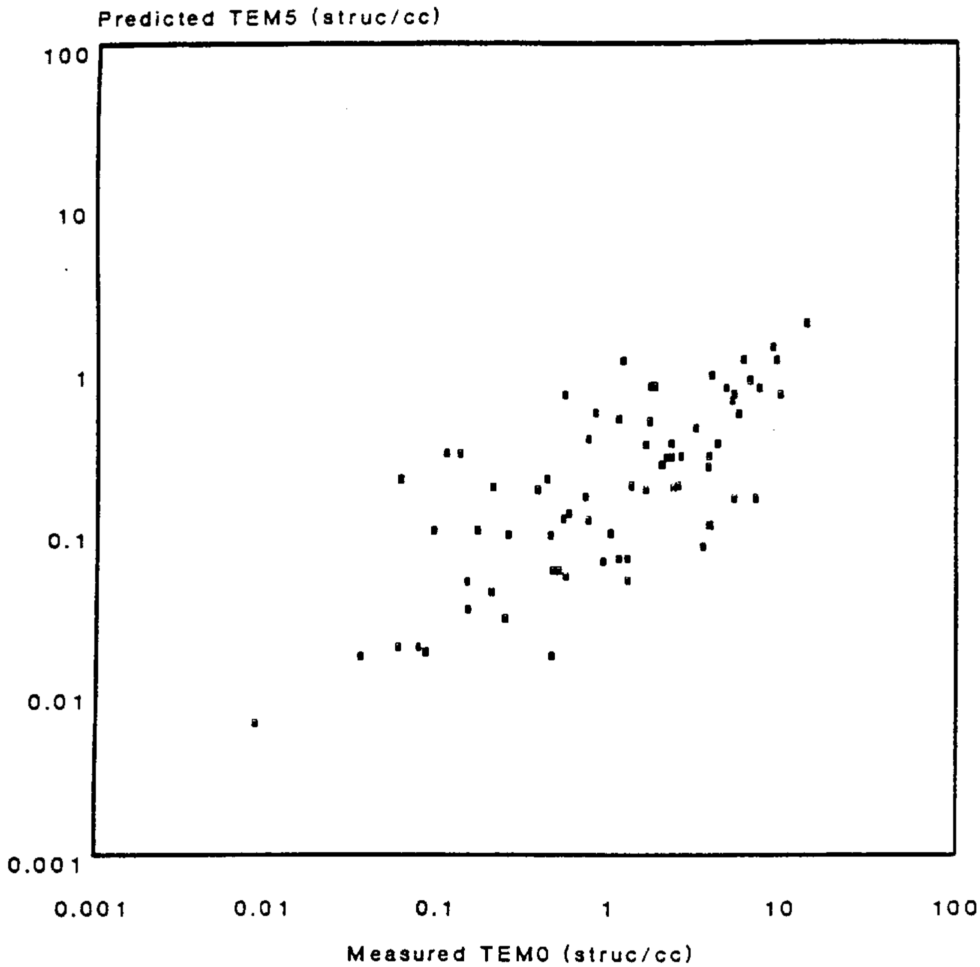

Figure 4-1. EPA Model Performance for Measured TEM0 vs Predicted TEM5 (n=72).

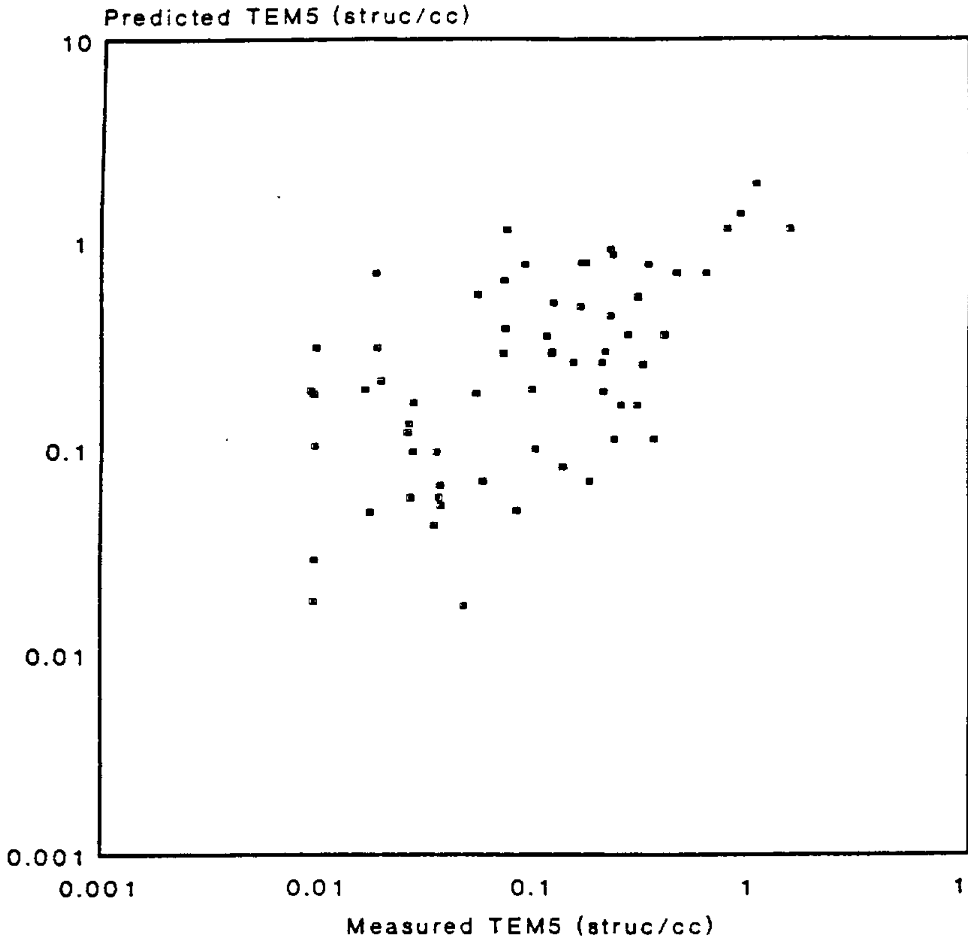

Figure 4-2. EPA Model Performance for Measured TEM5 vs Predicted TEM5 (n=64).

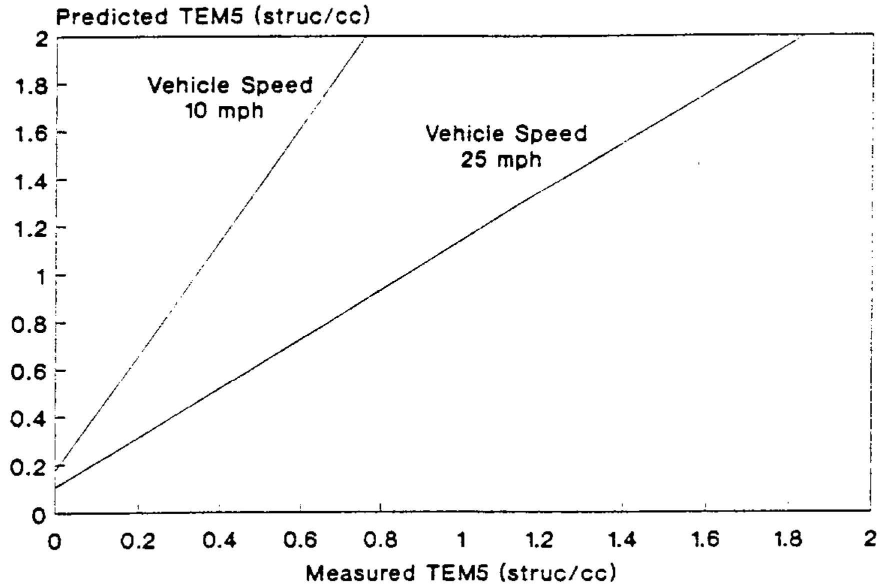

Figure 4-3. EPA Model Performance for Measured TEM5 vs Predicted TEM5 at 10 mph (n=25) and 25 mph (n=39).

Table 4-3. REGRESSION STATISTICS FOR EPA MODEL PREDICTED vs MEASURED ASBESTOS CONCENTRATIONS.

Figure	n	Dependent Variable	Independent Variable	Intercept	Slope	P-Value of Slope	Adjusted r^2
4-1	72	Predicted TEM5	Measured TEM0	0.105	0.097	<0.001	0.55
				—	0.115	<0.001	0.73
4-2	64	Predicted TEM5	Measured TEM5	0.185	0.961	<0.001	0.49
				—	1.275	<0.001	0.67
4-3	25 (10 mph)	Predicted TEM5	Measured TEM5	0.174	2.411	0.003	0.30
				—	3.627	<0.001	0.63
	39 (25 mph)	Predicted TEM5	Measured TEM5	0.108	1.030	<0.001	0.63
				—	1.193	<0.001	0.79

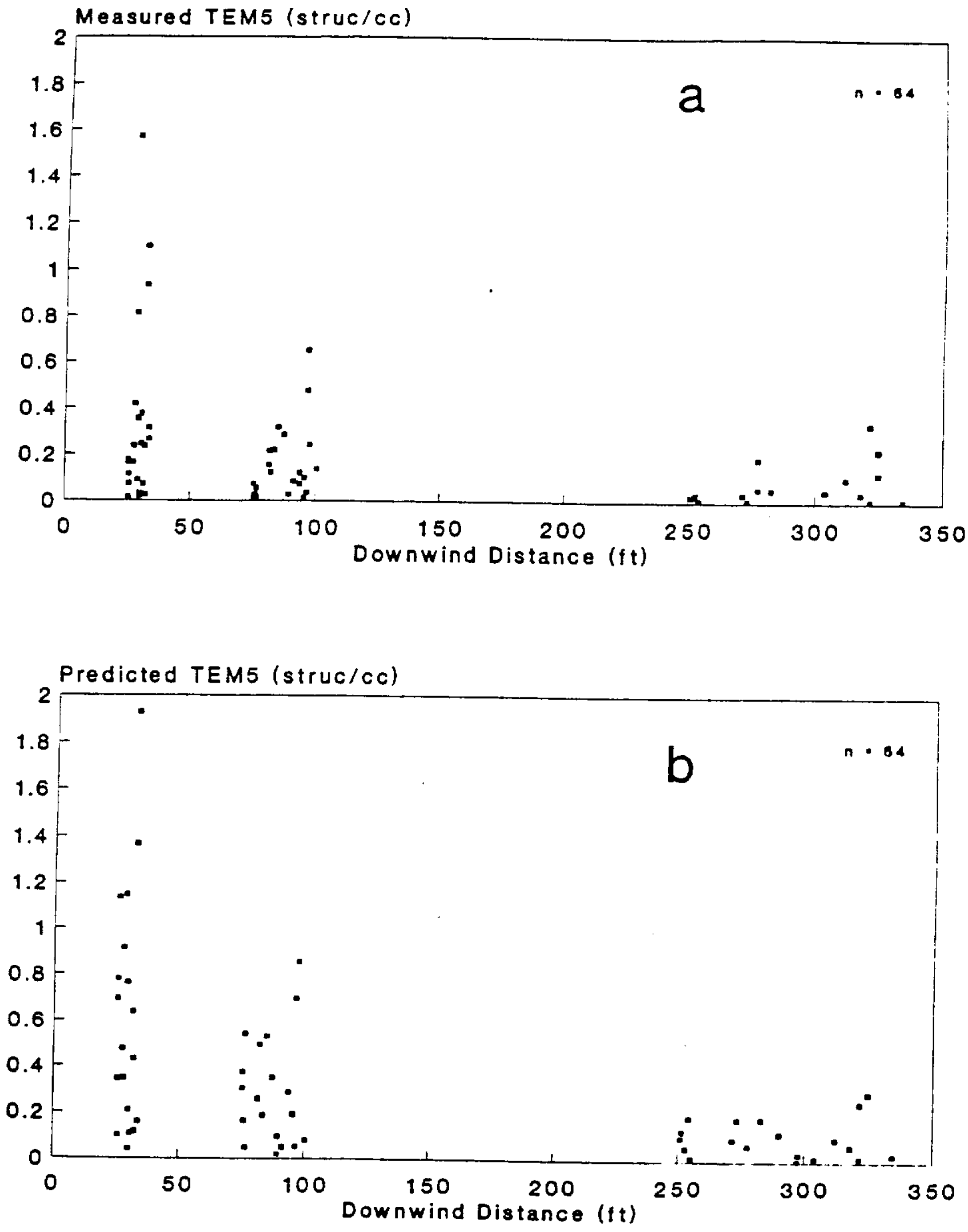

Figure 4-4. EPA Model Performance for Measured (a) vs Predicted (b) Profiles of Downwind Concentrations.

concentrations. The three clusters along the x-axis in each of the profiles represent the three downwind sampler distances of 25 ft., 75 ft., and 250 ft. corrected for wind direction according to Equation 4-1.

4.2 EVALUATION OF THE EPA MODEL STRUCTURE

The present EPA model for assessing asbestos concentrations downwind of an asbestos containing unpaved roadway consists of three model components:

(1) Particulate mass emissions from unpaved road;

(2) Dispersion of emitted asbestos containing particulate matters to downwind receptors; and

(3) Transformation of asbestos containing particulate matter into airborne asbestos fibers.

Using brackets to isolate each of these model components, respectively, the EPA model can be expressed as:

$$A = \left[n\ k\frac{S}{12}\frac{V}{48}\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{WH}{4}\right)^{0.5}\left(\frac{365-p}{365}\right)\right]\left[\frac{2}{(2\pi)^{0.5}\sigma_z U}\right]\left[1.7\ \frac{AC}{100}\ CF\right] \qquad (4\text{-}5)$$

where
A = TEM5 airborne asbestos concentration (structures/cc)
k = aerodynamic particle size multiplier
S = silt content of road surface (%)
V = vehicle speed (km/h)
W = vehicle weight (Mg=megagrams)
WH = number of wheels
AC = asbestos content of road surface (%)
n = vehicle frequency (vehicles/s)
σ_z = vertical dispersion parameter (m)
CF = conversion factor (assumes $3x10^{10}$ structures/g of asbestos)
U = wind speed (m/s)
p = average number of days per year with >0.01 inches of precipitation

The first component of the model is given by the Copeland Emission Factor model, which is said to be the best currently available model for particulate emissions from unpaved roadway. This is confirmed by personal communication with Mel Zeldin of SCAQMD and Drs. Charles Cowherd and Gregory Muleski of the Midwest Research Institute.

The only improvement that can be made on this emission factor equation would be to replace the last precipitation term with soil moisture content. As in the silt content, site-and test-condition specific soil moisture content will be a better parameter for hourly particulate emission rates than the annual number of days with measurable precipitation at a nearby NWS station.

The Gaussian line source dispersion model used in the second component also seems reasonable as evidenced by the similarity of downwind concentration profiles between the measured and model-predicted concentrations (see Figure 4-4).

The third component regarding the transformation of road surface material into airborne asbestos fibers appears to contain several unsubstantiated assumptions. The EPA model assumes that particulate mass emitted from unpaved road increases linearly with increasing vehicle speed as seen in the first component. It is also implicitly assumed that the number of asbestos fibers generated increases linearly with increasing vehicle speed. Although the first assumption seems reasonable, the second assumption does not seem to have been substantiated with any evidence.

4.3 ANALYSIS OF RESIDUALS

The robustness of a prediction model can be examined by plotting the residuals of model-predicted values less measured values against various model parameters. Figures 4-5 through 4-9 show such residual plots against five selected parameters of the EPA model: vehicle speed, traffic volume, asbestos content, moisture content, and silt content. In a residual plot, the model can be said to be robust with respect to a model parameter if residuals scatter randomly around zero at any value of the parameter. If the residual plot exhibits any trend over parameter values, then the model is said to be biased with respect to that parameter.

Figure 4-5 shows that the EPA model tends to overestimate asbestos concentrations at the lower vehicle speed of 10 mph. The EPA model was validated at 30 mph. Therefore, the

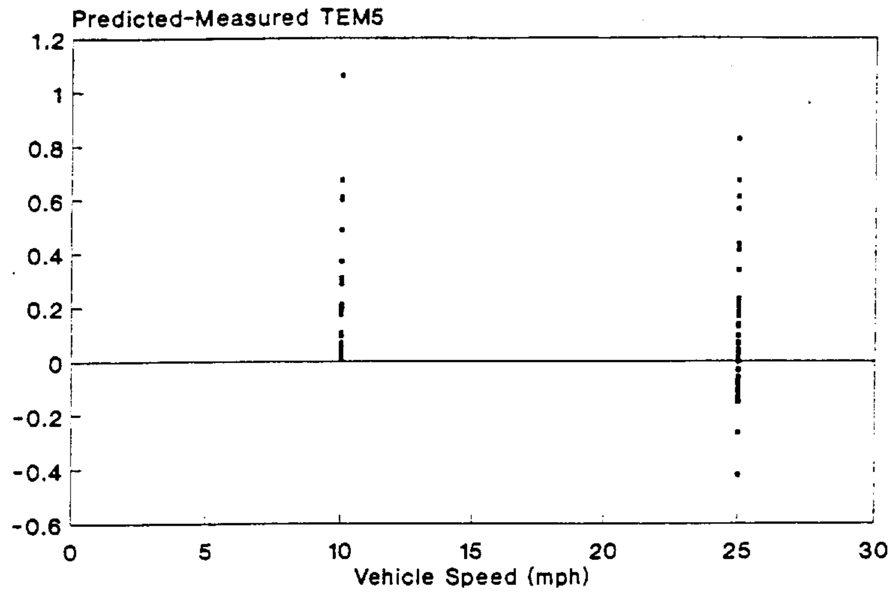

Figure 4-5. Residual Plot against Vehicle Speed.

model performance at 25 mph is quite good as evidenced by the even scatter of residuals around zero. The scatter pattern of residuals in this figure indicates that the number of asbestos structures generated by traffic on unpaved road increase more than linearly with vehicle speed. It can be interpreted that increasing vehicle speed not only increases particulate emissions but also generates more asbestos structures per unit of emitted particulate mass. Therefore, the number of airborne asbestos structures increases more than linearly with increasing vehicle speed. If this interpretation is correct, then the second assumption will turn out to be incorrect. Thus, the EPA model may need to be modified to reflect this fact.

Figure 4-6 shows that the EPA model tends to overestimate ambient asbestos concentrations at the two higher vehicle frequencies, 15 vehicles per hour and 45 vehicles per hour. Figure 3 shows that the model tends to overestimate at higher asbestos contents than 14 percent. Although these tendencies are difficult to explain as to the causes, appropriate correction terms to compensate the tendencies can be introduced to the model if the ARB wants such corrections.

Figures 4-7 and 4-8 show residual plots against bulk asbestos content and road moisture content, respectively. The EPA model, which instead of moisture content uses an annual average precipitation term that was held constant for this analysis, tends to overestimate ambient asbestos concentrations at higher road moisture contents. This is rather counter-intuitive because at the same location, the higher moisture content is expected to result in lower ambient asbestos concentrations. This can be explained by the limited number of sites tested, and the fact that the highest moisture contents happened to occur at the site with the highest bulk asbestos content (i.e., Site 3, see Table 3-4).

Figure 4-9 shows that the EPA model tends to overestimate ambient asbestos concentrations at the higher silt contents around 7.5 percent. The model assumes that asbestos concentrations increase linearly with increasing silt content of the road surface material. However, as with moisture content, silt content may have been coincidentally correlated with other road surface variables at the 4 sites, thus obscuring any direct relationship.

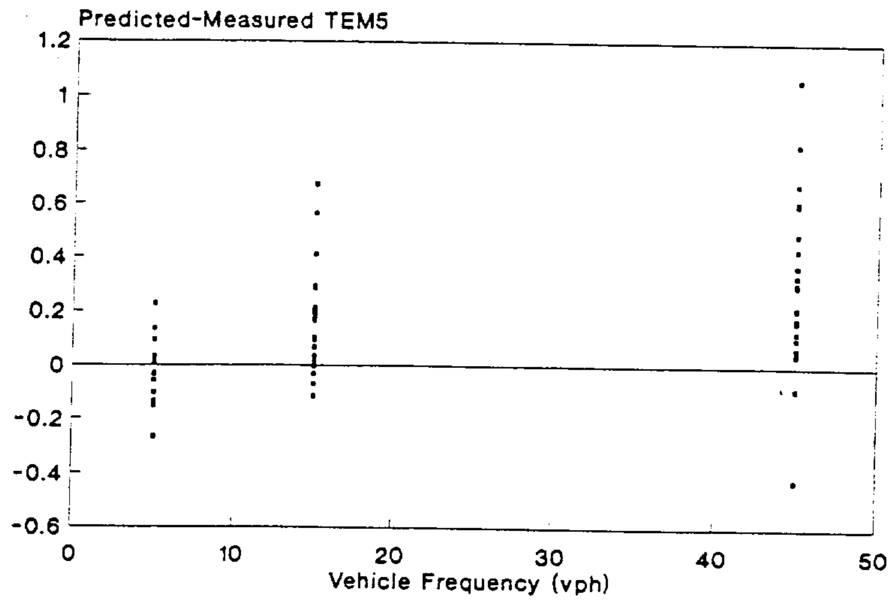

Figure 4-6. Residual Plot against Traffic Volume.

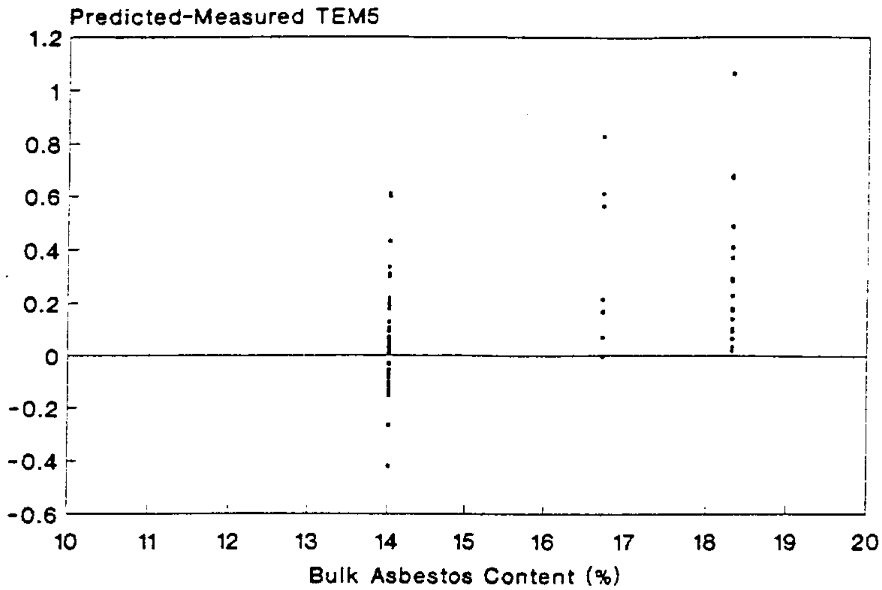

Figure 4-7. Residual Plot against Bulk Asbestos Content.

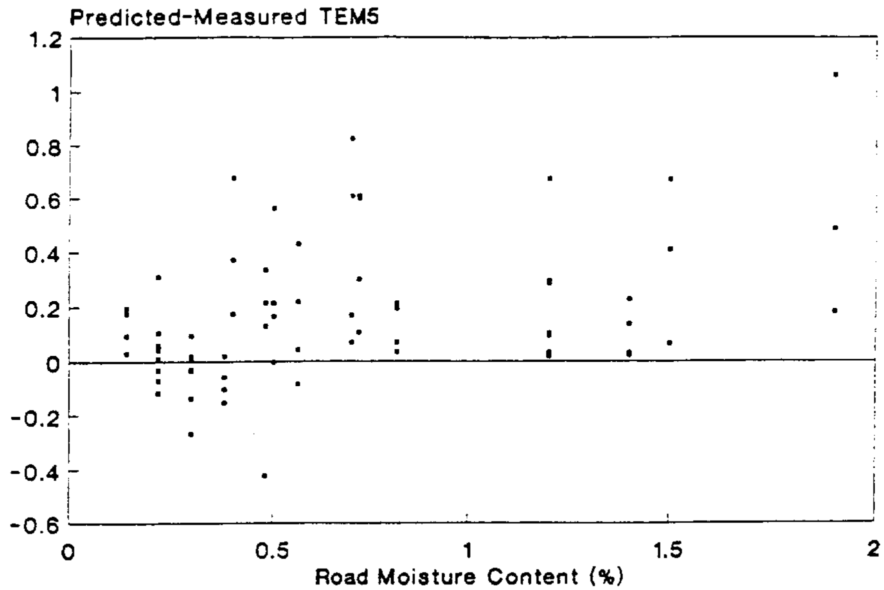

Figure 4-8. Residual Plot against Road Moisture Content.

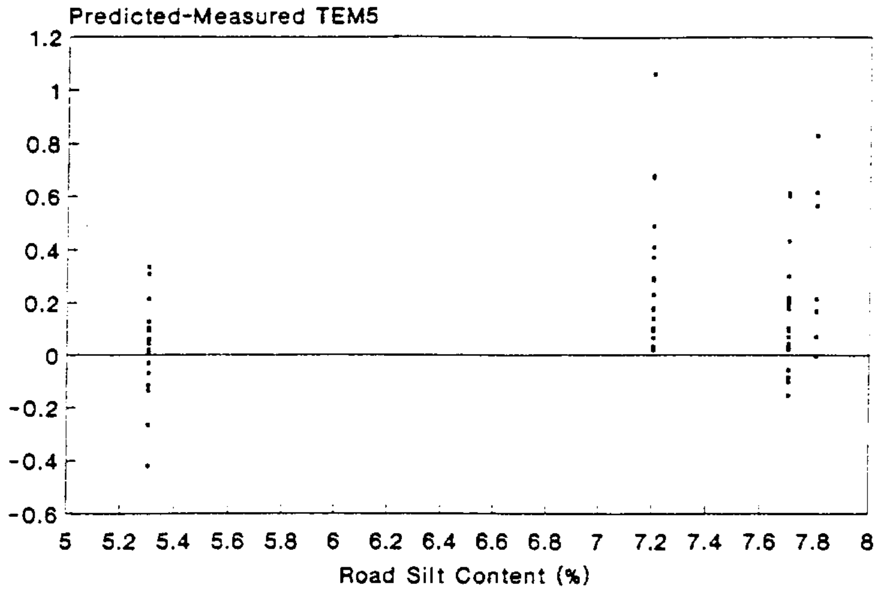

Figure 4-9. Residual Plot against Road Silt Content.

5.0 DEVELOPMENT OF MODIFIED ROAD MODEL

5.1 OBJECTIVES FOR MODEL IMPROVEMENT

The EPA model given by Equation (4-2) contains both a climatological parameter -- precipitation days -- and short temporal parameters such as the atmospheric stability and the dispersion coefficient. Although other model parameters such as vehicle speed, vehicle frequency, and wind speed can be either long-term (e.g., a year) averages or short-term (e.g., 1-hour) averages, the number of days per year with precipitation is by definition a long-term average. On the other hand, the dispersion coefficient and atmospheric stability are meaningful only for a time period of a few minutes to a few hours.

Because of the mixture of a climatological parameter and short temporal parameters in the same equation, the EPA model seems somewhat illogical in its current form. The model appears to be a product of a short-term model and an adjustment term for calculating a long-term average of the concentrations predicted by the short-term model. The precipitation days term of Equation (4-2) is indeed the adjustment term for long-term average concentrations under the following two assumptions;

(1) Road dust emissions arise only on days with no measurable precipitation; and
(2) The dispersion and traffic conditions remain the same over the period of interest.

The first assumption seems reasonable whereas the second assumption is more uncertain. Dust from the road will reach the receptor only while the wind direction has a component toward the receptor. Under most climatological conditions, this occurs less than 100 percent of the time.

As a predictive model, it should also provide the user an option of estimating short-term averages. For this purpose, the precipitation days term of the EPA model was replaced with a new model parameter for road surface moisture content that has proved to be useful for explaining an inverse relationship between dust generation and moisture content observed in the field experiments.

As described in the preceding section, the EPA model exhibits biases with respect to some model parameters. Thus it was a goal to reduce these biases by determining and applying a proper correction term to the EPA model. In addition, two additional features were considered important: a module to account for the effect of a finite road segment (instead of an infinite line source) on downwind concentrations; and a module to estimate short-term concentrations as well as long-term average concentrations.

5.2 DEVELOPMENT OF SHORT-TERM MODEL

To reduce the biases found in the EPA model evaluation (Section 4.0), a correction term, G, is explored in this section. For each of the 64 data points used in the model evaluation, G was calculated as:

$$G = \text{(Measured TEM5)/(Predicted TEM5)} \qquad (5\text{-}1)$$

where Measured TEM5 is the measured airborne asbestos concentration for structures $\geq 5\ \mu m$ and Predicted TEM5 is the airborne asbestos concentration predicted by the EPA model without the term for precipitation days (p). A series of multiple linear regressions were then calculated according to the equation:

$$\log G = b_1 \log X_1 + b_2 \log X_2 + ... + b_n \log X_n + \log C \qquad (5\text{-}2)$$

where b is the slope of the regression, X represents measured model parameters, and C is a constant. The regression was performed on several different combinations of variables such as vehicle frequency, vehicle speed, silt content, etc. The most plausible result was obtained from the use of vehicle speed and moisture content, as:

$$\log G = \log V - 0.6 \log M - 5.5 \qquad (5\text{-}3)$$

where V is vehicle speed and M is percent moisture content of the road surface. This equation explained about 48% of the variance in log G ($p < 0.001$) and was found to reduce 76% of the variance of the model prediction errors on the 64 data points. Thus an improved VRC model is written as:

$$[\text{VRC MODEL}] = [\text{EPA MODEL}] \times G \qquad (5\text{-}4)$$

$$= [\text{EPA MODEL}] \times 0.012 \times VM^{-0.6} \qquad (5\text{-}5)$$

or:

$$A = 1.7\ k\ \frac{2}{(2\pi)^{0.5}}\ \frac{S}{12}\ \frac{V^2}{48}\left(\frac{W}{2.7}\right)^{0.7}\left(\frac{WH}{4}\right)^{0.5}\frac{AC}{100}\ \frac{n}{\sigma_z}\ \frac{CF}{U}\ \frac{0.012}{M^{0.6}} \qquad (5\text{-}6)$$

This equation represents the short-term model for predicting hourly average concentrations for cases where some site-specific data on asbestos, silt, and moisture contents and on local wind conditions are available.

Figure 5-1 shows a scatter plot of the concentrations predicted by the VRC model vs measured concentrations. Although substantial scatter is still evident, it represents an improvement over the EPA model performance as shown in Figure 4-2. The VRC model explains 81% of the variance in the measured concentrations, compared to 67% explained by the EPA model.

5.2.1 DEFAULT VALUES

The computer code of the VRC model is designed to assign default values for all unspecified model parameters. The purpose of assigning default values is twofold:

(1) To provide a basis for sensitivity analyses and demonstration of the model.
(2) To provide model users with reference values.

In view of these purposes, default values should be selected to be as representative as possible of situations in which the model is likely to be used. Defaults were selected as follows:

Stability Class: Stability class is an alphabetic categorical variable with a lookup table (Table 4-2) to calculate a dispersion parameter, σ_z. Though the neutral class D is used as a default in the EPA model, and indeed is the most likely typical stability class in the long term, it is not considered representative of atmospheric stability during peak traffic hours. Thus stability class B was selected as the default because it represents an intermediate stability during daylight conditions.

k-factor: In accordance with AP-42, the default value for k is set to 0.36, which is the aerodynamic particle-size multiplier for particles $\leq 10\ \mu m$.

Silt Content: The default silt content was set to 7%, which was typical of the 4 field experiment sites, all of which were moderately worn roadways.

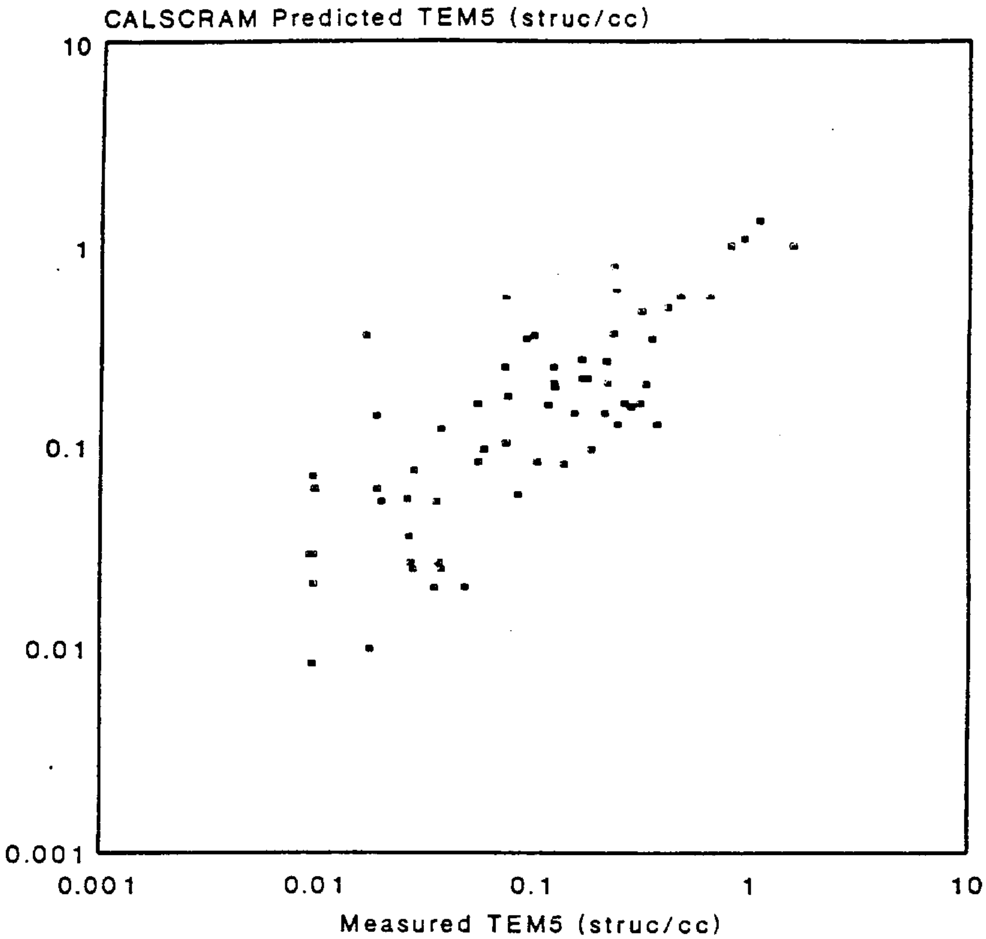

Figure 5-1. VRC Model Performance for Measured TEM5 vs Predicted TEM5 (n=64).

Vehicle Speed: The default vehicle speed was set to 25 mph, for reasons discussed in Section 2.2.3.

Vehicle Weight: The default vehicle weight was set to 1.8 tons, which is typical of a light truck or van.

Number of Wheels: The default number of wheels was set to 4.

Vehicle Frequency: The default vehicle frequency was set to 5 veh/h.

Asbestos Content: The default asbestos content was set to 10%, which is lower than typical asbestos contents in the Oakdale region where the field experiments were conducted, but may be more representative of serpentine-covered roads statewide.

H: The default value for H, the initial dispersion of the vehicle wake, was set to 1 m, which is roughly 50% of the height of a light truck or van.

Wind Speed: The default wind speed is set to 3 m/s, which is typical of wind speeds observed in the Oakdale area during the field experiments (mean wind speed for Stockton is 3.3 m/s; Fresno 2.8 m/s).

Moisture Content: The default value for road moisture content was set to 1%.

5.2.2 SENSITIVITY ANALYSIS

To determine model sensitivity to changes in model parameters, each input parameter was first decreased from default setting by 10% and then increased by 10% while all other input parameters were held at default levels. The mean deviation of the two resultant model outputs was then divided by the model output at default settings. Model parameters are ranked in Table 5-1 in descending order of the model's sensitivity to an equal percent change in these parameters. Sensitivity of the EPA model is shown for comparison. The model is most sensitive to changes in vehicle speed and least sensitive to changes in H. Since stability class is an ordinal variable and thus cannot be changed by a percentage as with other parameters, sensitivity of the model to changes in stability class as a function of downwind distance was separately computed (see Figure 5-2).

Table 5-1. MODEL SENSITIVITY

Parameter	Default Value	Sensitivity[a]	
		EPA Model	VRC Model
V	25 mph	10%	20%
k	0.36	10%	10%
S	7%	10%	10%
n	5 vph	10%	10%
AC	10%	10%	10%
U	3 m/s	10%	10%
d[b]	50 ft	7.3%	7.3%
W	1.8 tons	7%	7%
M[c]	1%	na	6%
WH	4	5%	5%
H[b]	1 m	2%	2%

[a]Sensitivity defined as the average percent change in output given a 10% increase or decrease in the value of the parameter at default conditions.

[b]Parameter sensitivity dependent on downwind distance, 50 ft in this analysis.

[c]Moisture content (M) is not included as a parameter in the EPA model.

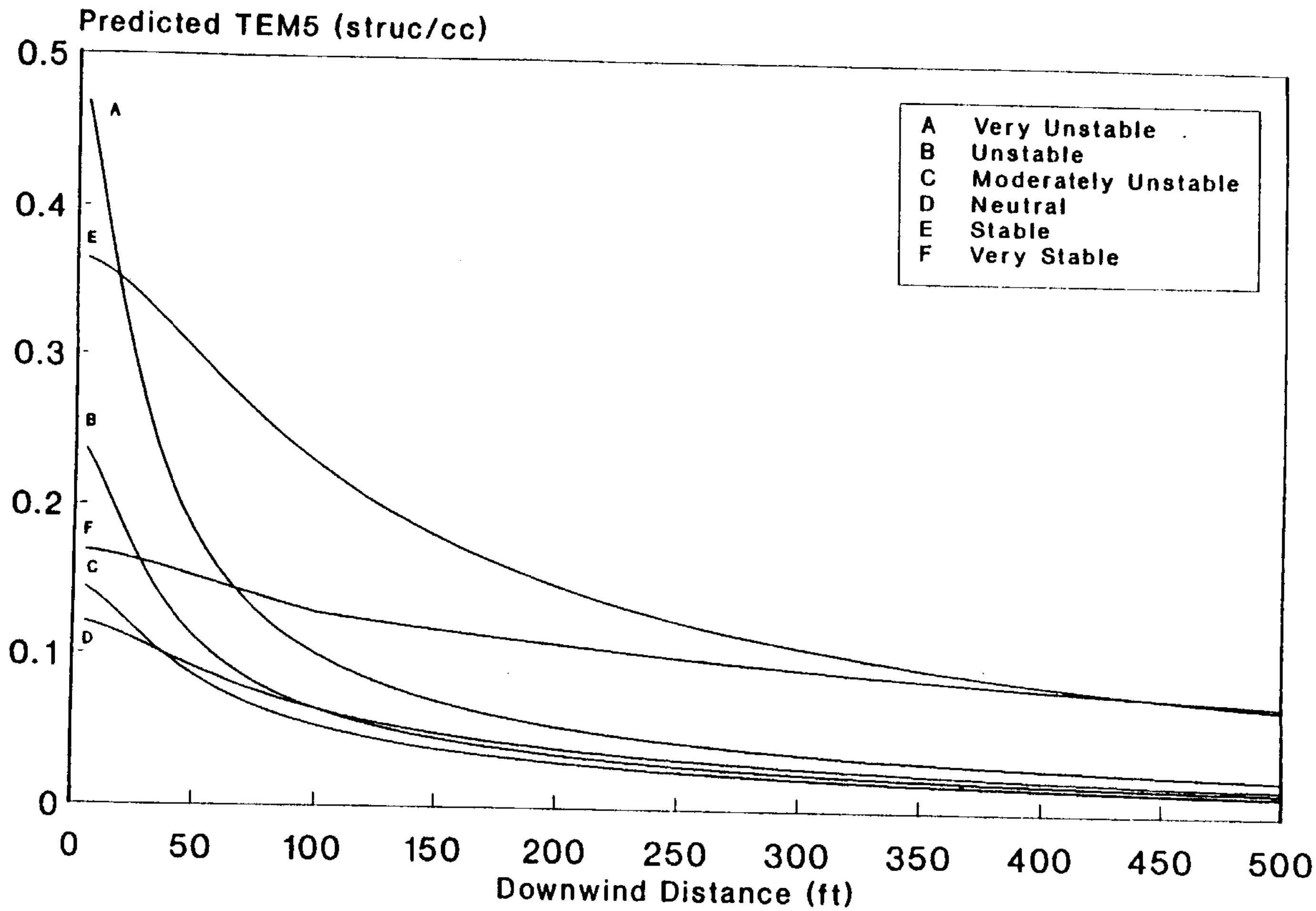

Figure 5-2. Asbestos Concentrations as a Function of Downwind Distance for Each Stability Class.

5.2.3 SHORT ROAD SEGMENTS

The EPA model is based on a line source dispersion equation given by Turner (1970). The equation assumes that the line source is infinite. This assumption has little impact on model predictions for longer road segments. However, in cases where the length of the road segment is less than about the distance from the road to the receptor, this will cause progressive overestimation with increasing distance from the road.

Turner (1970) also provides a correction term needed for short road segments which can be expressed as:

$$\frac{1}{\sqrt{2\pi}} \int_{p_1}^{p_2} e^{-p^2}\, dp \qquad (5\text{-}7)$$

where $p = y/\sigma_z$ and y is the lateral distance along the roadway. The values p_1 and p_2 are given for y = -L/2 and y = +L/2 where L is the length of the road segment. It is assumed that the receptor is directly downwind of the midpoint of the road segment, L.

Table 5-2 shows the effects of a finite road segment on downwind concentrations under various stability classes. The effects are most pronounced under A stability and the least under D stability.

5.3 DEVELOPMENT OF LONG-TERM MODEL

An easy-to-use long-term model was devised by introducing two adjustment terms to the VRC short-term model equation: climatological wind term and precipitation days term. The precipitation days term is the same as that of the EPA model, namely, (365-p)/365, where p is the number of days with 0.01 inches or more of precipitation.

The climatological wind term is introduced to account for receptor concentrations brought about by the wind blowing from several different directions over a year or other long period. Assuming that the emission rate remains the same over the period, a long-term average receptor concentration from the emission source is given by:

Table 5-2. EFFECT OF FINITE ROAD SEGMENT ON DOWNWIND CONCENTRATIONS.

Road Length (ft)	Downwind Distance (ft)	Downwind Concentration under Stability Class (struc/cc)			
		A	B	D	F
∞	50	.0636	.0519	.0424	.1517
∞	100	.0351	.0298	.0298	.1282
∞	500	.0082	.0072	.0082	.0504
200	50	.0635	.0518	.0424	.1515
200	100	.0350	.0297	.0297	.1280
200	500	.0069	.0068	.0082	.0504
50	50	.0627	.0514	.0424	.1506
50	100	.0309	.0281	.0296	.1280
50	500	.0023	.0027	.0059	.0487

Note: Wind speed set as: A - 2 m/s, B - 3 m/s, D - 6 m/s, F - 2 m/s

$$\frac{2Q}{(2\pi)^{0.5}} \sum_{i=1}^{8} \frac{f_i}{\sigma_{zi} U_i} \tag{5-8}$$

where Q is the emission rate, f_i is the fraction of the time that wind blows from the i-th sector of the wind rose for the area, U_i is the average wind speed of the i-th sector wind, and i (=1 to 8) is one of the 16 sectors of 22.5 degrees in the wind rose which has at least some component blowing from the roadway to the receptor. The dispersion coefficient σ_{zi} is computed in the same manner as for the short-term model using the mid-direction of each sector wind. The value for downwind distance used to calculate σ_z is given by:

$$x_i = \frac{x}{\cos(DEV_i)} \tag{5-9}$$

where x is the receptor distance from the roadway, x_i is the downwind distance corrected for wind direction, and DEV_i is the deviation of the mid-direction of the i-th sector wind from the perpendicular path of the roadway (see Eq. 4-1).

The long-term model is therefore expressed as:

$$A = 1.7\ kn\ \frac{S}{12}\ \frac{V^2}{48} \left(\frac{W}{2.7}\right)^{0.7} \left(\frac{WH}{4}\right)^{0.5} \frac{AC}{100}\ CF\frac{0.012}{M^{0.6}}\ \frac{15}{24}\ \frac{365-p}{365}\ \frac{2}{(2\pi)^{0.5}} \sum_{i=1}^{8} \frac{f_i}{\sigma_{zi} U_i} \tag{5-10}$$

5.4 DEVELOPMENT OF COMPUTER PROGRAM

A computer program called CALSCRAM (California Serpentine-Covered Roadway Asbestos Model) was written and compiled for IBM PC* and compatible computers in Microsoft QuickBasic** for use as an efficient means of processing model calculations. The program allows users to either manually enter model inputs or, for users needing to process large numbers of cases, use comma-delimited ASCII data files for model inputs. A user's manual for the program is provided in Appendix C.

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* IBM PC is a registered trademark of International Business Machines Corporation.

** QuickBasic is a registered trademark of Microsoft Corporation.

6.0 REFERENCES

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Cowherd, C., and C. Guenther (1976) "Development of a methodology and emission inventory for fugitive dust for the regional air pollution study." Prepared for U.S. Environmental Protection Agency, Office of Air and Waste Management, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

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APPENDIX A

Collocated Sampler Results

Table A-1. COLLOCATED SAMPLER RESULTS FOR SITES 1 AND 2.

Date	Run	Time Start	Veh. Speed (mph)	Veh. Freq. (vph)	Sampler Dist. (ft)	Sampler Height (m)	PCM5 (f/cc)	TEM5 (struc/cc)	TEM0 (struc/cc)
Site 1									
8/19/91	3	17:40	25	15	75	1.5	0.02	0.02	0.94
							0.01	0.10	2.56
8/20/91	5	14:28	25	5	25	1.5	0.05	0.32	7.25
							0.06	0.27	5.47
8/20/91	6	17:08	25	45	75	1.5	0.08	0.48	5.41
							0.07	0.65	10.04
8/23/91	7	12:35	10	15	25	1.5	0.01	0.02	0.44
							0.01	0.00	0.06
8/23/91		14:00	10	45	25	1.5	0.02	0.18	1.87
							0.01	0.17	1.76
Site 2									
8/21/91	2	14:40	25	45	25	1.5	0.09	1.57	9.57
							0.10	0.81	6.15
8/21/91	3	15:52	10	45	75	1.5	0.02	0.15	2.07
							0.01	0.22	2.04
8/21/91	4	17:10	25	15	250	1.5	0.01	0.06	1.31
							0.01	0.19	1.17
8/22/91	5	13:05	10	15	50up	1.5	0.01	0.00	0.01
							0.01	0.00	0.01
8/22/91	6	14:35	25	5	25	1.5	0.03	0.25	3.90
							0.02	0.38	3.99
8/22/91	7	15:55	10	5	75	1.5	0.01	0.00	0.08
							0.01	0.00	0.06

Table A-2. COLLOCATED SAMPLER RESULTS FOR SITES 3 AND 4.

Date	Run	Time Start	Veh. Speed (mph)	Veh. Freq. (vph)	Sampler Dist. (ft)	Sampler Height (m)	PCM5 (f/cc)	TEM5 (struc/cc)	TEM0 (struc/cc)
Site 3									
9/12/91	2	14:50	10	45	50up	1.5	0.01	0.00	0.03
							0.01	0.00	0.05
9/12/91	3	15:52	25	15	25	1.5	0.05	0.09	8.32
							0.05	0.35	5.33
9/13/91	4	12:12	10	15	75	1.5	0.01	0.02	0.11
							0.01	0.01	0.14
9/13/91	5	13:21	25	5	250	1.5	0.01	0.03	0.47
							0.01	0.04	0.51
9/13/91	6	14:28	10	5	25	3.0	0.01	0.00	0.05
							0.01	0.00	0.04
Site 4									
9/14/91	2	13:47	25	45	250	1.5	0.02	0.22	3.86
							0.03	0.12	2.66
9/14/92	3	15:45	25	15	75	1.5	0.03	0.12	2.34
							0.03	0.07	2.18

APPENDIX B

Current Airborne Asbestos Exposure Standards

The relationship between exposure to ambient levels of asbestos and health risk is a subject that includes many controversial and unresolved issues, such as the importance of differentiating among fiber types and sizes, the applicability of the original health data used to calculate cancer risks, and the extrapolation of high occupational exposures to low-exposure situatations. For further background on these issues, we strongly encourage the reader to consult the technical literature on asbestos-related health issues. However, for convenient reference, the following current exposure standards are presented:

Occupational Safety and Health Administration (OSHA)

Permissible airborne exposure limit for workers: 0.2 f/cc by PCM for fibers ≥ 5 μm, 8-hour time-weighted average.

Action level for asbestos in the workplace: 0.1 f/cc by PCM for fibers ≥ 5 μm, 8-hour time-weighted average.

National Institute for Occupational Health and Safety (NIOSH)

Standard for chrysotile asbestos: 0.1 f/cc by PCM for fibers ≥ 5 μm, 8-hour time-weighted average.

APPENDIX C

User's Manual for the CALSCRAM Computer Program

1.0 INTRODUCTION

The CALSCRAM program is intended to provide a cost-effective means for making preliminary estimates of airborne asbestos concentrations at receptor sites downwind of asbestos-containing serpentine-covered unpaved roads. At minimum, it requires the user to know the following information:

1. The bulk asbestos content of the road surface material, preferably as measured by ARB Test Method 435.

2. The silt content of the road surface material.

3. Typical traffic volume and patterns.

4. Typical wind speed and direction, and either typical number of days per year with 0.01 inches or more of rainfall, or the moisture content of the road surface material.

5. The downwind distance(s) of the receptor(s) of interest.

The user should also be familiar with each of the input parameters as listed in Table 1. Default values are provided by the program as a reference for users. Most input values are requested in English units (feet, miles, tons). These are internally converted to metric units by the program.

Model output is given as TEM5 asbestos concentration, which is defined as asbestos structures ≥5 µm in length as measured by transmission electron microscopy. The units are structures per cubic centimeter (struc/cc).

2.0 SETUP

The model was created in Microsoft QuickBasic and is designed to run on IBM PC or compatible computers operating under DOS 3.1 or later version. It is provided on a 3.5 inch floppy disk. It can be executed by either typing b:\CALSCRAM or by creating a subdirectory on a hard disk, copying the contents of the floppy disk to that directory, and typing CALSCRAM at the appropriate DOS prompt. Users should refer to a DOS reference guide if they are unfamiliar with the appropriate procedures.

3.0 EXECUTING THE PROGRAM

After an introductory screen, you are provided the option to quit the program or to continue with model implementation. There are two options for specifying input parameters: for on-screen input select 1; for file input select 2. If you are a first-time user and have not prepared an ASCII input file, select 1.

3.1 ON-SCREEN INPUT

The on-screen input option allows direct modification of input values while providing instantaneous model output. The output during manual input can be either case-specific (i.e., concentration averaged over a period of less than 3 hours) or long-term average concentration. The screen is initially set up for calculation of case-specific concentrations.

To modify input values or to activate model features, type the number associated with the parameter of interest at the prompt:

```
Select parameter to modify?
```

and hit enter. You will then be asked to enter a new value for the parameter. An explanation of each input parameter is provided below and in Table 1.

1. **Site ID:** The Site ID, which is optional, is user specified and does not affect estimates of airborne concentrations. It may consist of up to 8 characters.

2. **Stability Class:** The stability class (A, B, C, D, E, or F) is used to characterize atmospheric conditions that affect dispersion. Though the neutral class D is used as a default in the EPA model, and indeed is the most likely typical stability class in the long term, it is not considered representative of atmospheric stability during peak traffic hours. Thus stability class B was selected as the default because it represents an intermediate stability during daylight conditions.

3. **k-factor:** In accordance with AP-42, the default value for k is set to 0.36, which is the aerodynamic particle-size multiplier for particles $\leq 10\ \mu m$.

4. **Silt Content:** Silt content is the percent of the road surface material by dry weight that will pass a No. 200 sieve per ASTM Method D1140. The default silt content is set to 7%, which was typical of the 4 field experiment sites, all of which were moderately worn roadways.

5. **Vehicle Speed:** Vehicle speed is the average speed in miles per hour of all vehicles passing the subject road segment. The default vehicle speed is set to 25 mph.

Table 1. INPUT PARAMETERS FOR THE MODEL.

Input Parameter	Units	Default Value	Explanation
Site ID	none	none	User specified, up to 8 characters.
Stability Class	none	B	Atmospheric conditions (see Table #-#).
k	none	0.36	Particle size multiplier, as given by AP-42.
Silt Content	%	7	Percent of road surface material (by weight) passing a 200 Tyler mesh, measured by ASTM Method D1140
Vehicle Speed	mi/h	25	Average speed of vehicles traveling on subject road.
Vehicle Weight	tons	1.8	Average weight of vehicles traveling on subject road.
Number of Wheels	none	4	Average number of wheels of vehicles traveling on subject road.
Precipitation Days	days/yr	50	Number of days per year with 0.01 inches or more of precipitation. Sample values for California: Fresno 30, Red Bluff 70, Sacramento 57, Stockton 52.
Vehicle Frequency	veh/h	5	Average number of vehicle passes across subject road per hour.
Asbestos Content	%	10	Bulk asbestos content of road surface material, measured by ARB Test Method 435.
H	m	1	Initial vertical dispersion of the vehicle wake. At typical speeds, it is recommended that H be set to 50% of the average vehicle height.
Wind Speed	m/s	3	Average speed of wind blowing from the subject road toward the receptor.
Moisture Content	%	1	Percent of road surface material (by weight) that is moisture, measured by ASTM Method D2216.
Downwind Distance	ft	50	Distance from the road to the receptor, measured parallel to the prevailing wind direction.

6. **Vehicle Weight:** Vehicle weight is the average weight in tons of all vehicles passing the subject road segment. The default vehicle weight is set to 1.8 tons, which is typical of a light truck or van.

7. **Number of Wheels:** This is the average number of wheels of vehicles passing the subject road segment. The default number of wheels is set to 4.

8. **Vehicle Frequency:** The vehicle frequency is the average number of vehicle passes per hour over the subject road segment during the entire period of interest. The default vehicle frequency is set to 5 veh/h.

9. **Asbestos Content:** The asbestos content is the percent bulk asbestos content of the road surface material as determined by ARB Test Method 435. The default asbestos content is set to 10%. Typical asbestos contents for road surfaces consisting of mined serpentine rock in California are 5% to 15%.

10. H: H is the initial dispersion height of the vehicle wake. The default value is set to 1 m, which is roughly 50% of the height of a light truck or van.

11. **Wind Speed:** Wind speed is the average wind speed in meters per second. The default wind speed is set to 3 m/s, which is typical of wind speeds in much of California (some mean wind speeds for California: Bakersfield 2.9, Fresno 2.8, Red Bluff 3.9, Sacramento 3.7, and Stockton 3.3). This parameter becomes inactive if a long-term average is selected.

12. **Moisture Content:** Moisture content is the percent of the road surface material by dry weight that is moisture according to ASTM Method D2216. The default value for road moisture content is set to 1%. This parameter becomes inactive if a long-term average is selected.

13. **Downwind Distance.** Downwind distance refers to the distance in feet from the center of the roadway to the receptor. The downwind distance of the receptor is measured at its closest point to the roadway. The model is recommended to be used to determine case-specific concentrations only if the wind direction is within 45° of perpendicular to the roadway. If the wind is not perpendicular, the downwind distance must be adjusted by dividing the perpendicular distance by the cosine of the wind direction's deviation from perpendicular, thus giving the net travel distance of the induced dust from the road to the receptor. If you are determining a long-term average, the downwind distance is always measured along an axis perpendicular to the road orientation. The model then internally calculates the adjusted travel distance for each of the 16 wind sectors.

14. **Short Road Segment.** Since the basic model is based on an "infinite line source" assumption, it may overestimate concentrations for road segments that are less than about 1000 ft. Generally, the infinite line source assumption is reasonable if the receptor is closer to the road segment than the length of the straight road segment. To correct for a short road segment, enter "14" at the select parameter prompt. You will be asked to enter the length of the subject road segment. To return to a long road segment (i.e., infinite line source assumption), hit enter at this prompt.

15. **Long Term Average.** Long-term averages (e.g., annual averages) will generally be lower than short-term averages because of variable wind directions and precipitation. To estimate a long-term average, enter "15" at the select parameter prompt. Two selections will become available for modification: "Precipitation Days" and "Wind Sectors". These replace "Moisture Content" and "Wind Speed", respectively, which both become inactive. When estimating long-term averages, be sure that the vehicle frequency and other parameters are representative of the entire time frame. To return to a case-specific estimate, enter "15" at the select parameter prompt.

16. **Precipitation Days:** The precipitation days selection is activated for long-term averages only. Precipitation days are the number of days per year with 0.01 inches or more of precipitation. The default value for precipitation days is set to 50 (some mean precipitation days for California: Bakersfield 36, Fresno 34, Mount Shasta 90, Red Bluff 70, Sacramento 57, and Stockton 52).

17. **Wind Sectors:** The wind sectors option is activated for long-term averages only. Wind rose data will increase the accuracy of long term averages because of changes in wind speed and direction over time. The information required is the percent of time the wind direction falls under each of 16 wind rose sectors, the average wind speed for each sector, the road orientation, and the direction, perpendicular to the road orientation, of the receptor (receptor-normal direction). The first time you view the wind sector screen, the time percentages are filled with default values approximating the wind rose percents from Fresno. The wind speed is set to the default speed of 3 m/s. The road orientation is set to 90°, which is an east-west trending roadway, and receptor-normal direction is 180°, which means the receptor is on the south side of the roadway.

    By entering "17" at the select parameter prompt, you will access the wind sector screen. You will first be asked whether you wish make modifications to percent of time, wind speed, or road orientation (P, W, or R). At this prompt you can also return to the main screen by hitting enter. If you select P or W, you will be asked to first enter the sector for modification and then the new value. If you select R you will first be asked to enter the road orientation and the receptor-normal direction.

18. **Restore Defaults:** The restore defaults option allows you to delete all changes made during the on-screen input option and return all parameters to their default values. Default values for input parameters are listed in Table 1.

19. **Save Settings:** This option saves all current model inputs to a file. Note that only one test case can be saved in each file.

20. **Retrieve Settings:** This option retrieves from a file model inputs from previously saved test cases.

21. **Print:** This will produce a printout of the current case, including all model inputs and the output.

22. **Help:** Select this option for explanations of any of the input parameters or features in selections 1 to 21.

3.2 FILE INPUT

The file input option allows you to use an input file in comma-delimited ASCII format. The output can be sent to an output file, to a printer, or to the screen. Input files, which should be created within your database or spreadsheet software, must have the following comma-delimited fields:

1. Site ID	alphanumeric (up to 8 characters)
2. Stability Class	alphanumeric (A, B, C, D, E, or F)
3. k	numeric
4. Silt Content	numeric (%)
5. Vehicle Speed	numeric (mi/h)
6. Vehicle Weight	numeric (tons)
7. Number of Wheels	numeric
8. Vehicle Frequency	numeric (veh/h)
9. Asbestos Content	numeric (%)
10. H	numeric (m)
11. Wind Speed	numeric (mi/h)
12. Moisture Content	numeric (%)
13. Downwind Distance	numeric (ft)

The output during file input is "case-specific", which means that it is not averaged over 24 hours or annually. If the file input option is to be used to calculate long-term exposures, you must input typical or average values for each input parameter or, preferably, do enough model runs to represent the temporal variation in traffic and weather at the site and use the output to calculate a concentration averaged over the desired time scale.

Output can be sent to the screen, a printer, or a file by selecting S, P, or F at the output prompt.