$PM_{2.5}$ PM_{10} and TSP FORMATION, COMPOSITION, AND DEPOSITION at a STONE CRUSHING PLANT

VOLUME 1 REPORT

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AIR POLLUTION CONTROL SYSTEMS ENGINEERING

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ACRONYMS

CFR	Code of Federal Regulations
E	East
EDS	Energy Dispersive Spectroscopy
ENE	East-Northeast
ESE	East-Southeast
EPA	U.S. Environmental Protection Agency
FRM	Federal Reference Method
GMW	General Metal Works
IC	Ion Chromatography
ISC	Industrial Source Complex
NAAQS	National Ambient Air Quality Standards
NE	Northeast
NIST	National Institute of Standards and Technology
NNE	North-Northeast
NNW	North-Northwest
NW	Northwest
NSA	National Stone Association
PM	Particulate Matter

ACRONYMS (Continued)

PLM	Polarizing Light Microscopy
PTFE	Polytetrafluoroethylene
R&P	Rupprecht & Patashnick Co, Inc.
SE	Southeast
SEM	Scanning Electron Microsopy
SSE	South-Southeast
SSW	South-Southwest
SW	Southwest
W	West
WNW	West-Northwest
WSW	West-Southwest
WINS	Wells Impactor Ninety Six
XRD	X-Ray Diffraction

APPENDICES

VOLUME 2

$PM_{2.5}$ PM_{10} and TSP FORMATION, COMPOSITION, AND DEPOSITION at a STONE CRUSHING PLANT

1. SUMMARY

1.1 Purpose and Scope of the Test Program

The National Stone Association (NSA) sponsored this ambient air test program to compile data concerning the formation, composition, and deposition of particulate matter at a typical stone crushing plant. The primary purpose of this program was to provide technical data useful for supporting and expanding NSA's position taken in legal action with EPA regarding the fine particulate matter National Ambient Air Quality Standard (NAAQS). NSA studies have previously demonstrated that stone crushing plants have a negligible impact on fine particulate matter ambient levels. Additional data were needed concerning the penetration of crustal material into the intermodal size range of 1 to 2.5 micrometers and into the fine particulate matter distribution of less than 1 micrometer. This information was needed to confirm NSA's position that mineral particulate matter should be exempted from future fine particulate ($PM_{2.5}$) NAAQS.

A second purpose of this study was to further evaluate the deposition of PM_{10} and TSP (Particulate Matter larger than approximately 30 micrometers). In various meetings between EPA and NSA and in various EPA documents, EPA has stated that there is a significant difference between the emission inventory quantities of PM_{10} and TSP emissions and the observed mineral particulate matter levels on ambient air filters. NSA has previously contended that this very large inconsistency in the EPA data sets is due, in part, to emission factors biased to higher-than-true levels. NSA has also had reason to believe that coarse (2.5 to 10 micrometers) and supercoasre (>10 micrometer) particles are rapidly removed from the ambient air due to gravity settling and dry deposition processes. This study evaluated the PM_{10} and TSP concentrations as a function of distance from stone crushing plants. These data will be used to challenge EPA's assumptions regarding the importance of mineral particulate sources with respect to $PM_{2.5}$ ambient levels and to challenge dispersion models that fail to take into account gravity settling and dry deposition.

The test program was conducted by Air Control Techniques, P.C. in cooperation with personnel from Martin Marietta Aggregate's Greensboro, North Carolina Buchanan plant and Raleigh office. $PM_{2.5}$ monitoring was conducted using Rupprecht & Patashnick Co, Inc. FRM-2000 monitors that fully met the design specifications of 40 CFR Part 58, Appendix L. One $PM_{2.5}$ monitor was located upwind and away from the plant processing equipment on the Buchanan plant grounds. A second $PM_{2.5}$ monitor was located in the plant immediately downwind of the processing area. The monitoring locations met all applicable EPA requirements concerning ambient air monitoring.

PM_{10} monitoring was conducted using Andersen Samplers, Inc. and General Metal Works, Inc. high volume PM_{10} monitors that fully met the design specifications of the Federal Reference Method for PM_{10}

promulgated on July 1, 1987. One PM_{10} monitor was located upwind and away from the plant processing equipment on the Buchanan plant grounds. Three additional monitors were located in the plant along a line downwind of the processing areas.

TSP monitoring was conducted using General Metal Works, Inc high volume TSP monitors. The TSP monitors were located on the same four platforms as the PM_{10} monitors.

The ambient air monitoring network was operated for 14 days when the ambient winds were forecasted to be from the southwest to northwest. During these periods, the winds passed over the plant quarry and processing area and toward the three downwind monitoring locations. Filter samples were recovered each sampling day by Air Control Techniques, P.C. personnel.

The 47 mm filter media used in the $PM_{2.5}$ monitors were polycarbonate filters rather than the standard PTFE filters. The purpose of the $PM_{2.5}$ monitoring was to evaluate particle chemical composition in the intermodal size range of 1 to 2.5 micrometers, and the polycarbonate filters are considerably more appropriate for the chemical analyses needed. The $PM_{2.5}$ filters were sent to Research Triangle Institute (RTI) for weight gain determination using a state-of-the-art microbalance located in a temperature and humidity controlled room. RTI was selected for these filter analyses due, in part, to the fact that one of their divisions worked with EPA in the development of Appendix L and the general procedures used to prepare and weigh the filters. This same laboratory has also been awarded a multi-million dollar contract to serve as the lead laboratory providing $PM_{2.5}$ filter analytical services for the U.S. EPA and the States.

Following gravimetric analysis, a set of ten $PM_{2.5}$ filters was selected by Air Control Techniques, P.C. and prepared by RTI for analysis by scanning electron microscopy (SEM). The filters were analyzed using SEM with magnifications ranging from 20X to 20,000X. Air Control Techniques, P.C. requested that each sample be analyzed by means of energy-dispersive spectroscopy (EDS) to evaluate particle composition in the 0.3 to 4 micrometer (aerodynamic) size range. Twenty individual particles in each filter sample were chemically analyzed.

The differences between the upwind and downwind $PM_{2.5}$ ambient concentrations were evaluated to confirm, as previous NSA sponsored studies strongly indicated, that stone crushing plants have negligible $PM_{2.5}$ emissions.

The deposition of PM_{10} and TSP was evaluated using data from the set of four monitoring locations along a line upwind and downwind of the plant quarry and processing area. The ambient concentration data from this set of four monitoring stations provided a measurement of the rapid decrease in the concentrations of mass in these size ranges. These data can be used in conjunction with standard dispersion models to estimate the gravity settling and dry deposition rates for coarse and supercoarse particulate matter.

1.2 Conclusions

The following conclusions are based on the results of the $PM_{2.5}$ PM_{10} and TSP ambient air monitoring study conducted at the Greensboro, North Carolina Buchanan plant.

- Crustal material emitted from the stone crushing plant and adjacent natural and anthropogenic sources is limited to the greater than 1 micrometer size range. Crustal materials are not part of the ambient fine particle mode.
- The adoption of a PM_1 NAAQS instead of a $PM_{2.5}$ NAAQS would effectively exempt mineral particulate matter.

- There was no detectable impact of the plant operations on ambient $PM_{2.5}$ concentrations. These results are entirely consistent with previous NSA sponsored studies.
- PM_{10} and TSP particulate matter have different spatial and temporal trends than $PM_{2.5}$. It is apparent that $PM_{2.5}$ is part of a different mode of particulate matter than PM_{10} and TSP.
- The observed decrease in the concentrations of TSP and PM_{10} as a function of downwind distance confirmed that there is rapid loss of particulate matter in the coarse and supercoarse size ranges. The information concerning PM_{10} and TSP emissions now present in EPA's emission inventories is significantly biased high due to the failure to account for the rapid removal of large particles from the atmosphere.
- EPA and state agencies should not attempt to estimate the emissions of $PM_{2.5}$ or an alternative fine particulate matter size category by using PM_{10} and/or TSP emission factor data as a basis.

The results of this study support the technical arguments made by NSA with respect to the $PM_{2.5}$ NAAQS promulgated in July 1997, remanded in 1999, and presently subject to future litigation between EPA, NSA, and other industrial trade associations. The results of this study indicate that crustal material is part of the ambient air particulate matter coarse mode and should not be regulated as part of EPA's fine particulate control program. The results also indicate that the choice of PM_1 rather than $PM_{2.5}$ to define the fine mode will effectively eliminate the inappropriate control of crustal materials.

The study results shed further light on the significant discontinuity between EPA emission inventory data for PM_{10} and TSP and the observed low concentrations of crustal material on ambient filters. It is clear that the atmospheric removal rates for large particles is extremely rapid and must be taken into account when evaluating the contributions of various sources to observed ambient particulate matter concentrations.

2. TEST PROCEDURES AND PLANT OPERATING CONDITIONS

2.1 Selection of the Test Site

One of the purposes of this study was to evaluate the deposition patterns of different particle size ranges at a stone crushing plant. The National Stone Association and Air Control Techniques, P.C. applied the following criteria in selecting a plant site in this region.

- The plant must be sufficiently large and have processing equipment typical of stone crushing plants throughout the U.S.
- The prevailing wind patterns in the geographical area must allow for representative monitoring of emissions from the plant processing equipment, storage piles, and quarry operations.
- The plant must have sufficient land area to allow for monitoring of in-plant ambient particulate matter concentrations at least one-half mile downwind.
- With the inherent limitations of surrounding roads, there must be no major stationary sources of particulate matter emissions in the immediate area that could complicate the interpretation of the ambient concentrations being measured.
- The plant must be willing to cooperate in the study and to allow daily visits to the monitoring locations for servicing the ambient air monitors and the meteorological stations.

Preliminary discussions were conducted with representatives of a number of NSA member companies operating stone crushing plants. NSA and Air Control Techniques, P.C. selected the Martin Marietta Aggregates Buchanan plant in Greensboro North Carolina based on (1) aerial photographs, (2) site plans, (3) production rate data, (4) production characteristic data, and (5) a limited number of site visits. The Buchanan plant has a capacity of approximately 700,000 tons of stone per year. It operates four days per week for approximately 10 hours per day.

2.2 Selection of the Upwind and Downwind Deposition Pattern Monitoring Locations

The Buchanan plant entrance is a road on the southwestern edge of the facility. The scale office and truck scales are located on the entrance road that is oriented south-to-north from the plant entrance. The crushing and screening operations are located in the approximate center of the facility. There are also a number of product storage piles in this area. The quarry pit is located in the western portion of the facility.

The specific off-site and in-plant $PM_{2.5}$ ambient air monitoring locations at the Buchanan plant were selected based on the following criteria.

- The first downwind monitoring locations must be close to the center of the plant processing equipment.
- The second and third downwind deposition pattern in-plant monitoring locations must in-line with one another and be separated by a sufficient distance to show the particle deposition pattern.
- The third downwind monitoring location must be at least one-half mile from the edge of the plant quarry and/or plant processing equipment.

- The upwind monitoring location must be at a reasonable distance from local sources of ambient particulate matter that could bias the results, and the monitoring location must meet all applicable EPA requirements concerning ambient air monitoring.
- All three of the downwind deposition pattern monitoring locations must meet all applicable EPA requirements concerning ambient air monitoring.
- All four of the monitoring locations must be in areas that were not significantly influenced by adjacent stationary sources.
- There must be safe access to the monitoring location.

Color photographs located in the report appendix illustrate both the off-site and in-plant test locations in reference to the plant and surrounding areas.

During the pretest site visit to the Buchanan Plant, several possible upwind and downwind monitoring locations were identified based on information concerning (1) the prevailing wind directions, (2) the availability of electrical power, and (3) the adequacy of safe access.

The upwind monitoring location was selected to provide (1) the maximum distance from off-site particulate matter sources and (2) accessibility. The in-plant deposition pattern monitoring location sites were selected primarily to provide (1) representative measurement of emissions from the stone crushing plant at three different distances from the center of the plant processing equipment and (2) accessibility.

The upwind monitoring location is shown in Figure 1. The in-plant deposition pattern monitoring locations shown in Figure 1 are designated as locations "Downwind 1, 2, and 3". All of the monitoring locations were well within the property boundary of the Martin Marietta Aggregates, Buchanan plant.

The upwind monitoring location was approximately 1700 feet upwind from the center of the plant processing equipment. It was west of the plant processing equipment in an open, grass-covered pasture and separated from the plant by a two lane paved road that runs through the plant property. State Highway 421 was to the west approximately 800 feet from the upwind monitoring location. This position was also sufficiently far from a tree line. The ambient air monitors were located in the open field to avoid any localized effects of the prevailing off-site particulate matter concentrations. The three upwind monitors were positioned on scaffolding 6 feet above the ground. A small portable generator located approximately 100 feet downwind of the upwind monitoring station supplied power.

The downwind deposition pattern monitoring locations identified as Downwind 1, 2, and 3 were approximately 1150, 2200, and 3200 feet downwind and east of the center of the plant processing equipment respectively as seen in Figure 1. The downwind deposition pattern monitors were located in areas of grass and scrub brush. Each of the monitoring locations was sufficiently far from any tree lines. The monitors at each monitoring location were positioned on scaffolding 6 feet above the ground in order to avoid any localized effects of particulate matter from vegetation. Each of the in-plant deposition pattern monitoring locations was also on scaffolding 6 feet above the ground. Three small portable generators located approximately 100 feet downwind of each monitoring station supplied power.

Both the upwind and downwind monitoring locations were approximately three miles west of the ongoing construction of the outer interstate loop around Greensboro, North Carolina. Accordingly, there were a number of potential sources of particulate matter due to vehicle traffic and construction. The monitoring locations were selected to minimize differences in the vulnerability to these off-site particulate matter sources. When the winds were from the southwest to northwest, there were no apparent effects from this

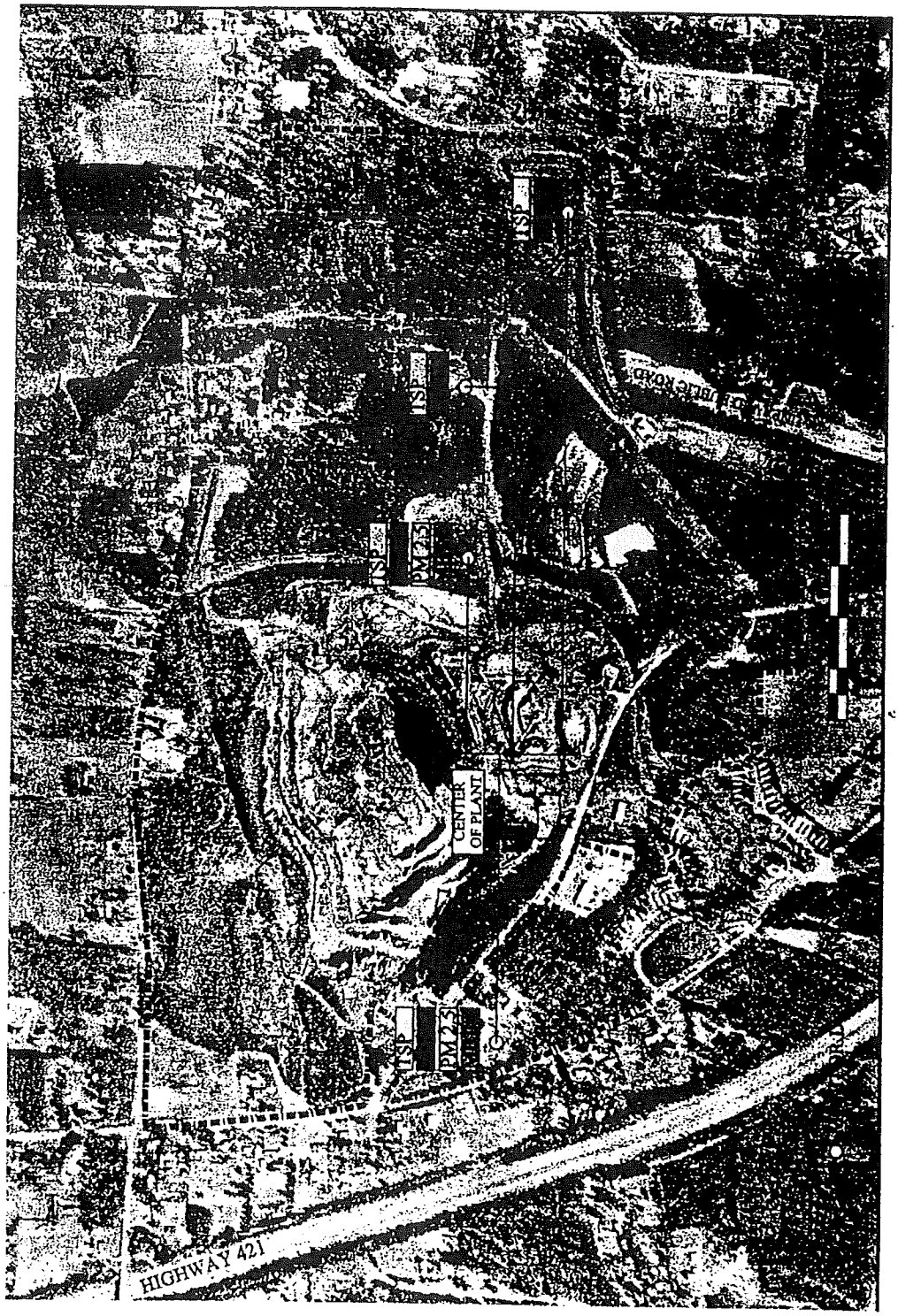

Figure 1. Overview of the Martin Marietta Aggregates, Buchanan Quarry

construction. With respect to the proximity to off-site sources, Air Control Techniques, P.C. believes that the Buchanan plant site is typical of a moderately populated eastern city.

Meteorological monitoring stations were mounted at both the Upwind 1 and Downwind 1 monitoring locations. These stations were used to monitor rainfall, wind speed, wind direction, and ambient temperature. A meteorological station was located at both monitoring sites in order to document differences in wind speed and direction due to land contours. A consistent difference in wind direction was observed as expected due to the localized effects of a tree line approximately 150 feet from the upwind monitoring location. Therefore, the Downwind 1 meteorological data were used in to determine the predominant wind direction on a daily basis. There were no trees or buildings within a four hundred-foot radius of the Downwind 1 monitoring location.

2.3 Ambient Monitoring Procedures

Ambient $PM_{2.5}$ Monitoring Procedures

Ambient concentrations of $PM_{2.5}$ particulate matter were measured following the guidelines of Appendix L proposed on December 13, 1996 and promulgated on July 18, 1997. The ambient $PM_{2.5}$ concentrations were determined based on actual conditions as required by Appendix L. The monitors used for this study were Model FRM-2000 $PM_{2.5}$ monitors manufactured by Rupprecht & Patashnick Co, Inc. (R&P). These instruments use an electrically powered pump to draw ambient air into a non-directional inlet and into a specially shaped inlet consistent with the requirements of Section 7.0 and the dimensions of Section 14.0 of Appendix L. The sample flow rate is maintained at 1.0 cubic meter per hour (16.67 liters/min. ±5%) as required by Appendix L, Section 7.4.1.

Rain and fog droplets are removed in an inertial preseparator near the top of the inlet tube. The sample gas stream then passes through a bug screen (fine wire mesh) and enters a WINS impactor. This portion of the $PM_{2.5}$ sampling instrument is shown in Figure 2.

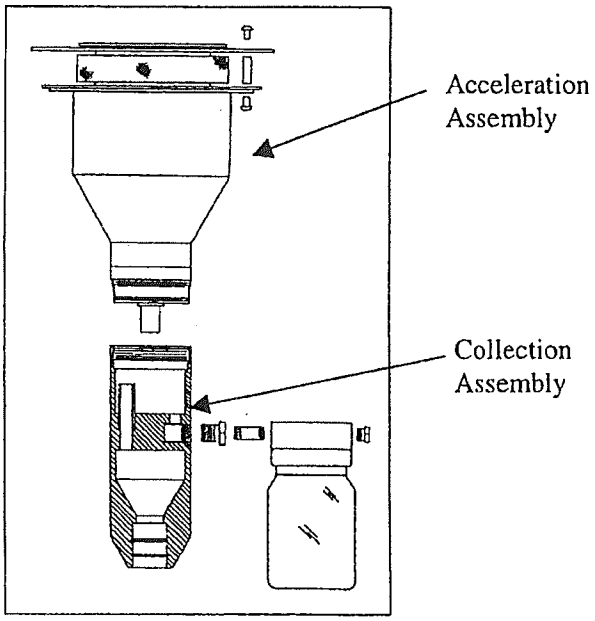

Figure 2. $PM_{2.5}$ Monitor Ambient Air Intake and Water Knockout

Particulate matter larger than 2.5 micrometers (aerodynamic diameter) is collected in the WINS impactor. A glass-fiber filter coated with exactly 43 drops of non-volatile oil is used to capture the particles larger than 2.5 micrometers.

The sample gas stream containing only the $PM_{2.5}$ particulate matter then passes downward to the filter cartridge. Air Control Techniques, P.C. used polycarbonate 47 mm filters to collect the $PM_{2.5}$ particulate matter rather than the conventional polytetrafluoroethylene (PTFE) filters specified in Section 6.0 of Appendix L. Air Control Techniques, P.C. made this modification to the method so that the filters could be analyzed using scanning electron microscopy (SEM) and energy-dispersive spectroscopy (EDS). The EDS was used to develop a particle by particle composition in various particle size ranges.

The polycarbonate filters have a smooth glass-like surface that is ideal for SEM and EDS analysis. The polycarbonate filters had the same pore size as the recommended PTFE filters, which have a rated removal efficiency of 99.7 percent as measured using monodisperse Dioctyl Pthalate (DOP) droplets having a physical diameter of 0.3 micrometers. The 0.3 micrometer size is at the generally accepted minimum efficiency point for filters.

The 47 mm filters were each mounted in a filter cassette that was sealed in a horizontal orientation underneath the down-tube of the sampling system. All of the filters used in this project were conditioned before the pre-sampling weighing in accordance with Section 8.2 of Appendix L. The filters were conditioned in a temperature and relative humidity controlled room having a temperature of 21 - 21.9°C and a relative humidity of 38 - 40%. The preconditioning equilibration times were at least 48 hours, significantly exceeding the 24-hours specified by Appendix L, Section 8.2.5. The filter conditioning times were extended based on RTI's initial experience in obtaining stable filter weights.

Using standard weights immediately before the beginning of the pre-sampling filter weight measurements, the analyst checked the calibration of the analytical microbalance used by RTI for this study. Appendix L, Section 8.1 requires that the balance be calibrated at least once per year. The balance used by RTI was a Mettler Toledo Model UMT2 with a readability of 0.1µg and a repeatability of 0.25µg. The microbalance was located in the same temperature and relative humidity controlled room used for the conditioning of the 47 mm polycarbonate filters.

An orifice located directly below the filter cartridge measures the flow rate of the sample gas stream. Leak checks were performed according to R&P's performance audits in the field prior to sampling and immediately following the final day of sampling. R&P completed a multi-point calibration of the sample flow rate. This calibration was conducted using an NIST traceable flow rate standard that is accurate to ± 2%. A single point verification of the sample flow rate was conducted by Air Control Techniques, P.C. upon arrival of the monitors prior to the test and prior to shipping the monitors at the conclusion of the tests. The single point flow verification is required by Section 9.1.

The field procedures for operating the $PM_{2.5}$ monitors, changing the filters, and transporting the filters conformed to the requirements of Section 10.0. Upon arrival at the monitoring location at the end of a sample period, the filter (cassette mounted) used for that 6-8-hour sample period was removed from the instrument and stored in a sample transport case. The data acquisition system of the FRM-2000 was interrogated to determine if all of the operating conditions monitored continuously and recorded every five minutes were within the required performance specifications. The monitor was then turned off and secured for the night. The test times were only 6-8 hours rather than the standard 24 hour sampling time period. This was done for three reasons (1) the sample times were during hours that the Buchanan plant was operating only, (2) Air Control Techniques, P.C. did not want to overload the filter samples thereby reducing the effectiveness of the energy-dispersive spectroscopy analysis, and (3) due to the remote sample locations small portable generators with approximately a 9 hour fuel supply were used to power the monitors. On each sample day, the generators were started and the monitors were energized and set

to run approximately 8 hours. Numbered, conditioned, and pre-weighed filters (cassette mounted) were placed into the instruments and sealed in the proper position. Each filter was recovered well before the 96 hour maximum allowed period of Section 10.10.

The filter in the WINS impactor was replaced every fourth sample day. This is three times as often as recommended by Appendix L. The frequent changing of the WINS impactor filter was considered prudent due to literature indicating that a bias to higher-than-true $PM_{2.5}$ concentrations is possible due to the entrainment of particulate matter from the surface of the impactor into the sample gas stream going toward the $PM_{2.5}$ filter.

The extensive quality assurance data recorded by each FRM-2000 instrument were downloaded into a field computer on a once-per-week basis. These data were scanned for any monitoring problems that could potentially affect the adequacy of the observed $PM_{2.5}$ concentrations. Air Control Techniques, P.C. believes that the R&P $PM_{2.5}$ monitors performed well.

Ambient PM_{10} Monitoring Procedures

Ambient concentrations of PM_{10} particulate matter were measured following the guidelines of Appendix J promulgated on July 1, 1987 by the U.S. EPA. The ambient PM_{10} concentrations were determined based on standard conditions as required by the PM_{10} standard. The PM_{10} samplers used for this study were Model 1200 units with mass flow controllers manufactured by Andersen Samplers, Inc. and General Metal Works. As shown in Figure 3, these instruments use an electrically powered fan to draw ambient air into a size selective inlet that is specially shaped to be consistent with the requirements of EPA Appendix J.

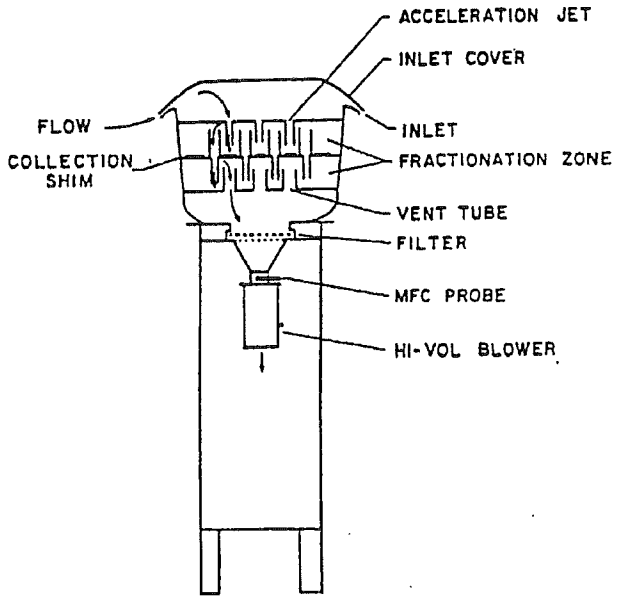

Figure 3. Model 1200 PM_{10} Monitor with Mass Flow Controller

The particle size discrimination characteristics of the Model 1200 (Figure 3) size selective inlet are dependent on the air velocity through the acceleration jets. A change in the entrance velocity will result in a change in the nominal particle size collected. For this reason, it is imperative that the flow rate

through the inlet be maintained at a constant actual flow rate of 1.13 actual cubic meters per minute (±10%). The sample flow rate is controlled by the use of a mass flow controller.

The inlet cover removes rain droplets. The sample gas stream then passes through a grid of acceleration nozzles. The larger than ten micrometer particles are then collected on a greased (Dow Silicon Grease #316) collection shim. The equal to and smaller than ten micrometer particles then pass through a bug screen (fine wire mesh) and are collected on a micro-quartz fiber filter.

Ambient TSP Monitoring Procedures

Ambient concentrations of total suspended particulate matter (30 micrometers and less) particulate matter were measured following the U.S. EPA guidelines Federal Register Volume 36, No 84 dated April 30, 1971. The ambient total suspended particulate matter (TSP) concentrations were determined based on standard conditions as required by the PM_{10} standard. The TSP monitors used for this study were Model GMWL-2310 outfitted with venturi flow controllers manufactured by General Metal Works. As shown in Figure 4, These instruments use an electrically powered fan to draw ambient air into the monitor inlet. The flow rate through the monitor is controlled by the flow across the critical venturi. The sample flow rate is determined by the pressure drop across the critical venturi.

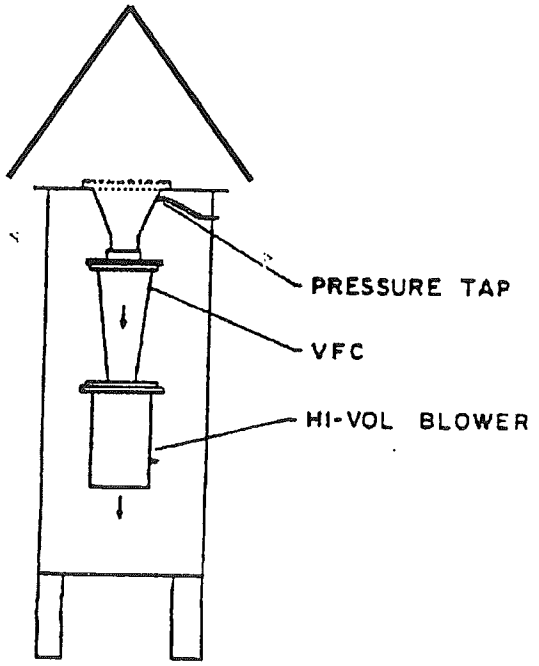

Figure 4. Model GMWL-2310 TSP Monitor with Venturi Flow Controller

The inlet cover removes rain droplets. The sample gas stream then passes through a micro-quartz fiber filter. The Model GMWL-2310 outfitted with a venturi flow controller is shown in Figure 4.

2.4 Meteorological Monitoring Procedures

Meteorological data were monitored on a continuous basis at the Buchanan plant. Air Control Techniques, P.C. installed a Davis Weather Wizard III monitoring station at the Upwind #1 and Downwind #1 monitoring stations. These instrument systems monitored the rainfall, wind speed, wind

direction, and temperature. Barometric pressure data were monitored by the R&P FRM-2000 $PM_{2.5}$ instruments.

The meteorological data were recorded continuously and reduced to 15-minute average values in a data acquisition system. These data were retrieved by Air Control Techniques, P.C. on a daily basis and are presented in the appendix to this report.

2.5 Plant Production Rates

The Buchanan Plant operated at normal levels throughout the period of the ambient air monitoring study. The production and material loadout rates for the sampling days are summarized in Table 1.

Table 1. Plant Production and Loadout Rates

Date	Production, Tons/Day	Loadout, Tons/Day
10/6/99	4572	2597
10/7/99	4364	4318
10/11/99	3942	2542
10/12/99	4541	3630
10/13/99	3231	1451
10/14/99	4173	2639
10/18/99	3617	1622
10/19/99	2869	4392
10/21/99	3430	3085
11/9/99	4010	3172
11/10/99	4000	4231
11/11/99	4348	1975
11/15/99	4322	3505
11/16/99	4025	4784

The plant conducted blasting at a frequency of one to three times per week during the study period. Blasts occurred on the following four sampling days: October 13th, October 21st, November 9th, and November 11th. All of the monitoring instruments operated throughout the blast period.

3. TEST RESULTS

3.1 Wind Directions

The wind directions during the 14 sampling days are summarized in Figure 5 for the downwind monitoring locations (each tic mark on the charts is equivalent to one day.). It is apparent from these data that the winds were predominantly from the west-northwest during the study period. However, there were a number of days in which the actual wind direction observed at the dominant downwind monitoring location were actually from the east, north, or south southeast despite the one-day advance weather forecasts.

The dominant downwind site (in-plant) wind direction was from the west-southwest to north-northwest on eight of the fourteen days. The in-plant winds were from the south-southeast to east-northeast on 5 days. The frequency of the winds from the south and east are not typical of this area during the fall. The dominant upwind site wind direction was from westerly directions on twelve days

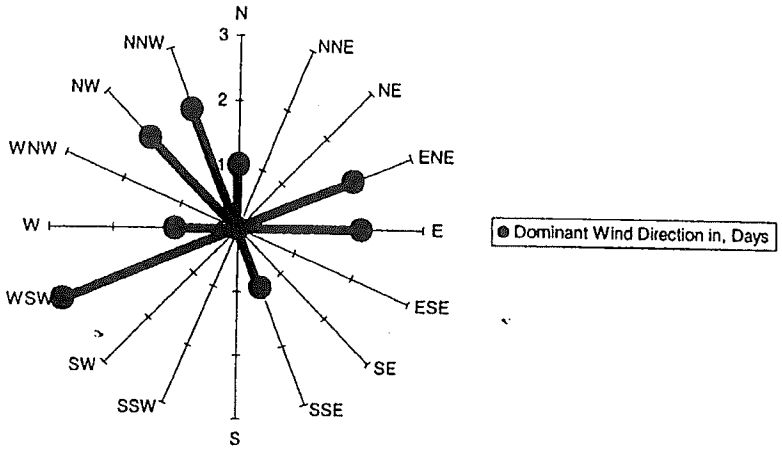

Figure 5. Wind Rose Showing the Downwind (In-plant) Dominant Wind Direction
(Note: Long lines for western winds indicate that the prevailing winds were primarily from the west.)

During the eight days that the wind was from the west, the air approaching the in-plant monitoring site passed over the stone crushing plant quarry, haul roads, and processing equipment. These wind direction data demonstrated that the in-plant monitoring site was properly selected. Accordingly, it was possible to evaluate the differences between the upwind monitoring location and the downwind monitoring locations to determine the extent to which the stone crushing plant contributed and the deposition patterns of the different particle size ranges.

3.2 $PM_{2.5}$ Data and Characteristics

The upwind $PM_{2.5}$ concentration averaged 10.3 $\mu g/M^3$ and varied from approximately 3.4 to 25.1 $\mu g/M^3$. The downwind concentration averaged 9.3 $\mu g/M^3$ for and varied from approximately 3.5 to 23.8 $\mu g/M^3$. The average $PM_{2.5}$ value of 10.3 $\mu g/M^3$ for the Upwind 1 location is similar to data presented by EPA[1] for the Eastern U.S. during the fall season. The use of EPA's fall $PM_{2.5}$ data is appropriate for comparison purposes due to the prevailing temperatures during most of the test period. The peak ambient temperatures were consistently in the range of 40 to 80°F during this period.

The concentration rose for the upwind monitoring location (Figure 6) shows the $PM_{2.5}$ maximum concentrations that occurred when the dominant wind direction for the monitoring day was from the west or west-southwest, the direction from U.S. Highway 421 (Figure 1). The upwind monitoring station concentrations were consistently low when the wind came from the east and passed over the stone crushing plant prior to approaching the monitoring instrument.

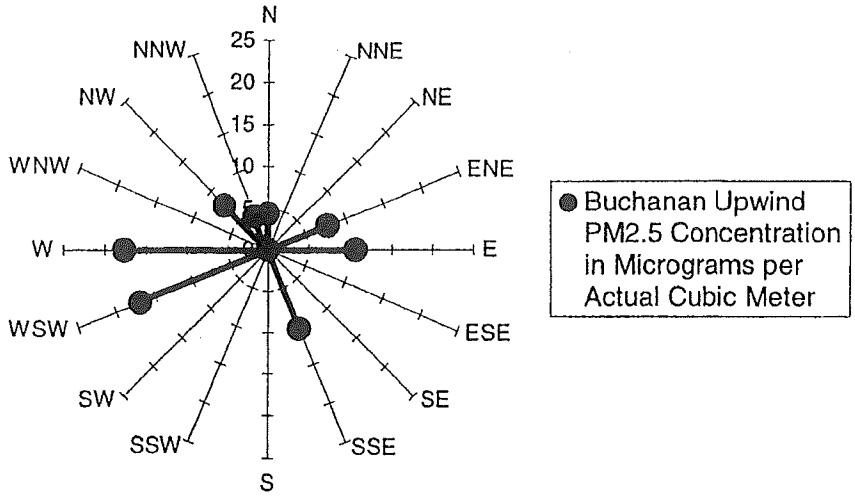

Figure 6. Upwind $PM_{2.5}$ Particulate Matter Concentration Rose (Note: Wind direction normalized to downwind conditions for comparison)

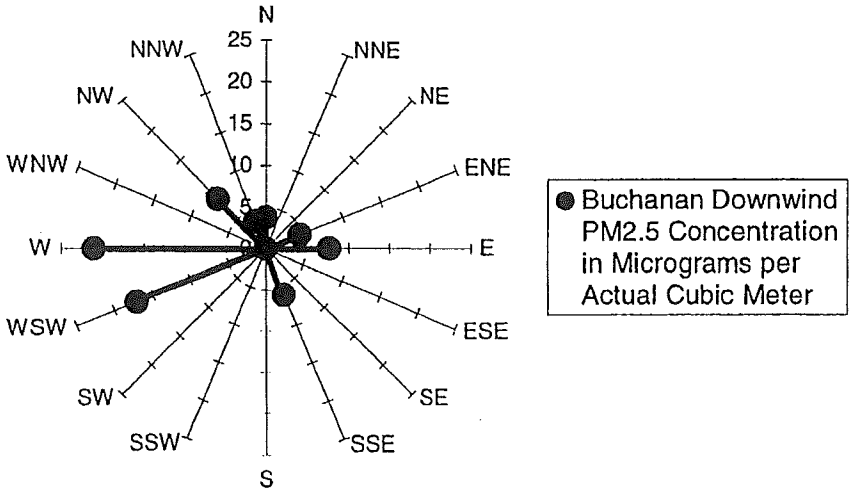

Figure 7. Downwind $PM_{2.5}$ Particulate Matter Concentration Rose
(Note: Highest concentrations were observed when winds were from the west.)

As shown in the Figure 7, the $PM_{2.5}$ concentration rose for the downwind monitoring site was very similar to that for the upwind site. The $PM_{2.5}$ maximum concentrations occurred when the dominant wind direction

for the monitoring day was also from the west. When the wind was from this direction, the air passed over the entire stone crushing plant and quarry prior to arriving at the monitoring instrument. Nevertheless, the ambient $PM_{2.5}$ concentrations were essentially identical to those observed in the upwind location. The very limited differences between the upwind and downwind $PM_{2.5}$ concentrations are illustrated in Figure 8.

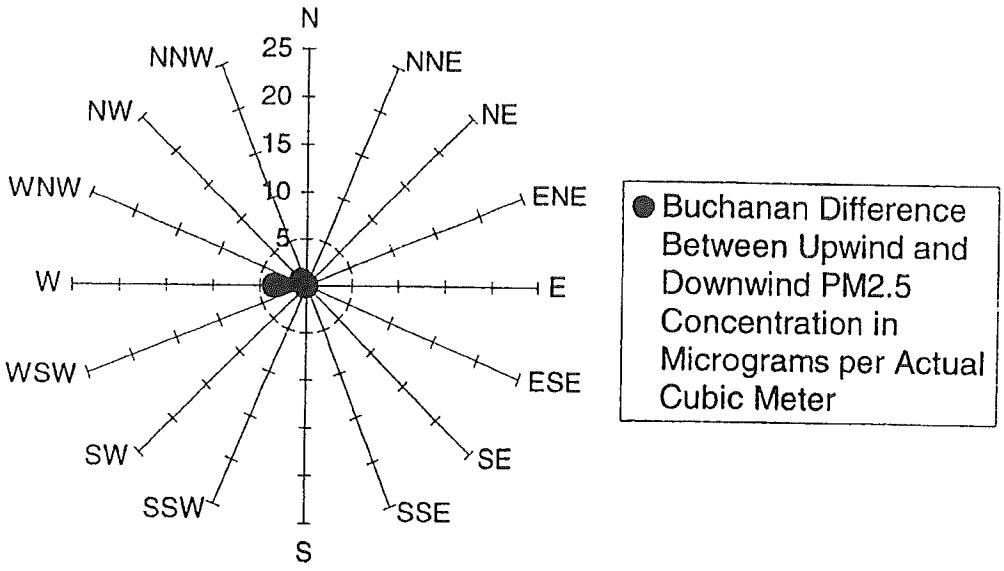

Figure 8. $PM_{2.5}$ Concentrations in the Upwind and Downwind Monitoring Locations

These data provide a clear indication that this very small difference observed between the Upwind 1 and Downwind 1 monitoring locations was due primarily to the precision of the $PM_{2.5}$ ambient concentration measurement method. A repeated measures t-test of the upwind and downwind $PM_{2.5}$ data confirms that there is no statistically significant difference in the two data sets. $PM_{2.5}$ ambient concentrations are unaffected by the presence of the stone crushing plant. This conclusion is identical to the results of NSA sponsored studies in Benson, North Carolina, Leesburg, Virginia, and Denver, Colorado.

The trends in the sampling day-by-sampling day $PM_{2.5}$ concentrations in the upwind and downwind locations are illustrated in Figure 9. The general relationship shown in this trend is consistent with EPA's conclusions that fine particulate matter is formed primarily from gaseous precursors during multi-day transport of air masses across the U.S. The upwind and downwind $PM_{2.5}$ concentrations are essentially identical regardless of the wind direction. This trend relationship could not exist if the stone crushing plant were a significant source of $PM_{2.5}$ emissions.

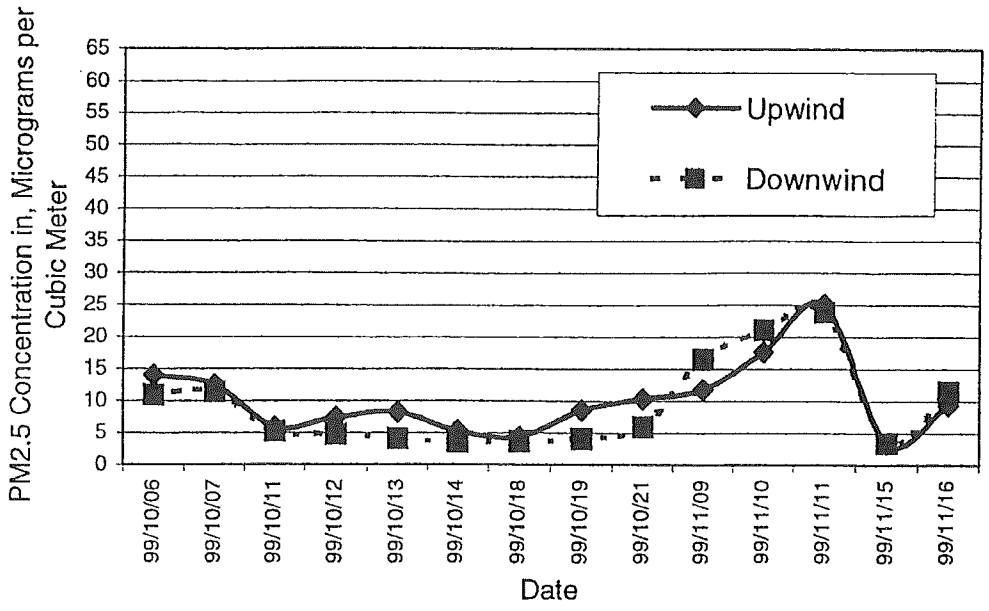

Figure 9. $PM_{2.5}$ Concentration Trend Data for the Buchanan Plant

The $PM_{2.5}$ concentration trends are entirely unrelated to plant operating conditions. For example, there is no relationship between the day-by-day $PM_{2.5}$ concentrations and the plant production and loadout rates presented in Table 1. For example, the correlation between the $PM_{2.5}$ concentration at downwind location 1 and the plant production and loadout rates are shown in Figures 10 and 11. The R^2 correlation for both of the data sets shown in these figures are less than 0.2 confirming that there is no relationship between plant operating rates and the ambient $PM_{2.5}$ levels even at the edge of the plant processing area. The plots for other monitoring locations have similar scatter.

There is also no relationship between the observed $PM_{2.5}$ ambient levels at any of the four monitoring locations and the occurrence of blasts in the quarry. Blasts were conducted on October 13th, October 21st, November 9th, and November 11th.

Wind Speed Analyses

An evaluation of the $PM_{2.5}$ concentration data as a function of the wind speed indicates that the concentrations at both locations (Figures 12 and 13) decrease slightly as the wind speed increases. This strongly indicates that wind blown fugitive emissions from the stone crushing plant are not a significant contributor to the ambient $PM_{2.5}$ emissions. EPA emission factors indicate that emissions from certain operations, such as storage pile stacking and reclaiming, increase as the wind speed increases. It is also logical to assume that emissions from quarry haul roads and other plant operations increase with wind speed. However, the opposite pattern was observed in this study. This is possible only if off-site $PM_{2.5}$ sources are exclusively responsible for observed ambient $PM_{2.5}$ concentrations. If the stone crushing plant were a detectable contributor to ambient $PM_{2.5}$ concentrations, the observed levels at high average wind speeds of 7 to 10 mph would have been significantly higher than those in the 1 to 3 mph range.

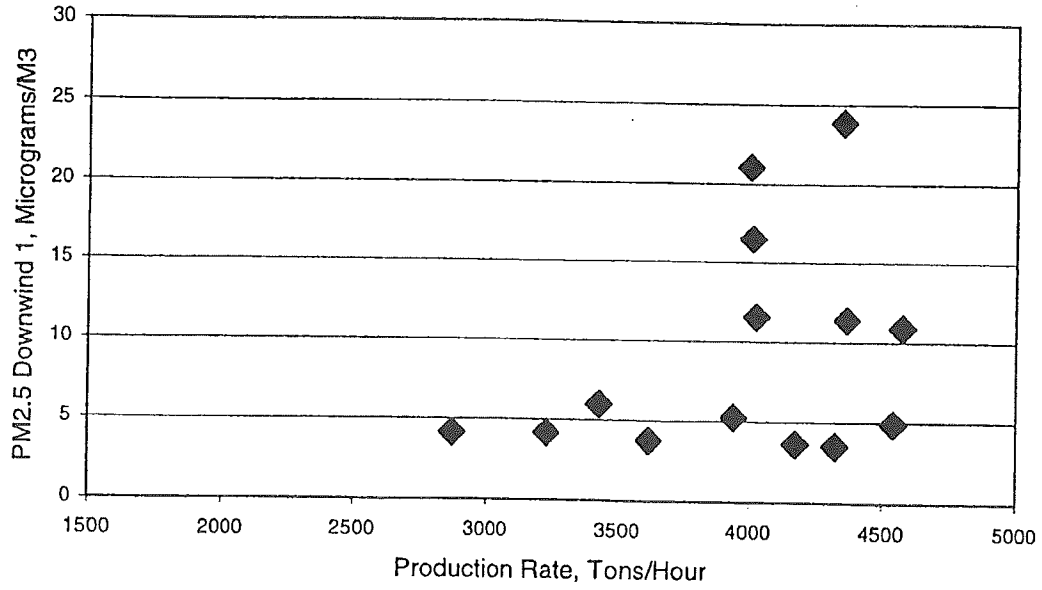

Figure 10. Lack of a Relationship Between $PM_{2.5}$ Concentrations at Downwind Location 1 and the Plant Production Rates

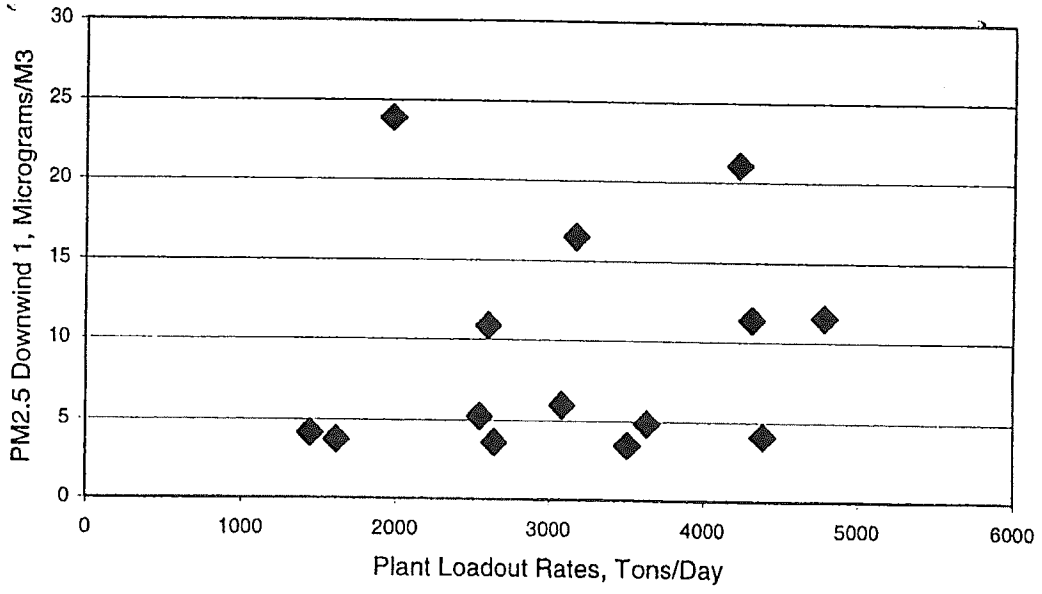

Figure 10. Lack of a Relationship Between $PM_{2.5}$ Concentrations at Downwind Location 1 and the Plant Loadout Rates

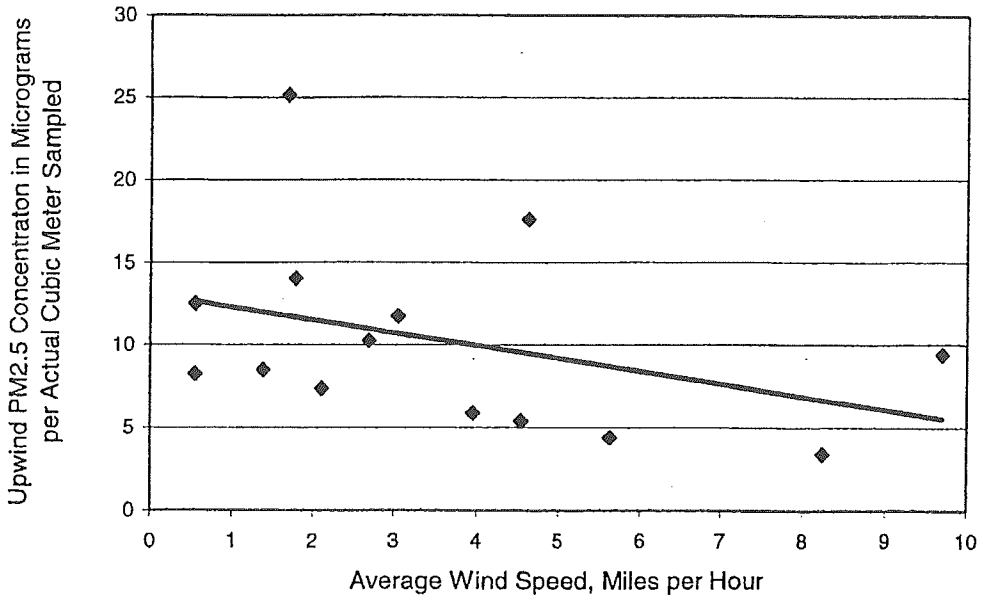

Figure 12. Upwind $PM_{2.5}$ Particulate Matter Concentrations as a Function of Wind Speed

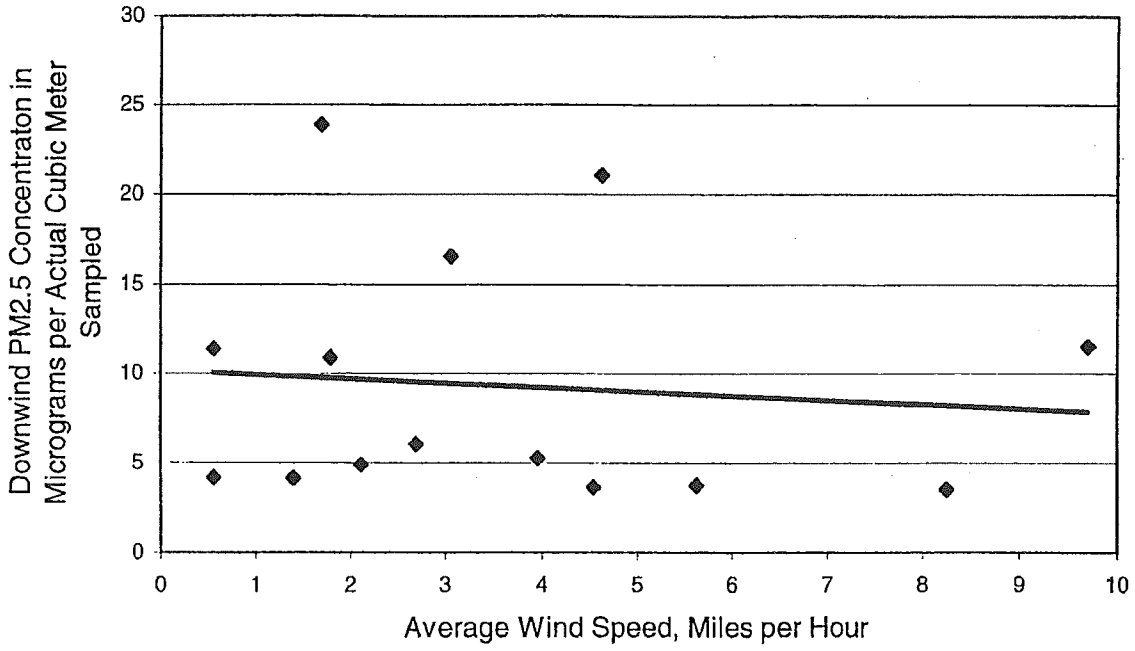

Figure 13. Downwind $PM_{2.5}$ Particulate Concentrations as a Function of Wind Speed

Intermodal Particulate Matter Chemical Analyses

Air Control Techniques, P.C. selected 10 sets of $PM_{2.5}$ filters for SEM and EDS analyses. A summary of these filters is provided in Table 2. This set of filters appeared to have slightly higher $PM_{2.5}$ concentrations downwind of the plant equipment. Accordingly, it would be possible that some $PM_{2.5}$ particles emitted from the equipment would be available on the filters and could be analyzed.

Table 2. Analyzed Filters

Date	Location	Filter Number	$PM_{2.5}$ Concentration, ug/M^3	Dominant Wind Direction
Oct. 13, 1999	Upwind	9	8.2	ENE
	Downwind	10	4.2	ENE
Nov. 9, 1999	Upwind	19	11.8	WSW
	Downwind	20	16.5	WSW
Nov. 10, 1999	Upwind	22	17.6	W
	Downwind	23	21.1	W
Nov. 11, 1999	Upwind	24	25.1	WSW
	Downwind	25	23.8	WSW
Nov. 16, 1999	Upwind	28	9.4	NW
	Downwind	29	11.5	NW
Oct. 24, 1999	Mt. Taylor, NM	N/A	N/A	N/A
	El Calderon, NM	N/A	N/A	N/A

Two of the samples were obtained in wilderness areas of New Mexico, using a battery powered pump and polycarbonate filters in a standard filter holder. The New Mexico samples were obtained to provide examples of PM_1 and intermodal crustal particulate matter far removed from any anthropogenic sources. Single particle EDS analyses were conducted to determine if crustal materials emitted from the stone crushing plant or other sources in the general vicinity were present as particles less than 1 micrometer aerodynamic diameter. EDS tests are conducted using an electron beam focused on individual particles by an electron microscope. Figure 14 illustrates individual particles resting on the surface of a polycarbonate filter.

The emitted X-rays from the particle probed by the electron beam are analyzed to determine the elements present in the particle. The X-ray spectra from 1 to 5 kev were scanned as part of the EDS analyses.

In addition to obtaining particle spectra, RTI also obtained background spectra of the polycarbonate filters used in the $PM_{2.5}$ ambient monitoring instruments. The background spectra are important because the electron beam partially passes through small particles, and the emitted X-rays are from the particle itself and the filter media underneath the particle.

Air Control Techniques, P.C. asked RTI to analyze particles in the size categories outlined in Table 3. The physical diameters are specified along with the aerodynamic diameters due to the differences in the size measurement techniques of the $PM_{2.5}$ ambient monitor and the scanning electron microscopy. The $PM_{2.5}$ instruments separate particles according to their aerodynamic diameter while the SEM inherently is limited to the projected area of the physical diameter.

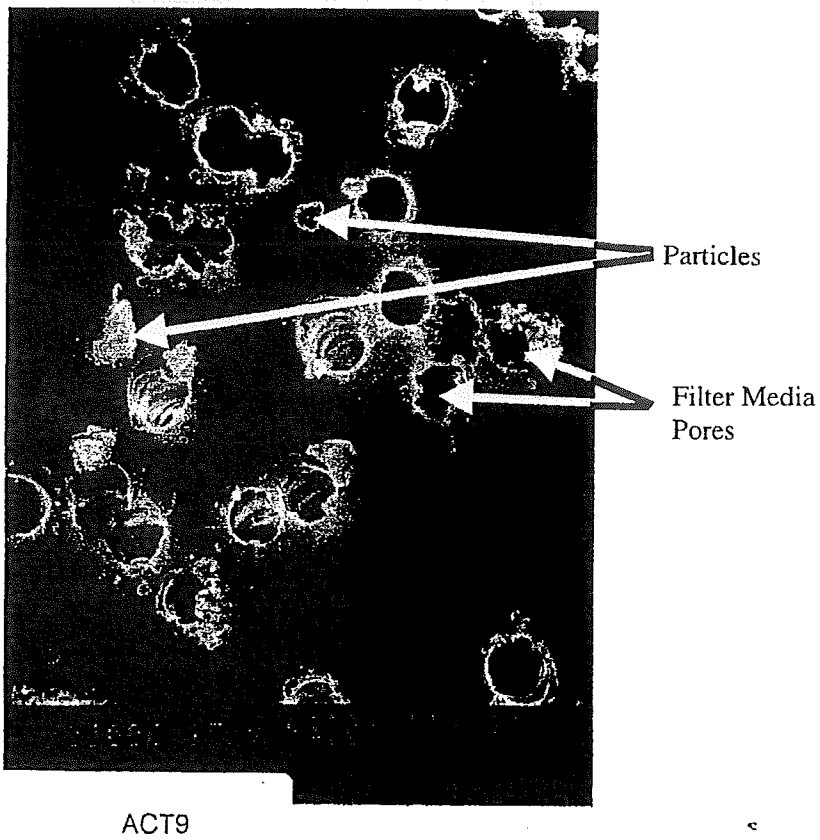

Figure 14. Particles Resting on the Surface of a Polycarbonate Filter
(Filter holes have not yet bridged over due to light particulate matter loadings.)

Table 3. EDS Analysis Size Categories		
Category	Physical Diameter Micrometers	Aerodynamic Diameter, Micrometers
1	≤ 0.33	≤ 0.54
2	> 0.33 to ≤ 0.67	> 0.54 to ≤ 1.0
3	> 0.67 to ≤1.0	> 1.0 to ≤1.6
4	> 1.0 to ≤1.5	> 1.6 to ≤2.5

The physical sizes were chosen based on an assumed particle density of 2.7 grams per cubic centimeter. The aerodynamic diameters were calculated based on Equation 1.

$$d_p = d_{pg}\sqrt{\rho_p} \qquad \text{Equation 1}$$

Where

d_p = Particle aerodynamic diameter, micrometers
d_{pg} = Particle physical diameter, micrometers
ρ_p = Particle density, grams per cm3

Based on this approach, the first two categories include particles that are in the PM_1 size range, and the second two categories include particles that are in the intermodal size range of 1 to 2.5 micrometers.

In evaluating the chemical composition of the particles, Air Control Techniques, P.C. asked RTI to use the following elements as indicators of crustal material.

- Aluminum
- Silicon
- Iron
- Calcium
- Magnesium
- Sodium
- Potassium
- Chromium

This list of elements is consistent with information concerning crustal materials provided in the October 1999 External Review Draft of the Particulate Matter Criteria Document published by EPA.

A variety of other elements were also included in the analyses to check for types of $PM_{2.5}$ and PM_1 particles not associated with stone crushing plants and sources of mineral particulate matter in general. These elements included the following.

- Sulfur (indicator of sulfates)
- Nitrogen (indicator of ammonia and nitrates)
- Carbon (indicator of carbonaceous particulate matter)
- Oxygen (indicator of carbonaceous particulate matter)

Carbon and oxygen are also present in the polycarbonate filter media. Accordingly, the presence of carbonaceous particulate matter could only be determined by observing shifts in the C to O levels from the filter media background tests.

The results of the EDS analyses are summarized in the appendix of this report. These results indicate that the crustal elements are only present in particles having an aerodynamic particle diameter larger than 1 micrometer. The distribution of aluminum and silicon, the two most commonly observed crustal elements, is summarized in Figure 15. It is apparent that aluminum and silicon increase above filter media background levels when the particle aerodynamic diameter increases above approximately 1.0 micrometers (PM_1 upper size limit). The presence of crustal elements only in the greater than 1.0 micrometer aerodynamic diameter size range is illustrated by the comparison of the X-ray spectra obtained from filter #10. For a 0.5 micrometer physical diameter (0.8 micrometer aerodynamic diameter) particle (Figure 16), and a 0.9 micrometer physical diameter (1.5 micrometer aerodynamic diameter) particle (Figure 17), and the filter media background (Figure 18). The aluminum and silicon peaks shown in Figure 17 are considerably above the background levels shown in Figure 18. This indicates that this 1.5 micrometer aerodynamic diameter particle has a crustal origin.

The three spectra shown in Figures 16-18 are typical of the spectra of all of the filter samples analyzed by EDS. The particles less than 1.0 micrometer aerodynamic diameter that were probed had negligible levels of crustal elements and relatively high carbon, nitrogen, oxygen, and sulfur levels. Particles dominated by these elements were present in all four size categories analyzed. However, the crustal elements were only present in particles having aerodynamic diameters larger than 1.0 micrometers.

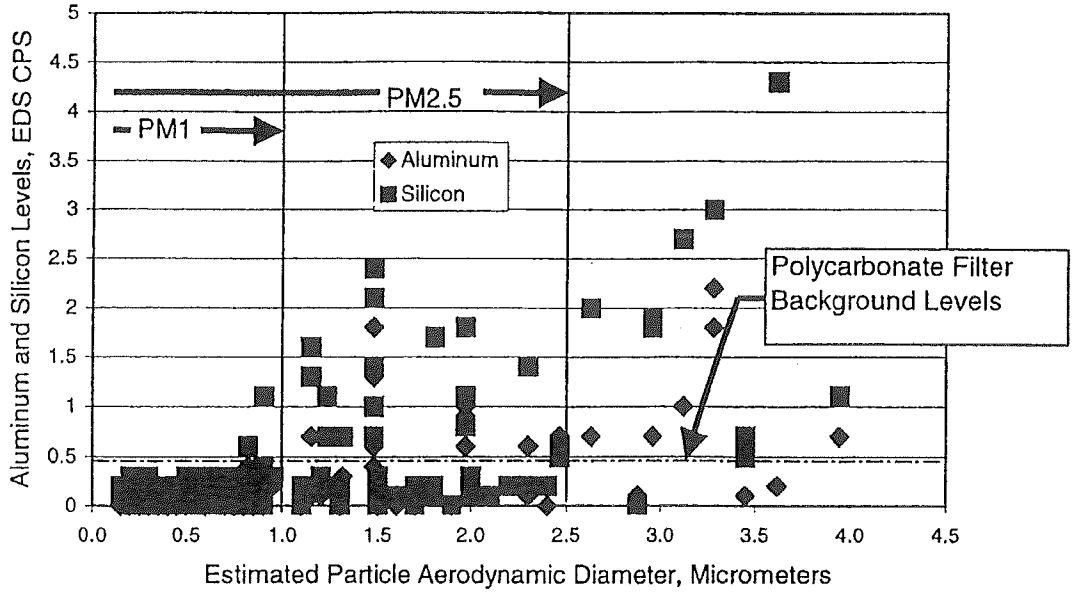

Figure 15. Distribution of Aluminum and Silicon in PM_1, Intermodal $PM_{2.5}$, and PM_{10} Particles

The EDS results for the samples obtained at the stone crushing plant are identical for the two samples obtained in wilderness areas of central New Mexico. For example, Figures 19 and 20 show the X-ray spectra for particles having aerodynamic diameters of 0.8 and 1.8 micrometers physical diameter (1.3 and 2.9 micrometers aerodynamic diameter) respectively. The filter media background spectra for the filter is shown in Figure 21. As with the stone crushing plant samples, the crustal elements were restricted to particle sizes larger than 1.0 aerodynamic diameter.

These results strongly indicate that EPA could use PM_1 as an effective means to define the fine particulate matter mode and avoid the confusion inherently involved with a $PM_{2.5}$ size definition that inadvertently overlaps with the lower portion of the coarse particulate matter definition. The use of $PM_{2.5}$ as the size definition will substantially complicate the development of fine particulate matter control strategies.

3.3 PM_{10} and TSP Ambient Air Concentrations

Concentration - Distance Profile Analyses

One of the purposes of this study was to evaluate the deposition patterns of different size ranges of particulate matter at a stone crushing plant. The average ambient air concentrations measured at the upwind monitoring location (Upwind 1 - 1700 feet from the center of plant processing) and the three downwind deposition monitoring locations (Downwind 1, 2, 3 - 1150, 2200, and 3200 feet respectively from the center of plant processing) of the Buchanan plant are illustrated in Figures 22 through 25. These figures concern only the test days when the wind was from a westerly direction in order to indicate the rate of change in the particulate matter levels for winds passing directly over the plant to the line of downwind monitoring stations.

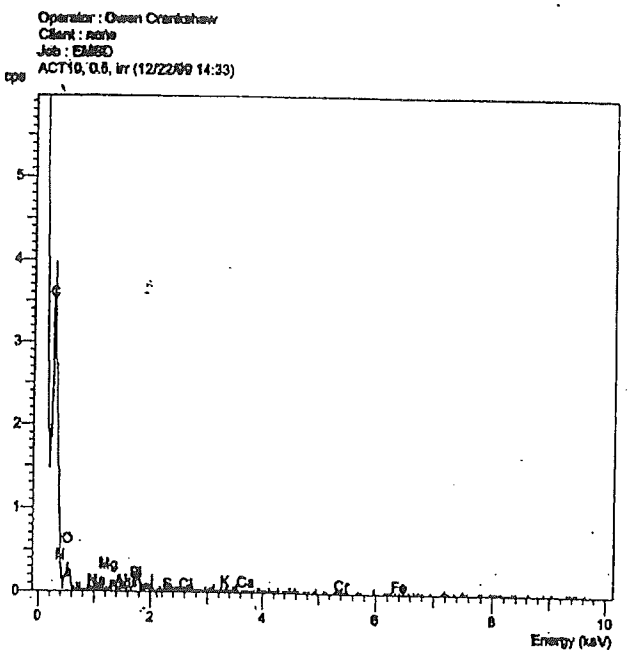

Figure 16. EDS Spectra for a 0.5 micrometer physical diameter (0.8 micrometer aerodynamic diameter) particle, Filter 10 Downwind Location, October 13, 1999

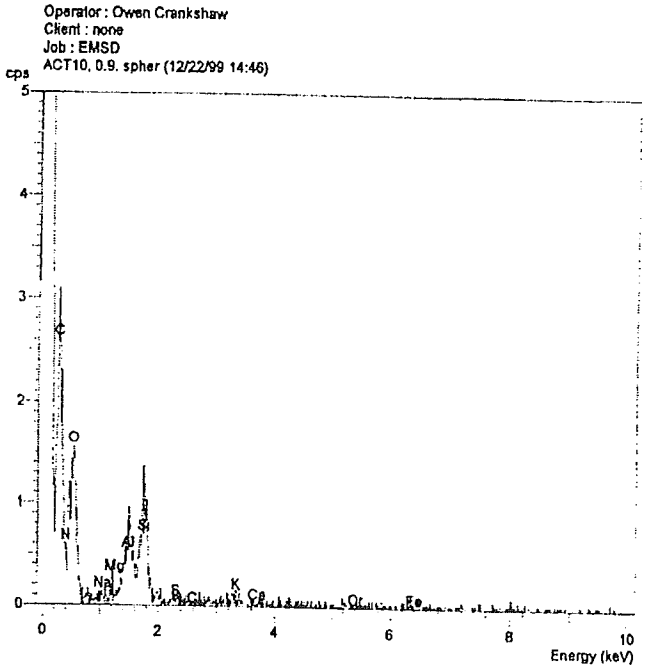

Figure 17. EDS Spectra for a a 0.9 micrometer physical diameter (1.5 micrometer aerodynamic diameter) particle, Filter 10 Downwind Location, October 13, 1999

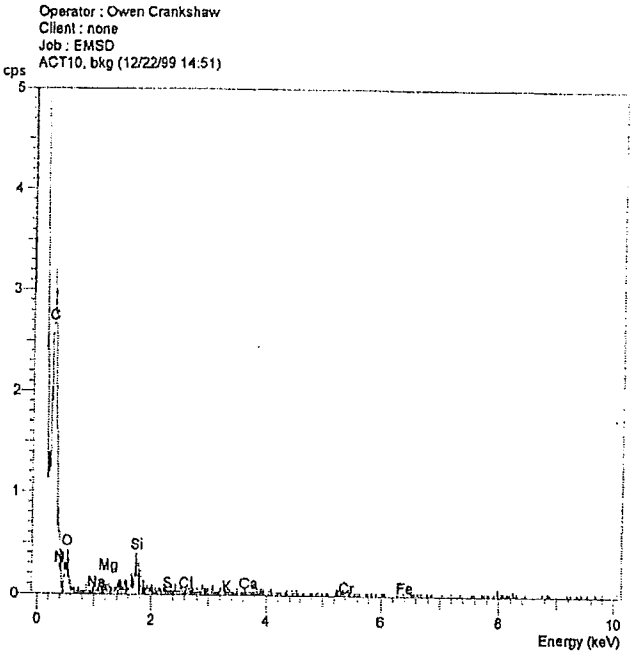

Figure 18. EDS Spectra for the Polycarbonate Filter Media, Filter 10 Background

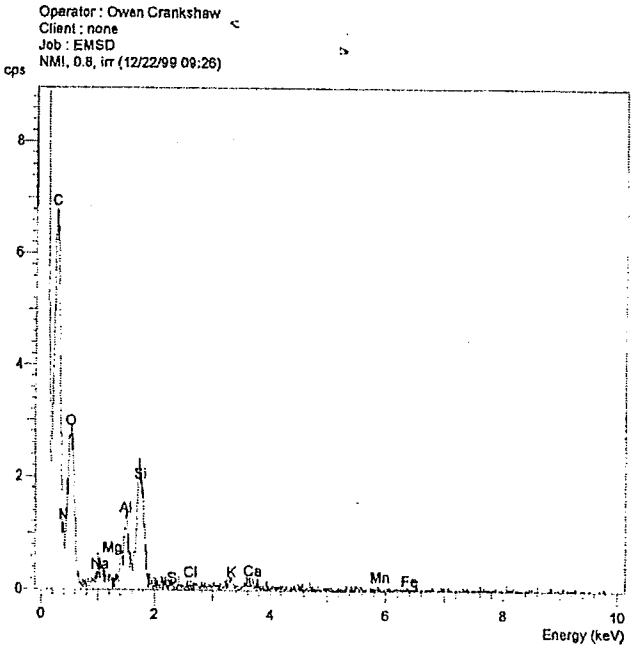

Figure 19. EDS Spectra for a 0.8 micrometer physical diameter
(1.3 micrometer aerodynamic diameter) particle,
Mt. Taylor, New Mexico October 24, 1999

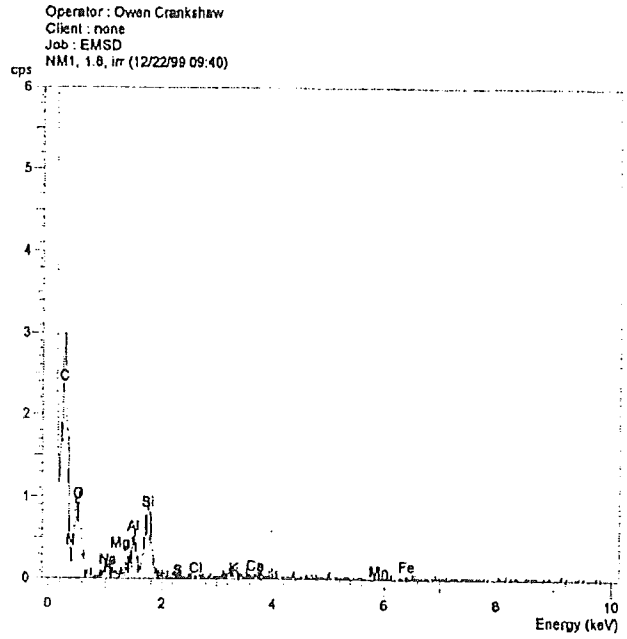

Figure 20. EDS Spectra for a 1.8 micrometer physical diameter (2.9 micrometer aerodynamic diameter) particle, Mt. Taylor, New Mexico October 24, 1999

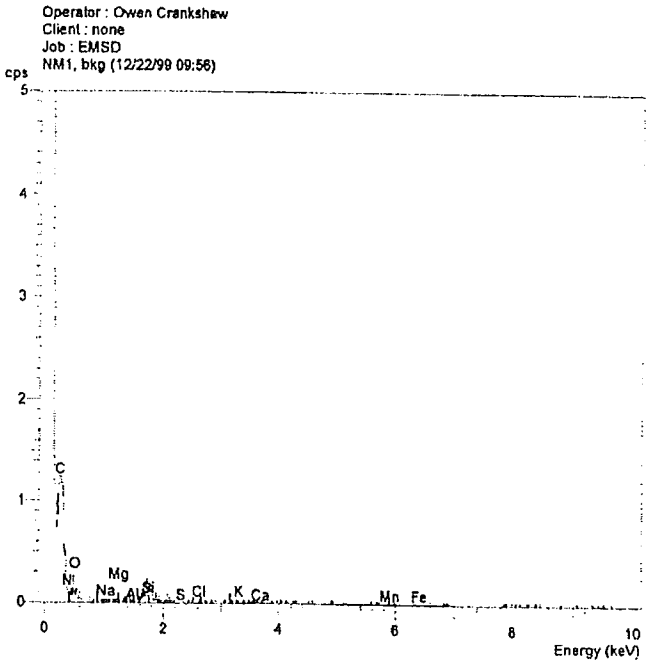

Figure 21. EDS Spectra for the Polycarbonate Filter Media, Mt. Taylor filter background

The particulate matter concentrations illustrated in Figure 22 were measured on November 9, 1999 when the winds were from the west at an average speed of 4.6 mph. The maximum wind gust during the sampling period was 9.9 mph. There is a slightly elevated PM_{10} level at the first downwind monitoring location near the edge of the plant processing area. The second and third monitoring locations had PM_{10} levels essentially identical to the upwind level. Overall, the PM_{10} data indicate that the emissions of PM_{10} from the plant are small, and there is rapid decreases in PM_{10} levels in the air moving downwind of the plant. The TSP concentration at the first downwind location was substantially above the upwind concentration. However, the TSP levels rapidly dropped as the ambient air moved to the second downwind location 1050 feet away. This indicates very rapid deposition of TSP.

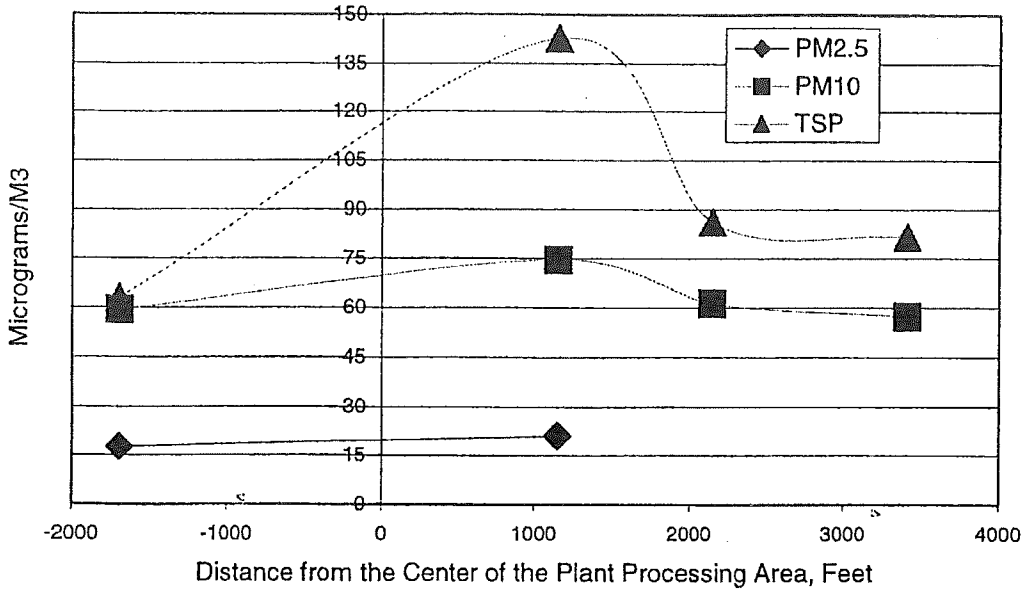

Figure 22. Concentration-Distance Profile for November 10, 1999, Winds from the West

Data from November 11, 1999 is illustrated in Figure 23. During this sampling period, the winds were from the west-southwest at an average speed of 1.7 mph. The peak wind speed during the sampling period was only 4.3 mph. There is no detectable increase in the $PM_{2.5}$ concentrations and only a slight increase in the PM_{10} concentrations. However, there is a moderate increase in the TSP levels from upwind to downwind locations. These TSP levels return to the upwind baseline levels in the time necessary for the air to move approximately 1050 feet from the first to the second downwind monitoring locations. This data set also indicates very rapid gravity settling and dry deposition of the large TSP sized particles and the moderately sized PM_{10} particles.

A moderate increase in TSP concentrations along the line of monitoring stations was observed on November 15, 1999 (Figure 24) when the winds averaged 8.3 mph and gusted to 17.1 mph. It is again apparent from these data that the TSP levels decreased very rapidly between the first and second downwind monitoring sites. This is similar to the rapid TSP removal rates illustrated in previous two figures.

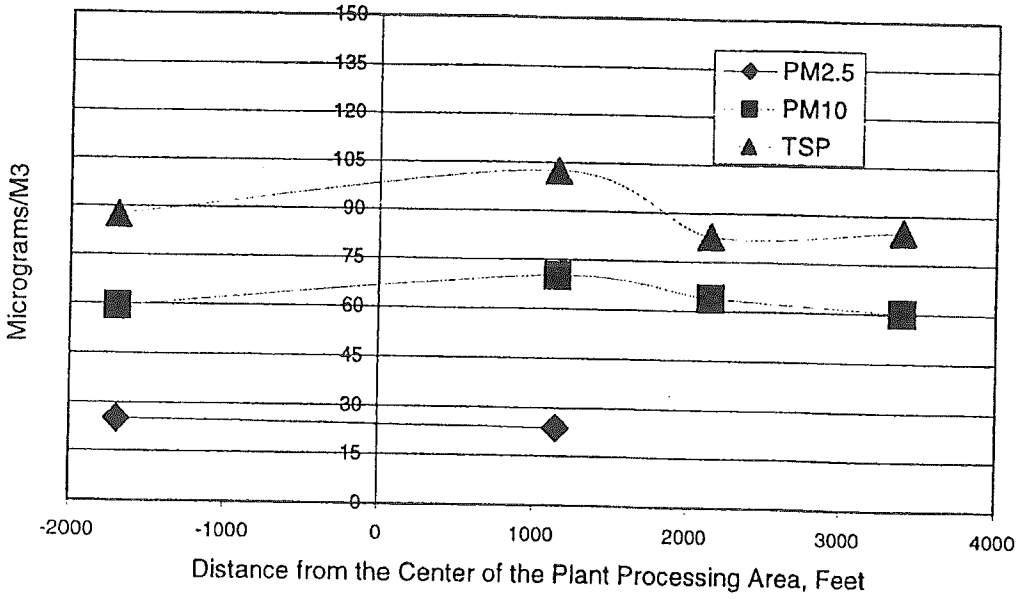

Figure 23. Concentration-Distance Profile for November 11, 1999, Winds from the West-Southwest

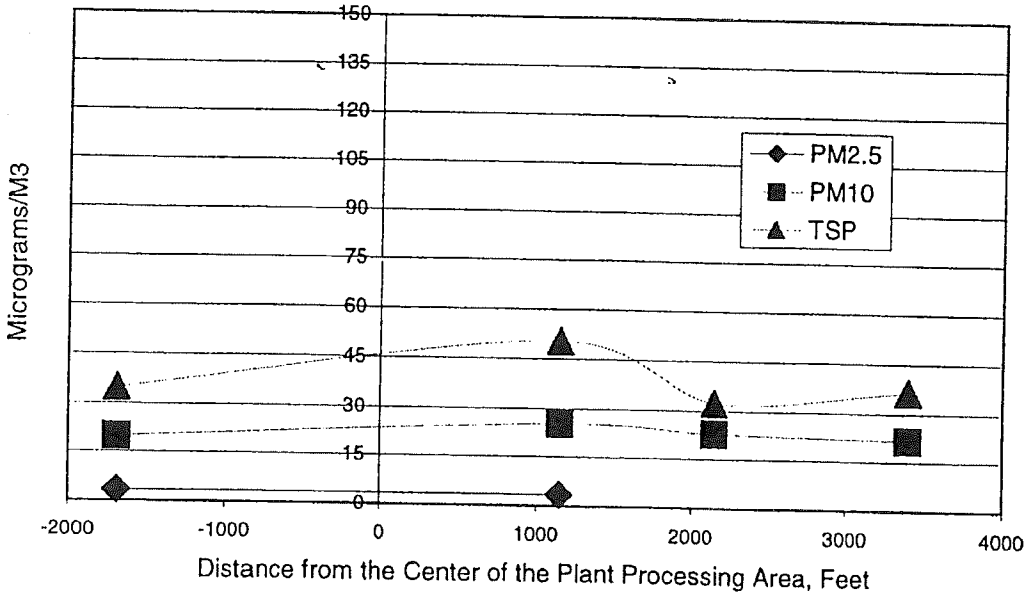

Figure 24. Concentration-Distance Profile for November 15, 1999, Winds from the North-Northwest

The PM_{10} concentrations on November 15, 1999 had a very slight increase from the upwind location to the first downwind location. However, the PM_{10} levels returned to the upwind baseline levels by the time the ambient winds reached the second downwind monitoring location. The observed PM_{10} levels along the downwind line of monitors is considerably lower than that indicated by standard dispersion models that do not take into account settling and deposition. The $PM_{2.5}$ levels on November 15, 1999 had essentially no increase across the plant processing area. The slight difference in the observed levels is within the measurement precision level of the $PM_{2.5}$ ambient monitoring technique.

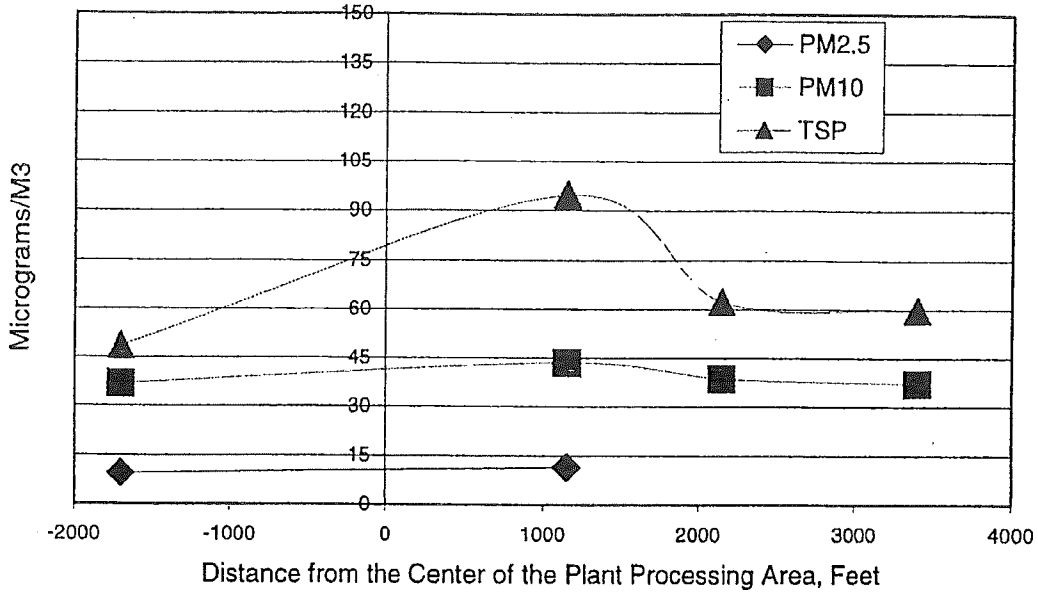

Figure 25. Concentration-Distance Profile for November 16, 1999, Winds from the Northwest

The particulate matter concentration profiles observed on November 16, 1999 (Figure 25) are similar to the other days analyzed. The dominant wind direction during this sampling day was from the northwest and average 9.7 mph. The peak wind speed during the sampling period was 19.7 mph. These average and peak wind speeds are above the normal levels for Greensboro, North Carolina in the fall. The PM_{10} concentrations increased slightly as the ambient air reached the first downwind monitoring location. The PM_{10} levels then quickly decreased to the upwind baseline levels. The TSP levels at the first downwind station were elevated as would be expected during a period of sustained moderate winds and gusty conditions. However, the downwind TSP concentrations rapidly decreased in the short time necessary for the air to reach the second downwind location. The TSP concentrations at the third downwind monitoring location increased slightly due to dust entrained by the nearby unpaved access road to this monitoring location.

The TSP monitoring data obtained during the test program at the Buchanan Plant indicate that TSP levels become slightly elevated after the winds pass over the processing area and then rapidly decrease to levels at or near the upwind levels. TSP size particles generated by the plant appear to be almost completely removed from the atmosphere in less than 1000 feet. These TSP concentration data could be further analyzed by conventional dispersion models to separate the concentration decreases due to normal atmospheric dispersion and due to gravity settling/dry deposition.

Future studies of TSP gravity settling/dry deposition should to focus on areas quite close to the plant processing equipment. There is little point in evaluating TSP gravity settling/dry deposition at distances exceeding 1000 feet from the edge of the processing area because essentially all of the TSP particles generated at the plant are already removed from the ambient air.

Wind Direction - Concentration

PM_{10} and TSP emissions from the stone crushing plant have an impact on the particulate matter concentrations at the first downwind monitoring location at the edge of the plant processing area. The two concentration roses for the Downwind 1 monitoring location (Figures 26 and 27) indicate that the PM_{10} and TSP maximum concentrations occurred when the dominant wind direction for the sampling period was from the west. During these conditions, the ambient air passes directly over the plant processing area and quarry.

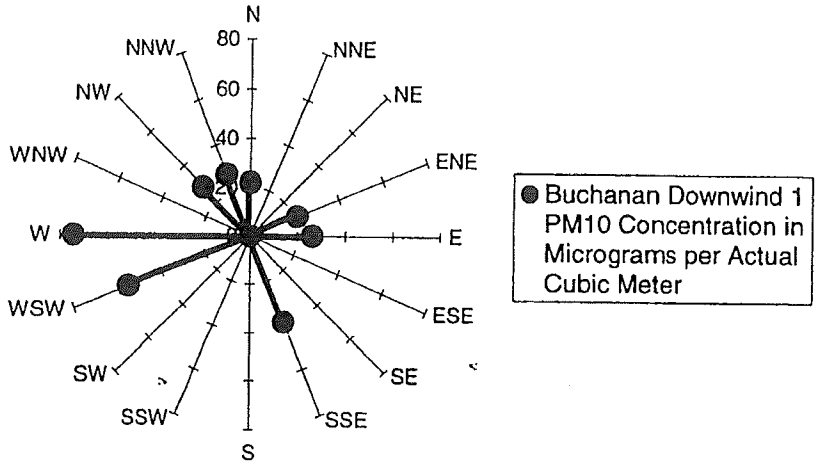

Figure 26. Downwind 1 Monitoring Location PM_{10} Particulate Concentration Rose

The lowest PM_{10} and TSP concentrations were observed at the Downwind 1 monitoring location when the wind direction was from the north and east-northeast. The winds coming from these directions hit the Downwind 1 monitors in a crosswind style; therefore, the effects of the plant cannot be determined.

The presence of a wind-dependent pattern in the TSP and PM_{10} concentrations is in direct contrast to the pattern observed for $PM_{2.5}$ particulate matter. For $PM_{2.5}$, there was no discernable difference in the upwind and downwind ambient air concentrations even though the downwind monitoring was conducted at the very edge of the plant processing area well within plant boundaries. These patterns clearly indicate that stone crushing plants are a slight source of PM_{10} and TSP emissions and a negligible source of $PM_{2.5}$ emissions. It also indicates that $PM_{2.5}$ is present as an entirely different ambient air particulate matter distribution than the mass present as PM_{10} and TSP.

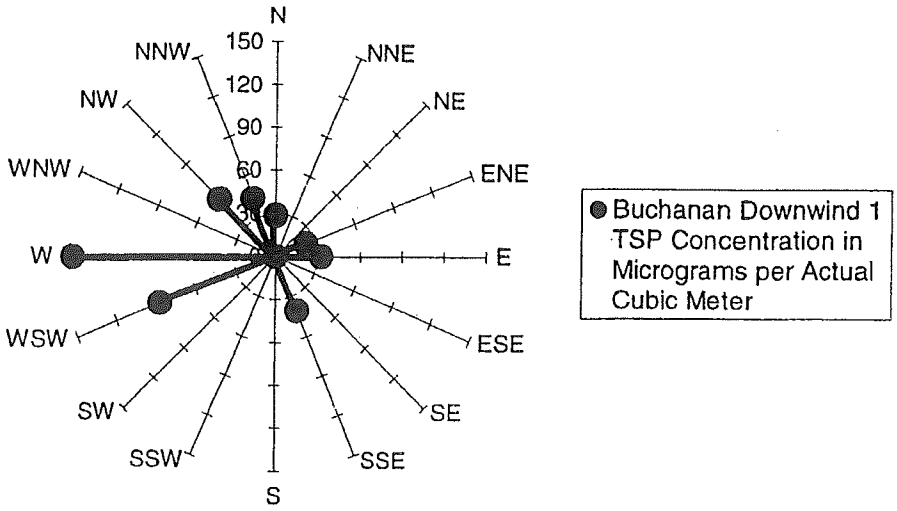

Figure 27. Downwind 1 Monitoring Location TSP Particulate Concentration Rose

It is also important to note that the PM_{10} concentrations observed, even in the first downwind location immediately adjacent to the plant processing equipment, were consistently below the prevailing National Ambient Air Quality Standards for 24-hour periods, despite sampling times of only 6 to 8 hours while the plant was active. This provides further evidence that the PM_{10} emissions from stone crushing plants are low. This conclusion is consistent with low PM_{10} emission factors measured in a series of NSA and EPA sponsored studies over the 1991 through 1996 period.

4. QUALITY ASSURANCE PROCEDURES

The data acquisition system of the FRM-2000 was interrogated to determine if all of the operating conditions monitored continuously and recorded every five minutes were within the required performance specifications. Quality assurance problems occurred with the Downwind 1 $PM_{2.5}$ sampler on a few occasions generally due to power fluctuations.

The power fluctuations were due to the use of a small portable generator. The power fluctuations affected the sensitive electronics of the $PM_{2.5}$ monitor that would shorten the test run. The power fluctuations did not affect the $PM_{2.5}$ samples because the monitor recorded the sample times. Therefore, the total flow rate was decreased as well as the total filter catch, so the concentration data were not affected. The power fluctuations were minimal and did not affect the PM_{10} or TSP monitors or samples.

According to the manufacturer and EPA Part 58 Appendix L, the temperature differential between the filter and the ambient air should not exceed 5°C for more than 10 consecutive minutes. This was never a problem during the study.

There were no quality assurance problems with the post sampling of the $PM_{2.5}$ filters. It should be noted that all the duplicate samples and certified weights were within the acceptance ranges as set forth in the EPA guidance document concerning $PM_{2.5}$ monitoring.

The Appendix of this report contains the daily $PM_{2.5}$ monitor filter data and the corresponding field data sheets for the entire study. Due to the voluminous quantity of 5-minute interval quality assurance data it has been made available on a set of computer disks. During all sample runs, with the exception of two all of the following sampling criteria were met (Table 4.)

- Sample time was greater than 6 hours.
- Sample volumes were greater than 6 liters.
- Average flow rate was 16.7 liters per minute ± 5%.
- The flow coefficient of variation was less than 4%.
- The filter temperature was never more than 5°C above the ambient temperature for more than 10 consecutive minutes.
- No power interruptions were recorded.

Table 4. Quality Assurance, Sample Volumes and Times

Test Location	Filter Number	Test Date	Sample Volume, Liters	Required Sample Volume, Liters	Sample Time, Hours : Minutes	Required Sample Time, Hours	Notes
Upwind 1	5	10/11/99	6.3	≥6	6:10	≥6	Power Interruption
Downwind 1	25	11/11/99	5.2	≥6	5:09	≥6	Power Fluctuation

6. REFERENCES

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5. Richards, J., T. Brozell, and J. Hayden. "Upwind-Downwind Ambient $PM_{2.5}$ Monitoring at Stone Crushing Plants." Environmental Manager, August 1999, Pages 17-26.