1.0 INTRODUCTION AND BACKGROUND

1.1 Problem Statement

A question has been raised about the impact of fugitive fumes and dust generated by blasting at Mountain-Top Removal (MTR) sites upon the quality of life in the surrounding area. Is it substantial (i.e., is there a health impact), and/or is it a significant nuisance affecting enjoyment of daily living? A lot of emotion has surrounded this issue, and yet surprisingly little data exists that addresses either topic; one could almost say no data. Complaints exist, but there is no real way do correlate these complaints to any specific levels of dust, of fumes, of the size of the explosive shot, nor anything else. There is no current way to determine which complaints are supportable and which are not. If the history of blast vibration complaints made versus those substantiated by vibration monitoring is any indication, the proportion of legitimate complaint is probably very low. But — how far can fugitive emissions be expected to travel and at what concentrations, anyway?

1.2 Literature Search

The literature search was disappointing, to say the least. In fact, the PI considered redoing the entire literature search from scratch until attending the Gillette, Wyoming, seminar on blasting fumes (see section 1.3). There is no available literature on the fume and dust content of moving clouds generated by surface blasting. There is some on the total content of fumes generated by blasting, but none on the content of visible clouds, and none on the dust content of the same clouds. The literature encountered was primarily aimed at identifying noxious airborne elements, on preventing such airborne contamination, and making measurements of them. Even the measurement information was of little use. It was primarily directed at making long-duration exposure measurements in a workplace, not the assessment of emissions from a single event .

Even so, some information is useful as background and for comparative purposes. Figure 1.1 shows the relative size of dust particles carried suspended in air vs. wind velocity and particle density. At lower velocities, particles would drop out of the airstream at calculable settling velocities. (To be strictly correct, the word "velocity" should really be "speed.") The graph readily shows that very small particles do not require much air speed to remain in suspension (1.00 ft/sec equals 0.682 miles/hour). However, there is no real way to use this information in a blasting event. Dust particles are imparted an undefined quantity of momentum by the blast, and initially the air and gases containing the dust is very turbulent. Also, if the dust cloud is heavy enough it will show some gas-like properties. In still air, the particles will diffuse rather than drop straight down, as this graph would imply. This phenomenon may be seen in the cast blast photographs in section 1.3 where in the later pictures when turbulence is no longer noticeable the cloud continues to expand as well as become thinner. The thinning could be a result of both phenomena, diffusion and settling. Some experts attribute some initial dispersion to the temperature difference between the emitted gases and ambient air. Not knowing the ration of emitted gas volume to air volume, this difference is impossible to calculate with any precision, and photographs do not indicate any continued rapid cloud rise as would be expected from a temperature difference after the initial force of the explosion has been expended. Continued rise is a slow-to-moderate rate as might be expected from diffusion, settling, and wind dispersion. Until actual cloud temperature measurements are made, this conjecture remains unproven.

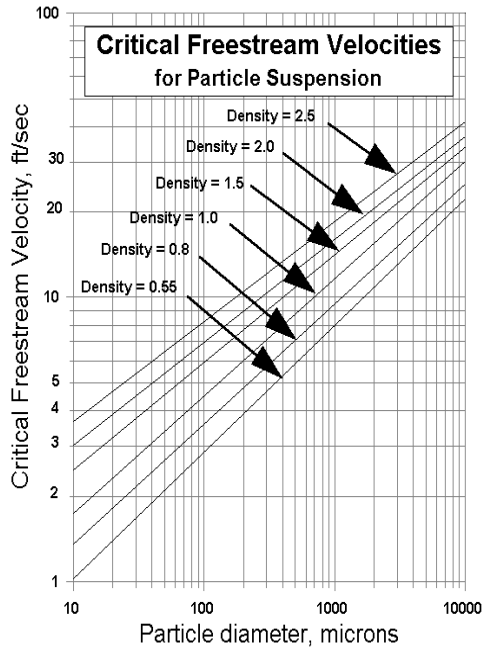

Figure 1.1. Particle suspension velocities (Adapted from Hesketh and Cross, 1983)

The single most useful reference on fugitive emissions was "Fugitive Emissions and Controls, by Hesketh and Cross, 1983, and this work focused on dust, only mentioning fumes. They did mention primary fugitive dust sources as being unpaved roads; mining, excavating, and crushing operations; and heavy construction operations as the first, fourth, and sixth primary

sources. Of particular interest is their citing EPA's emissions study showing that automobiles unpaved roads may produce up to 75 pounds of fugitive dust per vehicle mile traveled (VMT).[1] The EPA developed an emission factor for vehicles on unpaved roads:

$$E = (0.81)\,(s)\left(\frac{S}{30}\right)\left(\frac{365 - w}{365}\right)$$

Where E = lb of fugitive emissions / VMT
s = silt content of road surface material, %
S = average vehicle speed, mph
w = mean annual number of days with 0.01 in. or more of rainfall

Hesketh and Cross also cite an expert as stating that this equation might be modifiable for trucks on haul roads by pro-rating for truck tire surface. They cited no numbers for blasting.

1.3 Fume and Dust Standards

Numerous standards exist for fumes and dusts according to the environment, the work being performed, the governing agency, and more. These standards frequently vary. In fact, while the current American Conference of Governmental Industrial Hygienists (ACGIH) sets the TLV for carbon monoxide at 25 ppm, 30 CFR 75.322 sets it at 50 ppm for underground coal mines. Since the ACGIH is the most frequently cited and used set of standards in the United States, those standards are used as a basis for comparison in this study.[2] For this study, the substances of interest include nitrous oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), ammonia (NH_3), and dust. Table 1.1 lists the current (year 2000) exposure limits foer these substances as set by the ACGIH.

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[1]"Compilation of Air Pollutant Emission Factors," U.S. EPA #AP - 42 with supplements, February 1976.

[2]In fact, the carbon monoxide discrepancy used for this illustration results from an unfortunate line in 30 CFR that refers directly to the 1972 version of the ACGIH standards; thus those levels have become fixed in law and 29 years of increased understanding of chemical substances has gone unrecognized by federal law in this particular application.

Substance	TWA[a] (ppm or mg/m^3)	STEL[b] / C[c]	TLV Basis
Nitrous Oxide	50 ppm	—	Reproductive; blood; neuropathy; asphyxiation
Nitrogen Dioxide	3 ppm	5ppm	Irritation; pulmonary edema
Carbon Monoxide	25 ppm	—	Anoxia; CVS[d]; CNS[e]; reproductive
Ammonia	25 ppm	35 ppm	Irritation
Dust (PNOC)[f]	10 mg/m^3 (E[g],I[h]) 3 mg/m^3 (E,R[i])	— —	Lung Lung
Quartz	0.05 mg/m^3	—	Silicosis; pulmonary function; pulmonary fibrosis; cancer

Table 1.1 Threshold Limit Values (TLV's) as set by the American Council of Governmental Industrial Hygienists, 2000

a: TWA – Time Weighted Average
b: STEL – Short Term Exposure Limit
c: C – Ceiling Limit
d: CVS – Cardiovascular System
e: CNS – Central Nervous System
f: PNOC - Particulates Not Otherwise Classified (insoluble)
g: E – particulate matter containing no asbestos and <1% crystalline silica
h: I – inhalable fraction
i: R – respirable fraction

1.4 Familiarization Trip

The investigators made a trip in December of 1999 to observe a blast and obtain a feel for the distances and terrains involved. The following pages of photographs document that visit. Several major insights were gained on this visit.

There are three blasts in the following photographs. The first eight pages (pictures labeled DecBCast_xx) are of a major cast blast taken fro a distance of approximately 2,000 feet. The wind was very slight and to the left of the pictures at the blast initiation, and to the right for the last several pictures. The wind was primarily still for the majority of the pictures, which also meant for the majority of the cloud life. The pit is toward the right of the pictures. This shot

produced a very visible fume cloud. Items to notice in the pictures include:

- The dust cloud issued primarily from the cast material, which was cast substantially to the right.
- The fume cloud issued primarily from the shot location and did not move with the dust cloud.
- The wind died and the cloud did not move. (Contrast this to the shovel shot pictures following.)
- The cloud thinned out and became very diffuse, with the fumes intermingling, and when it did move, it moved toward the pit.
- If this had been an instrumented shot, it is unlikely that we would have obtained any measurements. The cloud did not travel to any spot where our devices might have been set.

This visit underscored the difficulties we had already anticipated regarding the forecast of wind velocity and locating adequate sites for instrumentation.

The photographs labeled DecBCush_xx are of a trim shot on a contour bench in excess of 2500 feet from our location (the same spot we photographed the cast shot from, but 90° to the right). Although we had light-to-no wind, the cloud travel from this shot indicates substantial air movement just ½ mile away at the same approximate elevation. There are no apparent fumes in this cloud.

Finally, the photographs labeled DecBShov_xx are of a shovel production shot a bit further to the right on the same bench as the trim shot. Both dust and fumes are apparent. From the pictures, it appears that the fumes traveled further and faster than the dust. This was not the case with the cast blast.

The immediate impact of this familiarization trip was to impress us with the variations inherent in surface blasting. At the same mining site where we could expect similar conditions, at spots withing 2500 feet of each other where weather variations would not be expected, we saw three very different clouds, one of which probably would not have reached our instrumentation.

Cast Shot

Cast Shot - 1

Cast Shot - 2

Cast Shot - 3

Cast Shot (Cont'd)

Cast Shot - 4

Cast Shot - 5

Cast Shot - 6

Cast Shot (Cont'd)

Cast Shot - 7

Cast Shot - 8

Cast Shot - 9

Cast Shot (Cont'd)

Cast Shot - 10

Cast Shot - 11

Cast Shot - 12

Cast Shot (Cont'd)

Cast Shot - 13

Cast Shot - 14

Cast Shot - 15

Cast Shot (Cont'd)

Cast Shot - 16

Cast Shot - 17

Cast Shot - 18

Cast Shot (Cont'd)

Cast Shot - 19

Cast Shot - 20

Cast Shot - 21

Cast Shot (Cont'd)

Cast Shot - 22

Cast Shot - 23

Cast Shot - 24

Cushion Shot

Cushion Shot - 1

Cushion Shot - 2

Cushion Shot - 3

Shovel Shot

Shovel Shot - 1

Shovel Shot - 2

Shovel Shot - 3

Shovel Shot (cont'd)

Shovel Shot - 4

Shovel Shot - 5

Shovel Shot - 6

Shovel Shot (cont'd)

Shovel Shot - 7

Shovel Shot - 8

Shovel Shot - 9

1.5. Wyoming Seminar

The PI attended a blasting seminar in Gillette, Wyoming, January 12-13, 2000. In conjunction with this seminar, on the 11th and again on the 13th of January, 2000, the PI was given a tour of the area around the Eagle Butte Mine, where much of the current controversy about NOx and post-blast emissions has centered in Wyoming. The Eagle Butte Mine in Wyoming is directly beside the major highway into Gillette and very close to a housing subdivision. This subdivision frequently finds itself in the path of the fume clouds from the adjacent mine. If the wind is in the right (or, more to the point, wrong) direction, the lay of the land is such that the clouds are funneled directly toward this subdivision. Most of the subdivision has been bought by the mining company, but there are still a few residents there fighting the mining company over this issue. This has been the focal point for much of the current western controversy.

The blasting seminar on January 12th and 13th in Gillette, Wyoming, focused on the NOx generation from blasting. This seminar seemed likely to provide information that would be useful in our investigation of fugitive fumes and dust from mountain-top removal blasting, and the principal investigator's (PI) visit was sponsored by the office of surface mining. The trip was substantially informative, especially from the perspective of determining what is not known. This seminar was established specifically to address this problem; there were no technical papers nor research papers presented. Rather it was a collection of experts from the mining industry, the explosive providers, government agencies, consultants, and the public who were brought together to address this specific issue. Presentations were intended to establish the state-of-the-art in the understanding and mitigation of fume clouds, and included a fair amount of anecdotal information as well. A number of issues and perspectives were immediately noticeable.

The seminar in Wyoming was an opportunity to determine exactly what the state of the art is insofar as fugitive fume analysis, monitoring, and control is. Although the technical blasting techniques are the same in the east and the west, there are a number of substantial differences in MTR blasting from that done in Wyoming, as highlighted during the conference:

, Wyoming charges are larger than for MTR (Up to 8,000,000 lbs vs. 500,000 to 1,000,000 lbs. with the average MTR round being smaller).

- In the west, there is a direct correlation to cloud size versus charge size, other factors remaining equal.
- Wyoming terrain is relatively flat, whereas MTR occurs in rugged terrain; also the west is primarily open plain whereas the east is totally forested. Lrge differences in air turbulence and directional changes may be expected.
- On average, territory around the Wyoming sites are sparsely populated (with exceptions), while there are more residents around MTR sites.
- There is currently a high level of interest and emotion surrounding the issue in Wyoming, whereas the issues around MTR revolve more about damage to the environment and ecosystems and until recently has not received much public attention.

These differences need to be considered when applying the Wyoming experience to our evaluation of MTR fugitive fume issues. Keeping these differences in mind, and others, is essential to determining which western experiences are applicable in the east.

The problem is undefined.

It was quite surprising to find out that no experts in attendance had any concrete evidence concerning the actual noxious gas levels in the visible clouds. Their relative concentrations remain unidentified. The associated impacts of various NOx levels as presented by the EPA at the seminar include:

ppm	Exposure time	Impact
0.1 - 0.8	Not given	Increased permeability (in vitro)
0.4	Not given	Asthmatic reaction
1.0	2 hours	Increased airway resistance
		Decreased T lymphocytes, NK cells
1.5	3 - 15 minutes	Bronchospasm
		Increased airway resistance
2.0	10 minutes	Decreased ciliary beat frequency
		Increased airway resistance
5.0	10 - 15 minutes	Impaired gas transport
		Decreased lung compliance [compressibility]
		Increased airway resistance
25.0	Not given	Immediate pulmonary edema
200	1 minute	Death

As can be seen from the above listing, exposure may lead to significant consequences, including death. However, there is no current knowledge of the concentrations of NO_2 to be found within

a visible cloud. Although these clouds may be quite compelling in appearance, large and a very deep rusty-brown fading to red and then yellow, no-one has any correlation as to appearance versus concentration. Intuitively on would think that a cloud that visible would contain more than 200 ppm (0.02%), but there is no evidence of death or serious health impairment. Several industry personnel present stated (to me, in response to questioning) that they have driven through, walked through, and even worked in such clouds without any impact to health.[3] This anecdotal evidence would indicate concentrations substantially less than 200 ppm if the above table is accurate.

Nor is there other field evidence. The region around the mines contains substantial wildlife. On this visit I observed a small herd of mule deer feeding on mining property between two surface operations, and I am told other wildlife is abundant. While mule deer may be large enough (and perceptive enough) to observe an approaching cloud and avoid it, the same is not true of smaller wildlife — rabbits, ground squirrels, birds, etc. There are no reports of dead wildlife being found in the wake of any of these clouds (nor has anyone admitted overtly searching for any). Given the level of emotional involvement of some of the attending groups, one would have to assume that any such discovery would have been given considerable attention.

In essence then, this is an undefined problem. There are no known concentration data, no real evidence of health damage, death, or even temporary impairment, only anecdotal incidents that cannot be weighed without some sort of official and scientific assessment. The current status is that strong debate and substantial activity is revolving around an issue that has not been truly defined.

No previous real attempt to define the issue has been made. One monitoring study was done, but not in such a manner as to define cloud concentrations. Six recording monitors were established at points of potential public access and run 24 hours per day for 30 days. The intent was to use blasting, weather, and wind records to determine sources when the monitors noted any concentrations of NOx. After 30 days, 5 monitors showed nothing, one monitor showed a brief exposure to 1 ppm. A professor from the University of Wyoming (Merl F. Raisbeck, DVM, PhD) stated that he tried to make such measurements about 15 years ago, but was able to

[3]This is not to say *no* impact; several did describe watering eyes, some burning, and some labored breathing; they also said such effects disappeared immediately when no longer exposed to the cloud.

find nothing.

No recommendations for measurements were made, and no effort is ongoing. NIOSH in Pittsburgh, through the work of Richard Mainero and James Rowland, is pursuing work on blasting fumes, but on a laboratory basis. This would provide information on total NOx's produced by an explosion under predetermined conditions of confinement, but would provide no dispersion or diffusion information. They have no, and at this time were preparing for no, field work. Most of the approaches discussed at this seminar were aimed at determining the total quantity of NOx generated by blasts; even the proposed monitoring attempts as described had this end as a goal. No discussion was made of assessing dispersion or diffusion, except for the guest speaker who discussed computer modeling.

Since actual levels of NOx are not known, discussions revolved around reducing or eliminating them. NOx's occur when blasting is inefficient, and most of the meeting was spent discussing causes of inefficiency and efficiency improvement.[4] There was limited discussion about reducing fumes by introducing another chemical into the ANFO or emulsion to act as an excess oxygen scavenger, which would reduce the produced NOx's. (There was no discussion of the fact that this approach could well elevate levels of ammonia.)

There was a limited discussion of things that might be done to treat the cloud itself. There was discussion of treating the surface of the site to be blasted. For example, what about a substance spread on the blast site prior to blasting that would react with NO_2? One person did mention the possibility of wetting the location down. (This may not be possible since this could damage the blasting circuit, electrical or nonel.) An aerosol might be developed that could be sprayed or released in a fume cloud. There might be artificial means of increasing dispersion rates. The meeting disbanded with no concrete suggestions or direction established.

Meeting Notes

What follows are summaries of some of the PI's notes taken during the meeting. Certain items were repeated numerous times, such as the assumed causes of inefficient blasts and red

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[4]Efficient blasting may reduce the problem, but the view as expressed tended to overlook the fact that blast efficiency is the goal of every explosives engineer, fume issues aside. Efficiency is an economic issue.

smoke, so the original notes are very repetitive.

James Roland III — NIOSH — A paper in the handout, but no handout of the talk.

As fuel oil goes up, CO goes up

As fuel oil goes down, NOx goes up.

As water content increases, so does NOx

Tried using Schedule 80 steel pipe (strong) vs. galvanized pipe (weak) for lab testing:

Loss of velocity in galvanized pipe

Little change in CO, but dramatic increase in NOx

Thus deviation from 6% FO, loss of confinement, and water contamination all contribute to NOx.

Rich Mainero — NIOSH

Common exposure standards for 10 hours per day, 40 hours per week:

NO — 25 ppm NO_2 — 1 ppm

Therefore concentrate on NO_2.

Water stemming lowered all NOX, but NO more than NO_2

Rock dust and sodium bicarbonate also lowered NOx's.

2. Ricky Vance — Nelson Brothers

Causes of NOx:

Environmental
- Water
- Geology
- Confinement
- Competency (of rock)

Application
- Powder factor
- Hole diameter
- Hole depth
- Burden & spacing
- Initiation type

Product
- Product sensitivity
- Loading contamination
- AN prill quality
- Density and reactivity
- Additives

Primer size
Timing
Sleep time

Worst blend for producing NOx — 50/50 ANFO/emulsion

Conclusions as to major causes:

Groundwater contamination

Effective diameter (D_e)being reduced by product being driven into cracks and fractures

Critical diameter and sensitivity — dropping below both because of loss in D_e

This is a problem with detonation becoming deflagration

Smaller holes lead to a smaller detonation front and less prill consumption within the detonation zone; is consumed by deflagration after the detonation front passes.

Q & A Session

ANFO/emulsion blends do not stratify with extended sleep time because of emulsion viscosity.[5]

Critical diameter of 40/60 is smaller than that of emulsion alone. (This underscores the importance of the stratification question.)

Correlation with explosive gas products versus theoretical models:

CO, CO_2 — Good correlation with theory

NO, NO_2 — poor correlation individually, but good correlation as a total

Jim Armstrong — Apogee Scientific — Measuring plumes

Good idea: tethered balloon system (Out of our budget range)

Used tracers for back-calculation to quantity generated. No mention of forward calculation for concentration (downstream).

A number of instruments were discussed in overview. Unfortunately, NOx's fall in a range difficult for most of them to measure accurately. The exception, and a good candidate for us to examine, are:

Differential Optical Adsorption Spectroscopy (DOAS) — in the UV range

Use photogrammetry for estimating plume volumes

(Both of these were subsequently determined to be infeasible for us.)

Q & A Session

Armstrong's recommendations:

At first, big jumps are better than small steps (in instrument resolution)

Try a number of methods — don't place all eggs in one basket

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[5]I later debated this point with the speaker. These were laboratory tests, and he conceded that field conditions may not be a match.

Minimize dust visual impact by looking at cloud vertically instead of horizontally.

Cloud color is not an indicator of concentration (this was repeated by several persons)

Sun angle, brightness, cloud cover, background, visible light path, etc, all change color

(It seemed obvious that this had been a topic discussed before; our own field work verified this.)

William R. Monnett — McVehil-Monnett Associates, Inc.

There is a lack of ability to calculate the NO to NO_2 conversion process

Discussed "puff" models (not useful to our application)

EPA Representative

Presented an interesting argument that the Cx/Nx ratio should be constant for any point in the cloud; therefore C, easier to measure, could be used to determine N.

Richard Turcotte — ICA/Orica.

Stated NOx problem is not in the chemistry, it is in the sensitivity

Stephen Burchell — Nelson Brothers

NOx causes: (note repetition)

- Ground conditions
  - Soft materials
  - Water saturation
  - Ground easily compressed and deformed (not like ours in WV!)
- Application
  - Large number of holes
  - Multiple rows — up to 5 (seems low to me)
  - Higher powder factor
  - Long delay times — often as long as 2 seconds. Typically use detonating cord, therefore down-hole delays can be long also.
- Product formulation and quality

Results:

- Considerable and repetitive stresses on undetonated holes
- Large fractures produced around undetonated holes
- Wet conditions make this worse
- Product is being driven into fractures
- The explosive environment is already poor without these additions
- Holes [may] drop below critical diameter
- Detonation becomes deflagration

Det cord shocks the explosive column, injects gases into it while it is waiting for detonator.

One cure: product with smaller critical diameter D_c

Emulsion, D_c <=1.25”
50/50 blend, D_c = 2.55”
30/70 blend, D_c = 3.05”

Recommendations:

Ground conditions:
- Dewater
- Learn more about the local ground conditions

Application:
- Avoid close burdens and spacings
- Avoid excess confinement [this seems to be contradictory]
- Avoid large numbers of rows
- Avoid initiation systems that disrupt the columns

Product:
- Load emulsions for increased sensitivity and smaller critical diameter

Q & A Session

ANFO is less likely to go into cracks than emulsion: “60/40 is like a solid, 40/60 is like a liquid”

Seismic velocity is around 2000 fps or less

1st row damages ground for 2nd row

Suzanne Wuerthele — EPA

Most available data comes from case histories and accident reports

$T_{1/2}$ of NO_2 in air is about 35 hours
1 ppm = 1.88 mg/m^3
Vapor density = 1.58
Odor threshold = 0.1 to 10.0 ppm
Acts on hemaglogin in the same fashion as CO
Welders have high exposure to NO_2
It “solubilizes” — ie, is soluble in water

Government Limits:

EPA NAAQS	0.05 - 0.09	[A TLV with a range???]
NIOSH STEL (15 min.)	1 ppm	
EPA significant harm level (1 hour)	2 ppm	
OSHA PEL (8 hour)	3 ppm	
OSHA STEL (15 minutes)	5 ppm	
NIOSH IDLH	20 ppm	

NAAQS = National Ambient Air Quality Standard

STEL = Short Term Exposure Limit

PEL = ? I assume this is equivalent to TWE or Time Weighted Exposure

IDLH = Immediate Danger to Life and Health

A risk analysis was promised, but not given. A list of risks was presented without statistical or mathematical analysis.

Liz Vandel — Kennecott Energy

Holding a blast for the proper wind direction has taken as long as two weeks.

Donnie Fullenwinder — Powder River Coal

"We overfuel to ensure that the product has enough fuel."

Q & A Session

Kennecott warns all persons within a 5-mile radius before blasting

Hole liners — time consuming, need extra labor, they twist and hang up, create cut-offs; best avoided whenever possible

Another perspective: Holes squeeze as they stand. Liners hang up, but you don't know it until you load and then the liner rips. They lost 13 of 122 holes, and the shot smoked anyway. (The holes were 105 - 107 feet long on a 20 degree angle.)

Aforementioned public area monitoring attempt: one person said monitors were "as close as three miles" while another said within 800 or 900 feet on I-90. There were 11 mines in the area.

Initiation systems: consensus — det cord

Move is to lower grain det cords to minimize shock and gas

At the end — a citizen mentioned a red-cloud study performed by New Mexico Tech in 1995 in conjunction with the Research Study Center for Energetic Materials. ("Chemical Kinetics ....." NFS grant CTS - 9417526.) This study measured levels of 64 ppm at the heart of a surface blast0. This raises some interesting questions:

1. This study was to find out more about the explosive reaction itself. Therefore these sensors were placed very close to the blasts (one blast destroyed 2 of 3 sensors). Therefore it isn't really applicable to blasting plumes.
2. If these sensors measured 64 ppm very close to a detonation's ground zero, what would the concentration be after it travels and disperses, even a little bit? Eg, a doubling of cloud diameter cubes the volume, resulting in a concentration of 4 ppm (assuming, of course, uniform diffusion). Even with non-uniform dispersion, the concentration will diminish at an inverse-exponential rate.

3. It is interesting that no one mentioned this report until a citizen brought it up at meetings end, yet several of the speakers were familiar with it after it was brought up.

At the end of the seminar the PI was able to arrive at three conclusions:

1. The literature search's results were, in fact, accurate. There were no materials published on fugitive emissions from blasting clouds.
2. The primary source of NOx fumes appears to be blasting inefficiency.
3. Blasting conditions in the east are much more favorable:

   Better confinement due to substantially stronger strata

   Less "sleep time" in the holes, even the larger blasts

   Smaller blasts, and therefore better control over them.

2.0 EXPERIMENTAL APPROACH

2.1 Parameters

The goal is to obtain adequate data to objectively assess the quantities of dust and fumes escaping the mine property, and identify if these levels constitute either a health risk (as defined by existing regulations) and/or a nuisance. The focus will be blasting. Originally, time and resources permitting, we had hoped also to obtain some limited measurements of drilling, hauling, and casting operations. Time and resources did not allow us to do this. Therefore, the decision was made to obtain measurements for:

- Nitrogen Dioxide
- Nitrous Oxide
- Carbon Monoxide
- Ammonia
- Total Dust
- Respirable Dust

2.2 Experimental Protocol

2.2.1 Anticipated Difficulties

The major anticipated problem was wind and weather. Fume and dust clouds have not been studied in this manner before. Although a couple of attempts have been made, all failed because of the inability to predict the cloud path. Until more is known, it is not permissible to "chase" a cloud, because we do not wish to expose any investigators to the cloud. Forecasting wind direction is more than strictly "weather forecasting." Even without change in the prevailing winds, local ground features such as ridges, pits, tree lines, etc., make ground level wind more turbulent and less predictable than that on a bare, flat surface. This difficulty was addressed on a site-by-site basis.

A lesser problem is the magnitude of the constituents of interest. Since this type of

investigation has not been done before, we did not know for sure what target range to design our sensors for. Since all of the anecdotal evidence we obtained indicated that the levels of toxic gases would be very low, we used monitors for low-level measurement, ones that cover official TLV ranges. This meant if higher levels were encountered we ran the risk of poisoning the sensors. This did not happen. Dust is less of a problem; dust collectors can cover a wide range of exposure limits without difficulty.

Coordination was another difficulty. With 17 different sensing units distributed (two multi-units at the main station and three single-sensing/pumping units at each of five other locations) over a broad area, coordinating the timing of unit operation is important, especially with the dust sensors. Therefore all of the pumping units obtained not only may be programmed to turn themselves on and off at predetermined times, and the gas units have time-based data-logging capacity. In practice, it turned out to be unrealistic to program the dust pumps ahead of time, so everything was turned on at the latest possible minute.

2.2.2 Method

The data collection effort has been designed to obtain the maximum quantity of data with the minimum number of instruments. A primary measurement station was established that produced the greatest quantity of information on a real-time basis. Measurements included total dust, NO, NO_2, NH_3, and CO. Every attempt was made to position this station so that the primary blasting cloud would pass over it.

If terrain permitted, two wings of instrument stations were established, one each to the right and left of the main station. Each of these stations contained three instruments: one for total dust, one for respirable dust, and one real-time data-logging NO_2 gas monitor. Our original hope was that if our main station is positioned correctly, these stations would give us an idea of the lateral dispersion and/or diffusion. If the main cloud passed to the right or left, all gas quantities could still be determined by correlation. The laws of diffusion indicate that the various gases should be uniformly dispersed. Thus the quantity of any gas at any station could be determined by:

$$Concentration\ Gas_{i,j} = \frac{Concentration\ (NO_2)_j}{Concentration\ (NO_2)_{base}} \times (Concentration\ GAS_i)_{base}$$

where i = specific gas of interest

j = location j

When conditions permitted, one station containing the same set of monitors will be established on the anticipated direct flow direction line from the base station. If the chosen direction of flow was close to accurate, it provided information on attenuation along the axis of cloud travel. Figure 2.1 shows an ideal station layout.

Other data collected included:

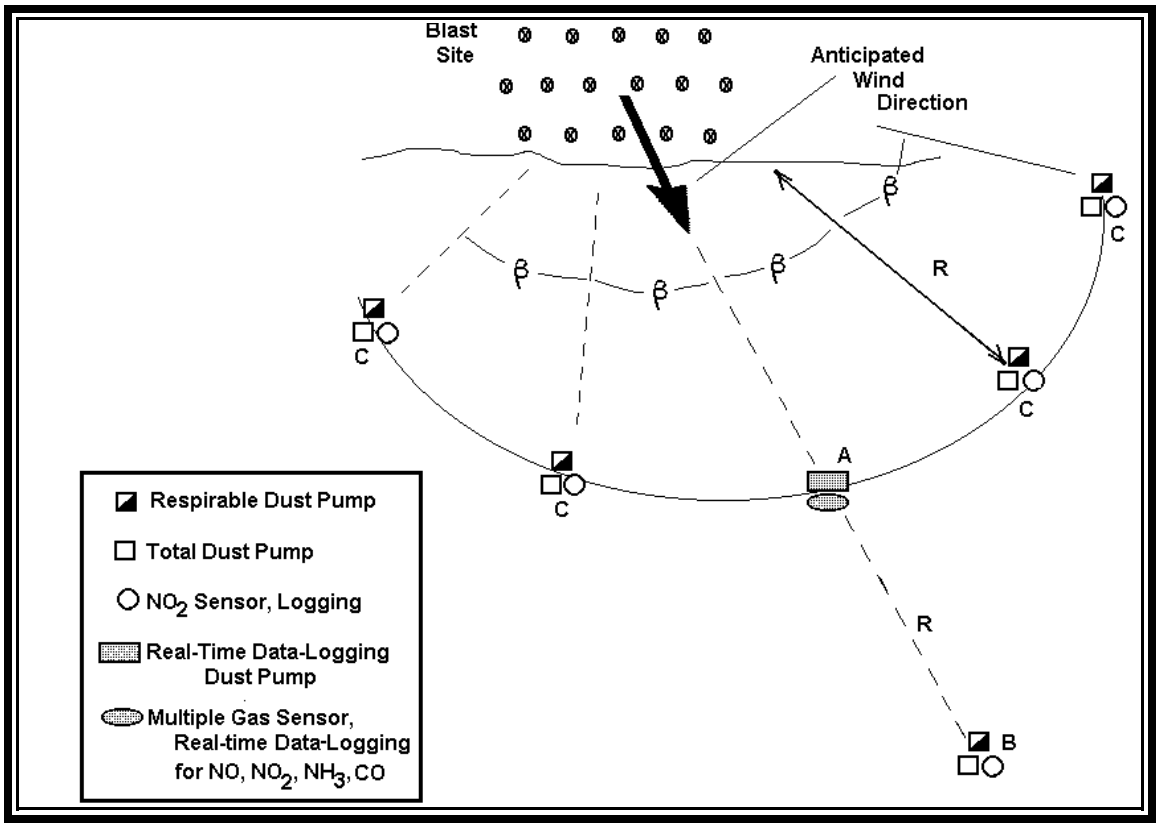
- Topographic map of site
- Mine map of site
- Information on blast size and design
- Relative position of all units as determined by GPS
- Photographic images of the blast

During the performance of the project, the NO_2 sensor on the main station never operated reliably enough to trust any ratio calculations performed with them. There were indications, such as the similarity of time-histories of the other gases, to indicate that this as a reasonable assumption.

Also, we expected difficulty in situating our stations in an ideal fashion because of terrain, but we under-estimated that difficulty. An examination of the maps in section 4 shows that on occasions we approached that configuration, but did not exactly match it. And more often we just had to accept what man and nature provided.

A final comment: This is a "quality-of-life" study. We have little interest in the <u>*total*</u> quantities created by an individual blast, as seems to be the focus of much of the Wyoming effort. We are interested in it only so far as it will help us determine concentrations of constituents in lateral movement of the cloud. This study has no agenda; we do not wish to prove these clouds "good" or "bad." We hope only to obtain real data that can be used to understand what is occurring in this phenomenon.

We would also like to note that this study touches on a lot of other interesting issues that are tempting to follow, such as improving blast design, researching dust and fume mitigation techniques,



and more. But since the resources available for this study are limited we must stick to the original scope of work: Is it harmful? Does it impact the quality of life?

Figure 2.1 Ideal Experimental Layout

1. Determine most likely direction for cloud travel
2. Distances to be governed by site layout and requirements.
   "Beta's" and "R's" to be as close to equal as possible
   R = radii from station to blast center, beta = angle between radii
3. Establish base station A
   Real-time dust monitor, data logging
   Total dust
   Dust distribution over time
   Real time gas monitor, data logging
   Monitor NO, NO_2, NH_3, CO
4. Establish wing stations C
   Total dust
   Respirable dust
   NO_2 data logger, concentration vs. time
5. Establish down-wind station B
   Total dust
   Respirable dust
   NO_2 data logger, concentration vs. time

2.3 Equipment

The following pages are excerpts from the product literature for the instruments that we used, providing specifications and basic overview information. Selection was based on the lowest thresholds available, by unit capability, and ultimately by cost. Dust units from SKC enabled us to program the units and download operational data. Although the gas units from Quest were not programmable, they did have the capacity to store and download data. More importantly, the Quest Multi-Log unit enabled the use of four toxic sensors, whereas competing four sensor units were limited to two toxic and two non-toxic gases.

We considered more sophisticated units, even remote gas sensing technologies. The original proposal called for gas chromatography and "one or two" blasts to be monitored. When we found out (thanks to an extended discussion with experts at NIOSH) that chromatography was not a reasonable option, we elected to use electro-chemical sensors and make more mine visits. For the information required, these units provided the best combination of accuracy and economy.

The final photograph in this section is of an assembled monitoring station. The dust pumps are housed in a sturdy plastic housing, with tubes leading out side. A pole is mounted on the case to suspend the dust cyclone and filter and the total dust filter above ground level. The NO_2 monitor is also hung here, housed in a protective foam rubber covering. Finally, crepe paper streamers are attached as a visual indicator of wind velocity.

AirChek 2000

The AirChek® 2000 with patented internal flow sensor brings advanced electronic flow control to air sampling from 5 to 3000 ml/min. This new technology allows the user to program a desired flow rate with an accuracy of ± 5% using the three-button keypad or a PC with optional DataTrac® 2000 Software; no tools needed. The internal flow sensor measures flow directly and acts as a secondary standard, constantly maintaining the flow rate. Flow can be calibrated by the user to an external primary standard and adjusted. The flow setting, achieved immediately at start-up, is automatically corrected for variations in temperature and pressure by built-in sensors. The AirChek 2000 samples up to eight hours on one battery charge.

Easy Three-button Programmability

Using the simple three-button keypad, set flow rate and run-time without screwdrivers. A convenient timed shutdown feature allows you to set the AirChek 2000 to run from 1 to 999 minutes.

Sampling Parameters at the Touch of a Button

Easily scroll through sampling parameters including time, flow rate, air volume, atmospheric pressure, and battery status.

CalChek™ — Direct Communication to a Primary Standard

Automatically calibrate your AirChek 2000 sample pump (v. 2.59 or higher) to a desired flow using the CalChek feature with CalChek Communicator and a DC-Lite Calibrator. CalChek provides complete calibration flexibility with two calibration options:

CalChek
Direct Communication to a Primary Standard

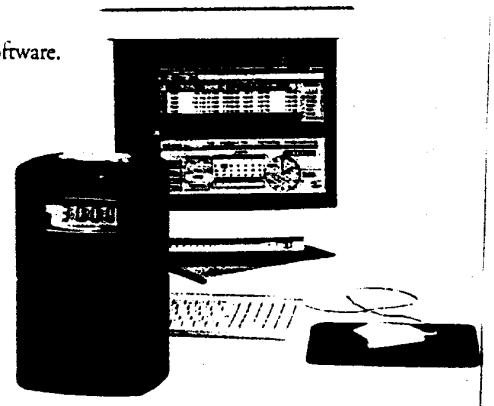
Single Point quickly verifies flow before and after sampling

Multiple Point corrects across a range of flows (750 to 3000 ml/min) after maintenance or to meet calibration requirements for quality programs

For complete documentation of calibration and sampling history, use DataTrac 2000 Software (v. 3.59 or higher).

PC Programmability

Program the AirChek 2000 with a PC using DataTrac 2000 Software.



- **Program a complete running sequence, even at different flow rates.**
- **Program delayed start, timed shutdown, or perform sequential sampling.**
- **Save an AirChek 2000 program in pump memory for later use.**
- **Download CalChek calibration data from pump to PC for complete documentation.**
- **Download sampling data to a PC for a complete history of exposure monitoring.**
- **Create a complete report, save to a file, and import into a word processing document, or print a hard copy.**

AirChek 2000

➤ **Wide flow range - 5 to 3000 ml/min**
- The AirChek 2000 is the best choice for most sampling applications: low flow range of 5 to 500 ml/min requires an easy-to-use low flow adapter kit. (Low flow does not include some electronic readout options.)

➤ **Security system protects data**
- Security code requirement minimizes accidental changes and maintains sample validity

➤ **Automatic features maintain sample integrity**
- Auto shut-off with low battery or restricted flow
- Adjustable flow fault shutdown from 5 seconds to 4 minutes with a PC and DataTrac 2000 Software
- Auto-restart from flow fault attempted every 5 minutes for a maximum of 10 times
- Run-time data stored in memory

➤ **Intrinsically safe**
- Versatile for all industries and safe in explosive environments: UL and cUL Listed

➤ **Large, easy-to-read LCD displays:**
- Flow rate
- Temperature
- Battery status
- Time-of-day
- Run-time
- Atmospheric pressure
- Volume
- Flow fault

➤ **Automatically corrects for temperature and atmospheric pressure**

➤ **Multi-tube sampling feature**
- Optional multiple adjustable low flow holders allow simultaneous 2-, 3-, or 4- tube sampling

➤ **Lightweight, with water-resistant case**
- Lightweight (22 oz)
- RFI/EMI-shielded, impact-resistant case
- Covers protect ports from water
- CE-approved

➤ **Lithium backup battery**
- Internal lithium battery preserves data when the battery pack is removed

➤ **Real-time clock**
- Displays 12-hour standard or 24-hour military time

➤ **CalChek — Direct communication* to a primary standard**
- Fast & easy calibration without manual adjustments

Performance Profile

Flow range:	750 to 3000 mL/min (5 to 500 mL/min requires optional low flow adapter kit)
Compensation range:	3000 mL/min at 15" water back pressure 2500 m L/min at 20" water back pressure 2000 mL/min at 30" water back pressure 750 mL/min at 40" water back pressure
Accuracies:	**Timing:** 1 min/month @ 25 C **Atmospheric Pressure:** ± 0.3" Hg **Flow Rate:** ± 3% of setpoint after calibration to desired flow
Battery Charge Level Indicator:	Icon displays at full, mid, and low charge
Temperature range:	**Operating:** 32 to 113 F (0 to 45 C) **Charging:** 32 to 113 F (0 to 45 C) **Storage:** -4 to 113 F (-20 to 45 C)
Run-time:	With battery pack, run-time is 10 hrs for 2000 ml/min and up to 30 inches back pressure.
Timer Display Range:	1 to 9999 minutes (6.8 days). If the run-time exceeds 6.8 days, the timer display rolls over to 1. Times greater than 9999 minutes are only displayed on a PC using DataTrac 2000 software.
Time Display:	Time-of-day in hours and minutes (12- or 24-hour clock) with AM and PM indicators.
Flow Fault:	If flow drops by more than 5%, pump stops and holds historical data. Auto-restart attempted every 5 minutes up to 10 times.
Battery Pack:	Removable battery pack with rechargeable NiCad battery, 4.8 V x 2.0 Ah. Optional removable battery pack with rechargeable NiMH battery, 4.8 V x 4.0 Ah.
Size:	5.6 x 3 x 2.3 (14.2 x 7.6 x 5.8 cm)
Weight:	22 oz (624 gm)
RFI/EMI Shielding:	RFI/EMI-shielded case, CE-approved
Intrinsic Safety:	UL and cUL Listed

2.7

Cyclones Used With AirChek 2000

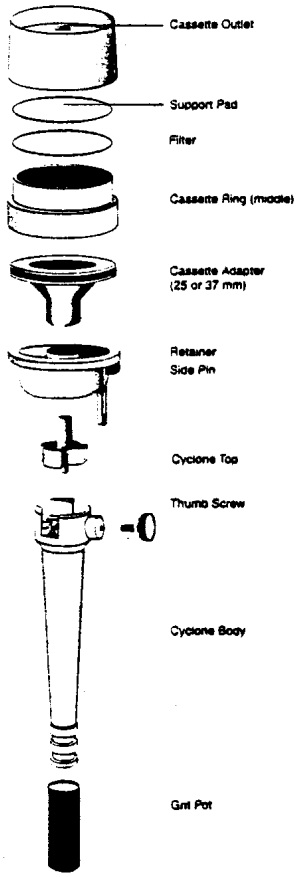
GS Respirable Dust Cyclone

Meets ACGIH Sampling Criteria

- **Prevents static collection effects**
- **2.75 L/min flow rate provides greater sensitivity and sampling accuracy**
- **Meets ACGIH sampling criteria for respirable dust**
- **Tangential inlet design decreases particle impaction**
- **Eliminates ambient wind speed and orientation effects**
- **Designed to overcome problems with the Dorr-Oliver cyclone**

GS Cyclone's Unique Design

- **Conductive plastic construction** prevents static collection problems with charged particles
- **Tangential inlets** lessen sampling errors that can occur when particles impact on the wall of the cyclone opposite the inlet
- **Multiple inlets** eliminate sensitivity to wind velocity and user orientation to the contaminant source



GS Cyclone Superior Performance

With low mean bias and higher flow rate requirements, the GS Cyclone provides better sampling accuracy and greater sensitivity when compared to the performance of other cyclones at the same cut-point. Furthermore, the multiple inlet GS Cyclone overcomes sampling problems that have been reported with the single inlet Dorr-Oliver cyclone.

The Multiple Inlet GS Cyclone

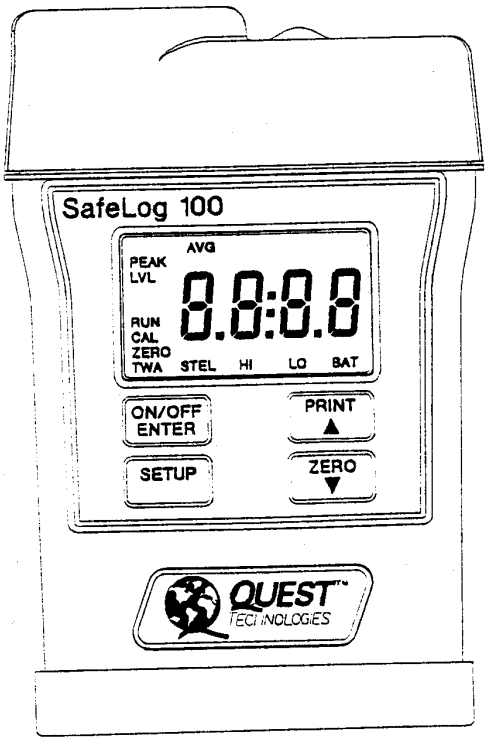
The GS Cyclone is a 10 mm lightweight conductive plastic unit that holds a standard 3-piece cassette with filter for the collection of respirable dust particles. The GS Cyclone's removable cassette adapter securely holds the filter cassette in place during sampling. Designed to meet the ACGIH/CEN/ISO curve, the GS Cyclone has a 50% cut-point of 4.0 µm (bias within ISO/NIOSH requirements) at 2.75 L/min.*

** Calibrated at U.K. Health and Safety Laboratory and University of Minnesota (wind tunnel).*

SafeLog 100

FEATURES

- **Single Gas Portable Monitor**
  - Selection of ten different interchangeable sensors
- **Quest Smart Sensor Technology:**
  - CO, H_2S, O_2, NH_3, Cl_2, HCN, SO_2, NO, NO_2, ETO
  - On-board memory contains sensor specific data
  - Automatic sensor recognition
- **Datalogging extended memory capacity:**
  - Over 60 hours at one minute sample intervals
  - Download via an RS-232 interface
  - Real-time clock and date stamps all data & alarm occurrences
  - Parallel Printer
- **Supported by *QuestSuite™* for Windows software**
- Ease of operation via oversized four button key pad
- Large four digit display with backlighting
- Simple zero and calibration functions
- Piercing two tone horn and flashing bright LED alarms
- Powered by a single, user replaceable, 9 volt battery. No tools required.
- RFI/EMI Resistant
- Lightweight and extremely rugged impact resistant ABS housing
- Quest Quality, Performance and Dependability



The Quest SafeLog 100 is an extremely rugged, lightweight personal single gas datalogging monitor. Designed for today's demanding work environments, the unit features a large four digit display with backlighting and pulsating warning horn and visual alarms.

The SafeLog 100 is protected in an impact resistant ABS housing to take the punishments of real life work conditions. The unit is powered by a user replaceable 9 volt battery that will supply approximately 100 hours of continuous operation.

User flexibility is as simple as selecting from ten different interchangeable electrochemical sensors to meet your specific application requirements. Quest smart sensor technology includes automatic sensor recognition and on-board memory which contains specific sensor identification: alarm set points, calibration data and temperature compensation information that can travel with the sensor from one unit to another.

The SafeLog 100 measures gas concentration at one sample per second. Featuring an extended memory capacity, it datalogs 60 plus hours (continuous or multiple sessions) of 1 minute historical data including the high level for the minute, STEL, TWA and temperature. The real-time 24-hour clock times and date stamps all data and alarming events. All recorded information can be easily transferred to a printer or computer for record keeping and further data manipulation. In addition, the SafeLog 100 is uniquely supported by QuestSuite™ for Windows, a totally integrated data analysis software package.

All unit operations are easily employed through an oversized 4 - button keypad. Once the unit is activated, it automatically conducts a brief function self check and then proceeds to the run mode. Zeroing and calibration are only a button away. This translates into uncomplicated, but very reliable instrument operation so the user can concentrate on other matters at hand.

SafeLog 100

In addition to having an Ingress Protection (IP54) rating and offering excellent Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI) protection, the SafeLog 100 was designed to meet or exceed internationally recognized approvals. Necessary requirements for today's gas monitoring applications.

Combining the above with Quest proven quality, performance and dependability makes the SafeLog 100 the right choice for your single gas monitoring needs.

SPECIFICATIONS

Size:
4.5" x 3.0" x 1.5"
(11.4 cm x 7.6 cm x 3.8 cm)

Weight:
8.8 ounces (250 g)

Power:
9 volt alkaline battery

Sensors:
Electrochemical

Battery Life:
100 hours

Measurement:
Continuous (1 sample/second)

Display:
4 digit backlit LCD

Alarms:
Pulsating dual tone and flashing LED.
Remote alarm jack

Alarm Thresholds:
High level, High level pre-alarm (through *QuestSuite™* only), Low level (O_2 only), STEL, TWA, Low battery

Memory:
Over 60 hours at 1 minute sample intervals

Output:
Jack for data output
Serial and Parallel

Operating Safety Chirp Indicator:
User has choice of ON/OFF

Temperature Range:
-10 to 40°C (14 to 104°F) operating
-15 to 60°C (5 to 140°F) storage

Humidity Range:
0 to 99% relative humidity, non-continuous, non-condensing
15 to 90% relative humidity, continuous, non-condensing

Ingress Protection Rating:
Certified to IP54

Intrinsic Safety:
UL, cUL, Class I, II & III, Division 1, Groups A thru G, EEx (European)

RFI/EMI Protection:
Special shielded case and internal circuit protection meets or exceeds ANSI Standard C95.1-1982 and EN50082-2

Sensor Specifications:

Gas	Range	Resolution
Oxygen O_2	0-30%	0.1%
Carbon Monoxide CO	0-999 ppm	1 ppm
Hydrogen Sulfide H_2S	0-500 ppm	1 ppm
Chlorine Cl_2	0-20 ppm	0.1 ppm
Hydrogen Cyanide HCN	0-50 ppm	0.1 ppm
Ammonia NH_3	0-50 ppm	1 ppm
Sulphur Dioxide SO_2	0-50 ppm	0.1 ppm
Nitric Oxide NO	0-100 ppm	0.1 ppm
Nitrogen Dioxide NO_2	0-50 ppm	0.1 ppm
Ethylene Oxide ETO	0-20 ppm	0.1 ppm

HAZ-DUST II

HAZ-DUST II Real-time Personal Dust Monitor

The HAZ-DUST II real-time personal dust monitor, with internal sampling pump, datalogger, and communications software, uses near-forward light scattering technology to measure airborne dust particle concentration. Unique signal processing internally compensates for noise and drift, while allowing high resolution, low detection limits, and excellent baseline stability.

➤ **Instantaneous readings in mg/m³**

- The HAZ-DUST II uses optical light scattering to calculate and display airborne dust concentrations immediately and continuously when activated; real-time data reported in mg/m³

➤ **Displays TWA, STEL, min, and max levels**

- Instantaneous readouts of all data on the 4-line backlit LCD

➤ **High sensitivity — 0.01 to 200 mg/m³**

- Selectable dual-range feature for measurement between 0-20 or 0-200 mg/m³ with an ultimate sensitivity down to 0.01 mg/m³

➤ **Compact and lightweight**

- Small and lightweight, 3.5 x 9 x 2.5 inches (8.9 x 22.9 x 6.4 cm), 3 lbs (1.4 kg), the rechargeable NiCad battery, electronics, and datalogger are enclosed in a compact case that attaches to a worker's waist

➤ **True breathing zone measurements of inhalable, thoracic, and respirable dust**

- Attach the miniature sensor to a worker's pocket or collar for true breathing zone measurements; unique sensor design allows interchangeable sampling heads to collect concurrent filter samples

➤ **Four-key programmable operation**

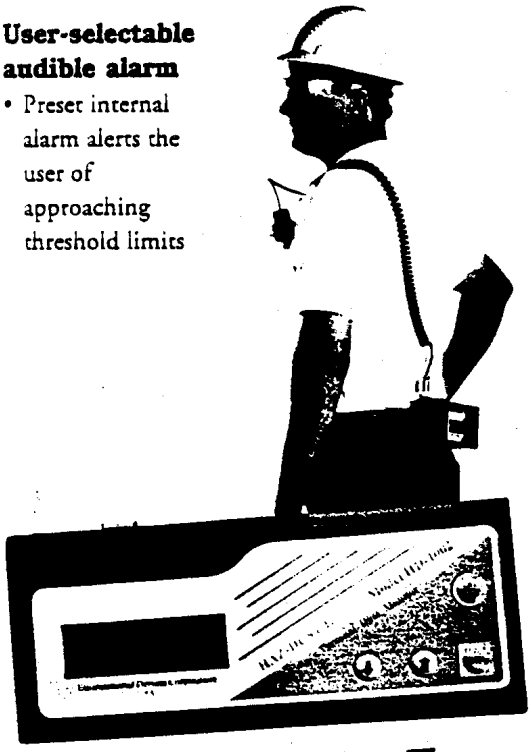
- Access features and programming options through easy menu selection

➤ **Displays respirable, thoracic, or inhalable particulate mass**

- Respirable display is calibrated using Arizona Road Dust (ARD) and compared to a sample using NIOSH Method 0600 for respirable dust (accuracy ± 10%); menu-select alternate displays of either thoracic or inhalable particulate mass on the LCD

➤ **User-selectable audible alarm**

- Preset internal alarm alerts the user of approaching threshold limits



➤ ***True Breathing Zone Measurements***

HAZ-DUST II

SPECIFICATION	RANGE
Calibration	NIOSH 0600 with ARD
Accuracy	± 10%
Precision	0.02 mg/m^3
Sensing range	0.01 to 200 mg/m^3
Particle size range	0.1 to 10 µm Respirable 0.1 to 50 µm Thoracic 0.1 to 100 µm Inhalable (IOM)
Recording time	1 second, 1 minute and 10 minute averages
Flow rate	1.5 to 2.3 LPM
Memory	21,500 data points
Locations	Up to 999 storage locations
Output	RS-232
Operating temperature	32 to 120° F (0° -50°C)
Humidity range	95% non-condensing
Battery	Rechargeable NiCad
Battery life	8 hours
Charging time	8 hours
Size	9 x 3.5 x 2.5 in (22.9 x 8.9 x 6.4 cm)
Weight	3 lbs. (1.4 kg)

MultiLog 2000
SPECIFICATIONS

The "Industrial Hygiene" selection is the most advanced level and, in addition to all the features supplied in the Basic Mode, this mode displays average level, TWA, peak values, STEL, and peak STEL for all installed sensors.

The MultiLog 2000 has an extended memory capacity for storing information while in the RUN mode. The user can select logging intervals from a wide time history selection. For example, the unit will log for 78 hours at one minute intervals. There are three ways of logging; summary data for the session, continuous, or action level triggered. You can retrieve logged information by sending the data to a computer via a serial RS-232 interface or to a printer via a parallel interface.

Choice of three long lasting interchangeable power supplies including standard user replaceable Alkaline batteries, or rechargeable Nickel Cadmium and Nickel Metal Hydride battery packs. The battery pack can be changed in a hazardous environment and the rechargeable packs can be rapidly recharged in less than two hours.

For remote sampling applications, the optional sample draw pump will draw a sample in excess of 50 feet and uses the unit's electronics to sense a flow restriction. Dedicated confined space kits are available to enhance your specific gas monitor applications.

Several notable standard features include automatic one button calibration, password protection, and an intelligent zero function that prevents the user from zeroing in a contaminated environment.

Supported by the totally integrated data analysis software, QuestSuite™ for Windows, the MultiLog 2000 is the answer to your rigorous portable multi-gas data logging requirements today and into the future.

Sensor Specifications:

Gas	Range
Combustible Gases	0-100% LEL or 0-5.0% by volume CH_4

Size:
6.9" x 3.4" x 2.0"
(17.5 cm x 8.6 cm x 5.1 cm)

Weight:
22 ounces (0.6 kg)

Power:
Alkaline battery pack (uses two replaceable "C" cells) or rechargeable Nickel Cadmium or Nickel Metal Hydride battery packs

Battery Life:
16 hours with alkaline. Minimum 10 hours with the NiCad or NiMH battery packs

Display:
Two line alphanumeric back lighted LCD

Alarms:
Pulsating dual tone and flashing visual alarms

Alarm Thresholds:
High level. High level pre-alarm (through *QuestSuite™* only), Low level (O_2 only), STEL, TWA. Low battery

Operating Safety Chirp Indicator:
User has choice of ON/OFF and frequency of occurrence

Sensors:
Combustible gases/methane (catalytic diffusion type), oxygen and toxic electrochemical gas sensors

Sensor Configurations:
Oxygen and Combustibles, and up to two toxic gases, or oxygen or combustibles and up to three toxic gases, or up to four toxic sensors simultaneously

Measurement:
Continuous (one sample/second)

Data Logging:
78 hours at one minute sample intervals: summary, continuous or level triggered. Serial RS-232 interface. Battery backed up memory (via lithium battery)

Temperature Range:
-10 to 40°C (14 to 104°F) operating
-15 to 60°C (5 to 140°F) storage

Humidity Range:
0 to 99% relative humidity, non-continuous, non-condensing
15 to 90% relative humidity, continuous, non-condensing

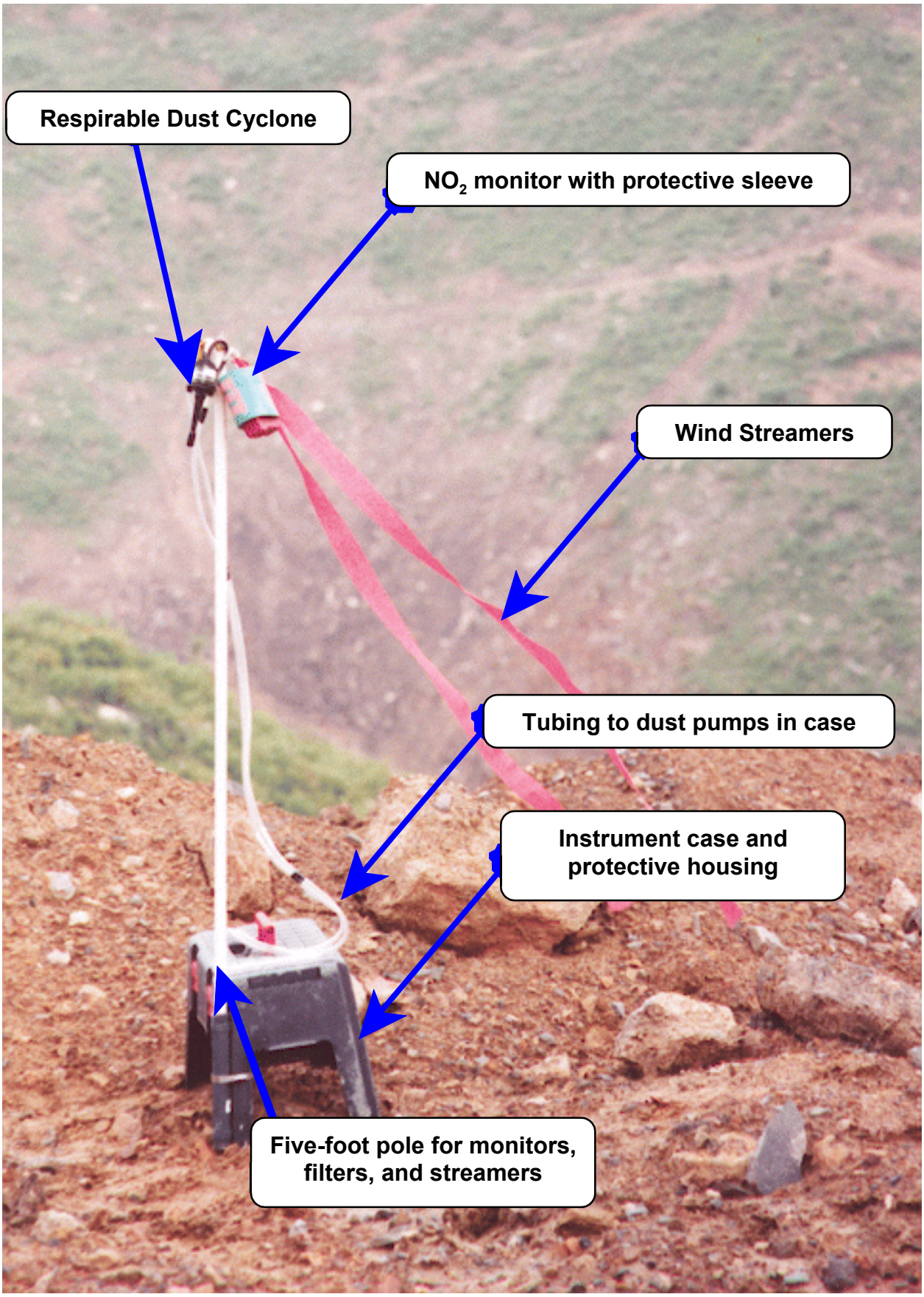
Ingress Protection Rating:
Certified to IP54

Intrinsic Safety:
UL, cUL, Class I, II & III, division 1, Groups A thru G, EEx (European)

RFI/EMI Protection:
Special shielded case and internal circuit protection meets or exceeds ANSI Standard C95.1-1982 and EN50082-2

Sensor Specifications:

Gas	Range	Resolution
Oxygen O_2	0-30%	0.1%
Carbon Monoxide CO	0-999 ppm	1 ppm
Hydrogen Sulfide H_2S	0-500 ppm	1 ppm
Chlorine Cl_2	0-20 ppm	0.1 ppm
Hydrogen Cyanide HCN	0-50 ppm	0.1 ppm
Ammonia NH_3	0-50 ppm	1 ppm
Sulphur Dioxide SO_2	0-50 ppm	0.1 ppm
Nitric Oxide NO	0-100 ppm	0.1 ppm
Nitrogen Dioxide NO_2	0-50 ppm	0.1 ppm
Ethylene Oxide ETO	0-20 ppm	0.1 ppm


Respirable Dust Cyclone
NO_2 monitor with protective sleeve
Wind Streamers
Tubing to dust pumps in case
Instrument case and protective housing
Five-foot pole for monitors, filters, and streamers

3.0 SITE DESCRIPTIONS

All of the cooperating mines were located in south-western West Virginia in different counties. All were mountain-top removal operations, and all three mines belonged to different coal operating companies. Probably most important for this study, each was distinctly different in its production characteristics.

All three mines provided maximum access to their operations and gave full cooperation. The investigators were permitted to choose the blasting events to monitor and choose how and where to locate their monitoring equipment. It is unusual for researchers to receive such a free hand at mining facilities, but these mining operations deemed the work to be important enough to facilitate our activities and permit us to perform our tasks as we though best.

Table 3.1 following provides a basic comparison of these mining sites.

	Mine A	Mine B	Mine C
Annual Production Tonnage	2,000,000 tons	5,500,000 tons	800,000 tons
Approximate Burden Moved, yd^3/year	20,000,000 to 24,000,000 yd^3	60,000,000 yd^3	8,000,000 to 10,000,000 yd^3
Approximate Number of Production shots per year	260	300	> 240
Approximate Weight of Explosives Used per Year, Lbs	14,400,000 lbs	64,000,000 lbs	6,000,000 lbs
Primary Excavation Method	Front-End Loader Scraping	85% Dragline & Shovel 15% Front-End Loader	Front-End Loader Scraping

Table 3.1 Comparison of Cooperating Mine Sites

4.0 FIELD MEASUREMENTS

Field measurements were made over the spring and summer of 2000. Miners vacation stopped most mining activities, and therefore most field work, in the first two weeks of July, three weeks at one mine.

4.1 Preliminary Familiarization Trip

A trip to mine A on May 31 was the first one where measurements were taken, and it was the one where lessons in application and equipment usage were learned. It was originally hoped that this data would be useable in the pool of overall information for the project, but too many errors occurred to be comfortable with the values obtained, at least those that *were* obtained.

Figure 4.1-1 shows the layout of the blasting arrangement. It was a three-bench contour blast that was close to the top of the ridge. The stations were selected with regard to the prevailing wind, and one was placed on the ridge behind, but close to, the blast. This latter station was situated here in case material or fumes were thrown up and behind the blast. Pages 4.3 through 4.5 are the photographs of the blast. In a close examination of photo A0531_12 one can see one of the measurement stations just below and to the right of the picture center. In the next picture the blast initiation can be seen, and the following five photographs show the cloud development and movement. It is clear, especially in photo A0531_18, that the bulk of the cloud moved down the valley behind the trees. There were no locations suitable for measurement stations in the valley. Only stations 3 and 5 and the main station were exposed to any fumes or dust, and that was quite minimal, especially station three. The station placed on top of the ridge behind the blast recorded nothing at all. More importantly, immediately after the blast the crew returned to work. The driver in the backhoe in photo A0531_25 had not been told to wait until we recovered our equipment. He drove past all measurement stations while they were still in operation. It is highly likely that the bulk of any measured dust and any CO detected by the main station would have been the result of this machine's passing rather than the blast. It would not

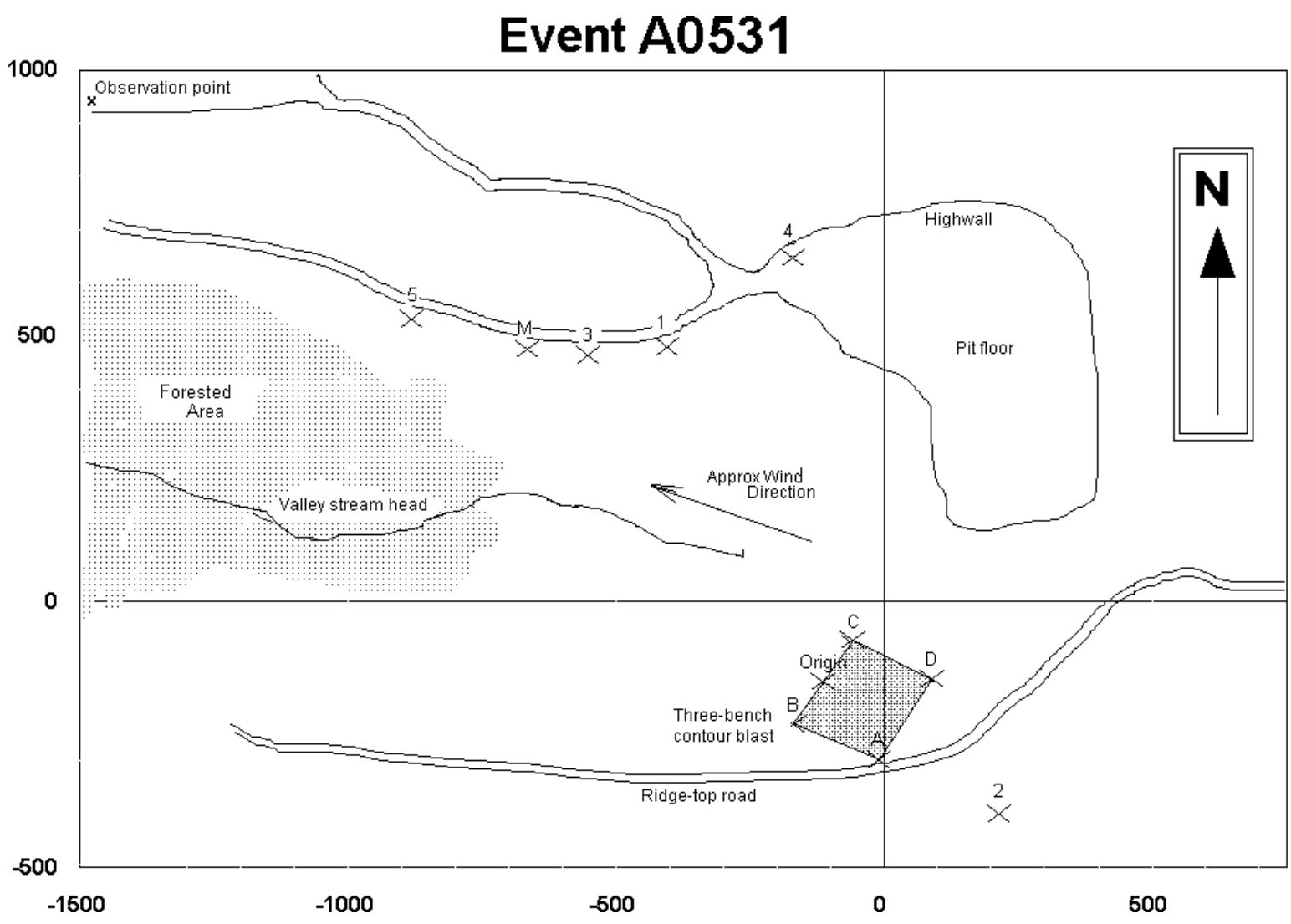

Event A0531
1000
500
0
-500
-1500
-1000
-500
0
500
Observation point
Highwall
Pit floor
N
Forested
Area
Valley stream head
Approx Wind
Direction
Three-bench
contour blast
Origin
A
B
C
D
Ridge-top road
1
2
3
4
5
M

Figure 4.1 - 1

Event A0531 - 1

Event A0531 - 2

Event A0531 - 3

Event A0531 - 4

Event A0531 - 5

Event A0531 - 6

Event A0531 - 7

Event A0531 - 8

Event A0531 - 9

have been possible separate the dust, although it would have been possible to separate the CO according to the time of detection. But this was just one of many lessons learned on this trip.

We had originally hoped to control the running time on all of our instruments. The dust pumps are all programmable, and we set them to start 30 minutes before the blast. (The main station and the gas detectors all record real-time data, so setting the start time was not crucial on them.) After all of our stations were set and we were ready for the blast, we were told that the shot initiation time had been moved up an hour. We then had to quickly return to each station and reprogram the pumps. At this point we still hoped to let each pump run two hours, but subsequently the reality of moving equipment after the shot eliminated that as a possibility. Even if it hadn't been for the backhoe, traffic on the pit floor would still have raised dust that would have reached the measurement stations. It became obvious that instruments would have to be set and turned on just before the blast, and turned off as soon after the blast as possible. This represented a major change to our original plans.

We had originally hoped to photograph the cloud resulting from the blast from two different angles approximately 90° apart and try to determine cloud size from the opposing pictures. In practice we found that the cloud appearance will change according to viewing angle relative to sunlight, according to the background behind the cloud (which will always differ when shooting from opposing angles), and even with different exposure settings on the camera. Later on, we found out that clouds passing overhead could change the appearance of the blast plume. These effects are especially noticeable with regard to colors within in the plume and when the plume becomes diffuse and thin.

Initially we had hoped for the possibility of recording two blasts on the same day. The length of time required for data down-loading, site evaluation, and equipment movement and re-setup demonstrated that this would only be possible if the two blasts were on the same property and had a minimum time window of four hours between them. Travel time between mines, even relatively close mines, was too great. Also, since most mines try to set off their major blasts during shift change, so even two on one site was not possible.[1]

Finally, no matter how much practice one has in the laboratory, it is not the same as using equipment in the field. On this trip we learned about mistakes easily made in equipment set-up

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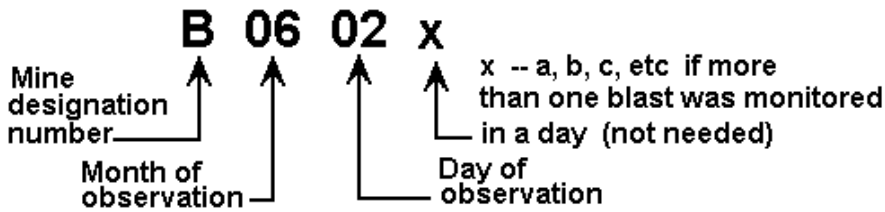
[1]In addition, if a mine did have several shots in one day, the extra shots were normally "utility shots," events that are smaller and drilled shallower than standard production shots.

and programming. And it was our first actual experience in determining how difficult determining average wind direction was going to be. Wind directions on the ridge, in the valley, and at the observation site were all different, at least what minimal wind there was. We had anticipated this difficulty, but this experience verified these concerns.

4.2 Field Measurements

A simple system was set up for identifying the blasting events from their data record names. Illustrated simply:



Thus event B0602 was a blast that was monitored at mine B on June 2nd. (The year 2000 is implicit since this was a single-season research effort.)

The following ten sections summarize each successful set of blast measurements made and contain photographs of all but one (event B0627). We did not keep records of all attempts, but this represents about half of all visits made. Reasons for failure to collect data during unsuccessful visits include:

Lack of any adequate site to locate instruments. This was the most common reason. If the prevailing wind direction was moving from the site directly over an adjoining valley, and there were no roads or other development for access close to the shot in the valley, measurements could not be made. Setting up within forested area would certainly yield biased or altered data.[2] As it was, we had difficulty achieving the distances we had initially wanted to maintain between the stations and the shot.

Change in weather during or after set-up. Twice we had all instruments set and ready to go, and

[2]These sites may be more reasonable to try in a larger project that could provide a greater quantity of data points for statistical validity. However, for a limited number of data points, the trees represent an insulating barrier that can not be correlated to open-air measurements and thus are an additional unquantifiable variable.

just before the shot the wind changed direction, in one case by 180° when a weather front moved in. Even if there had been time to relocate, in both cases the new wind direction was toward an area where there were no adequate areas to reset the stations.

Rain. Our gas detectors are exposed to the elements and are not water-proof. We did take measurements in light drizzle or intermittent rain, but not in steady rain. Also, it was our feeling that such weather would reduce the levels of dust and fumes in the plume, and the data pool would be too small to be able to separate out precipitation impacts.

Severe weather. Twice, blasts were postponed indefinitely due to lightening in the area.

4.2.1 Event A0622

Weather

Observations: 79°F, 73.0% relative humidity, partially cloudy
Wind: 7.5 mph

Blasting Data

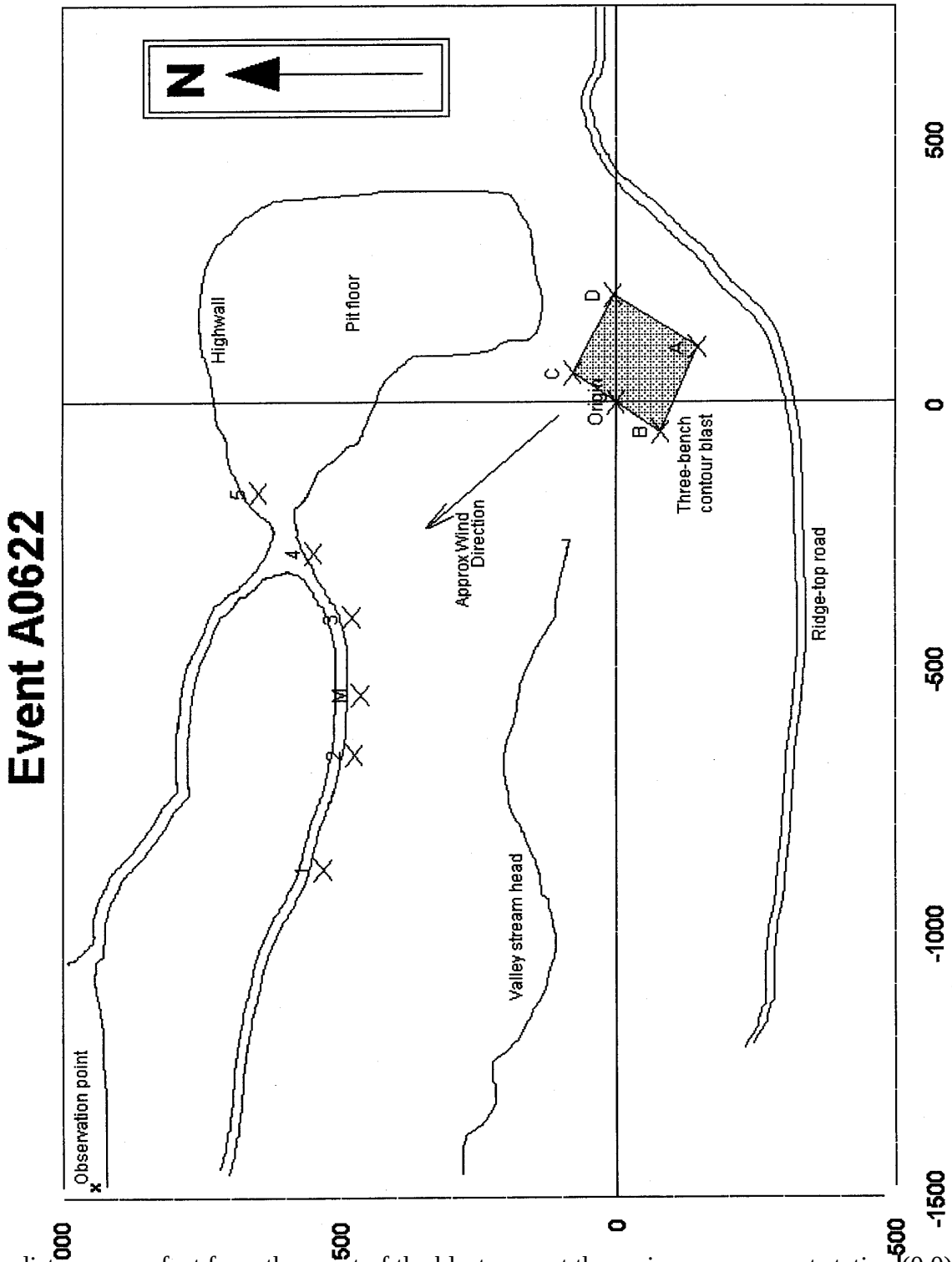
Time of ignition:	1309 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	7.785”
Hole Depth:	70’
Number of holes:	76
Stemming used:	13’ of drill cuttings
Explosive types used:	ANFO, Trojan C-20 1-lb primer, nonel
Weight of explosive used:	78,052 lbs
Weight of explosive used per hole:	1,026 lbs
Cubic Yardage Moved:	63,840 yd^3
Powder Factor:	1.22

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.09 mg
Respirable Dust Maximum:	0.11 mg
NO_2 high:	0.4 ppm
Duration of maximum NO_2 exposure:	1.0 min
Duration of maximum dust exposure:	Not detected

Main Station Data

NO High:	0.6 ppm
CO High:	5 ppm
NH_3 High:	7 ppm
Dust:	Not detected



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event A0622 -1

Event A0622 -2

Event A0622 -3

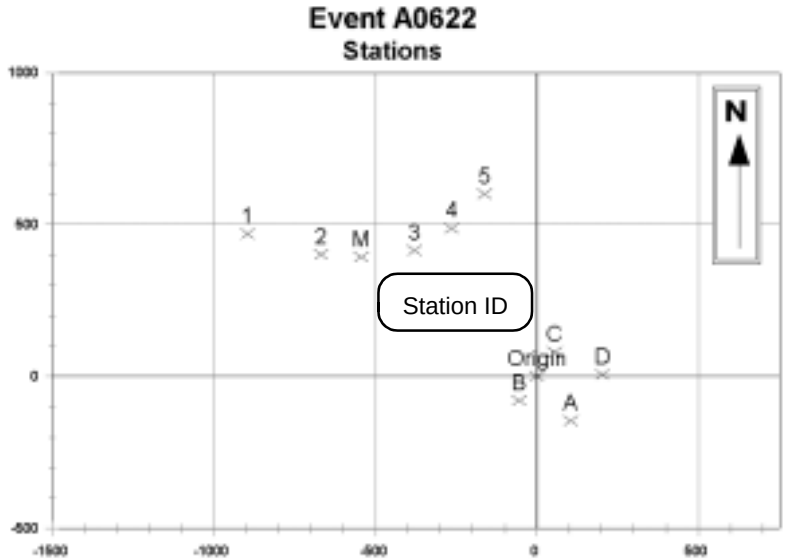
Event A0622 -4

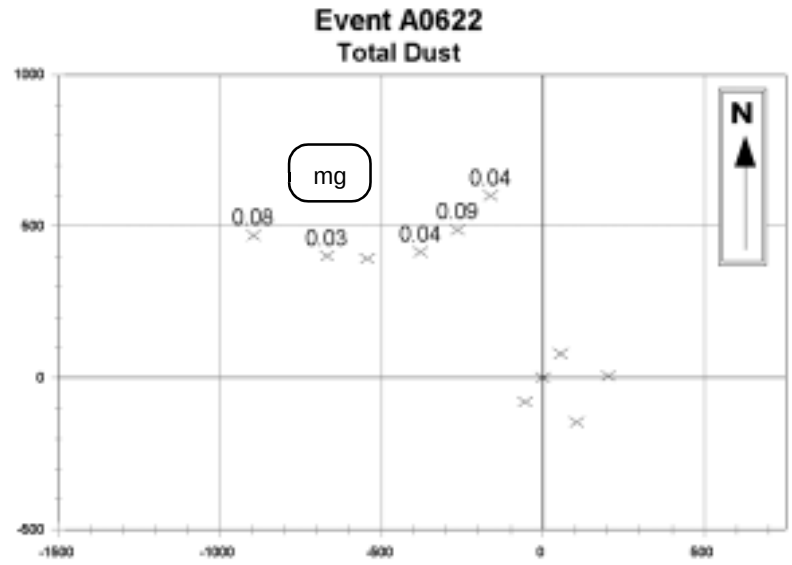
Event A0622 -5

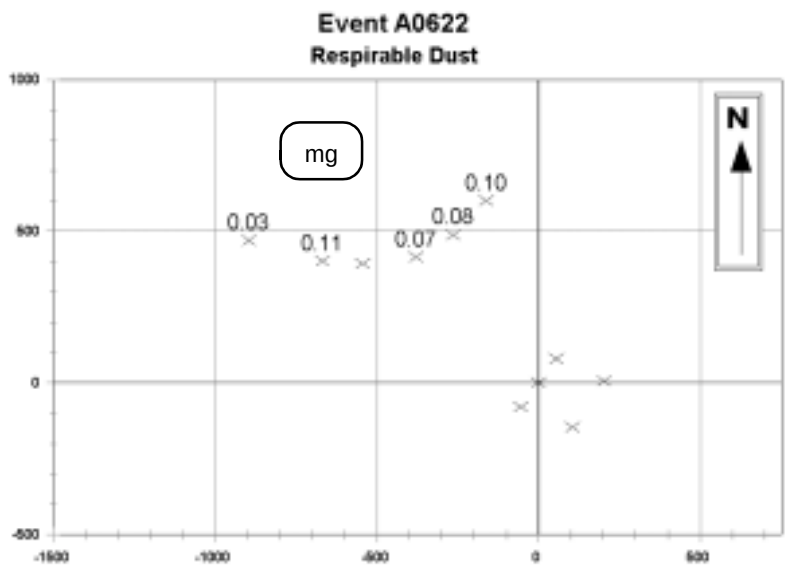
Event A0622 -6

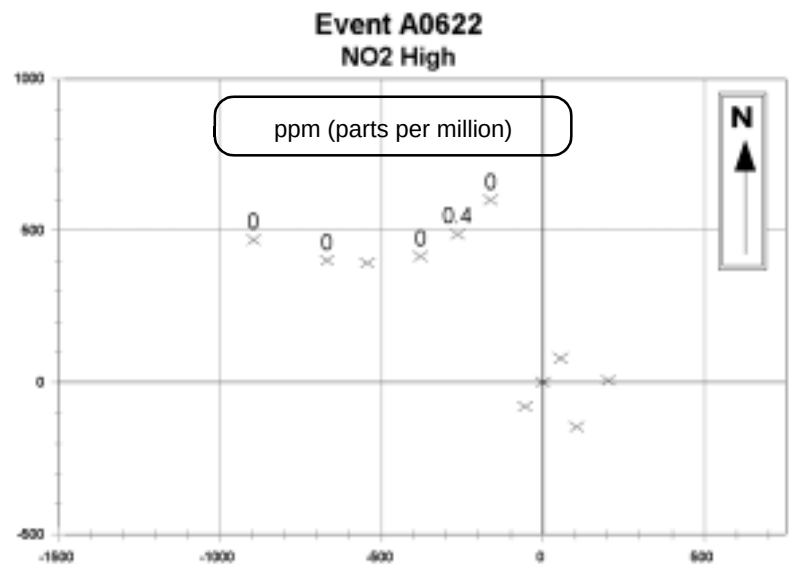
Event A0622 -7

Event A0622 -8

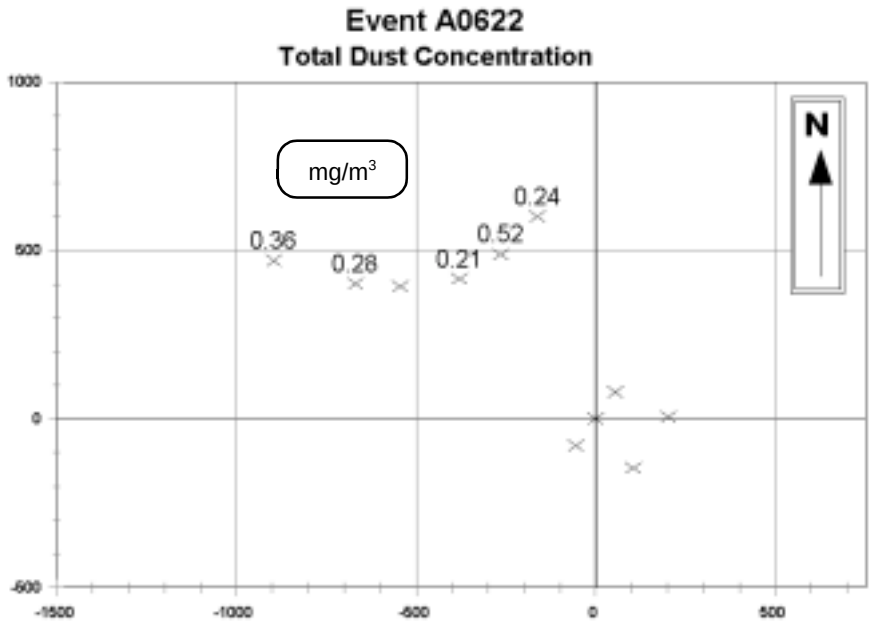


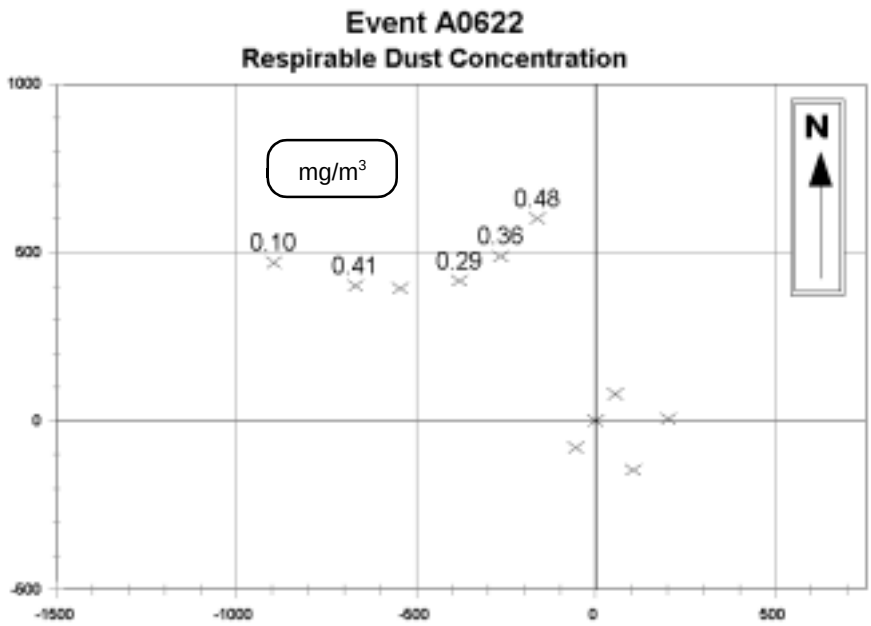






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.2 Event A0727

Weather

Observations:	88°F, 48.0% relative humidity, sunny and clear
Wind:	6.6 mph

Blasting Data

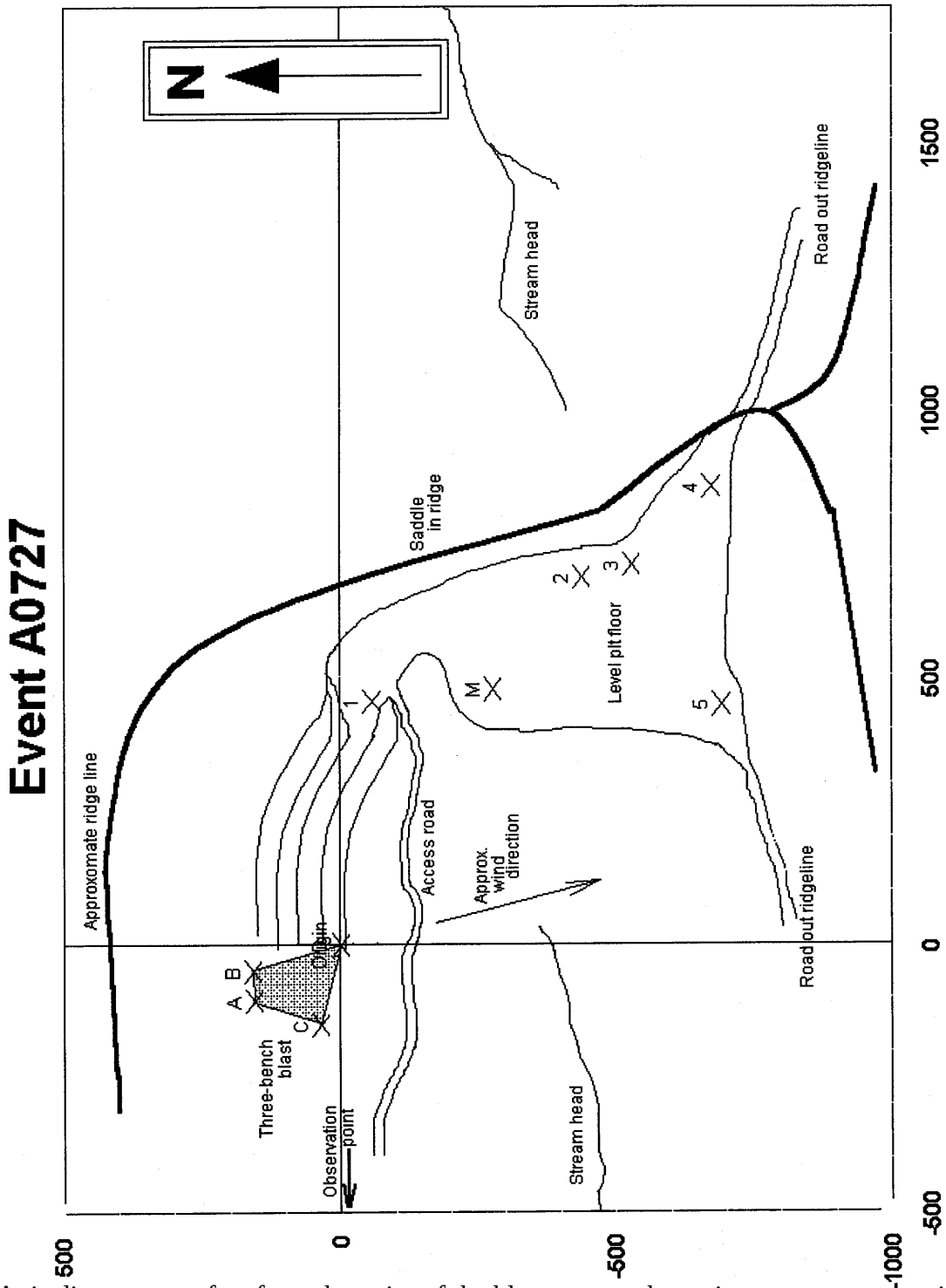
Time of ignition:	1453 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	7.825”
Hole Depth:	103’, 86’, 71’, and 67’
Number of holes:	10, 12, 12, and 14, respectively
Stemming used:	13’ of drill cuttings
Explosive types used:	ANFO, 1.25 cast primers, nonel
Weight of explosive used:	58,164 lbs
Weight of explosive used per hole:	1,212 lbs
Cubic Yardage Moved:	46,224 yd^3
Powder Factor:	1.26

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.23 mg
Respirable Dust Maximum:	0.17 mg
NO_2 high:	1.4 ppm
Duration of maximum NO_2 exposure:	2.00 min
Duration of maximum dust exposure:	2.44 min

Main Station Data

NO High:	48.7 ppm
CO High:	694 ppm
NH_3 High:	168 ppm
Dust:	64.92 mg/m^3



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event A0727 -1

Event A0727 -2

Event A0727 -3

Event A0727 -4

Event A0727 -5

Event A0727 -6

Event A0727 -7

Event A0727 -8

Event A0727 -9

Event A0727 -7

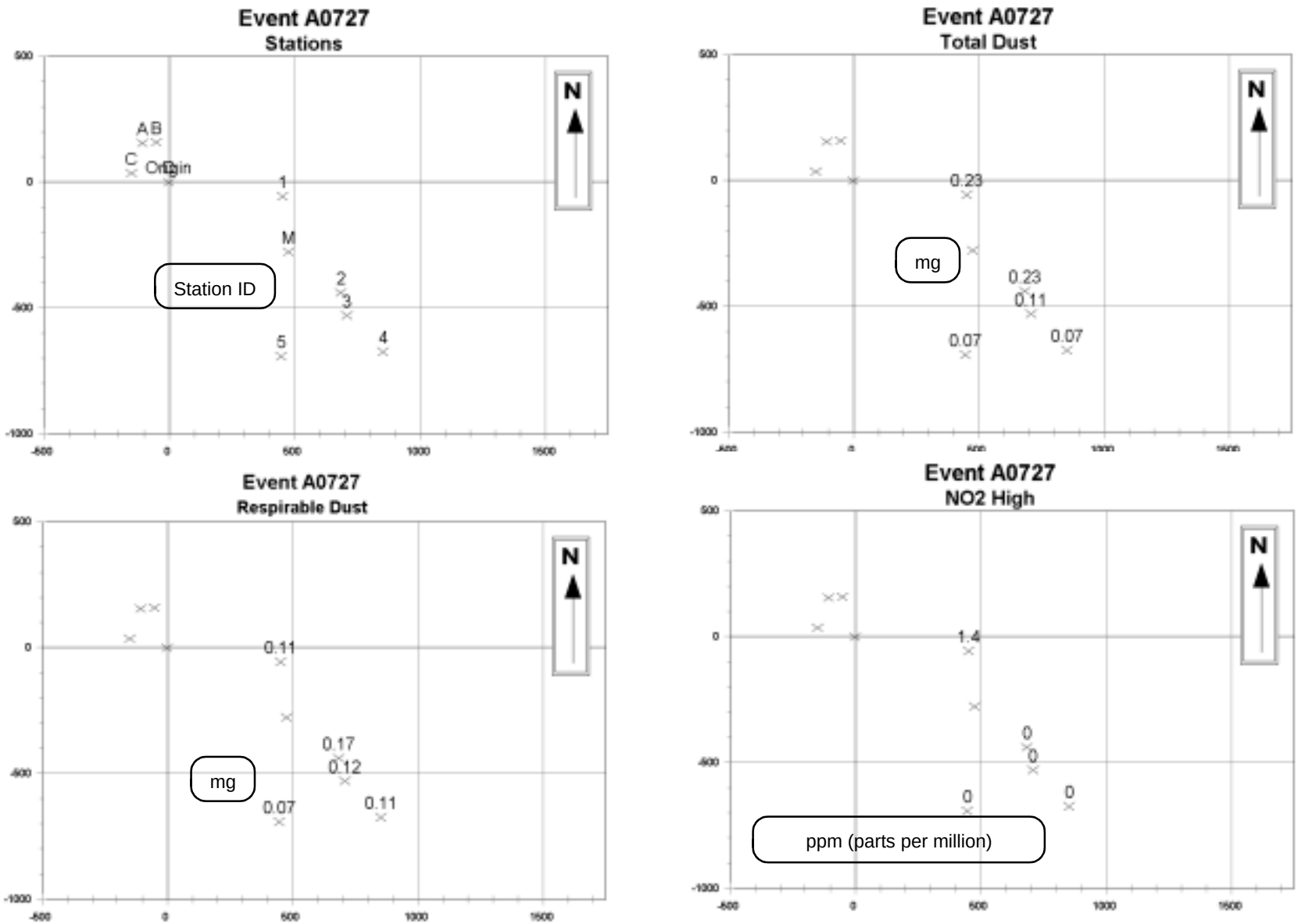
Event A0727 -8

Event A0727 -9

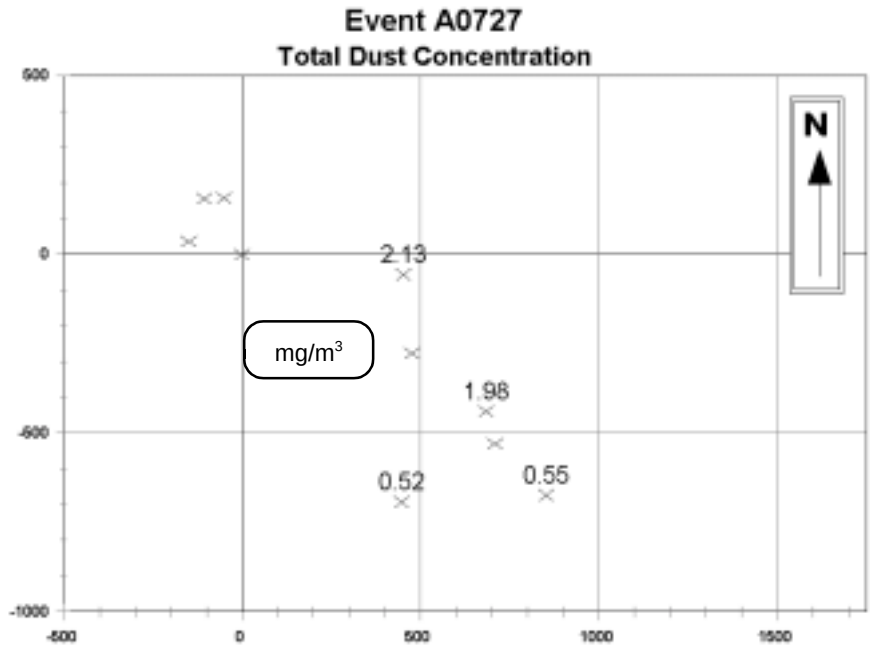
Event A0727 -10

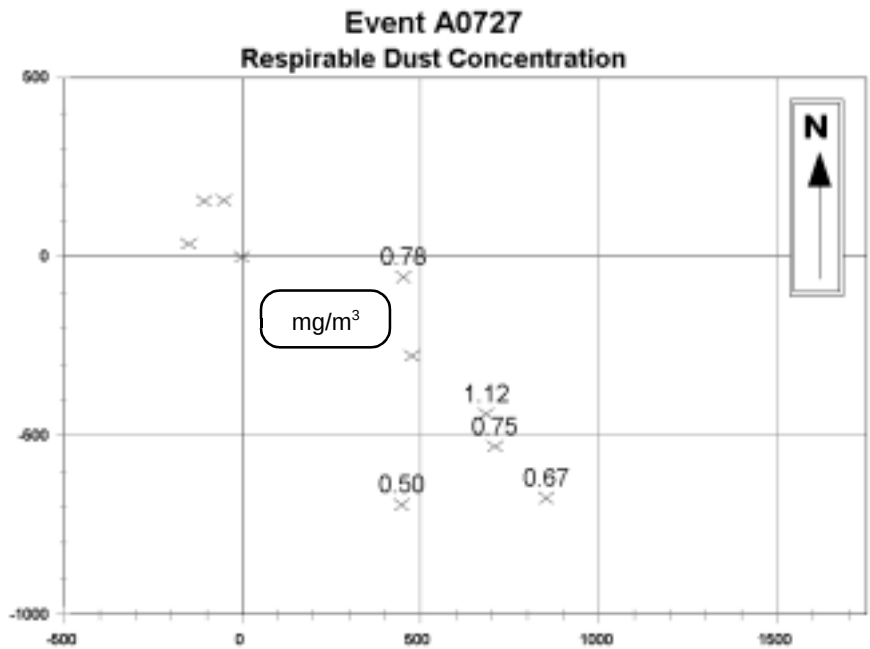
Event A0727 -11

Event A0727 -12



Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.3 Event B0602

Weather

Observations:	94°F, 40.8% relative humidity, clear and sunny
Wind:	8.2 mph

Blasting Data

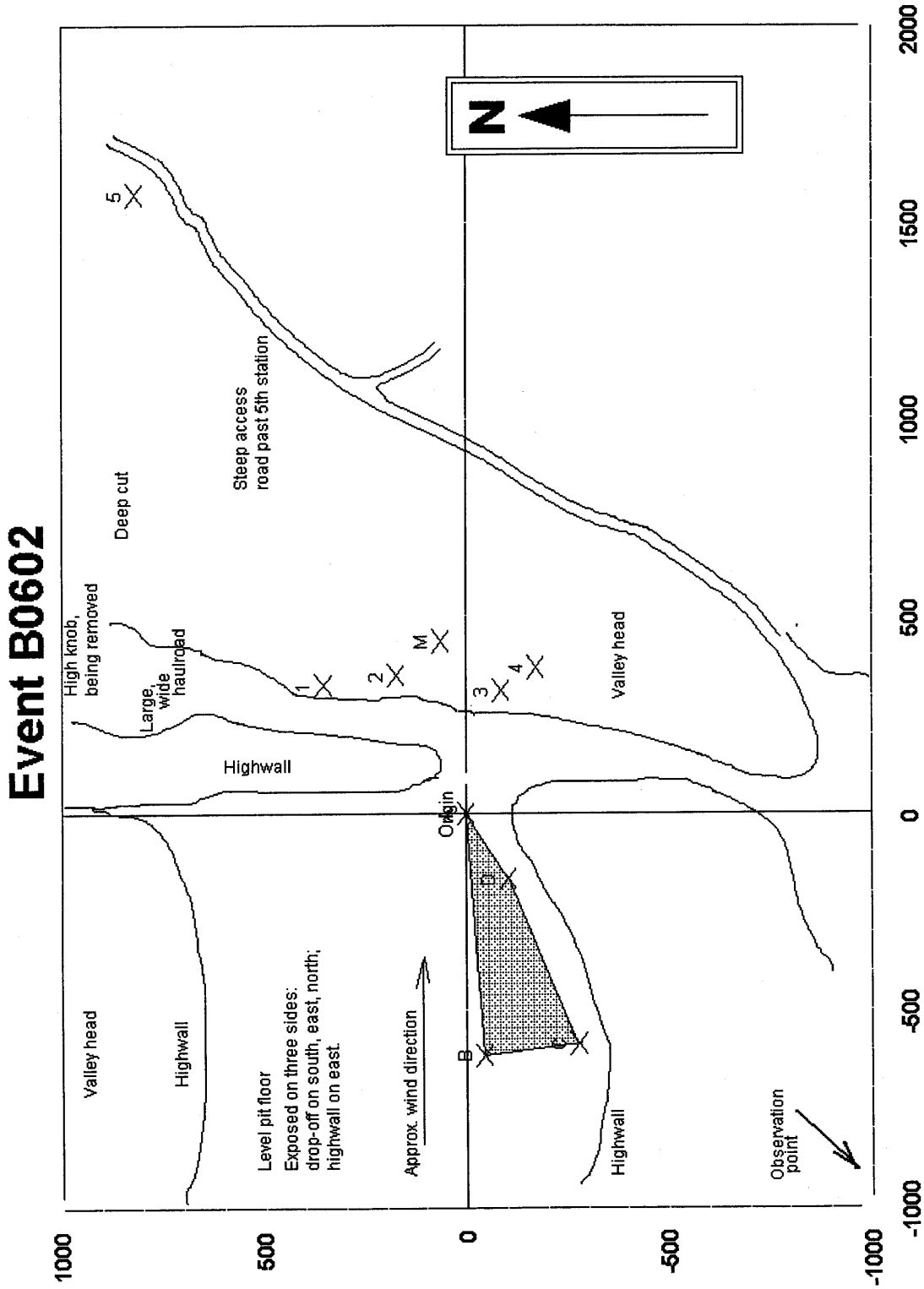
Time of ignition:	1538 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	9”
Hole Depth:	53’
Number of holes:	126
Stemming used:	12’ drill cuttings
Explosive types used:	ANFO 60/40, Pentex 3/4-lb primers, nonel
Weight of explosive used:	192,270 lbs
Weight of explosive used per hole:	1,526 lbs
Cubic Yardage Moved:	154,583 yd^3
Powder Factor:	1.24

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.48 mg
Respirable Dust Maximum:	0.34 mg
NO_2 high:	2.2 ppm (main station)
Duration of maximum NO_2 exposure:	1 min
Duration of maximum dust exposure:	0.37 min

Main Station Data

NO High:	20.7 ppm
CO High:	780 ppm
NH_3 High:	28 ppm
Dust:	47.67 mg/m^3



Axis distances are feet from th point of the blast nearest the main measurement station (0,0)

Event B0602 - 1

Event B0602 - 2

Event B0602 - 3

Event B0602 - 4

Event B0602 - 5

Event B0602 - 6

Event B0602 - 7

Event B0602 - 8

Event B0602 - 9

Event B0602 - 10

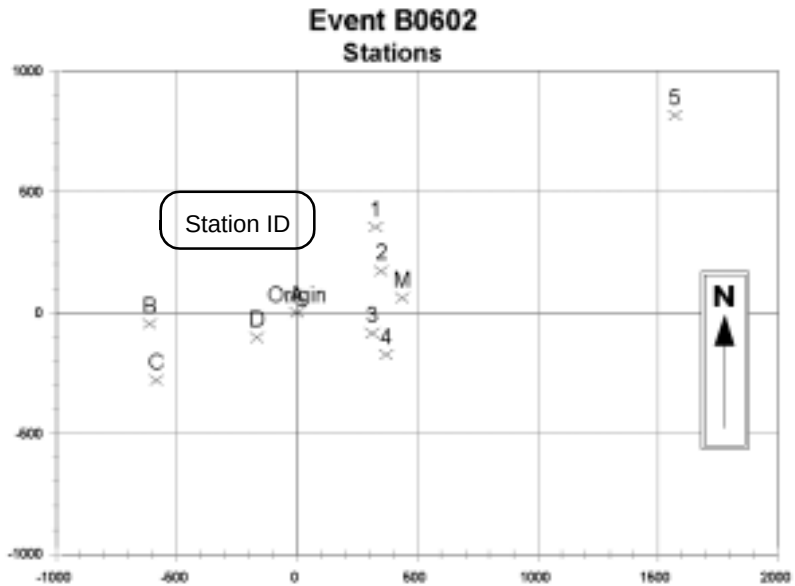
Event B0602 - 11

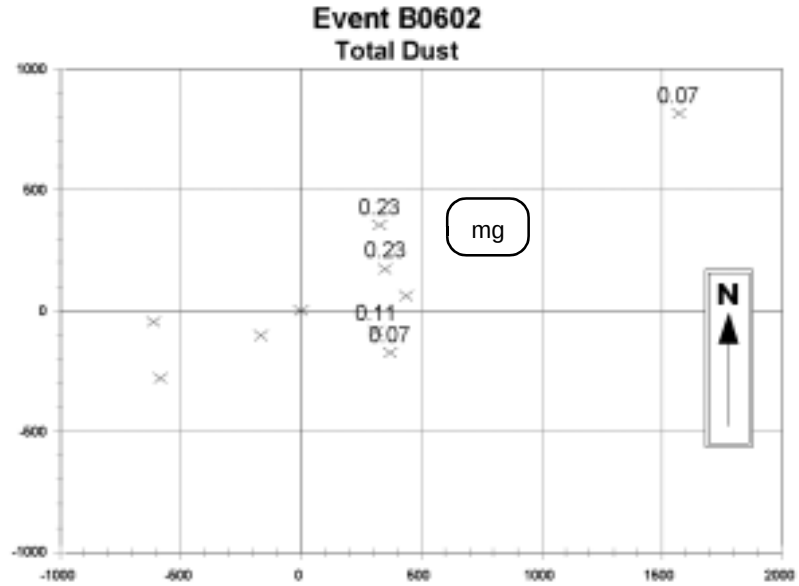
Event B0602 - 12

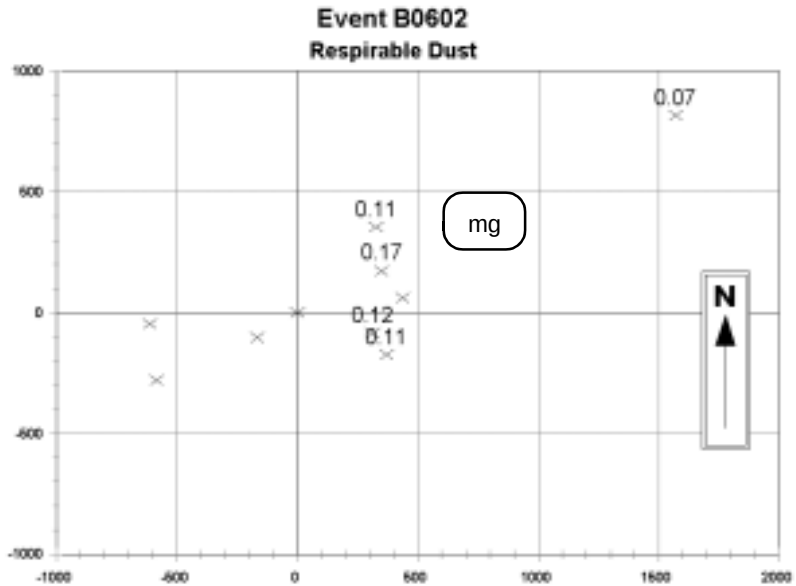
Event B0602 - 13

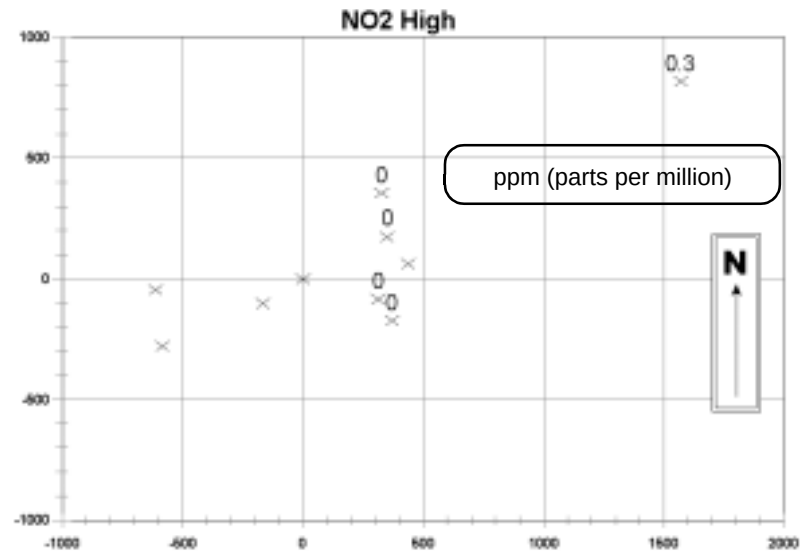
Event B0602 - 14

Event B0602 - 15

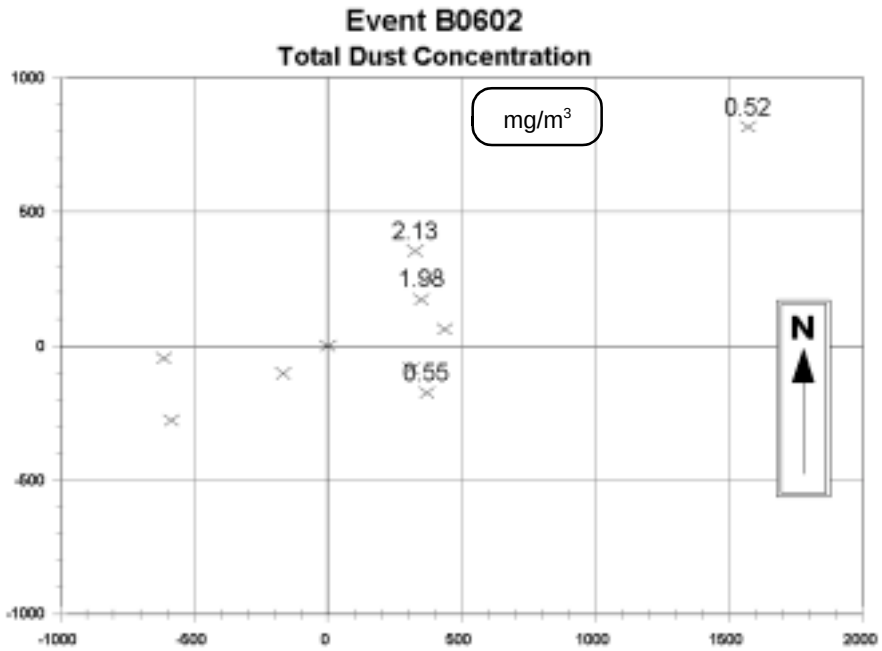


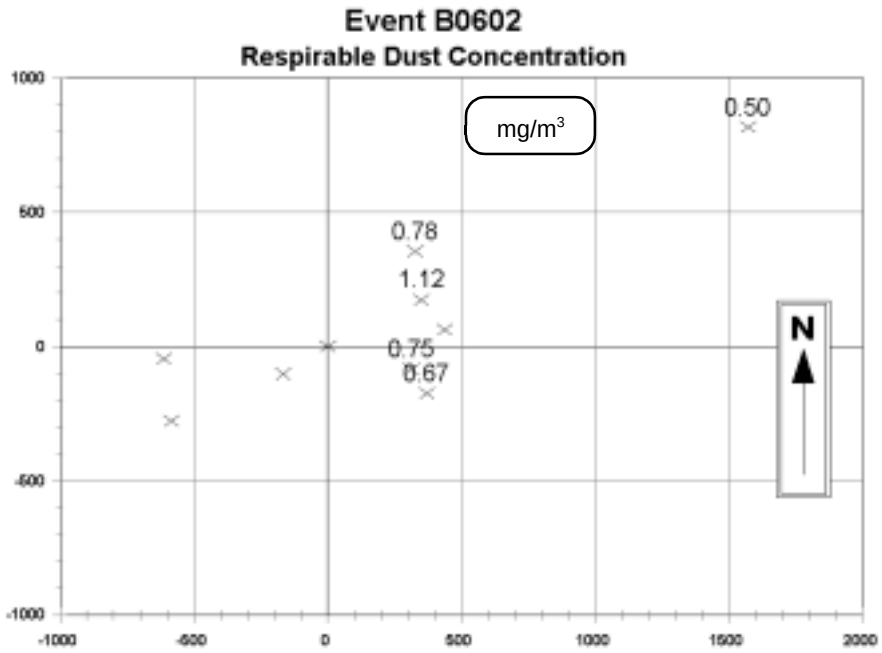






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.4 Event B0619

Weather

Observations:	74°F, relative humidity 86.0%, cloudy with intermittent drizzle
Wind:	4.9 mph

Blasting Data

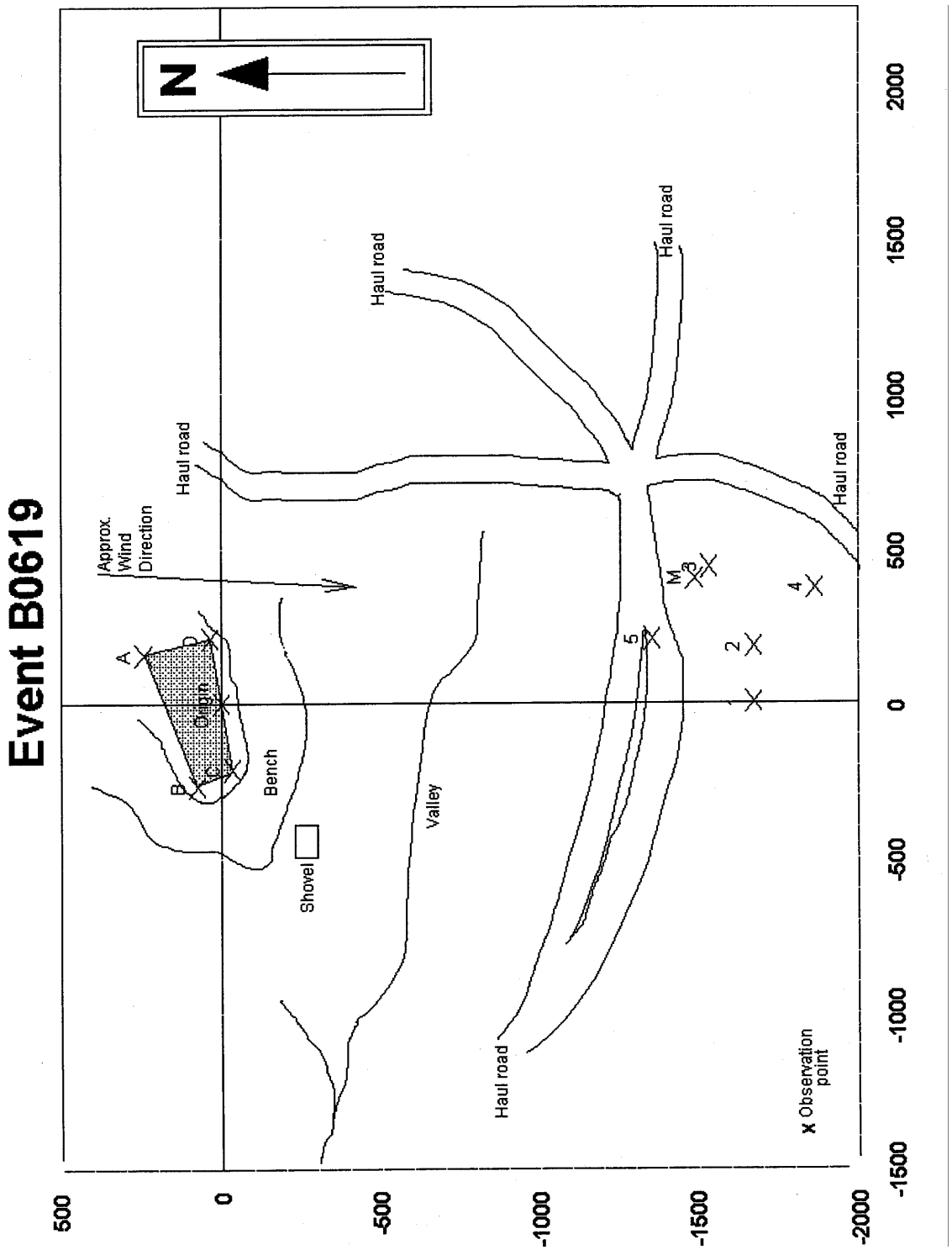
Time of ignition:	1531 hrs
Strata blasted:	Shale and sandstone
Hole Diameter:	9”
Hole Depth:	54’
Number of holes:	120
Stemming used:	11’ drill cuttings
Explosive types used:	ANFO 60/40, 3/4-lb cast primers, nonel
Weight of explosive used:	191,011 lbs
Weight of explosive used per hole:	1,592 lbs
Cubic Yardage Moved:	150,000 yd^3
Powder Factor:	1.27

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.10 mg
Respirable Dust Maximum:	0.12 mg
NO_2 high:	1.4 ppm
Duration of maximum NO_2 exposure:	4 min
Duration of maximum dust exposure:	0

Main Station Data

NO High:	9.8 ppm
CO High:	88 ppm
NH_3 High:	11 ppm
Dust:	0.23 mg/m^3



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event B0619 - 1

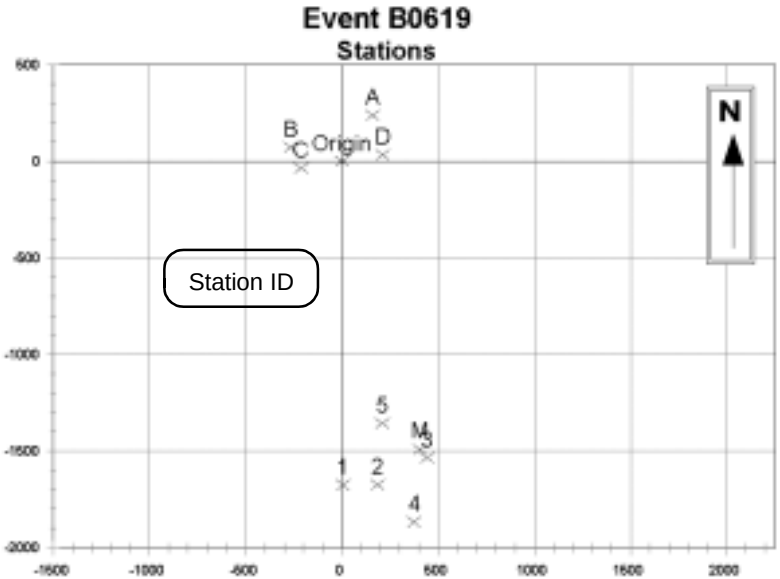
Event B0619 - 2

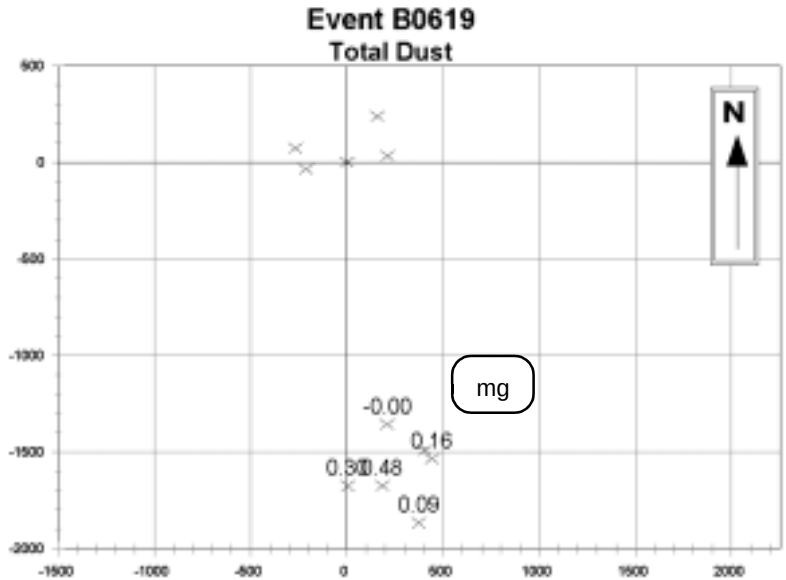
Event B0619 - 3

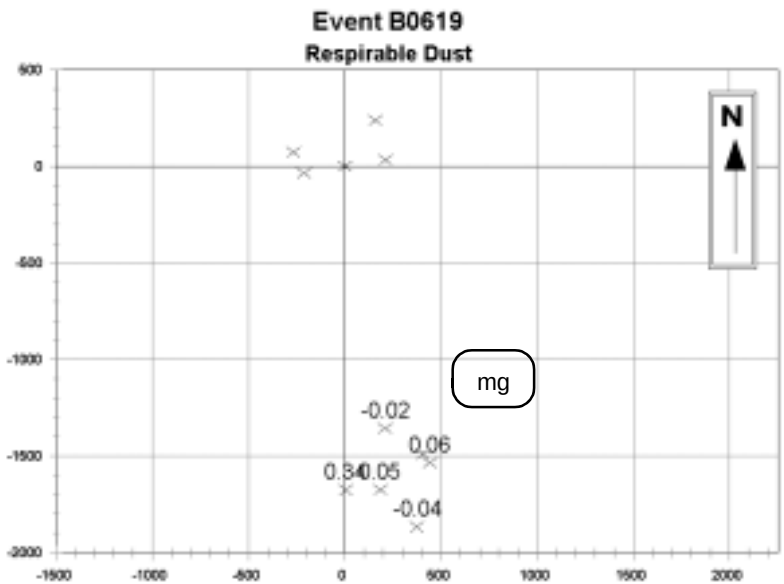
Event B0619 - 4

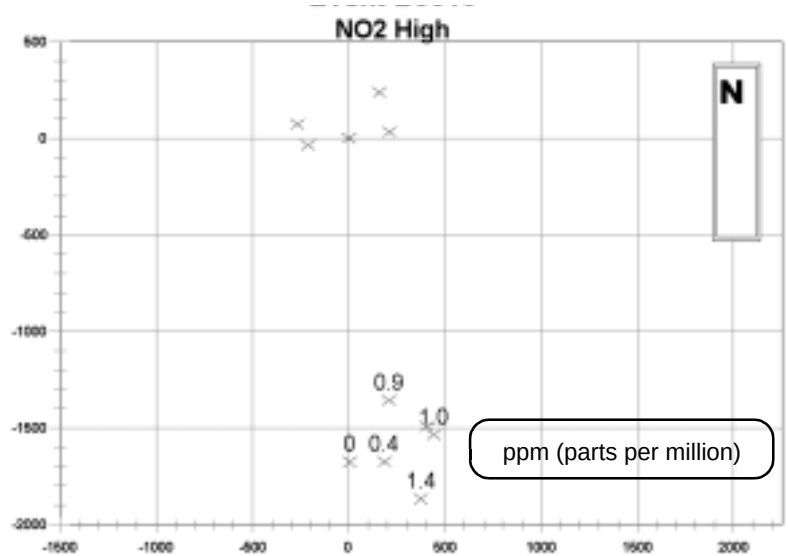
Event B0619 - 5

Event B0619 - 6

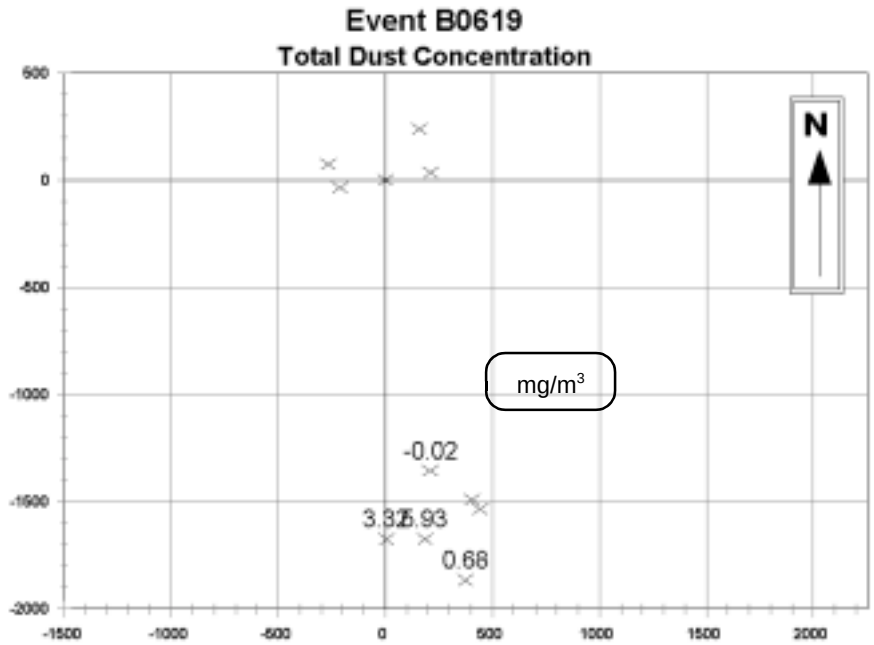


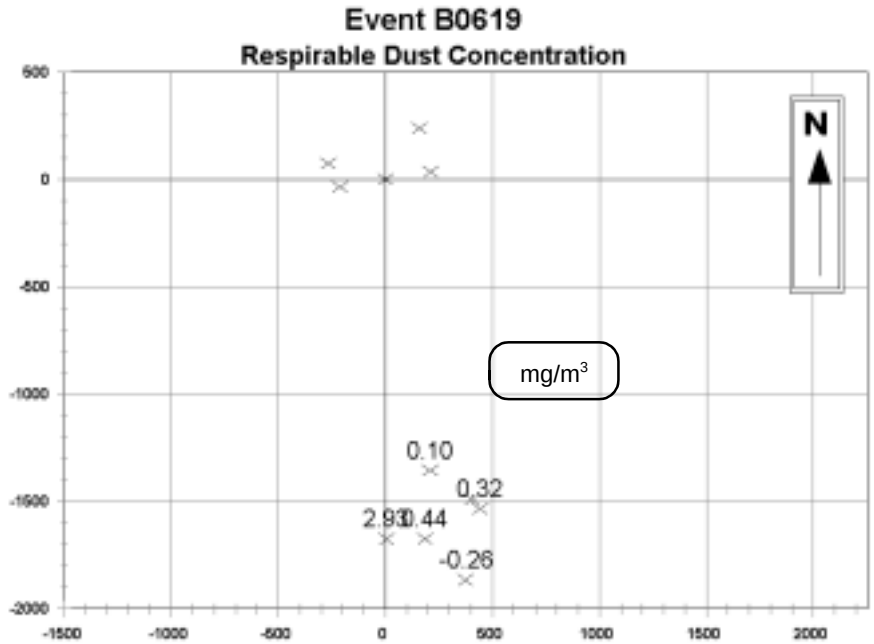






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.5 Event B0620

Weather

Observations:	105°F (approx 85 in shade), 54.0% relative humidity, sunny and clear
Wind:	1.0 mph

Blasting Data

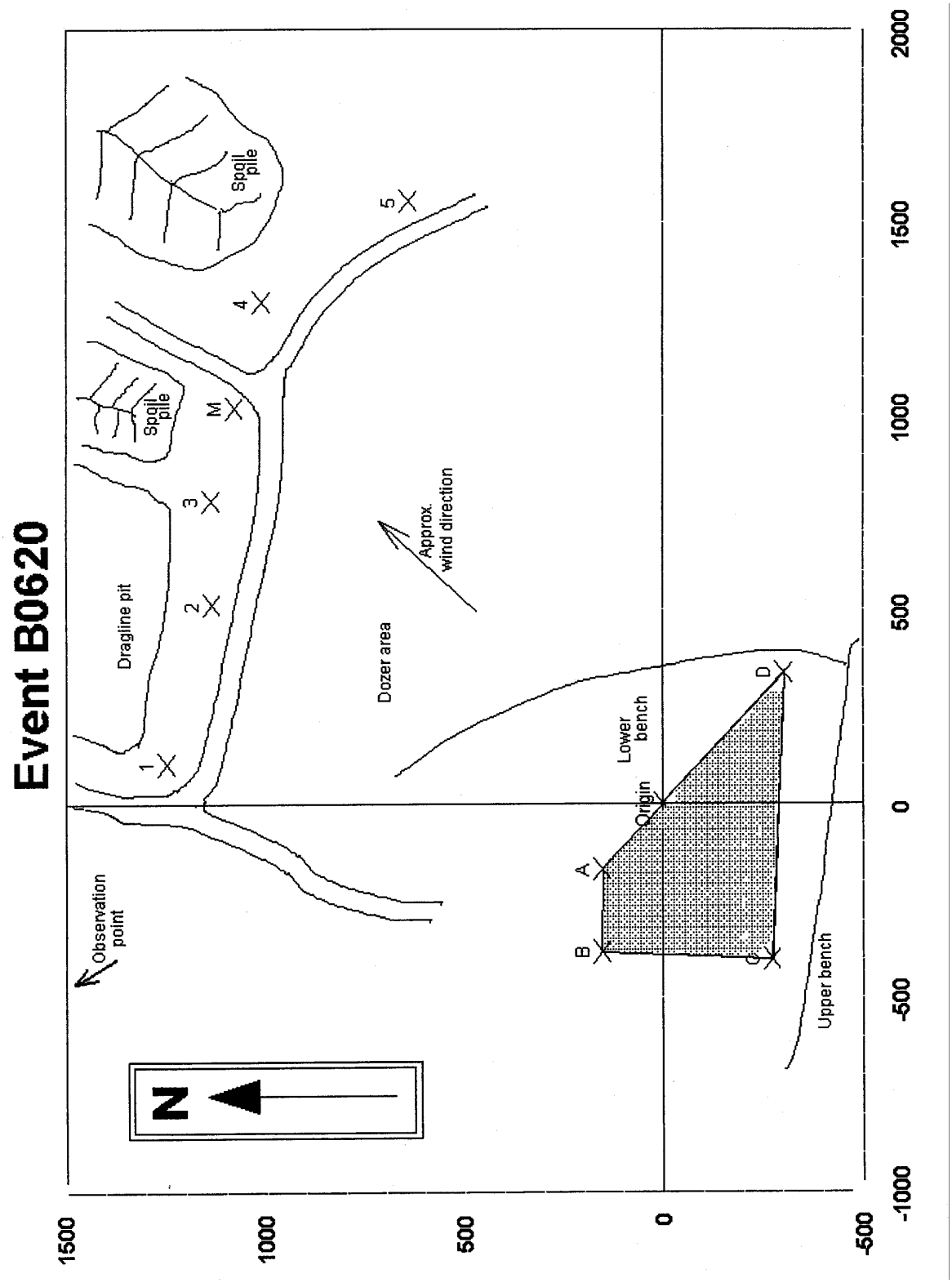
Time of ignition:	1532 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	10.625”
Hole Depth:	67’
Number of holes:	253
Stemming used:	16’ drill cuttings
Explosive types used:	ANFO 50/50, 3/4-lb pentex primers, nonel
Weight of explosive used:	669,863 lbs
Weight of explosive used per hole:	2,648 lbs
Cubic Yardage Moved:	492,207 yd^3
Powder Factor:	1.36

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.09 mg
Respirable Dust Maximum:	0.10 mg
NO_2 high:	3.6 ppm
Duration of maximum NO_2 exposure:	4 min
Duration of maximum dust exposure:	0

Main Station Data

NO High:	1.6 ppm
CO High:	20 ppm
NH_3 High:	25 ppm
Dust:	0



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event B0620 - 1

Event B0620 - 2

Event B0620 - 3

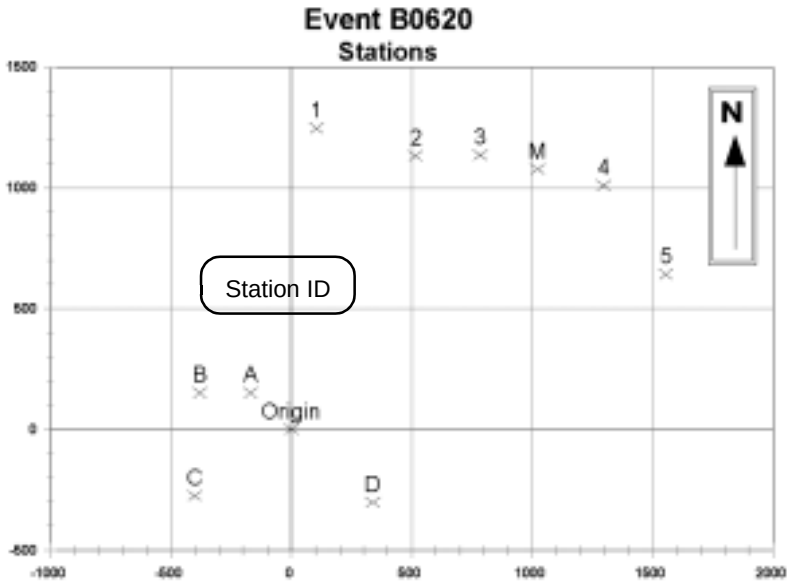
Event B0620 - 4

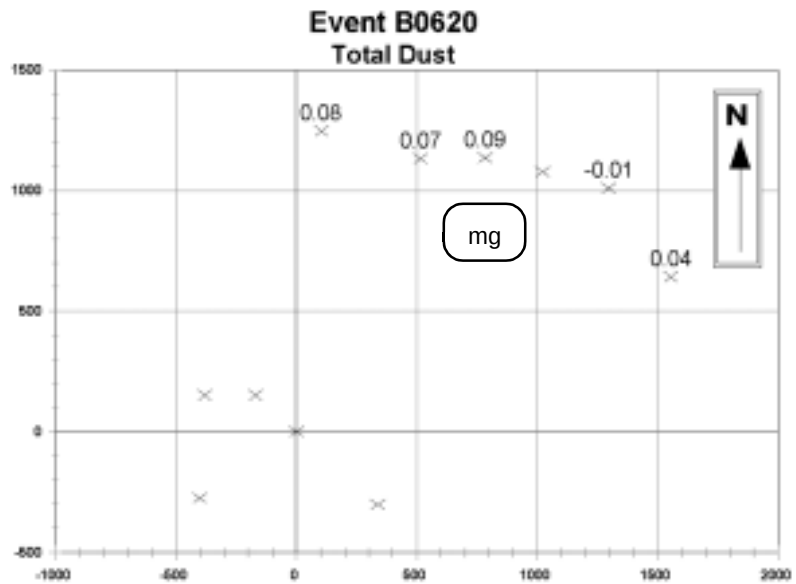
Event B0620 - 5

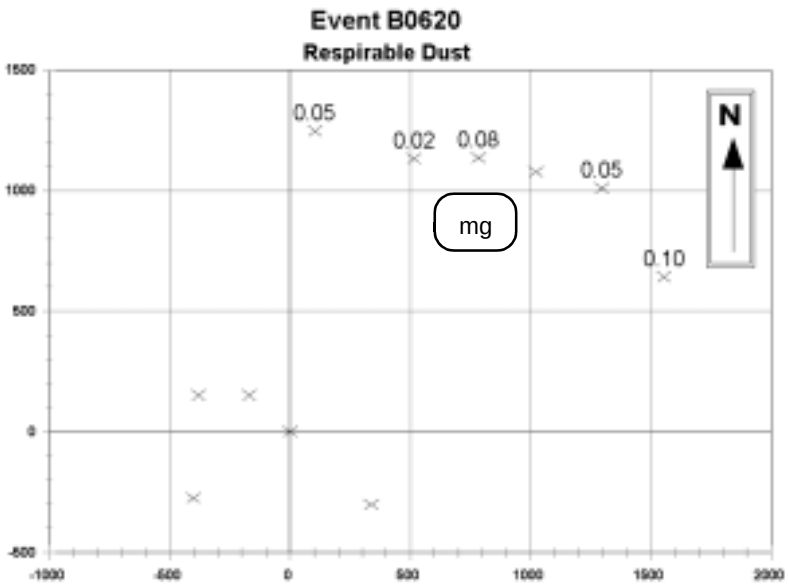
Event B0620 - 6

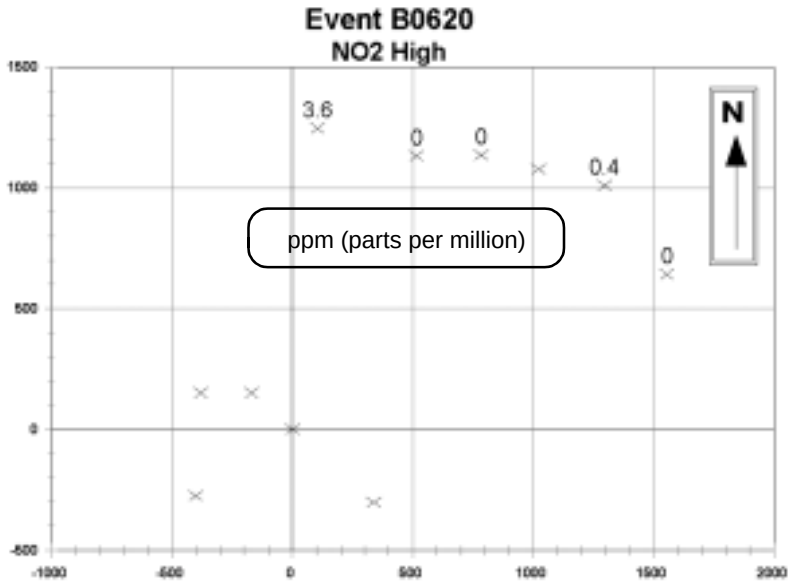
Event B0620 - 7

Event B0620 - 8

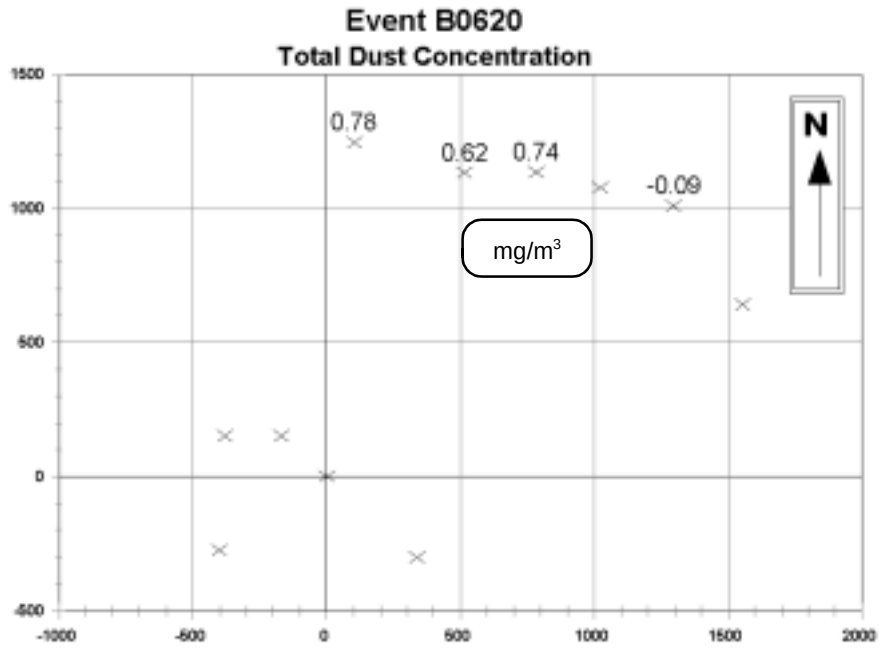


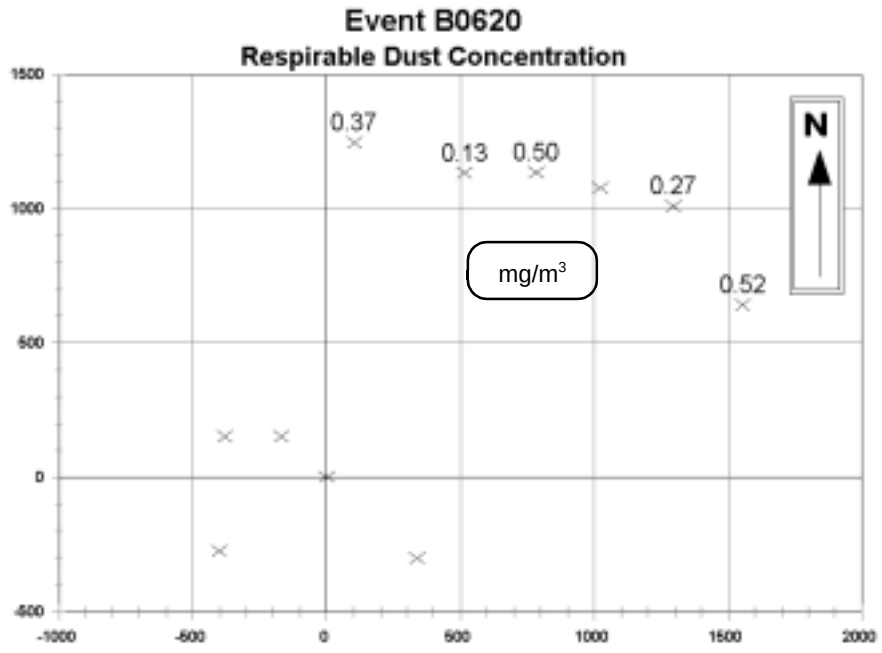






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.6 Event B0627

Weather

Observations:	77°F, 83.0% relative humidity, cloudy, intermittent rain
Wind:	2.3 mph

Blasting Data

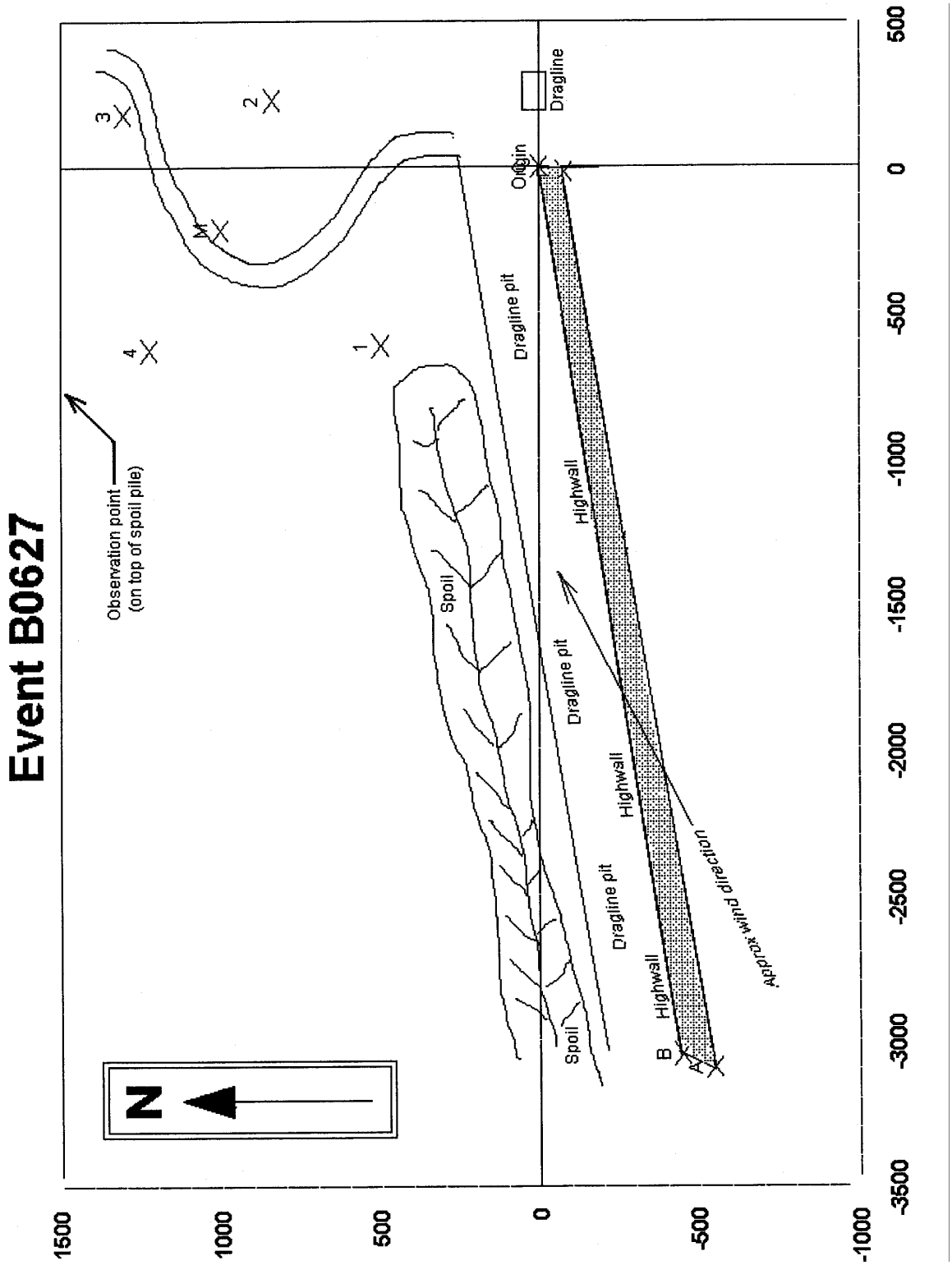
Time of ignition:	1125 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	10,625”
Hole Depth:	92’
Number of holes:	346
Stemming used:	12.5’ of drill cuttings and #57 crushed limestone
Explosive types used:	ANFO 50/50, optimizer 3/4-lb primers, nonel
Weight of explosive used:	1,159,517 lbs
Weight of explosive used per hole:	3,351 lbs
Cubic Yardage Moved:	1,018,624 lbs
Powder Factor:	1.14

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.15 mg
Respirable Dust Maximum:	0.12 mg
NO_2 high:	0.5 ppm
Duration of maximum NO_2 exposure:	1 min
Duration of maximum dust exposure:	0

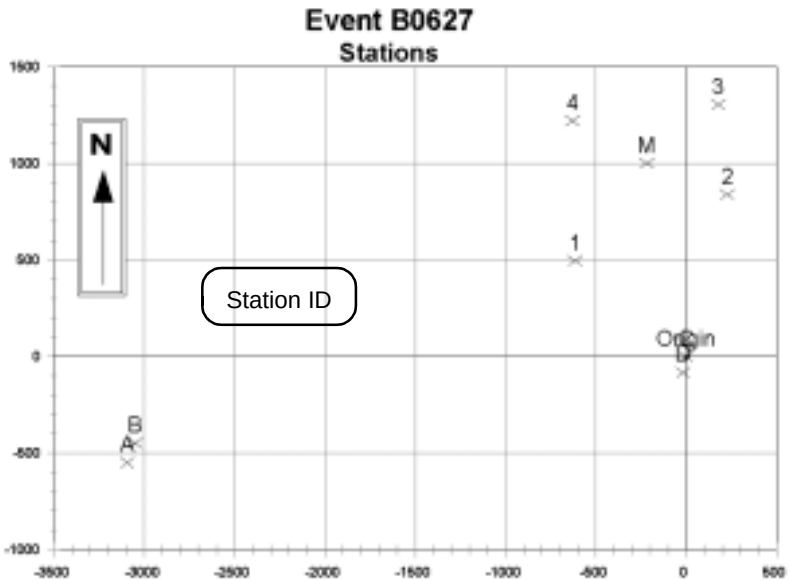
Main Station Data

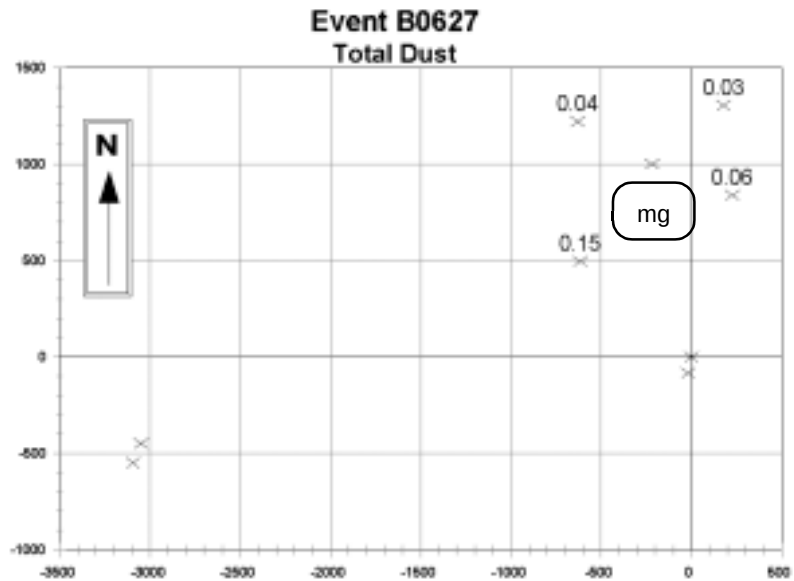
NO High:	0
CO High:	2 ppm
NH_3 High:	N/A
Dust:	0

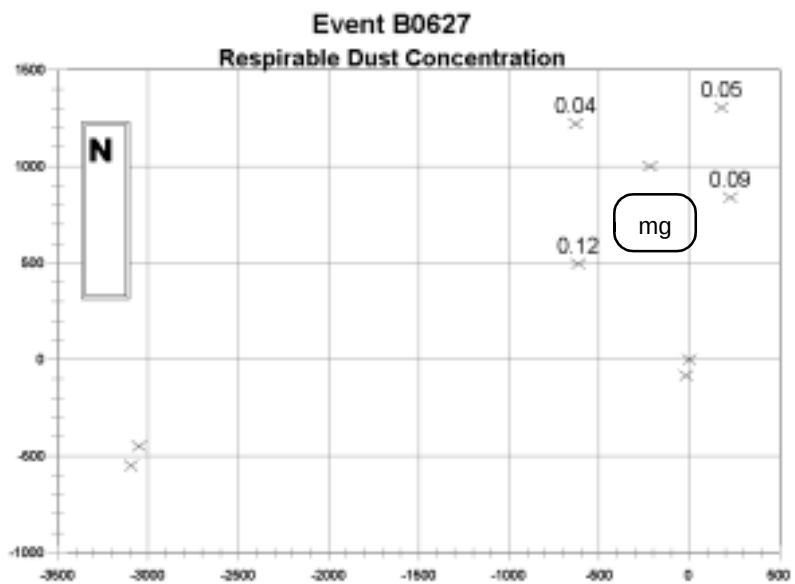


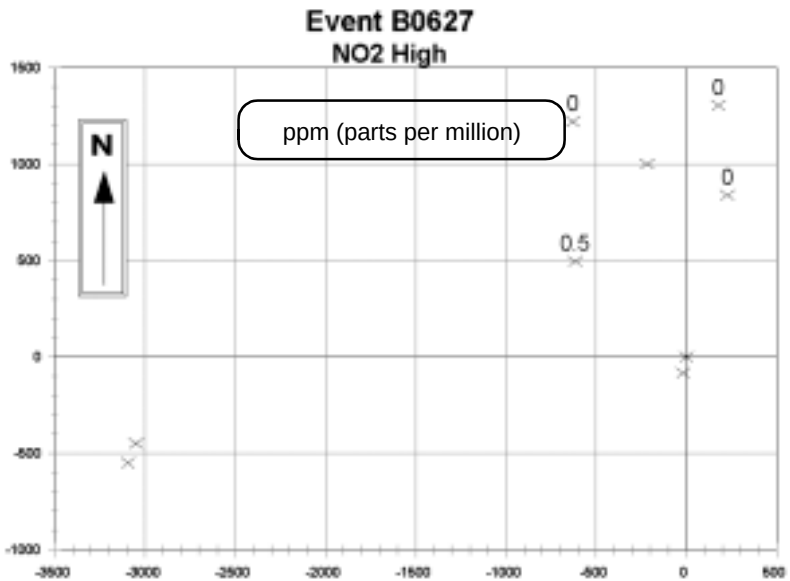
Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

No Photographs
For Event B0627

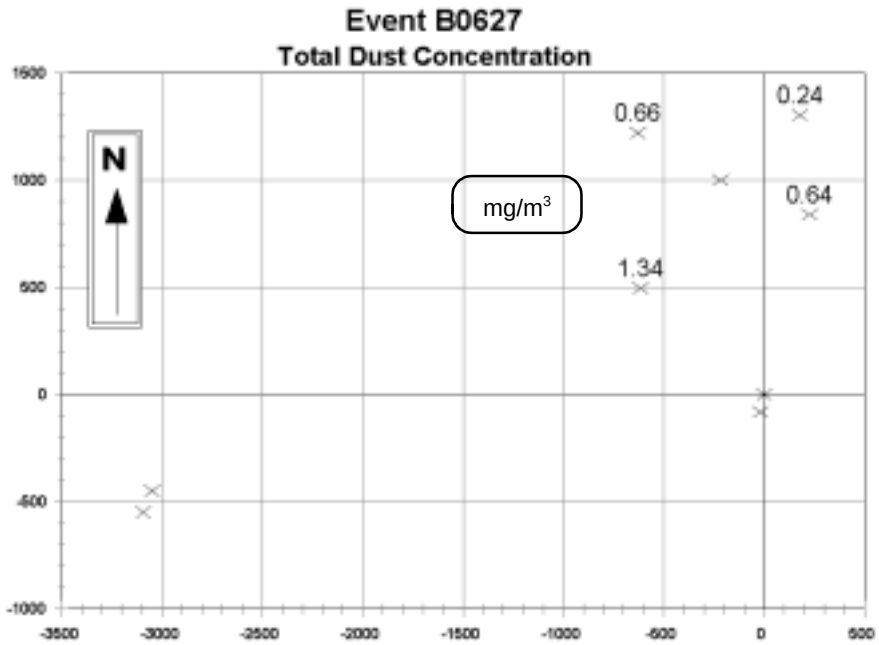


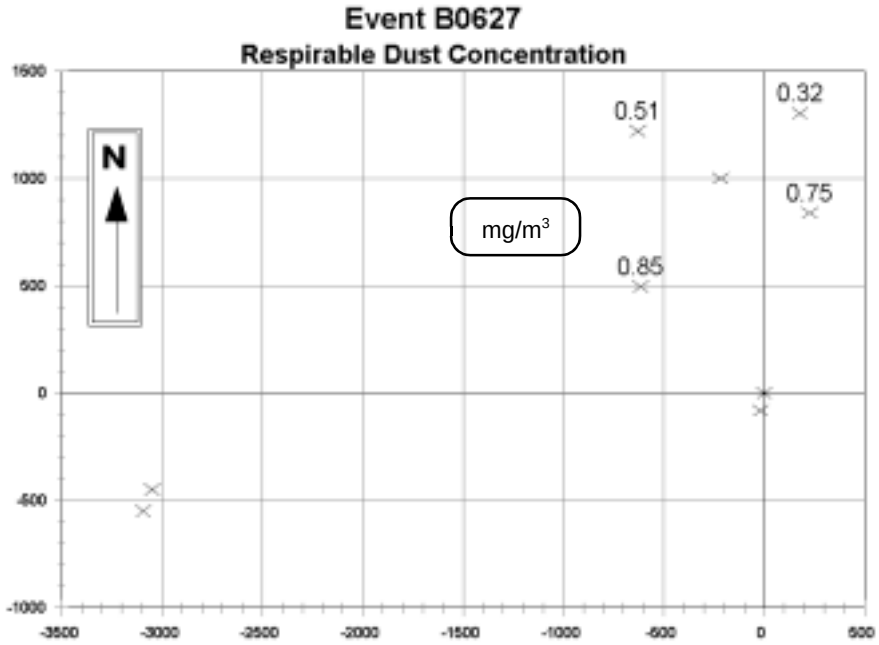






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.7 Event B0816

Weather

Observations:	90°F, 52.0% relative humidity, sunny and clear
Wind:	5.2 mph

Blasting Data

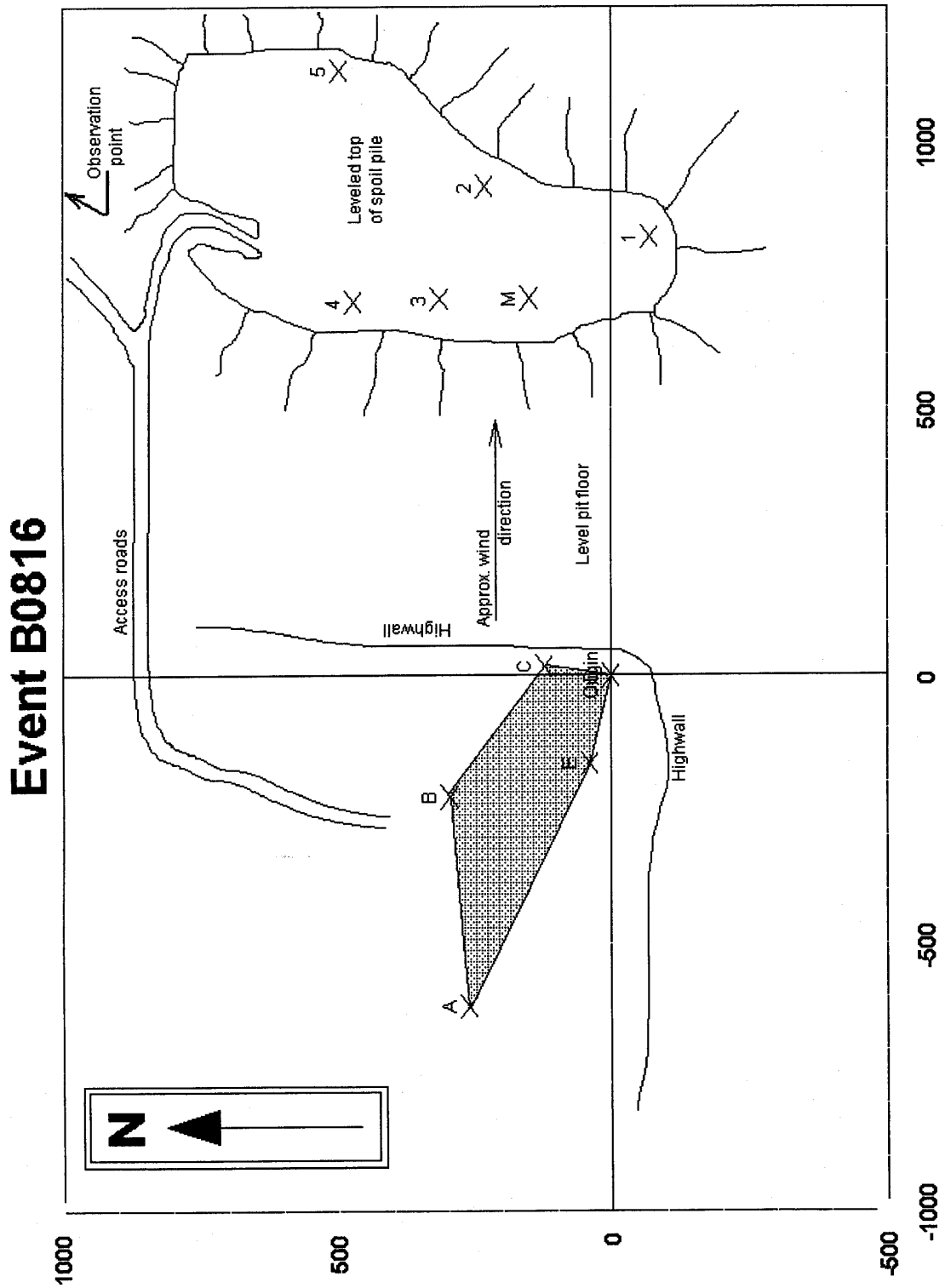
Time of ignition:	1531 hrs
Strata blasted:	Sandstone and shale
Hole Diameter:	10.625”
Hole Depth:	58’
Number of holes:	118
Stemming used:	11’ drill cuttings
Explosive types used:	ANFO 60/40, pentex 3/4-lb primers, nonel
Weight of explosive used:	287,930 lbs
Weight of explosive used per hole:	2,440 lbs
Cubic Yardage Moved:	198,730 yd^3
Powder Factor:	1.45

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.66 mg
Respirable Dust Maximum:	0.10 mg
NO_2 high:	0.8 ppm
Duration of maximum NO_2 exposure:	2 min
Duration of maximum dust exposure:	0

Main Station Data

NO High:	6.5 ppm
CO High:	196 ppm
NH_3 High:	68 ppm
Dust:	15.95 mg/m^3



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event B0816 - 1

Event B0816 - 2

Event B0816 - 3

Event B0816 - 4

Event B0816 - 5

Event B0816 - 6

Event B0816 - 7

Event B0816 - 8

Event B0816 - 9

Event B0816 - 10

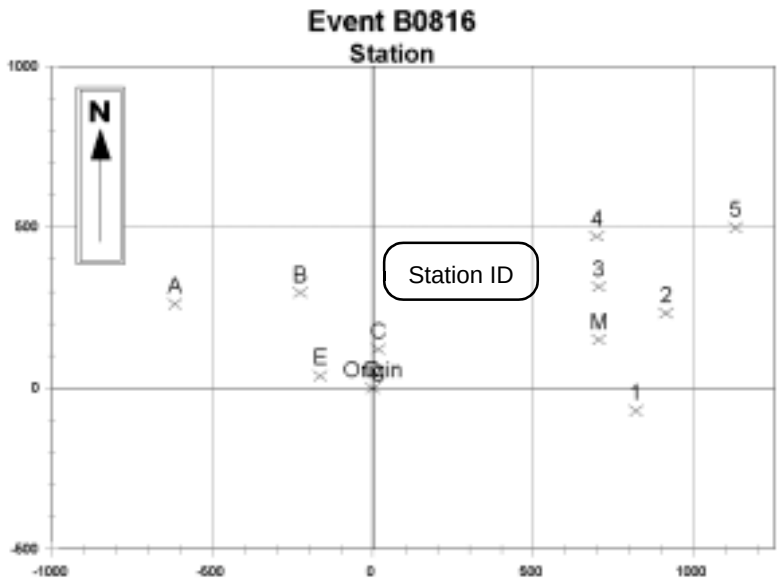
Event B0816 - 11

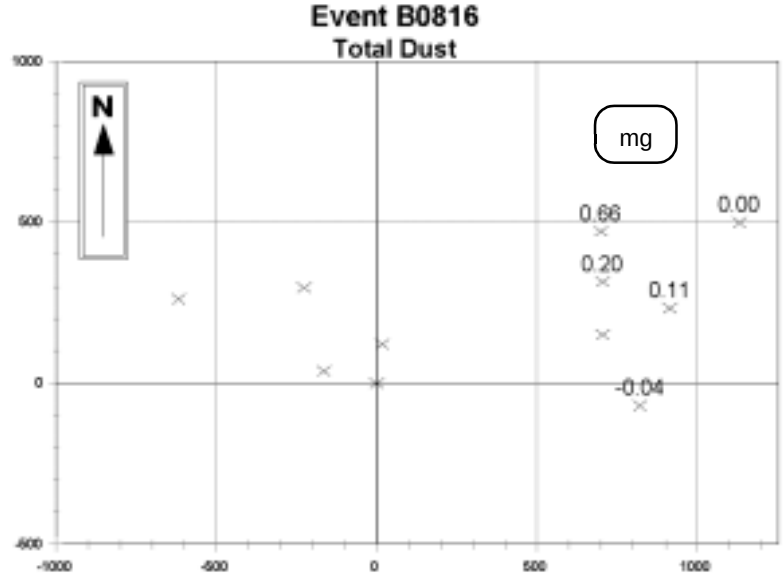
Event B0816 - 12

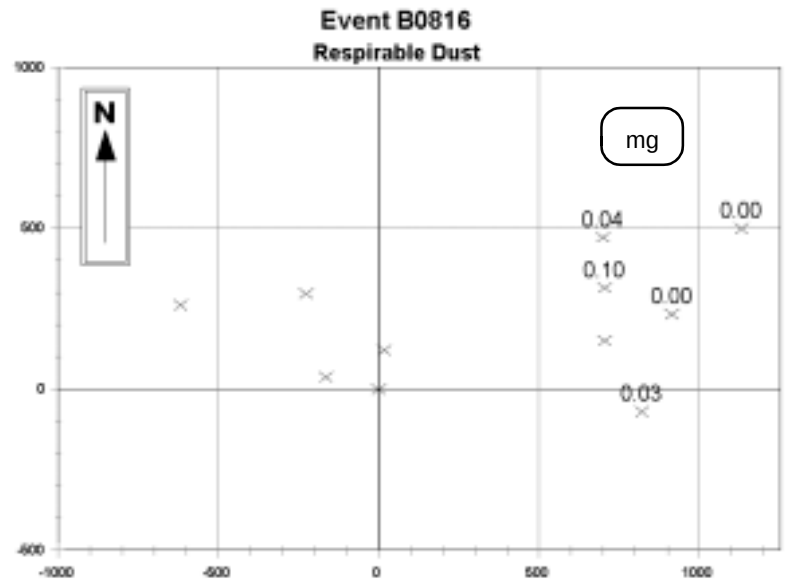
Event B0816 - 13

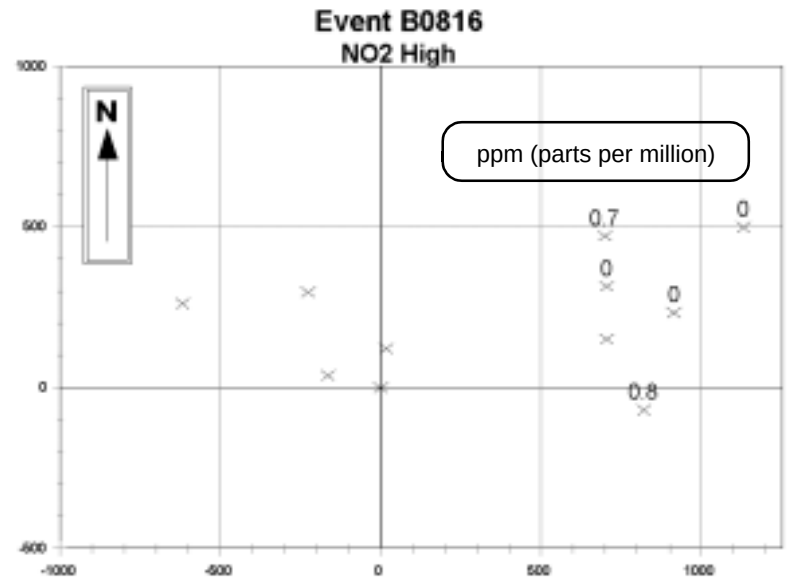
Event B0816 - 14

Event B0816 - 15

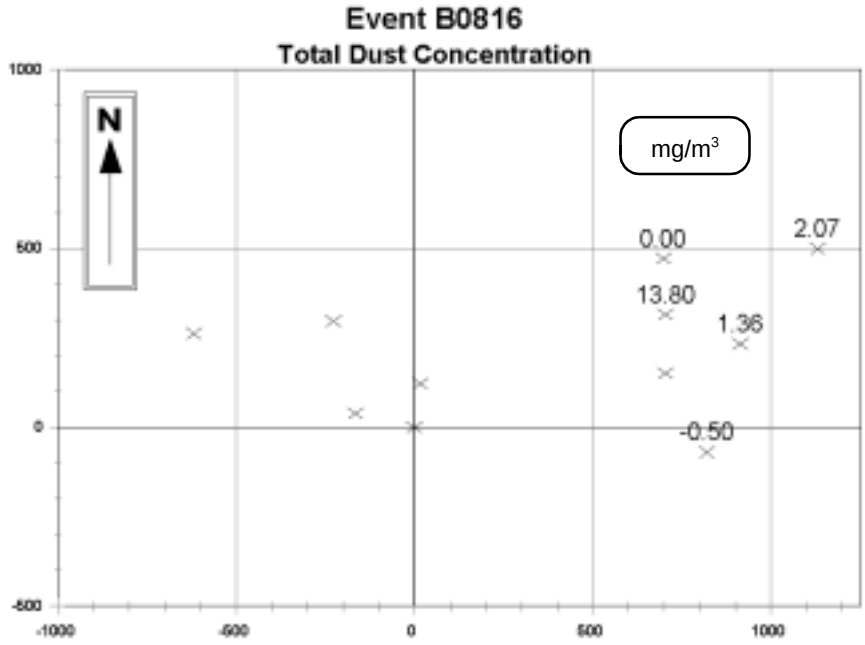


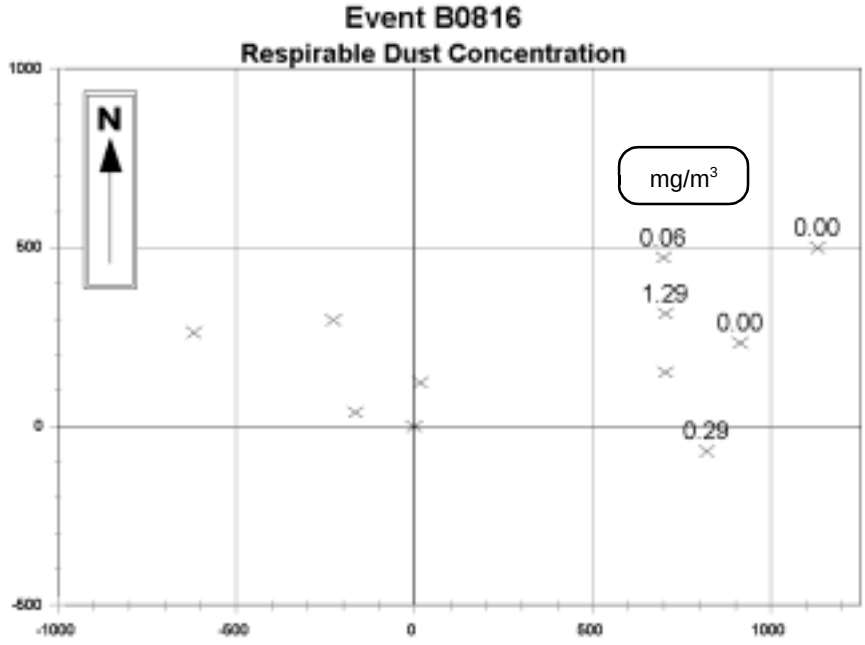






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.8 Event C0712

Weather

Observations:	89°F, 62.0% relative humidity, sunny and clear
Wind:	0.0 fpm

Blasting Data

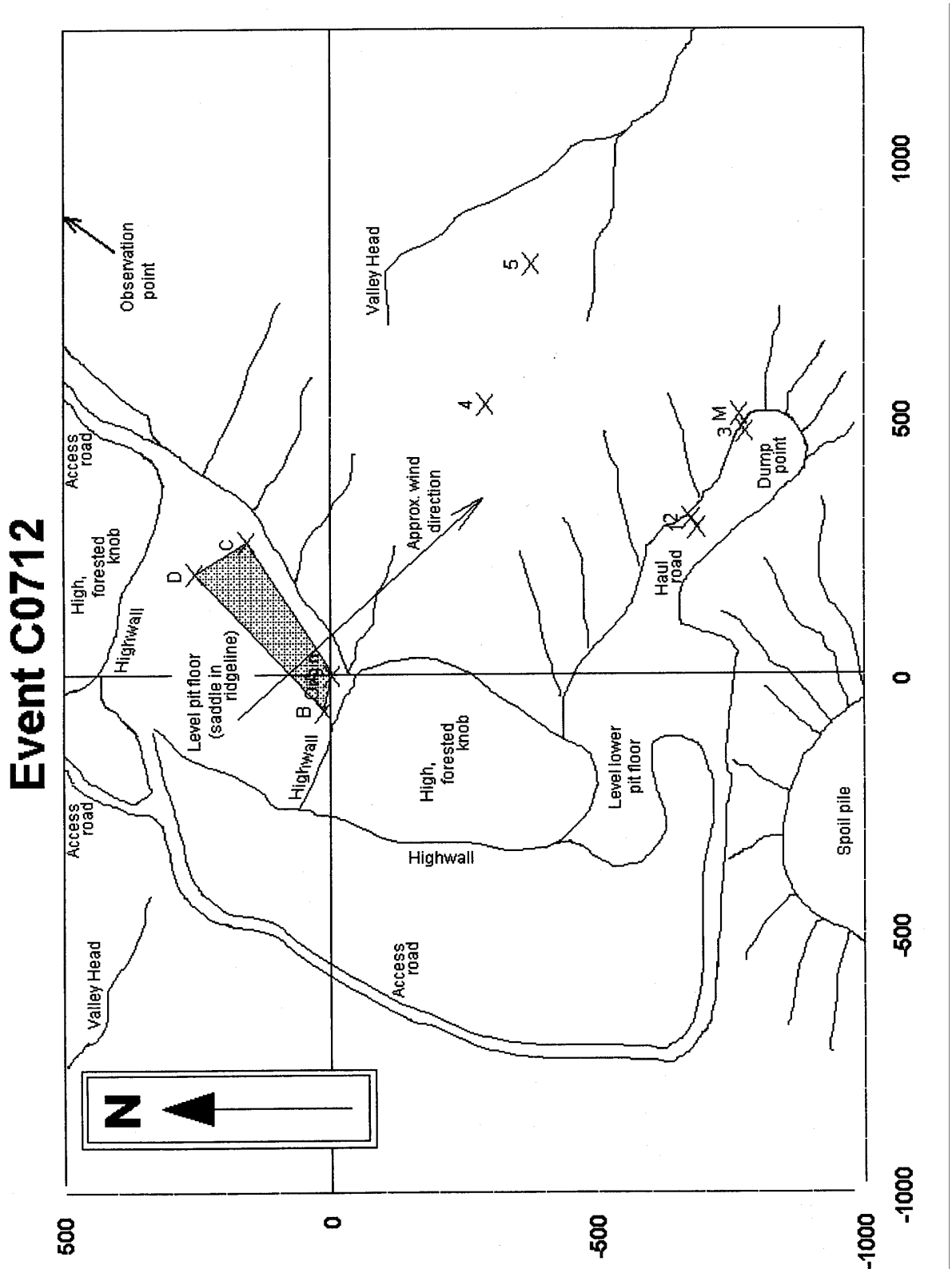
Time of ignition:	1520 hrs
Strata blasted:	Sandrock and shale
Hole Diameter:	7.875”
Hole Depth:	53’
Number of holes:	105
Stemming used:	8’ drill cuttings
Explosive types used:	ANFO, Austin 3/4-lb primers, nonel
Weight of explosive used:	85,156 lbs
Weight of explosive used per hole:	811 lbs
Cubic Yardage Moved:	70,490 yd^3
Powder Factor:	1.21

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.13 mg
Respirable Dust Maximum:	0.15 mg
NO_2 high:	0.5
Duration of maximum NO_2 exposure:	1 minute
Duration of maximum dust exposure:	0

Main Station Data

NO High:	0.7 ppm
CO High:	3 ppm
NH_3 High:	N/A
Dust:	15.87 mg/m^3



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event C0712 - 1

Event C0712 - 2

Event C0712 - 3

Event C0712 - 4

Event C0712 - 5

Event C0712 - 6

Event C0712 - 7

Event C0712 - 8

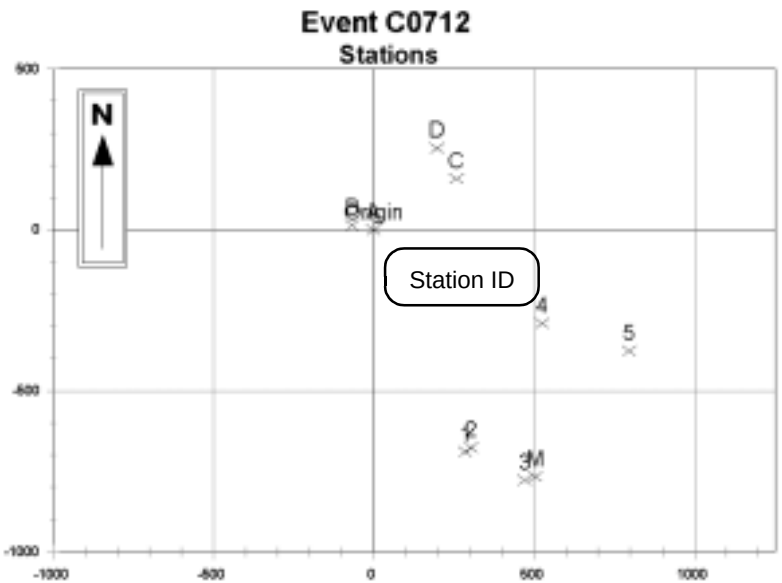
Event C0712 - 9

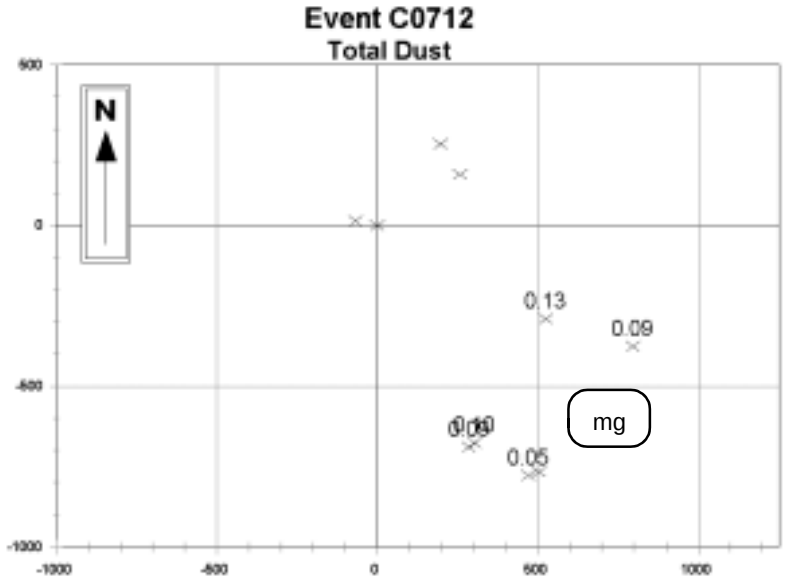
Event C0712 - 10

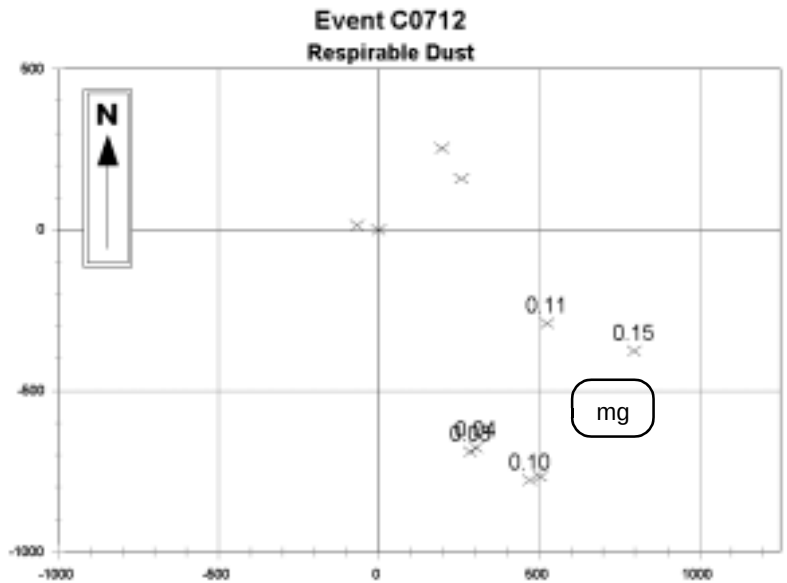
Event C0712 - 11

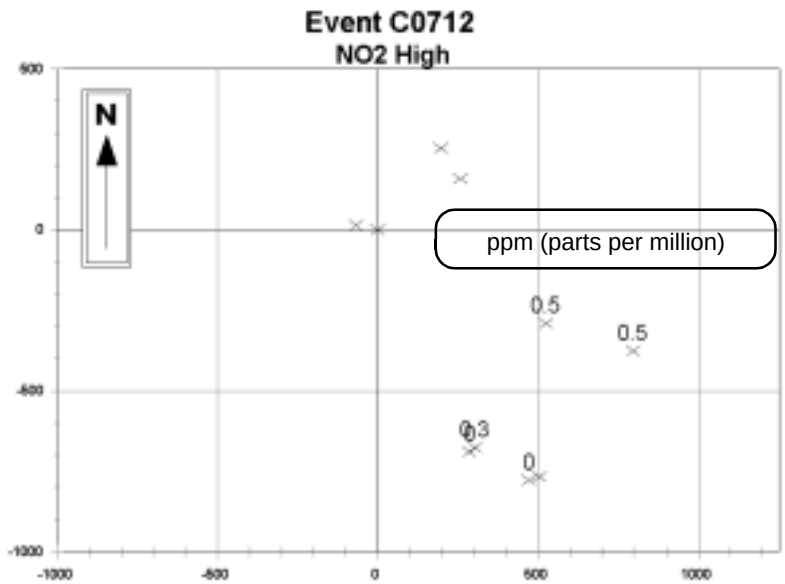
Event C0712 - 12

Note gas cloud at bottom
of freshly blasted pit

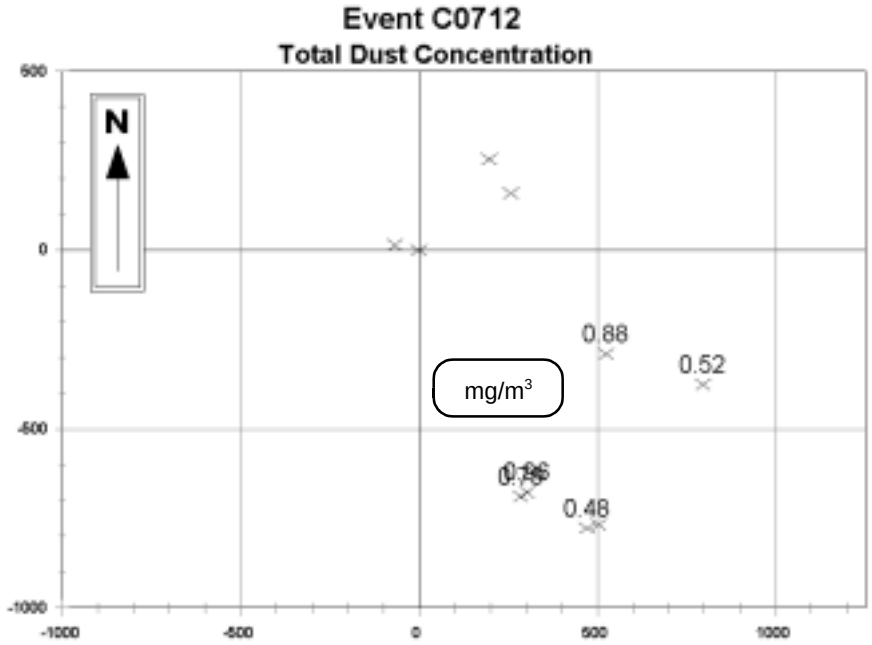


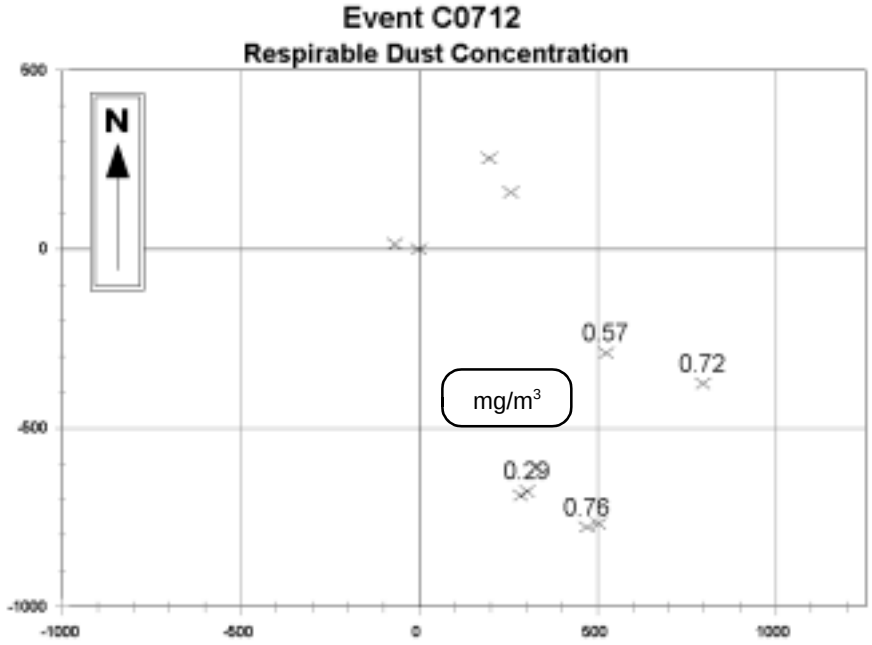






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.9 Event C0714

Weather

Observations:	89°F, 36.0% relative humidity, scattered clouds
Wind:	2.8 mph

Blasting Data

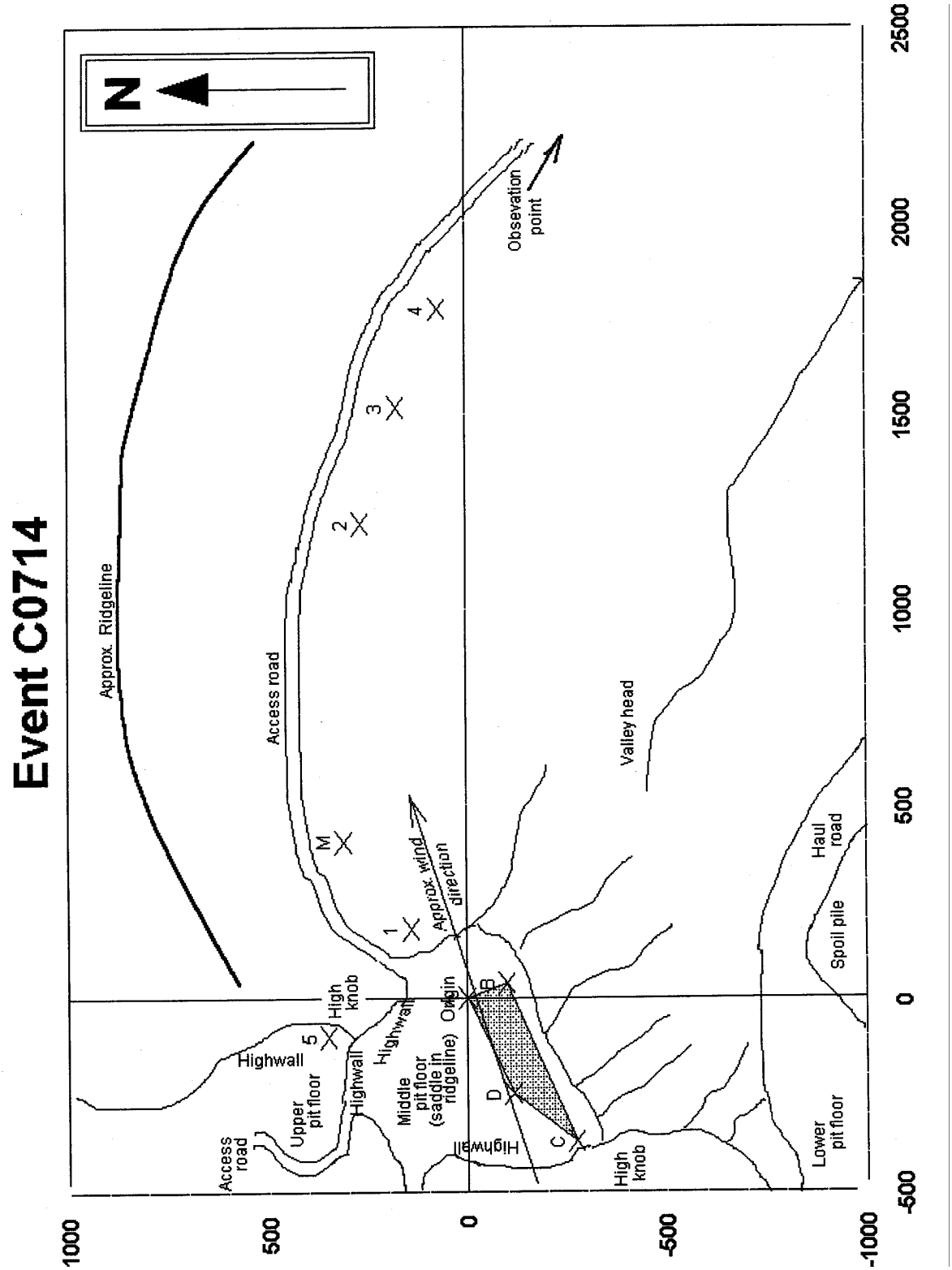
Time of ignition:	1456 hrs
Strata blasted:	Sandrock and shale
Hole Diameter:	7.825”
Hole Depth:	57’
Number of holes:	120
Stemming used:	8’ drill cuttings
Explosive types used:	ANFO, Austin 3/4-lb primers, nonel
Weight of explosive used:	99,465 lbs
Weight of explosive used per hole:	829 lbs
Cubic Yardage Moved:	82,080 yd^3
Powder Factor:	1.21

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.38 mg
Respirable Dust Maximum:	0.21 mg
NO_2 high:	4.2 ppm
Duration of maximum NO_2 exposure:	4 min
Duration of maximum dust exposure:	0

Main Station Data

NO High:	4.7 ppm
CO High:	8 ppm
NH_3 High:	13 ppm
Dust:	N/A



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event C0714 - 1

Event C0714 - 2

Event C0714 - 3

Event C0714 - 4

Event C0714 - 5

Event C0714 - 6

Event C0714 - 7

Event C0714 - 8

Event C0714 - 9

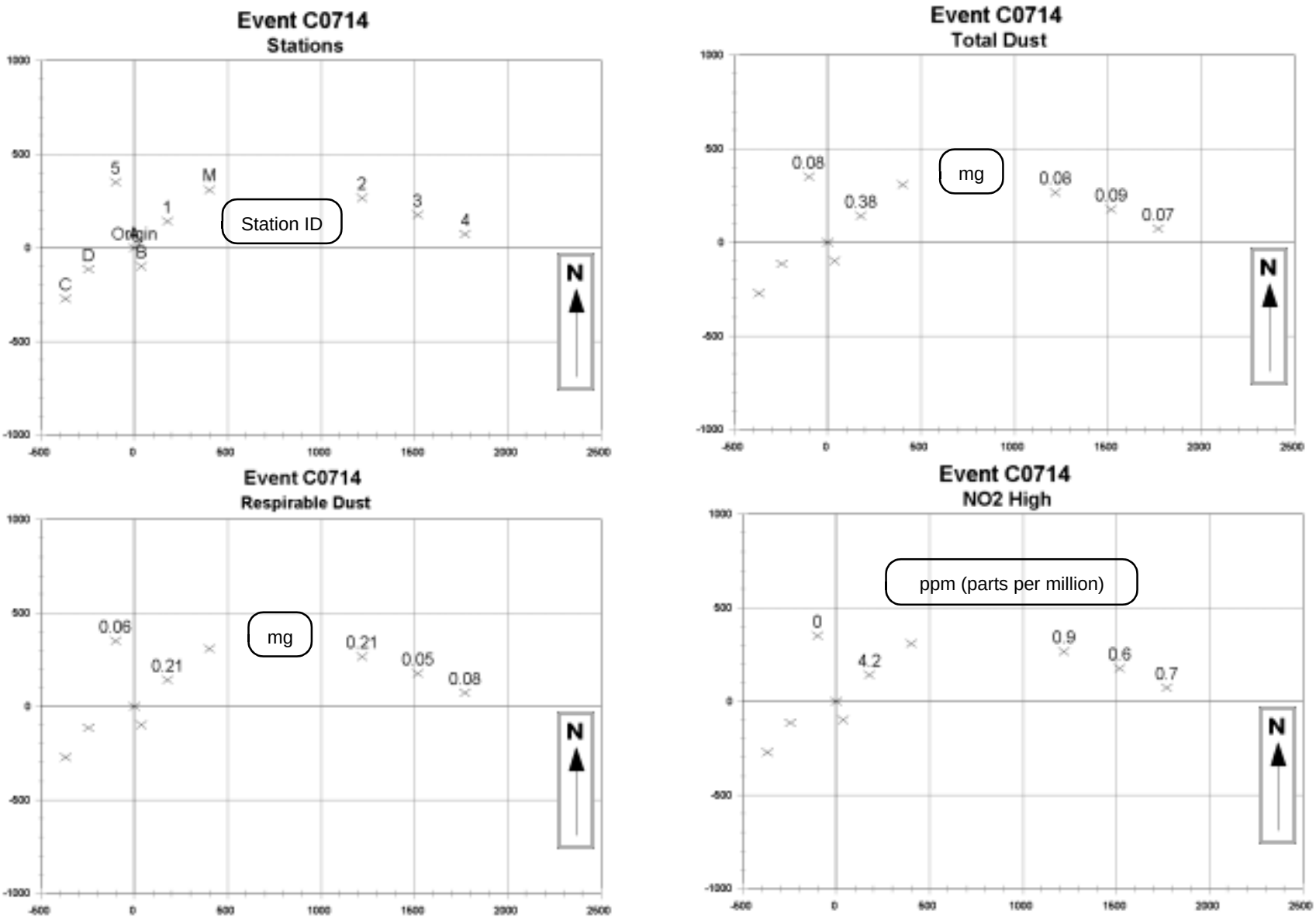
Event C0714 - 10

Event C0714 - 11

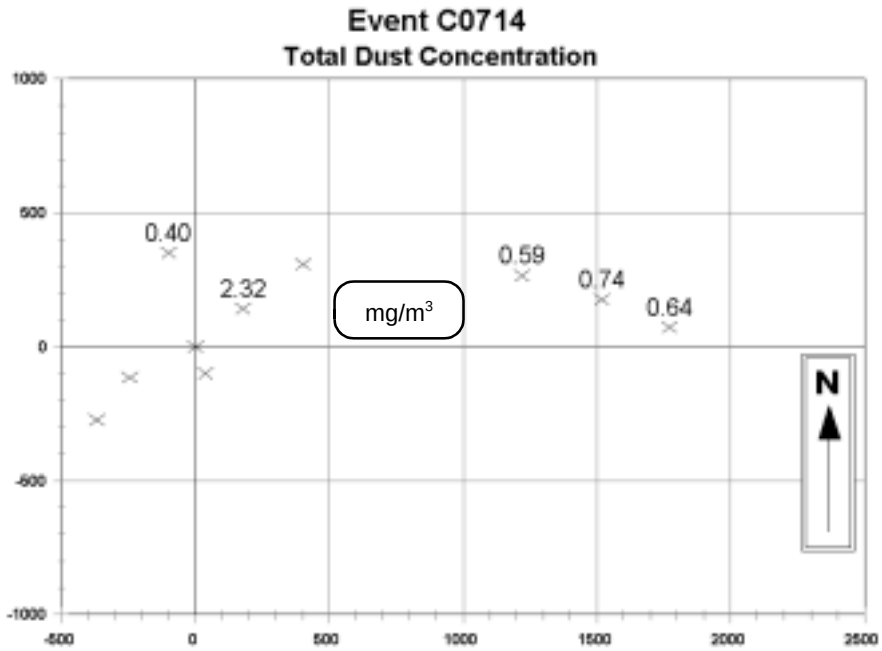
Event C0714 - 12

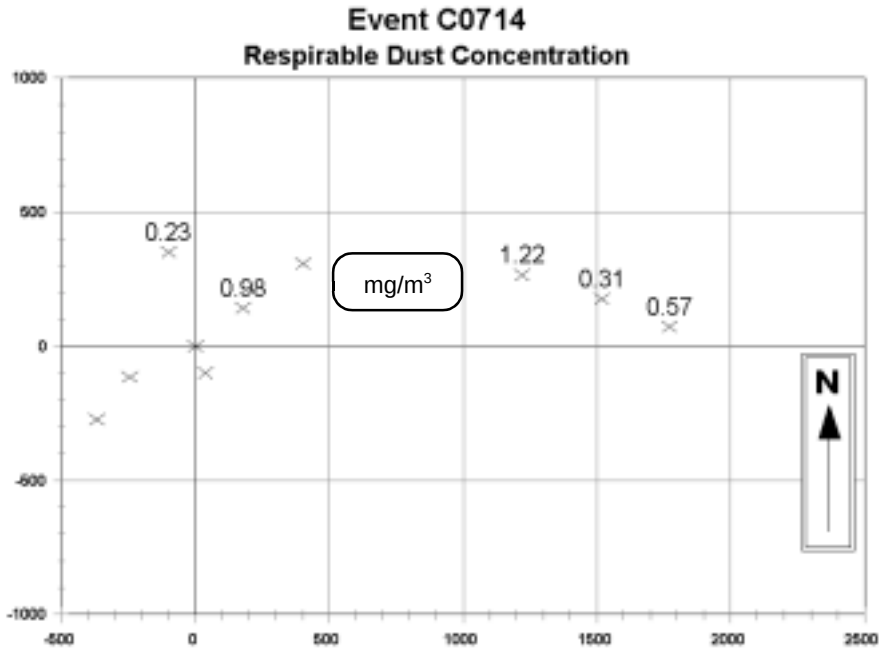
Event C0714 - 13

Event C0714 - 14



Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

4.2.10 Event C0726

Weather

Observations: °F, cloudy
Wind:

Blasting Data

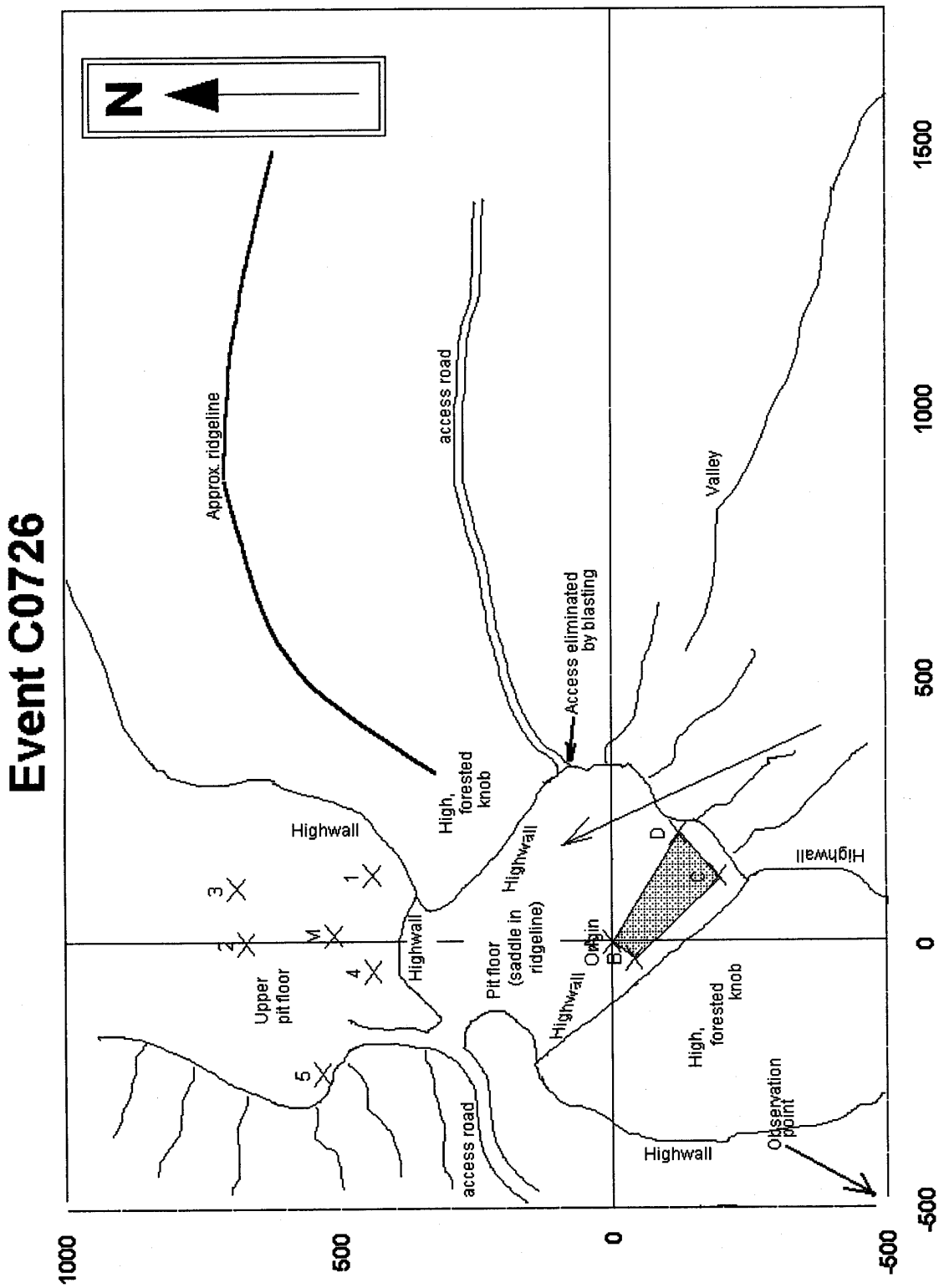
Time of ignition:	1627 hrs
Strata blasted:	Shale
Hole Diameter:	7.825”
Hole Depth:	57’
Number of holes:	72
Stemming used:	10’ drill cuttings
Explosive types used:	ANFO, Austin 3/4-lb primers, nonel
Weight of explosive used:	60,900 lbs
Weight of explosive used per hole:	846 lbs
Cubic Yardage Moved:	49,248 yd^3
Powder Factor:	1.24

Event Summary Data for Satellite Stations

Total Dust Maximum:	0.29 mg
Respirable Dust Maximum:	0.10 mg
NO_2 high:	0.8 ppm
Duration of maximum NO_2 exposure:	2 min
Duration of maximum dust exposure:	0

Main Station Data

NO High:	15.6 ppm
CO High:	54 ppm
NH_3 High:	N/A
Dust:	N/A



Axis distances are feet from the point of the blast nearest the main measurement station (0,0)

Event C0726 - 1

Event C0726 - 2

Event C0726 - 3

Event C0726 - 4

Event C0726 - 5

Event C0726 - 6

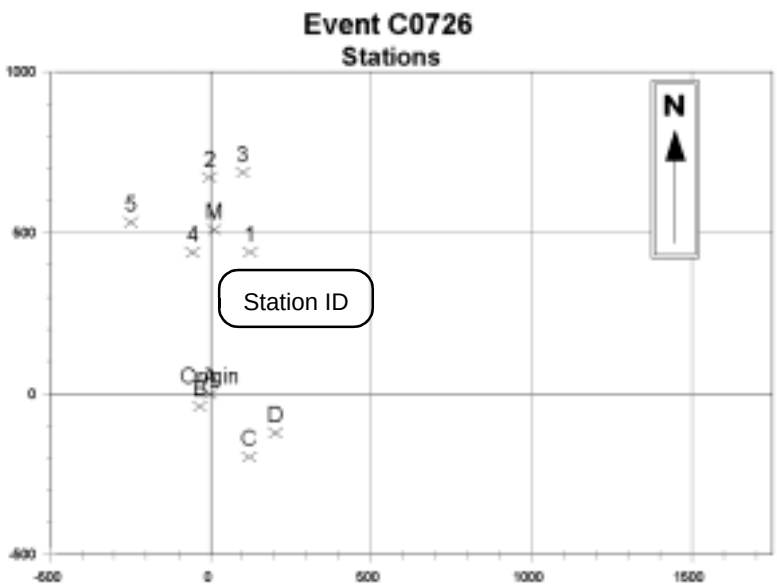
Event C0726 - 7

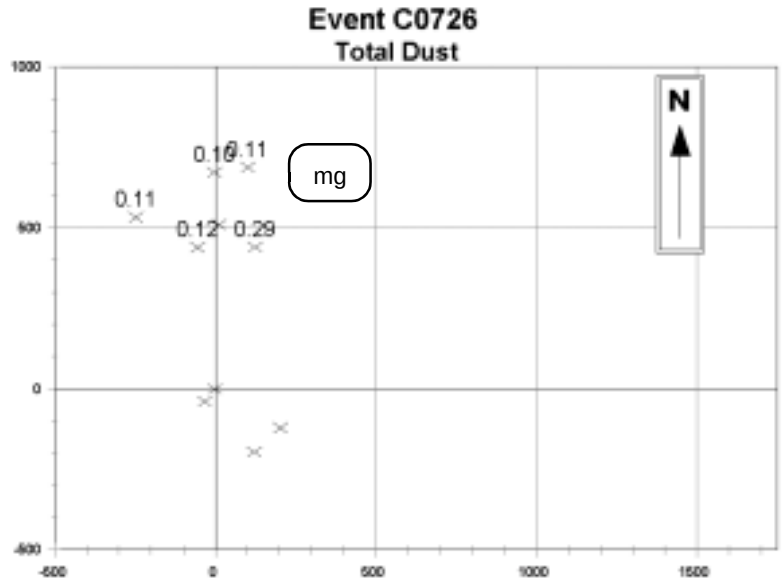
Event C0726 - 8

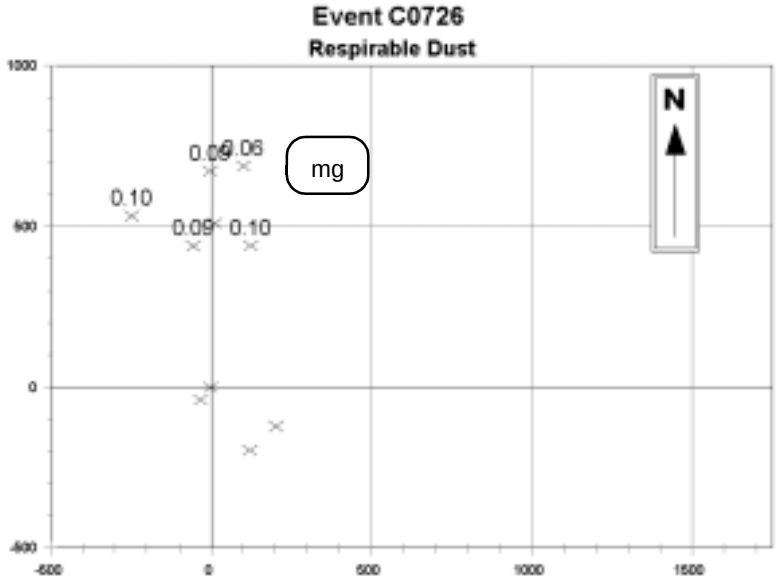
Event C0726 - 9

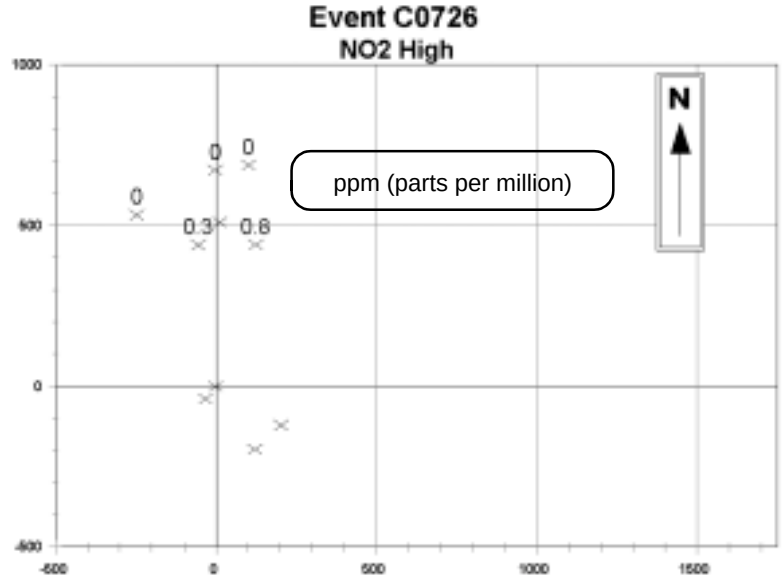
Event C0726 - 10

Event C0726 - 11

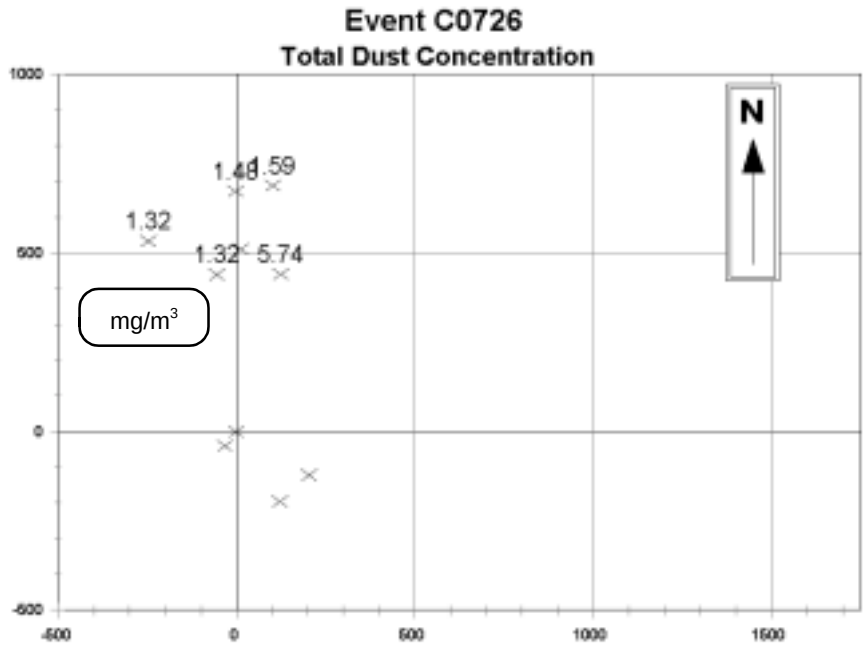


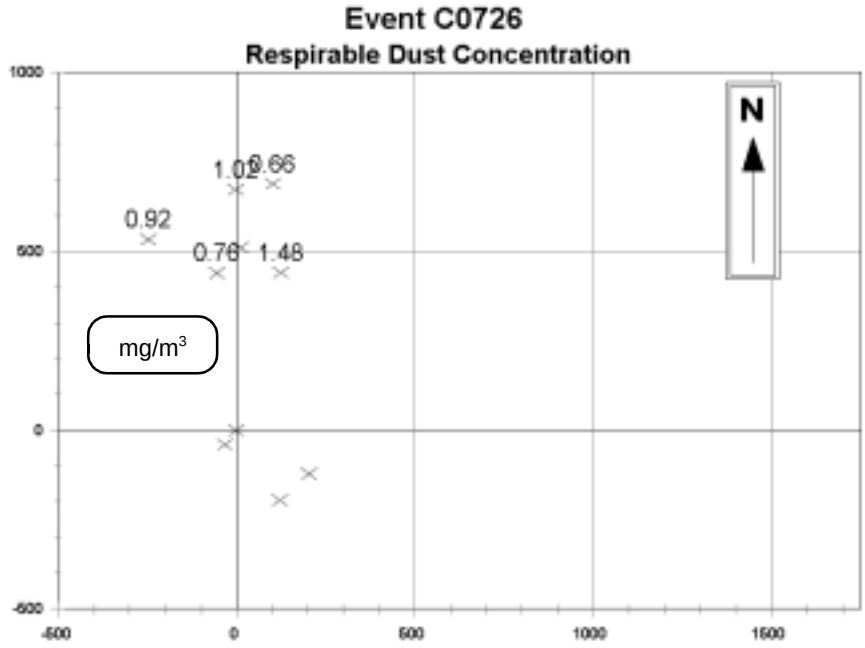






Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)





Note: All axis are feet distance from point of blast nearest to main measurement station (0,0)

5.0 DISCUSSION

The results may viewed in various fashions, and here we have tried to present the information in as broad a manner as possible. A visual representation of shot-and-measurement layouts helps provide a feel for what was actually occurring in the field. Statistical analyses of the chosen parameters versus distance provide a view of what happens as the plume travels as well as helping to quantify the observations in a logical fashion. Similar statistical analyses of the chosen parameters versus individual blasting events provides yet another way of observing the same data, but versus differences in the events themselves rather than by distance. In our investigation we have a data pool of ten events with 1, 5, or 6 values available for each of several variables of interest. These are:

Measured Variable	Where measured	Number of data points available per event
Total Dust	Satellite stations, main station	6
Respirable Dust	Satellite stations	5
Nitrogen Dioxide	Satellite Stations, main Station	6
Nitrous Oxide	Main Station	1
Carbon Monoxide	Main Station	1
Ammonia	Main Station	1

Table 5.1. Accounting of data collection points

Thus for distance variables (dust, fume concentration, etc.) we have 50 or 60 data points to assess; for blasting variables (powder factor, weather, etc.) there are 10 data points. Of course, this is with all instruments running properly. In the course of the investigation there were times when some instruments failed to perform as expected. The largest single disappointment was the failure to obtain good NO_2 data at the main station. We never were able to properly balance the MultiLog unit with the NO_2 sensors. Two items need discussion here before viewing the measurement data: wind velocity and sample weighing results.

Wind velocity[1] proved to be very difficult to determine with any precision, or even with much confidence in the general direction. We originally expected difficulty with this determination, but field experience demonstrated it to be most troublesome. On one blasting location, *on the drilled, explosive-loaded portion only*, it was possible to measure wind directions over a +200° spread depending upon where the investigator stood. It was possible to stand in one spot and measure a 90° variation over a 10-minute period. Similar variations in speed were also measurable. Then, at the measuring stations, it was frequently possible to determine different values for each. The assumption is, of course, that this was all due to terrain. Still, the investigators could frequently judge a general direction to expect a cloud to travel in. In every case we attempted to locate the main station so that it would intercept the main body of the cloud from the blast. On occasions we missed (which always resulted in a total miss by all stations), but frequently we managed to come very close. In the end, we used the orientation of the main station from the blast site as the best indicator of primary wind direction, and then made adjustments if needed based on our observation of cloud travel direction.

Dust sampling cassette weights were determined by standard procedure, but to 0.01 milligram rather than 0.001 milligram. The equipment we had available was purchased in line with the original dust measurement standards and for this kind of initial investigation was quite adequate. We had some wider-than-expected variation in the control cassettes that we used (we weighed and assembled our own). Even with dessication, the control filters occasionally had more pre- and post-measurement variation than the active sample filters. These variations were small enough to be negligible, but where monitors recorded close to zero dust this infrequently resulted in a slight negative dust reading. We reported these and all dust weights as calculated.

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[1]Remember, for calculation and analysis, velocity is a vector consisting of both magnitude and direction. Thus use of the term velocity implies consideration of both wind direction and wind speed.

5.1 Viewing the Data by Relative Location

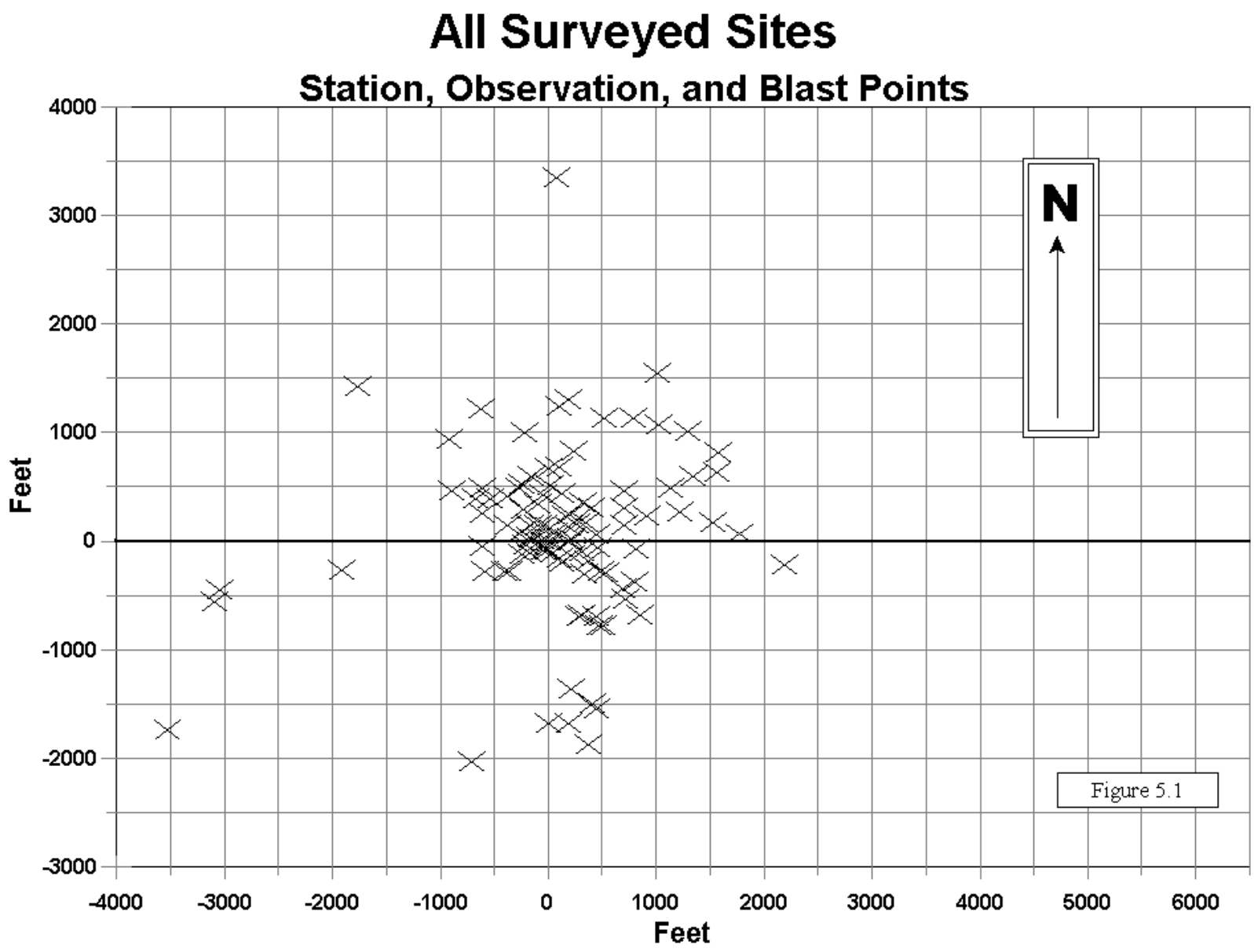
The positions of the monitoring stations, the observation points, and the corners of the shot being fired were all determined by use of a hand-held global positioning (GPS) unit. These points were then used to map all of the locations, with the point of the shot closest to the main monitoring station serving as the origin for the plot maps, or "ground zero."

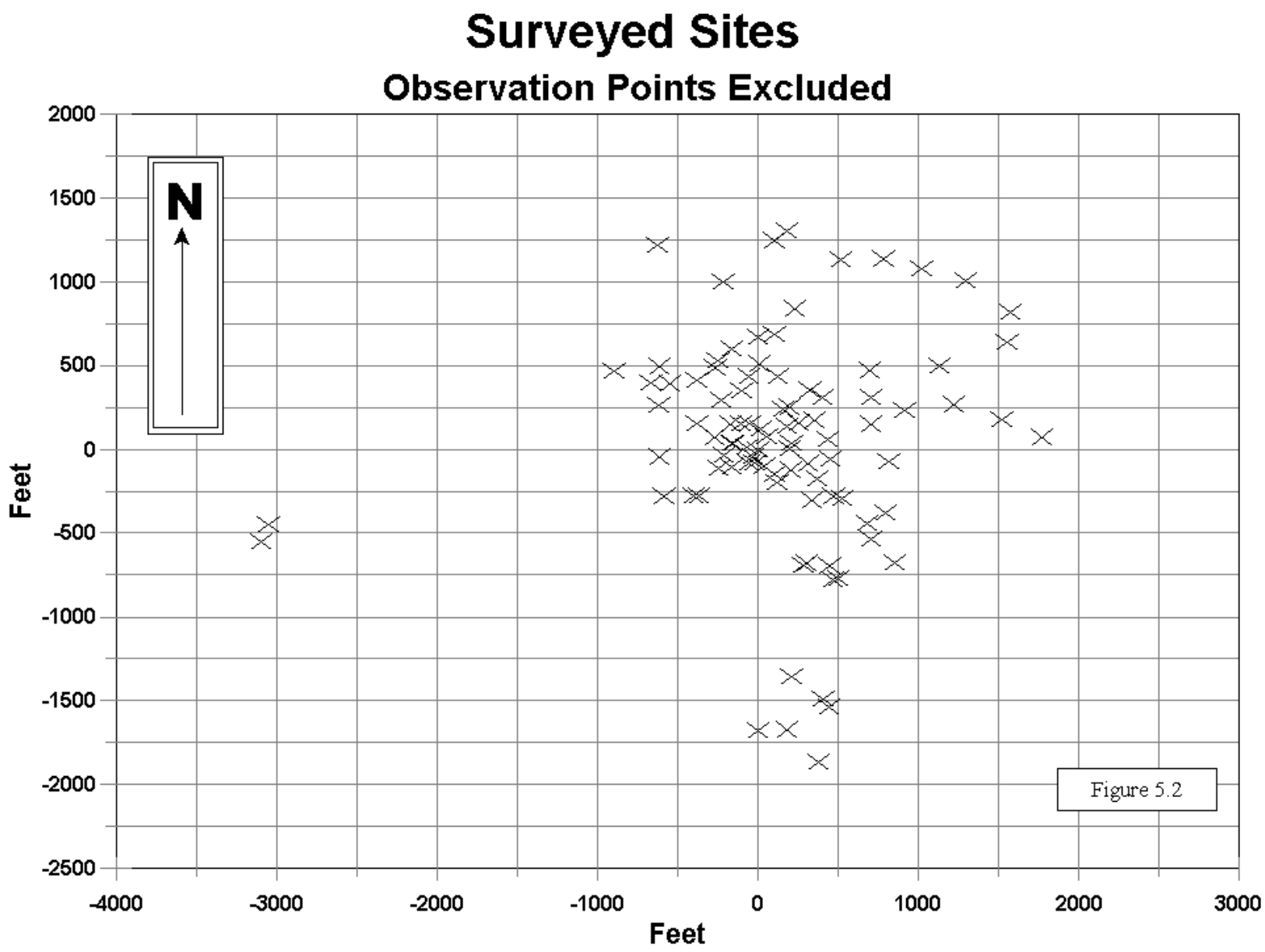
5.1.1 Relative Locations Mapped by True North

Figure 5.1 is a map of all surveyed points. Because the observation points tended to be at greater distances from the blasts and in directions that were not chosen for monitoring considerations but for viewer safety, another map was generated that eliminated the observation points (Figure 5.2), leaving the shot area corners and the station locations. Even this is a bit confusing because of some shot layouts. (The two points at approximately -3100, -500 are the corners of a dragline cast shot). So we also generated a map of monitoring locations only (Figure 5.3). This map also has labeled which monitoring units were located on which sites. A number of things may be noticed in this figure.

These stations were all set as closely as possible to the expected down-wind directions for the blasting events. The map clearly shows that the most expectable wind direction was from the south-east, and the least expectable from the south-west. There were both north winds and south winds, the former being somewhat surprising and possibly a phenomena due to ridge-and-valley configuration. The maximum station distance from the blast was 1903 feet, and the minimum 228 feet, with an average station distance of 943 feet. While these distances were closer than originally desired, it was a fortuitous occurrence due to the rapid fall-off in dust and fume concentrations versus distance. Because of public complaints we had originally expected to see substantial values at 2,000 feet and beyond.

Figures 5.4, 5.5, 5.6, and 5.7 show the measured values for total dust, respirable dust, nitrogen dioxide, and nitrogen dioxide adjusted for zero values, respectively. These maps also have 500-foot and 1000-foot radii drawn on them as a visual aid. With the exception of a couple of outliers, the decline in values is quite noticeable.


All Surveyed Sites
Station, Observation, and Blast Points
N
Figure 5.1
Feet
Feet
4000
3000
2000
1000
0
-1000
-2000
-3000
-4000
-3000
-2000
-1000
0
1000
2000
3000
4000
5000
6000


Surveyed Sites
Observation Points Excluded
N
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
Feet
-4000
-3000
-2000
-1000
0
1000
2000
3000
Feet
Figure 5.2

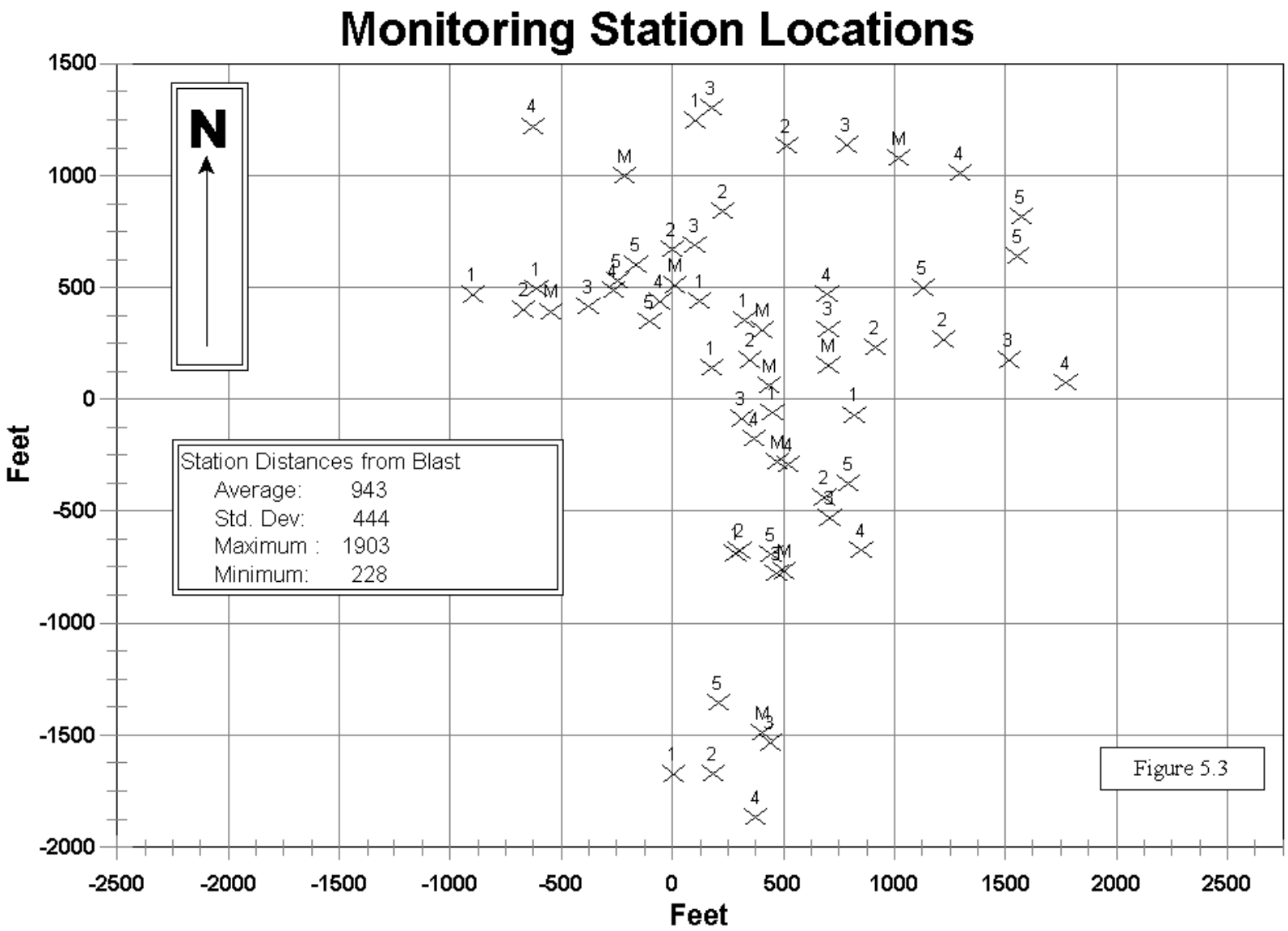
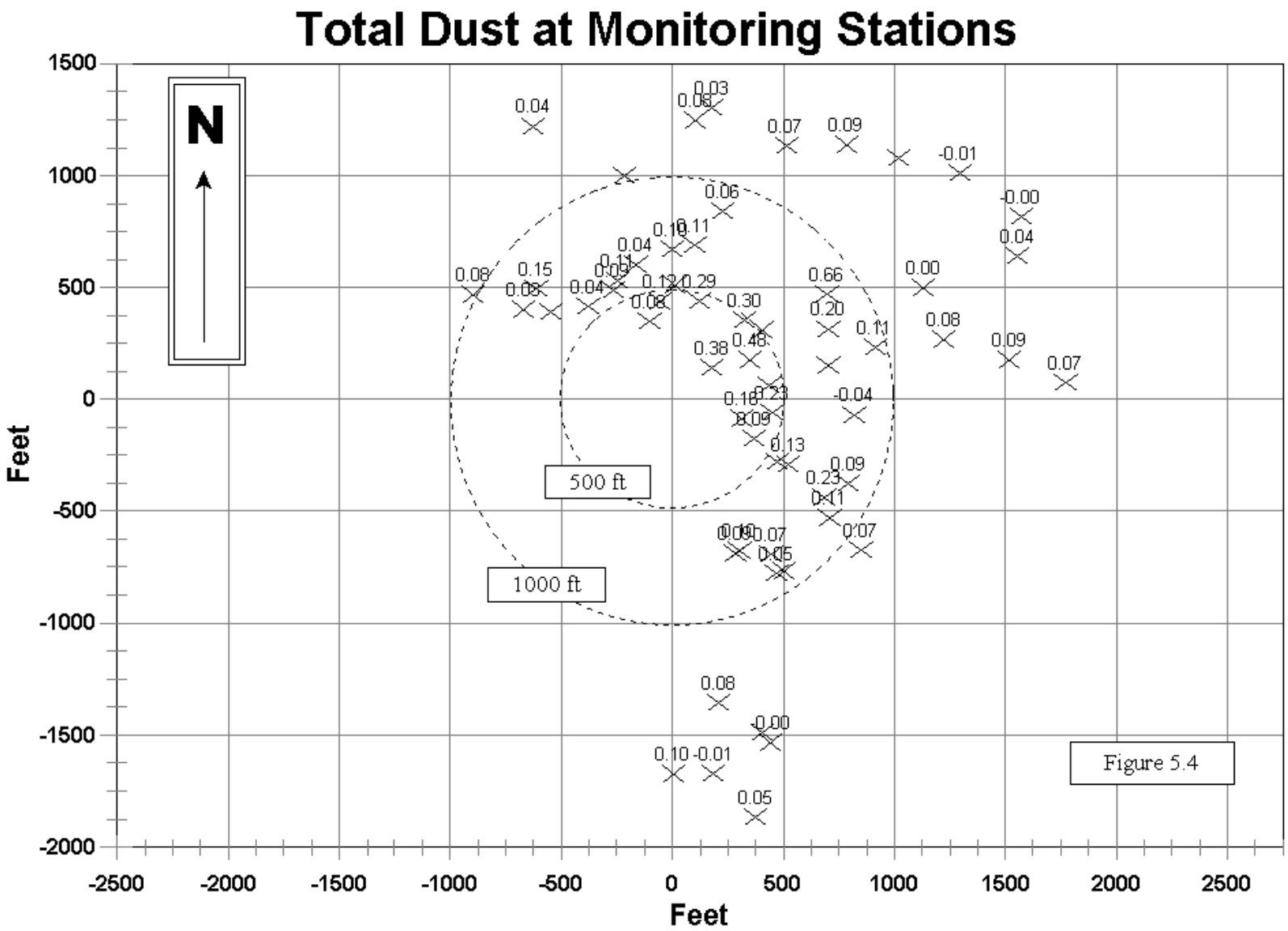
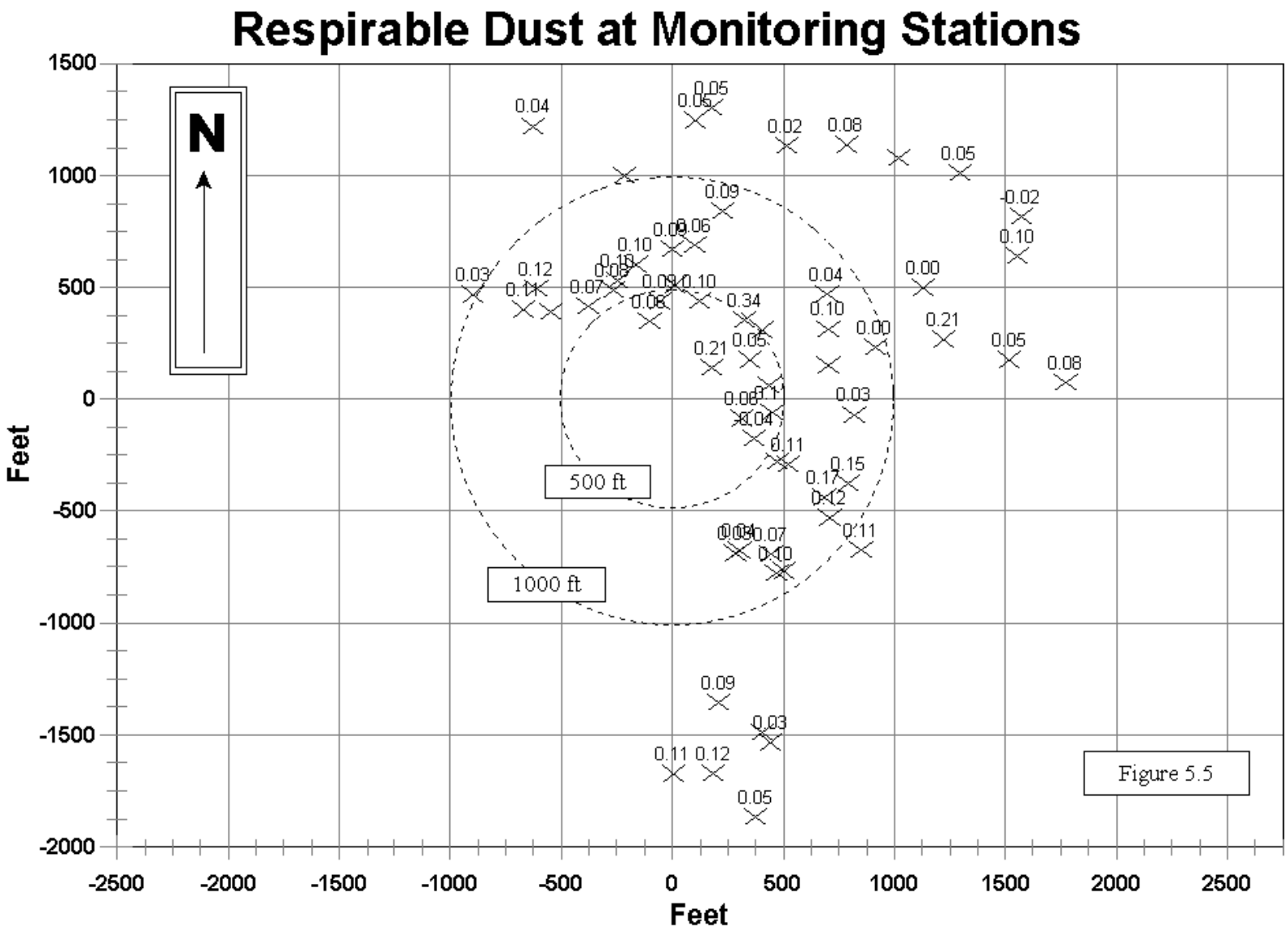
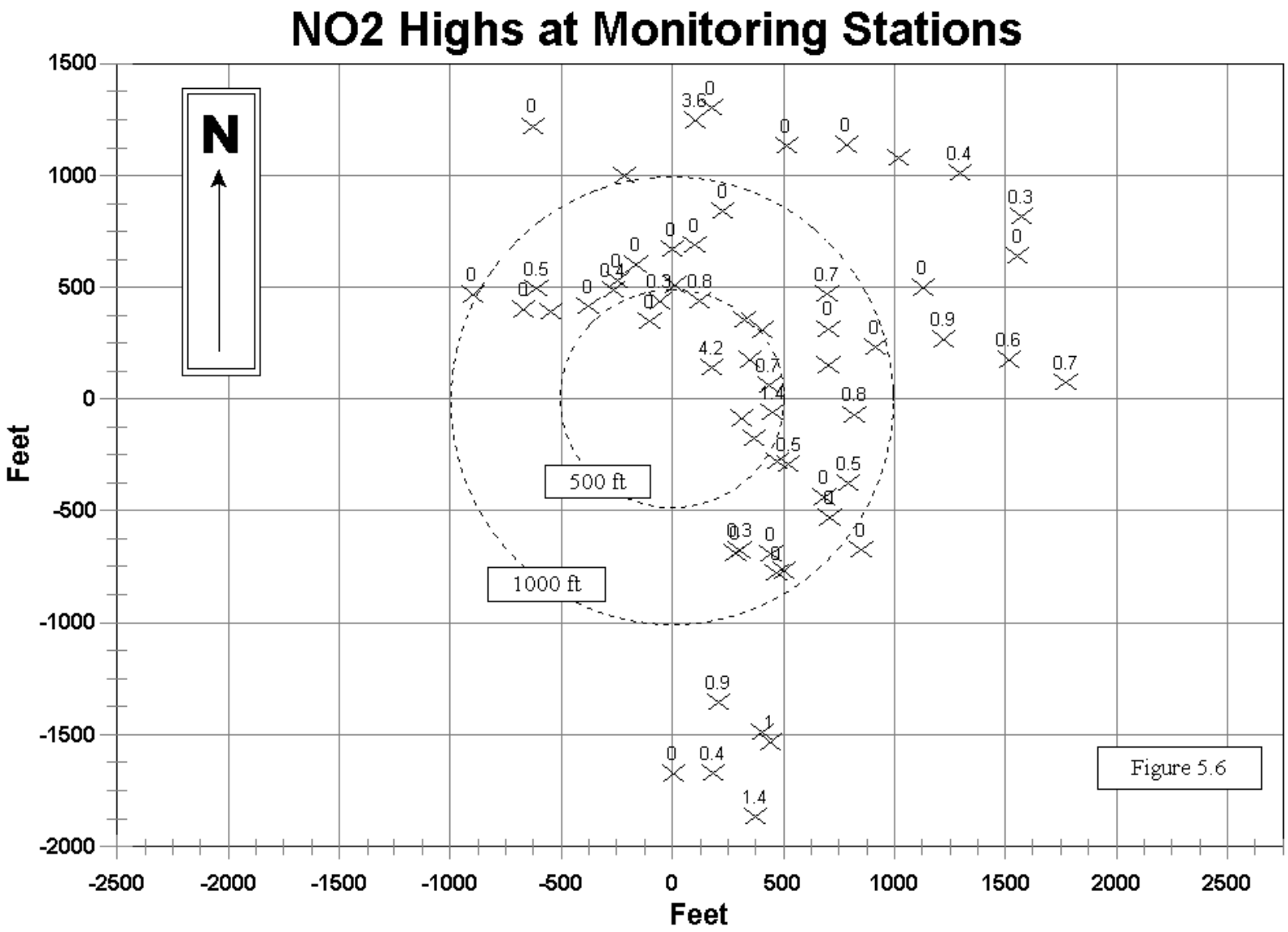
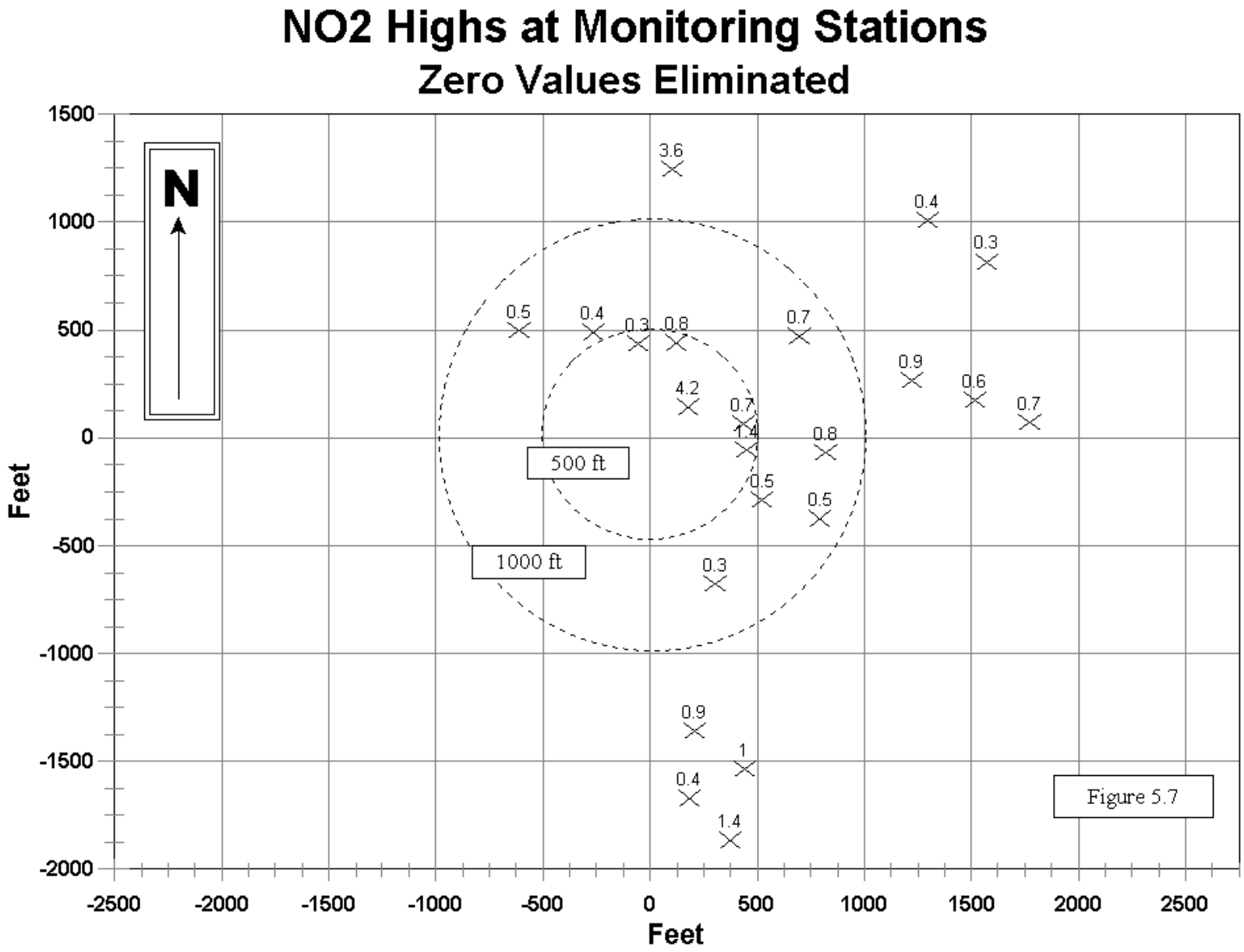

Monitoring Station Locations
N
Station Distances from Blast
Average: 943
Std. Dev: 444
Maximum : 1903
Minimum: 228
Feet
Feet
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

Figure 5.3


Total Dust at Monitoring Stations
N
500 ft
1000 ft
Figure 5.4
Feet
Feet
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500


Respirable Dust at Monitoring Stations
N
500 ft
1000 ft
Figure 5.5
Feet
Feet
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

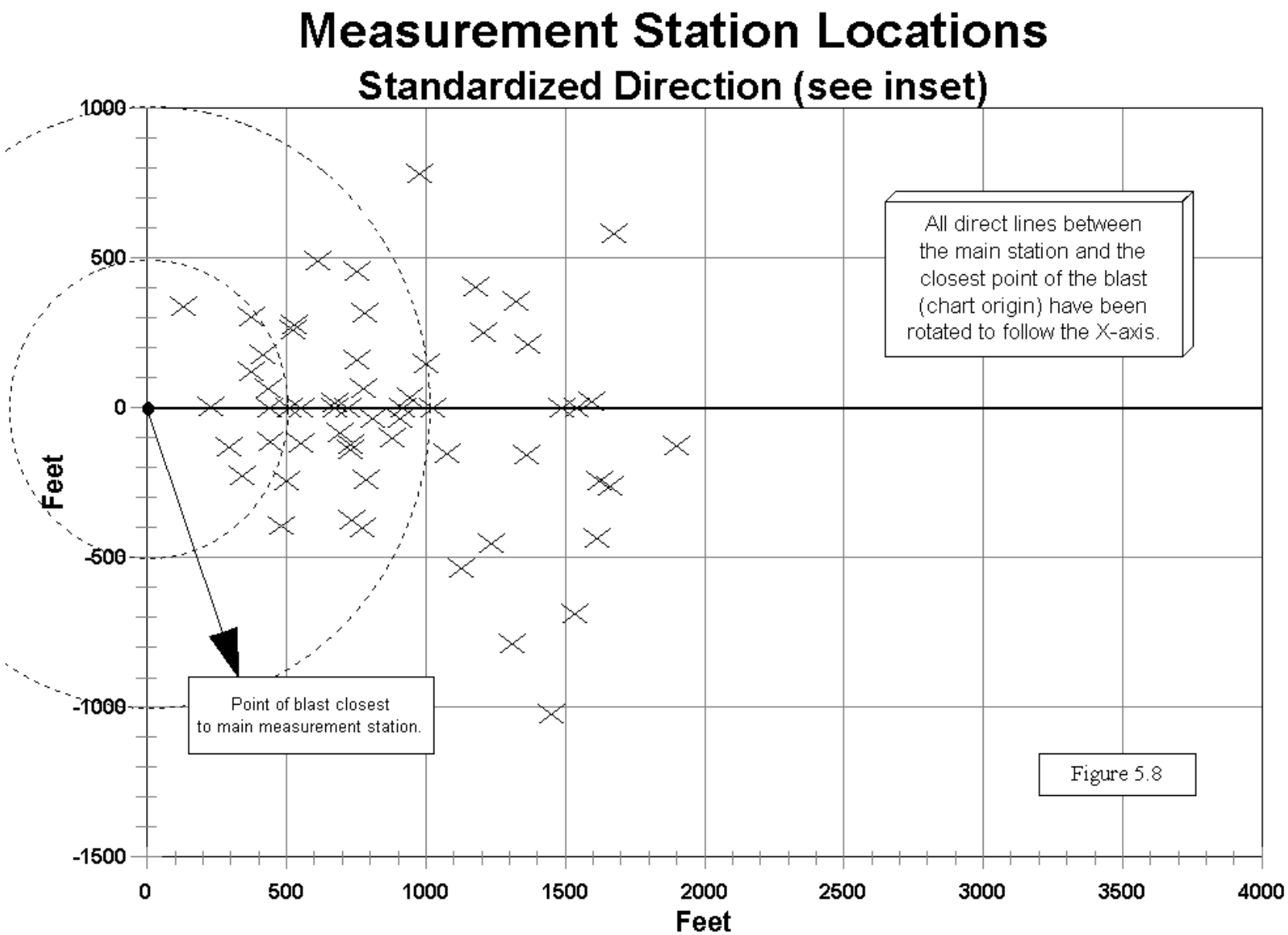

NO2 Highs at Monitoring Stations
N
500 ft
1000 ft
Figure 5.6
Feet
Feet
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500


NO2 Highs at Monitoring Stations
Zero Values Eliminated
N
500 ft
1000 ft
3.6
0.4
0.3
0.5
0.4
0.3
0.8
0.7
0.9
0.6
0.7
4.2
0.7
1.4
0.8
0.5
0.5
0.3
0.9
1
0.4
1.4
Figure 5.7
Feet
Feet
1500
1000
500
0
-500
-1000
-1500
-2000
-2500
-2000
-1500
-1000
-500
0
500
1000
1500
2000
2500

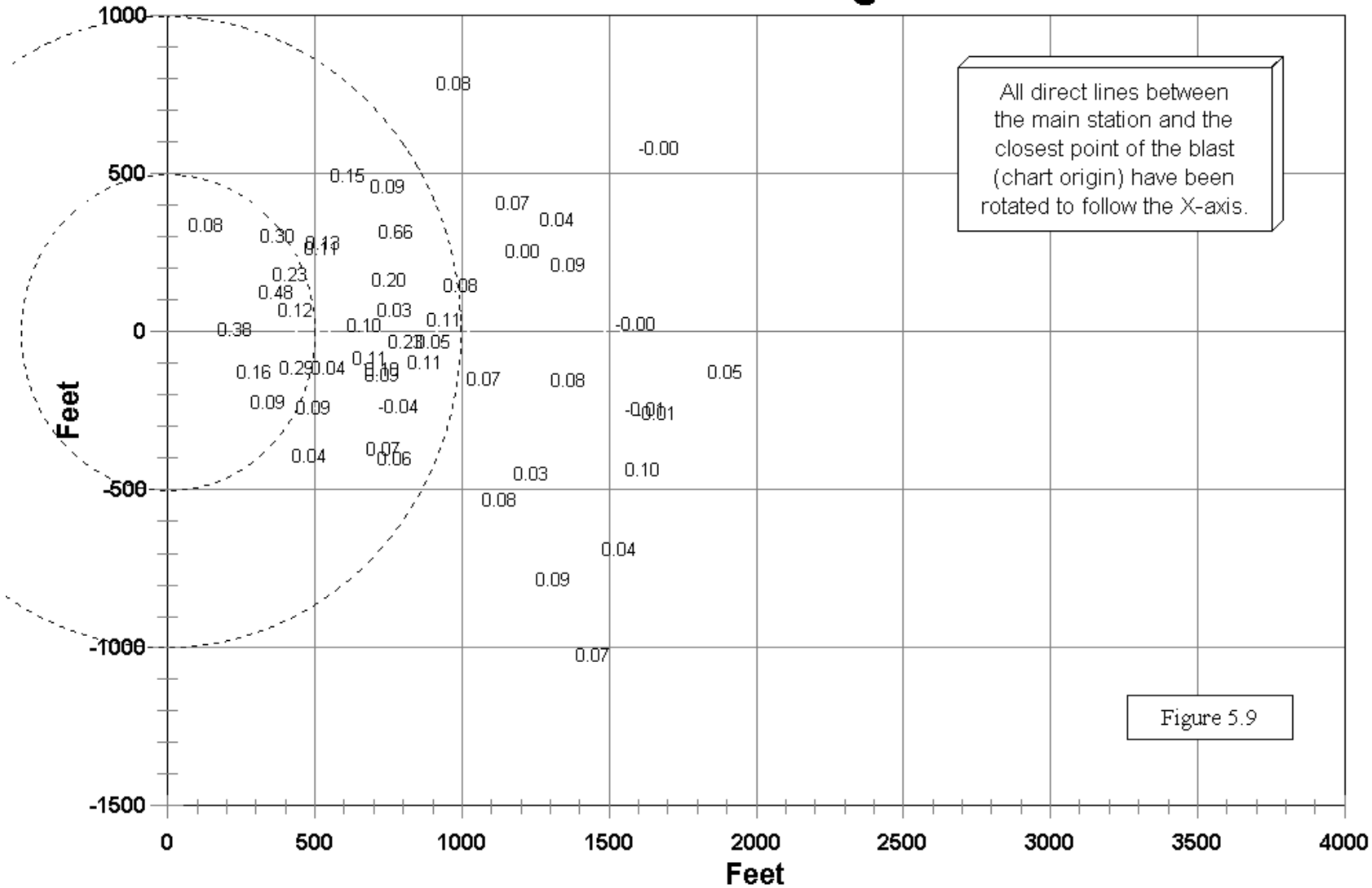
The extra graph for NO_2 values was to see what the data looked like if the very high number of stations that read no NO_2 emissions were eliminated. (A similar approach was used for all variables in section 5.3.) It is not easy to tell which stations were in the cloud but registered no NO_2, and which registered zero because they were bypassed by the cloud. The "correct" zeros — those that were in the cloud — may be inferred by comparing dust measurements at the same station locations, but this would be inexact at best. Looking at both graphs is a visual aid. We also treated each grouping, with and without zeros, statistically. Correlations generally improved.

5.1.2 Relative Locations Mapped by General Wind Direction

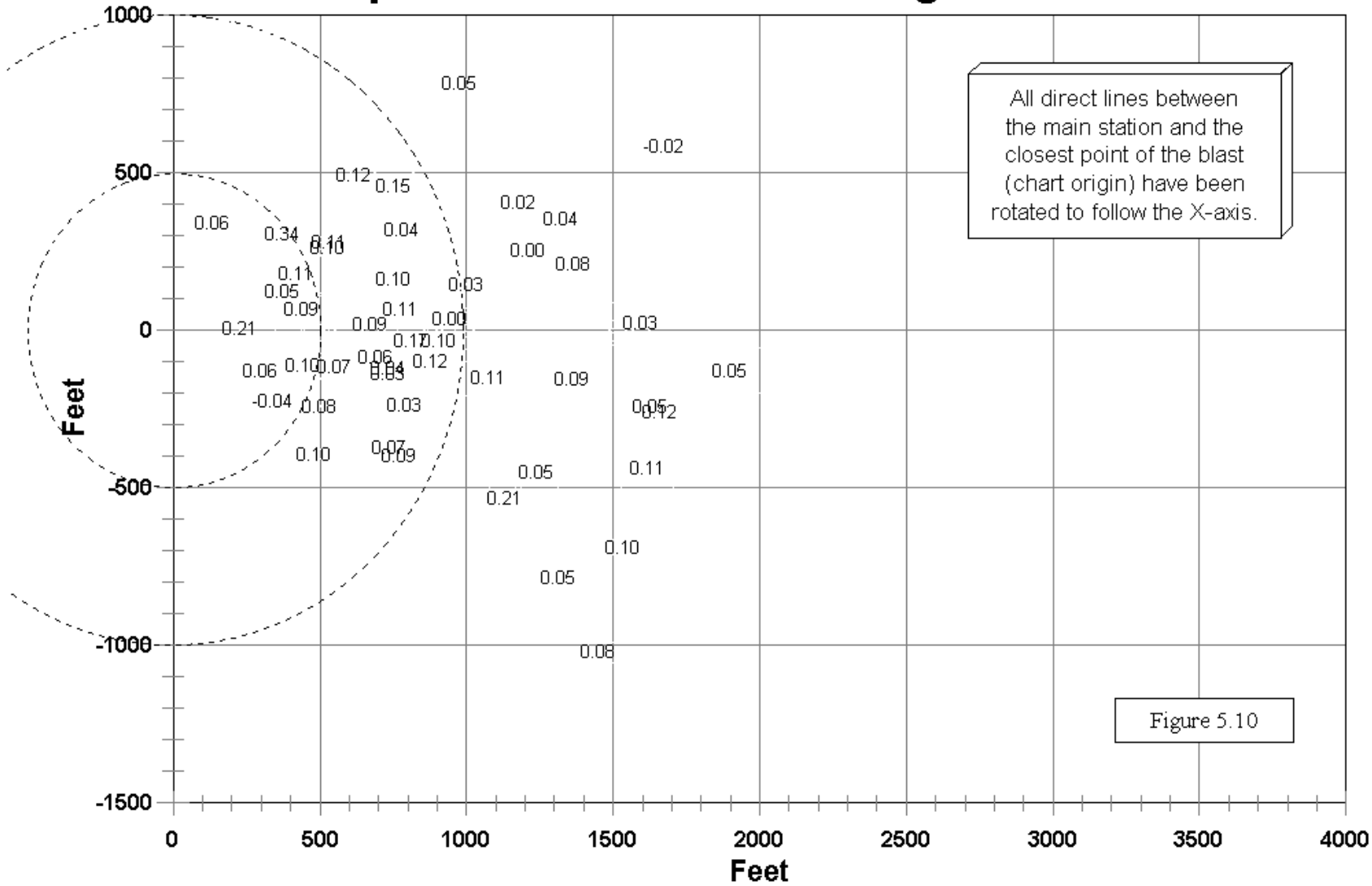
The best way to compare data from different events is to place them on a uniform basis for comparison. Since we always strived to place the main station directly downwind of the blast, the line connecting the closest point of the blast with the main station should provide a basis of comparing blasts in the same direction of cloud travel. So as another visual aid, we rotated all of the maps so that line connecting these points would fall on the x-axis, and the main station location would have a y-value of zero. The result of these rotations is shown in Figure 5.8. All of the monitoring stations fall within an approximate 90° arc drawn from the closest point of the blast and centered on the x-axis. Figures 5.9, 5.10, 5.11, and 5.12 reproduce the total dust, respirable dust, nitrogen dioxide, and nitrogen dioxide adjusted for zero values given earlier, but now on a uniform direction basis.


Measurement Station Locations
Standardized Direction (see inset)
All direct lines between the main station and the closest point of the blast (chart origin) have been rotated to follow the X-axis.
Point of blast closest to main measurement station.
Figure 5.8
Feet
Feet
1000
500
0
-500
-1000
-1500
0
500
1000
1500
2000
2500
3000
3500
4000

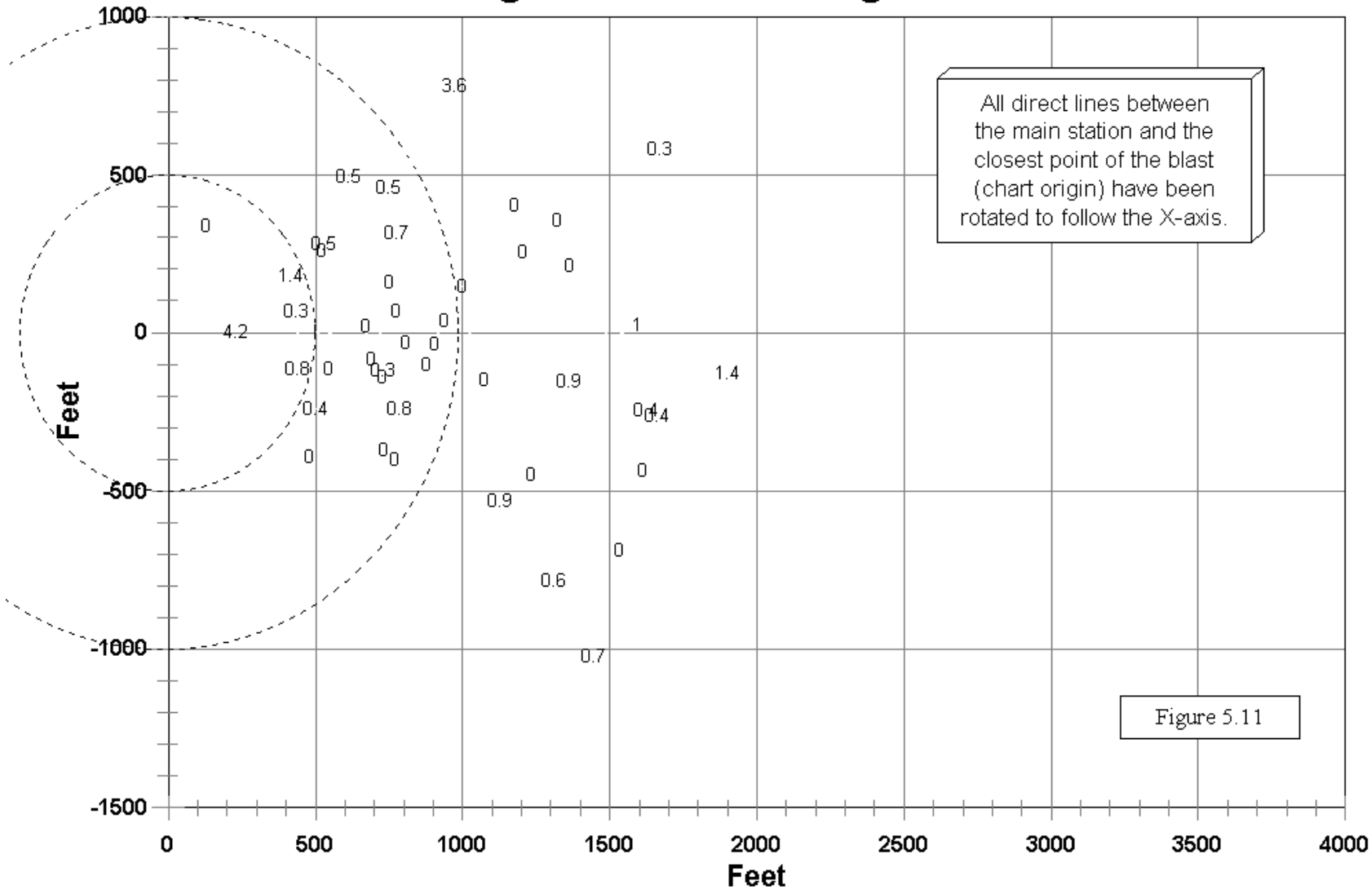
Total Dust at Monitoring Stations



Respirable Dust at Monitoring Stations



NO2 Highs at Monitoring Stations



NO2 Highs at Monitoring Stations

Zero Values Disregarded

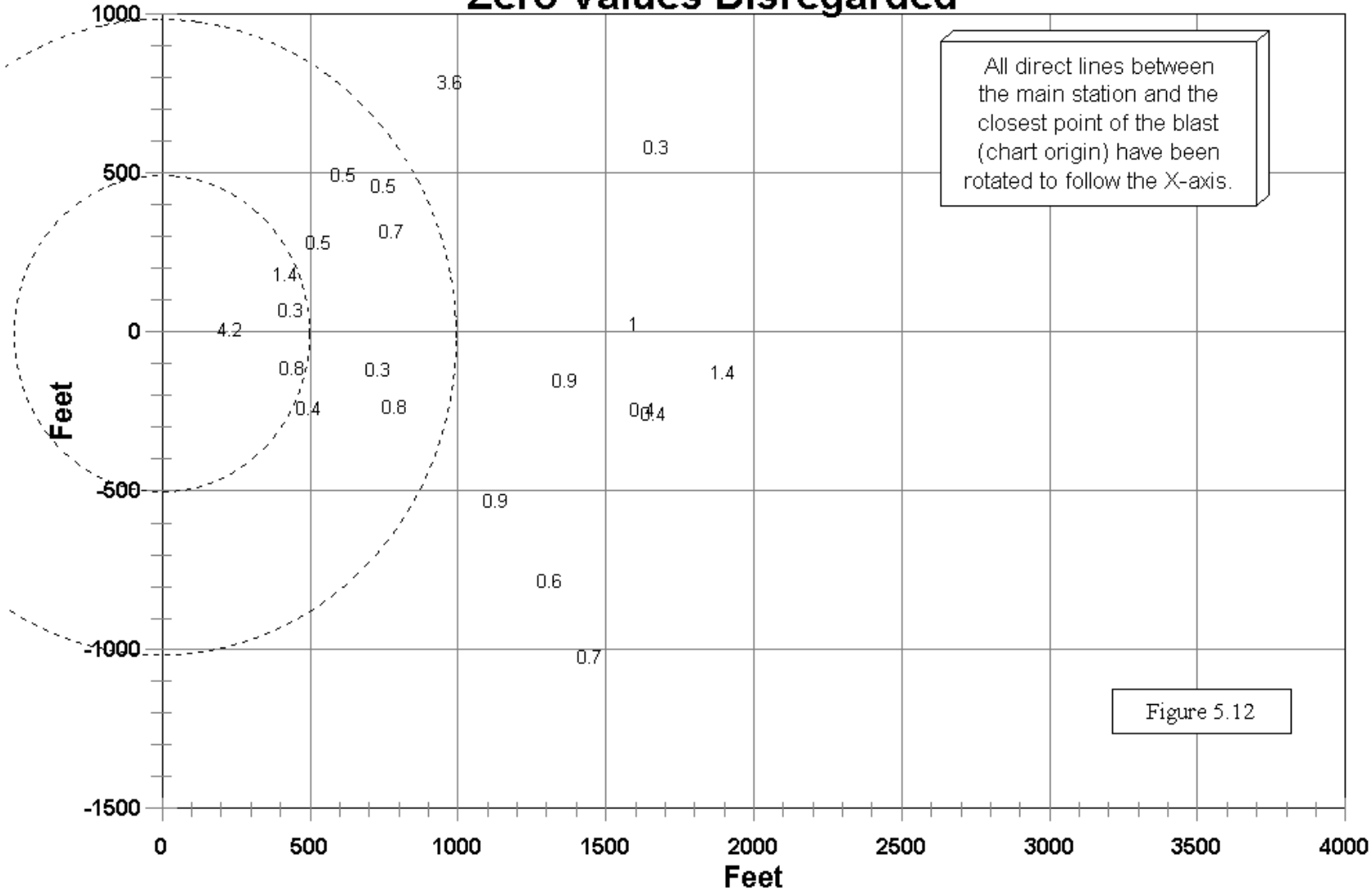


Figure 5.12

5.2 Assessing the Data by Distance

Although the results from statistical analyses it is still of value to look at the data in this fashion. The trends all follow the expected patterns, that is decreasing with distance from the blast location. Total dust decreases more rapidly than respirable dust, as one would expect based on Stoke's Law. The same is true of NO_2 concentrations. But there are enough exceptions and variations that individual correlation coefficients are not good. There are a lot of variables in operation in the dispersion/dilution process of the blast cloud that are not easily measurable, nor statistically isolatable without a substantially larger pool of information and data. We have just 5 individual data for each contaminant at each of ten individual blasting events, a very limited data pool. The primary parameters that most logically could improve the correlations are 1) a reliable way to include and account for wind velocity, and 2) develop a method to account for not only the distance from the blast site but the lateral off-set from the line of wind direction. We have not found a way to obtain data good enough for the first, and we do not have enough data for the second. When one considers that wind velocity is probably the largest single controlling variable, the correlations with the data we do have become interesting, indeed.

The over-all evidence is clear. Substantial quantities of dust and fumes just do not travel very far from the blasting sites. If we had been able to place the majority of our instrumentation at 1,500 to 2,000 feet away or more as was our original intent, we may not have been able to obtain many measurable results at all. Viewed in this light, the limited station placement options presented to us by the terrain was a fortuitous situation that provided more data than we otherwise would have acquired.

Figure 5.13 is a very busy graph showing all of the data obtained at the monitoring stations. With the exception of a couple of outliers, the trend of lesser values as distance increases is clearly visible. (One point for total dust, 0.66 mg at 750 feet, is off of the chart.) All of these values are examined individually in subsequent figures.

Two fits were found for each set of data, a linear best-fit, and then the best fit model was selected from several different options. These included the following:

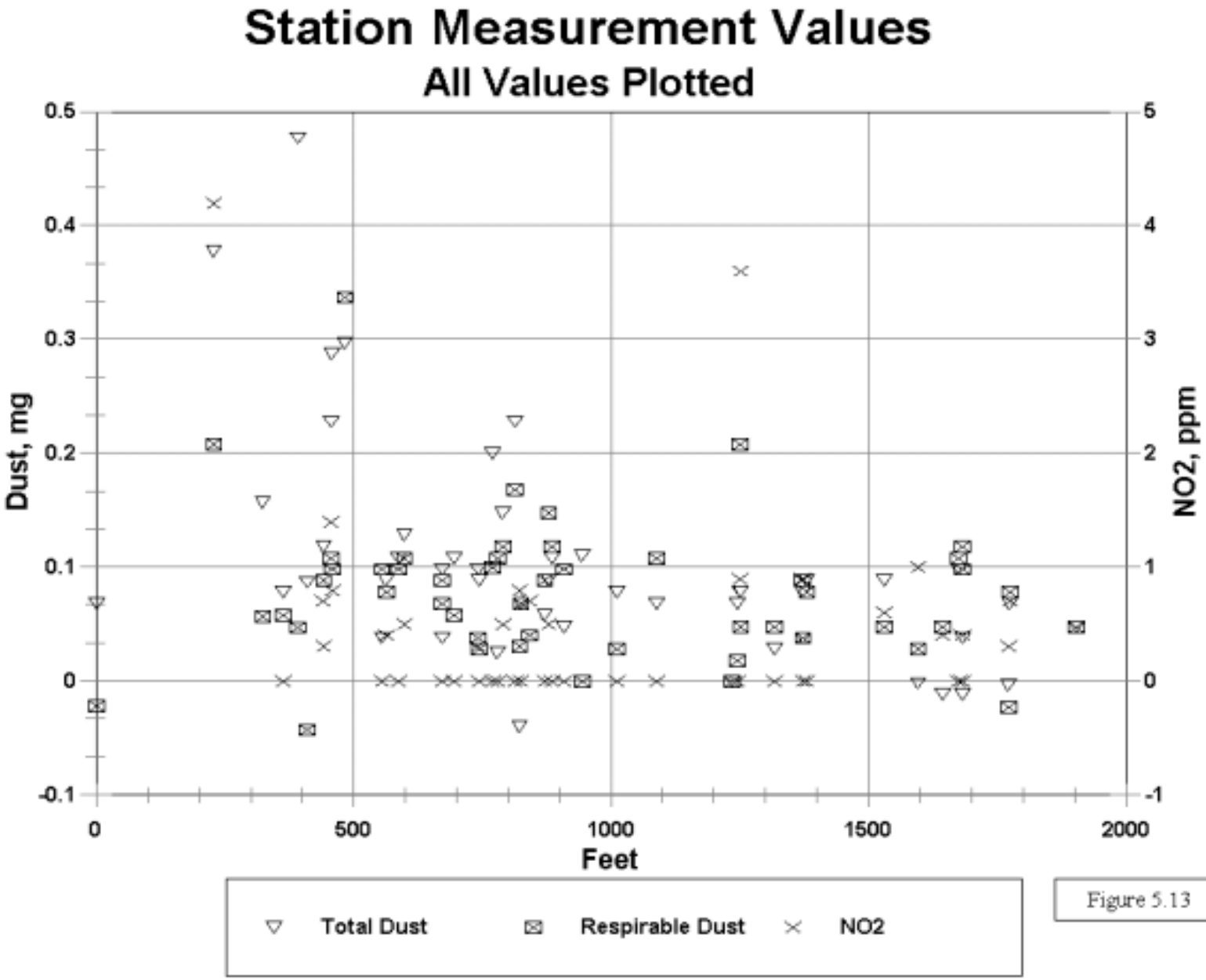

Station Measurement Values
All Values Plotted
Dust, mg
NO2, ppm
Feet
0.5
0.4
0.3
0.2
0.1
0
-0.1
5
4
3
2
1
0
-1
0
500
1000
1500
2000
Total Dust
Respirable Dust
NO2

Figure 5.13

1. Linear: $y = a + bx$

2. Quadratic: $y = a + bx + cx^2$

3. Power Law: $y = a + x^b$

4. Geometric Series: $y = ax^{bx}$

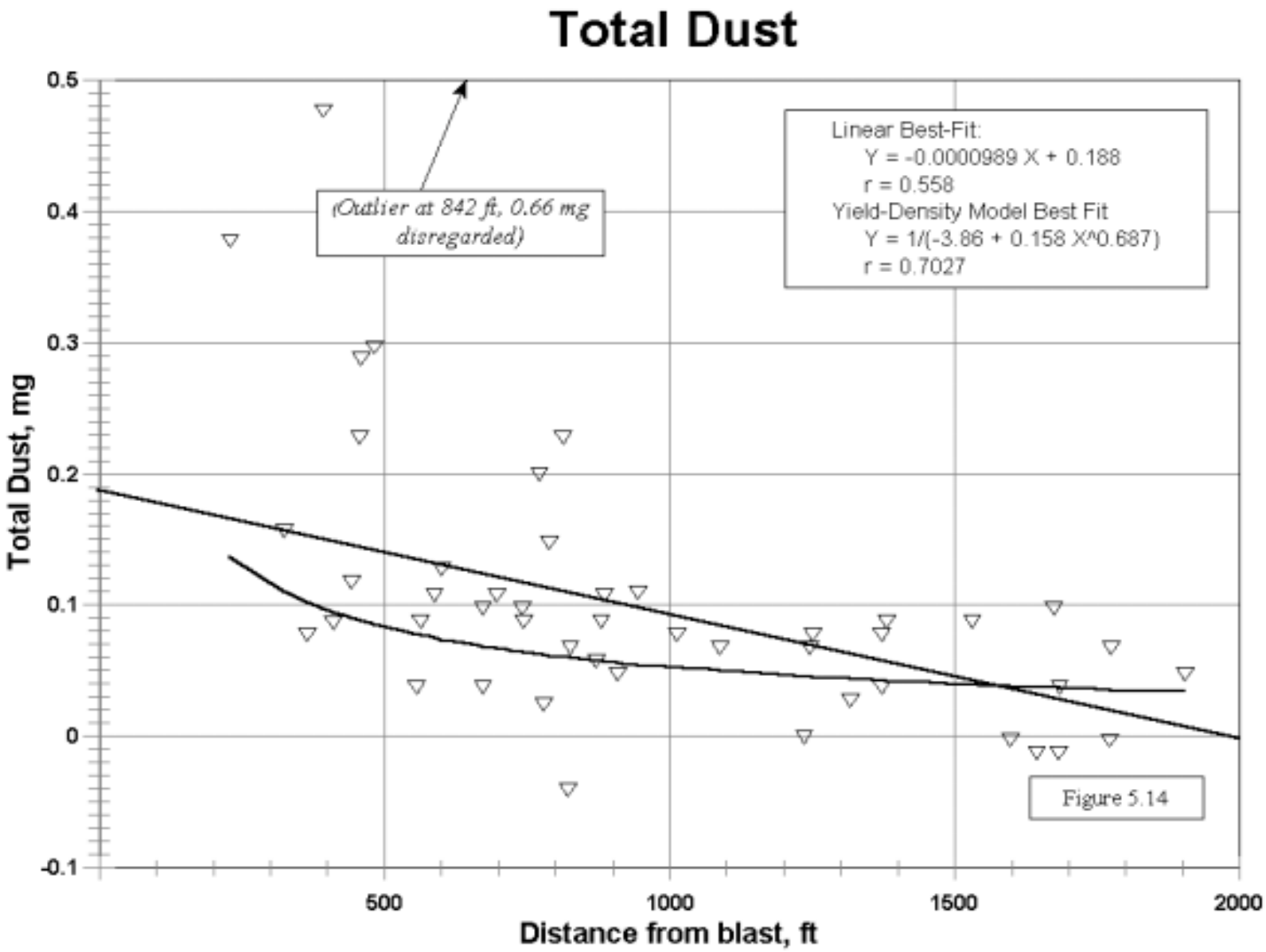
5. Logarithmic: $y = a + b\ln(x)$

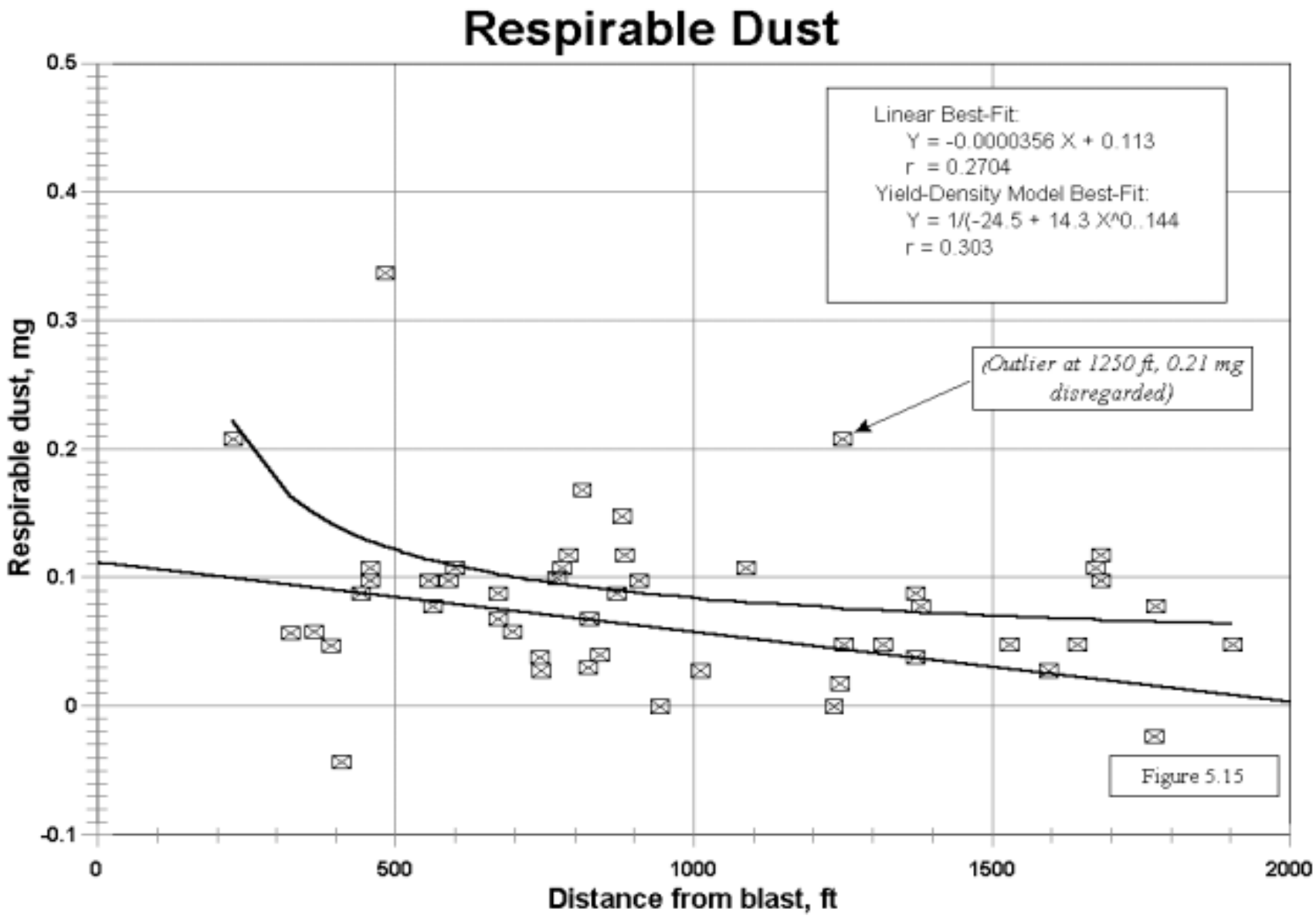
6. Yield-Density Model (Harris): $y = \frac{a}{a + bx + c}$

7. Saturation Growth Rate Model: $y = \frac{ax}{b + x}$

After examining all four data sets with all 6 models, it was found that the Harris Yield-Density model fit best, if not superbly (note the fit on respirable dust). Figures 5.14 through 5.17 show the data, the linear fit, and the Harris Yield-Density model fit for total dust, respirable dust, nitrogen dioxide, and nitrogen dioxide adjusted for zero values, respectively.

A word of caution about comparing blasting events: Each blasting event is truly unique. No two blasts have the same quantity of explosives, the same number of holes, the same depth of drilling, the same drilling diameter, and, most importantly, the same geology. All of these would have to be equivalent for the shots to be equivalent. Even at one mine where the same drill is used, on a long contour repeating the same pattern, depth, and charging procedures, there is still the ever-changing stratigraphy. The spacing may be close, but not precisely the same. The holes will have slight deviations. And more. Then for measurements at a distance, there is the changing weather, including wind, on top of everything. In other words, it is very difficult to combine information from different blasts and be sure that “apples and apples” are being compared.


Total Dust
Linear Best-Fit:
Y = -0.0000989 X + 0.188
r = 0.558
Yield-Density Model Best Fit
Y = 1/(-3.86 + 0.158 X^0.687)
r = 0.7027
(Outlier at 842 ft, 0.66 mg disregarded)
Figure 5.14
Total Dust, mg
Distance from blast, ft
0.5
0.4
0.3
0.2
0.1
0
-0.1
500
1000
1500
2000


Respirable Dust
Linear Best-Fit:
Y = -0.0000356 X + 0.113
r = 0.2704
Yield-Density Model Best-Fit:
Y = 1/(-24.5 + 14.3 X^0..144
r = 0.303
(Outlier at 1250 ft, 0.21 mg disregarded)
Figure 5.15
Respirable dust, mg
Distance from blast, ft
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
500
1000
1500
2000

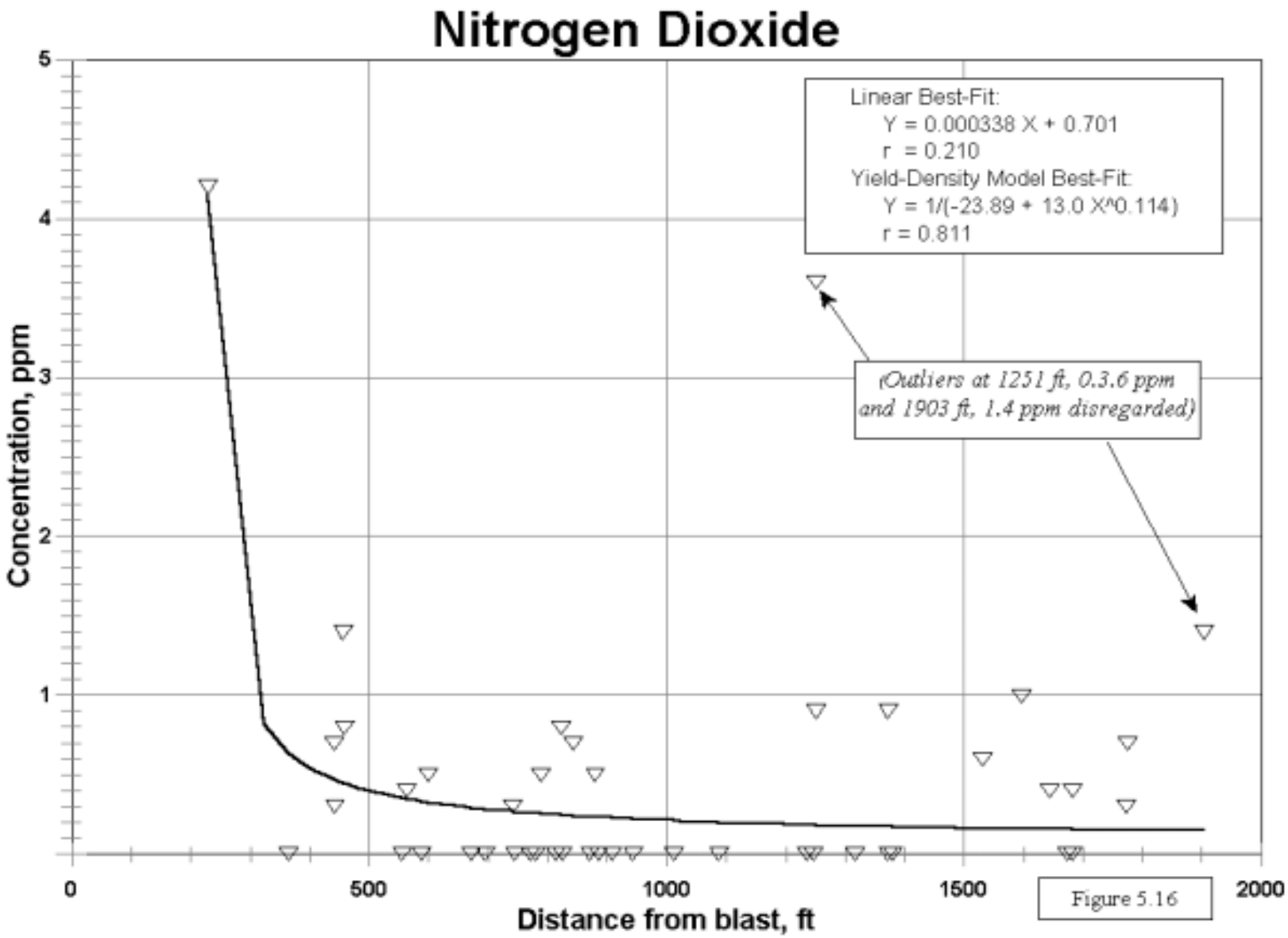

Nitrogen Dioxide
Linear Best-Fit:
Y = 0.000338 X + 0.701
r = 0.210
Yield-Density Model Best-Fit:
Y = 1/(-23.89 + 13.0 X^0.114)
r = 0.811
(Outliers at 1251 ft, 0.3.6 ppm and 1903 ft, 1.4 ppm disregarded)
Concentration, ppm
Distance from blast, ft
0
500
1000
1500
2000
1
2
3
4
5

Figure 5.16

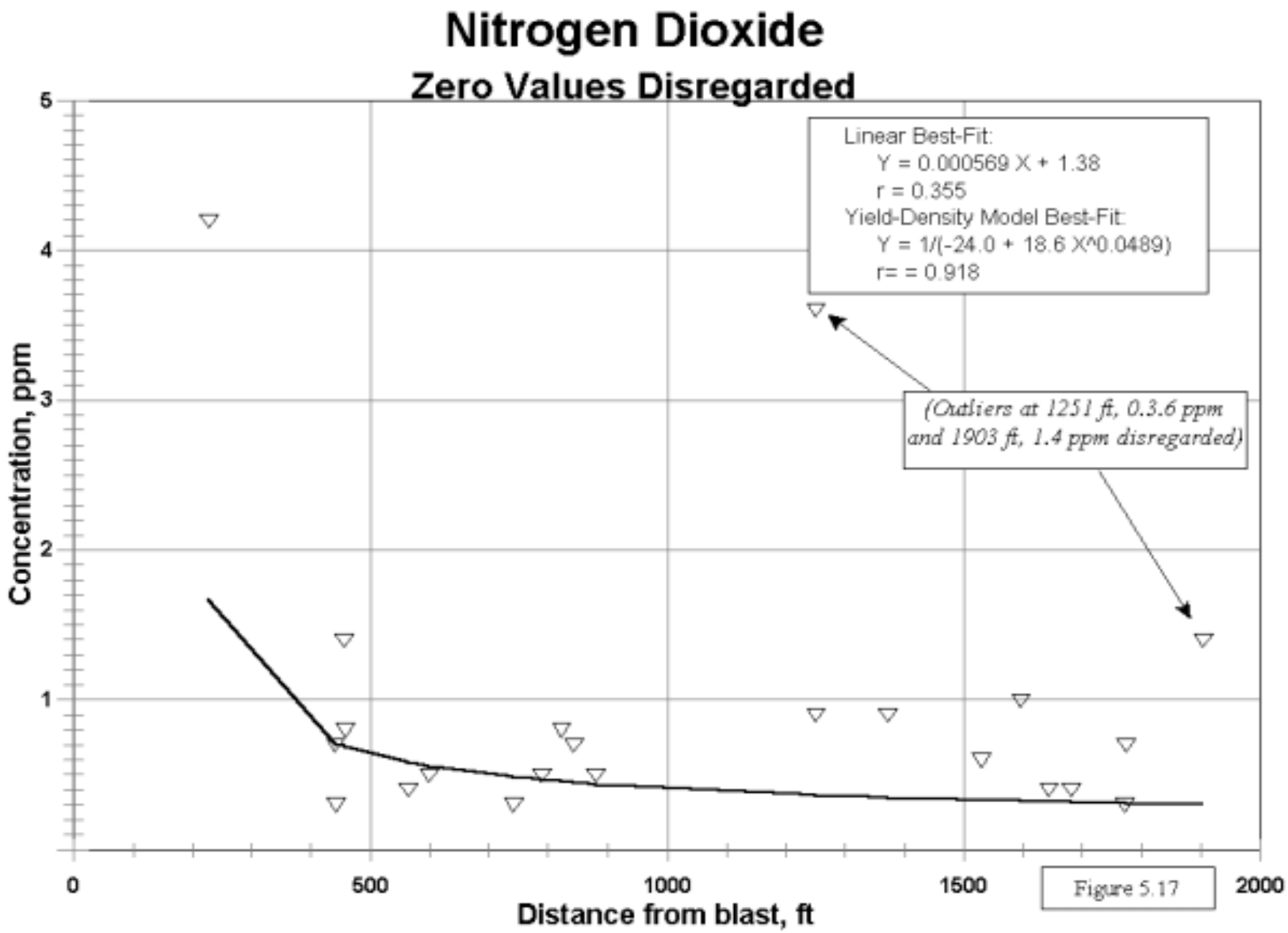

Nitrogen Dioxide
Zero Values Disregarded
Linear Best-Fit:
Y = 0.000569 X + 1.38
r = 0.355
Yield-Density Model Best-Fit:
Y = 1/(-24.0 + 18.6 X^0.0489)
r= = 0.918
(Outliers at 1251 ft, 0.3.6 ppm and 1903 ft, 1.4 ppm disregarded)
Concentration, ppm
5
4
3
2
1
0
500
1000
1500
2000
Distance from blast, ft

Figure 5.17

Summarizing the linear fits and the best fits:

Total Dust:

$$y = 0.188 - 0.0000989\,x \qquad r = 0.558$$

$$y = \frac{1}{3.86 + 0.158\,x^{0.687}} \qquad r = 0.703$$

Respirable Dust:

$$y = 0.113 - 0.0000356\,x \qquad r = 0.270$$

$$y = \frac{1}{24.5 + 14.3\,x^{0.144}} \qquad r = 0.303$$

Nitrogen Dioxide:

$$y = 0.701 + 0.000338\,x \qquad r = 0.210$$

$$y = \frac{1}{23.0 + 13.0\,x^{0.114}} \qquad r = 0.811$$

Nitrogen Dioxide Adjusted for Zero Values:

$$y = 1.38 + 0.000569\,x \qquad r = 0.355$$

$$y = \frac{1}{24.0 + 18.6\,x^{0.0489}} \qquad r = 0.918$$

Note the substantial improvement in the correlation factor made in the nitrogen dioxide fit resulting from neglecting the zero values.

The main station values provide a single data point for each parameter per event. Thus there is no real way to compare them versus distance because of the various differences between

blasting events. None-the-less, figures 5.18 and 5.19 show these values, with the individual events labeled on graphs. These graphs provide a couple of unexpected surprises. The dust concentrations shown in Figure 5.18 for events A0727 and B0602 are quite high, but they are maximums not average exposures. While it would be easy to count these as anomalous, event A0727 also had a very high NO concentration — almost triple the second highest reading. Looking at figure 5.19, these same two sites show anomalously high readings for CO. Taken in conjunction, it is apparent that these high readings are not instrument aberrations. Quite possibly a portion of the blasting cloud reached these sites relatively undiffused and undispersed. This conjecture is strengthened by the stations' close proximity to the blast, 550 feet and 460 feet, respectively. Given the turbulent and chaotic nature of a blasting cloud as compared to, say, a stack plume, this is probably reasonable.

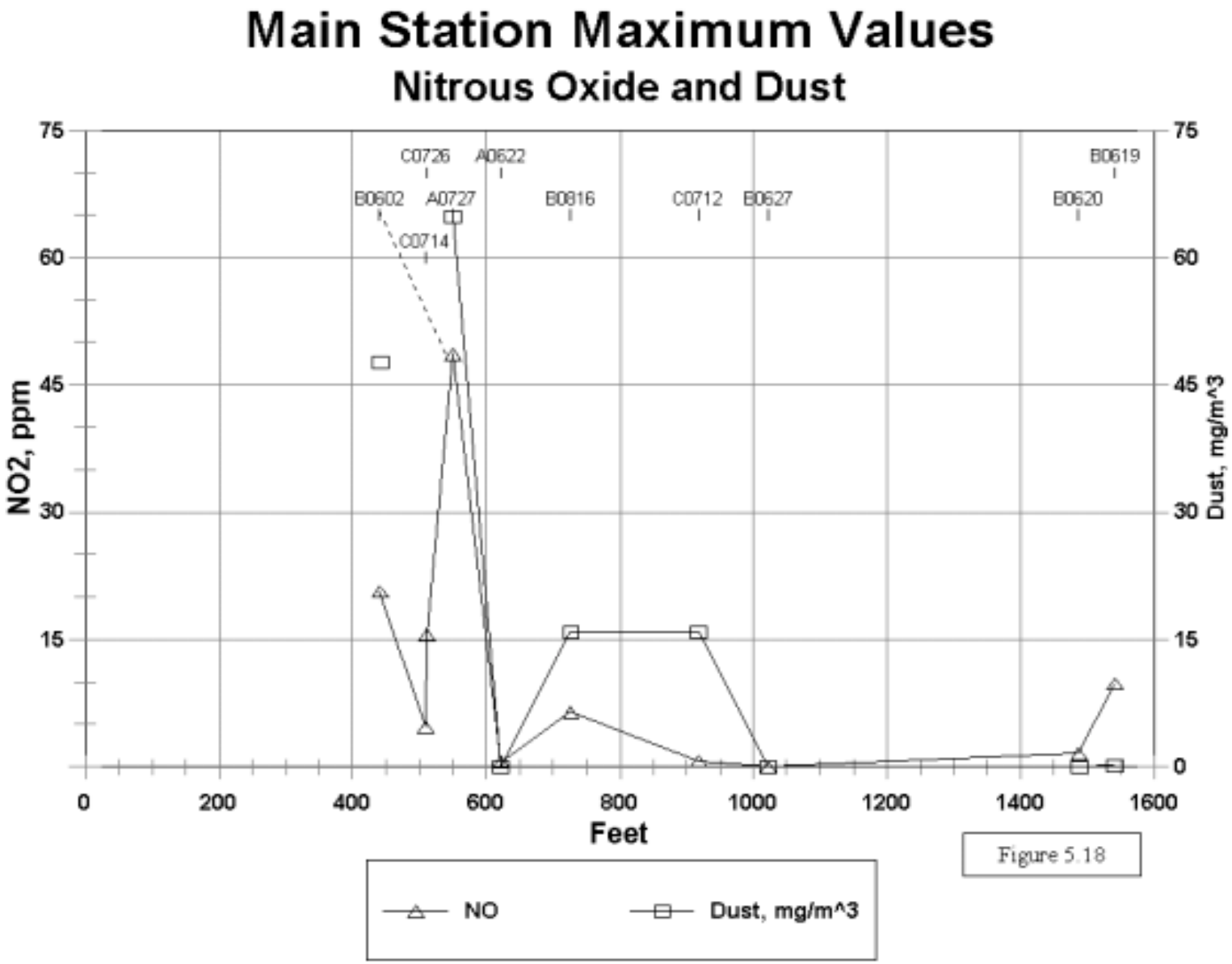

Main Station Maximum Values
Nitrous Oxide and Dust
NO2, ppm
Dust, mg/m^3
Feet
C0726
A0622
B0619
B0602
A0727
B0816
C0712
B0627
B0620
C0714
NO
Dust, mg/m^3

Figure 5.18

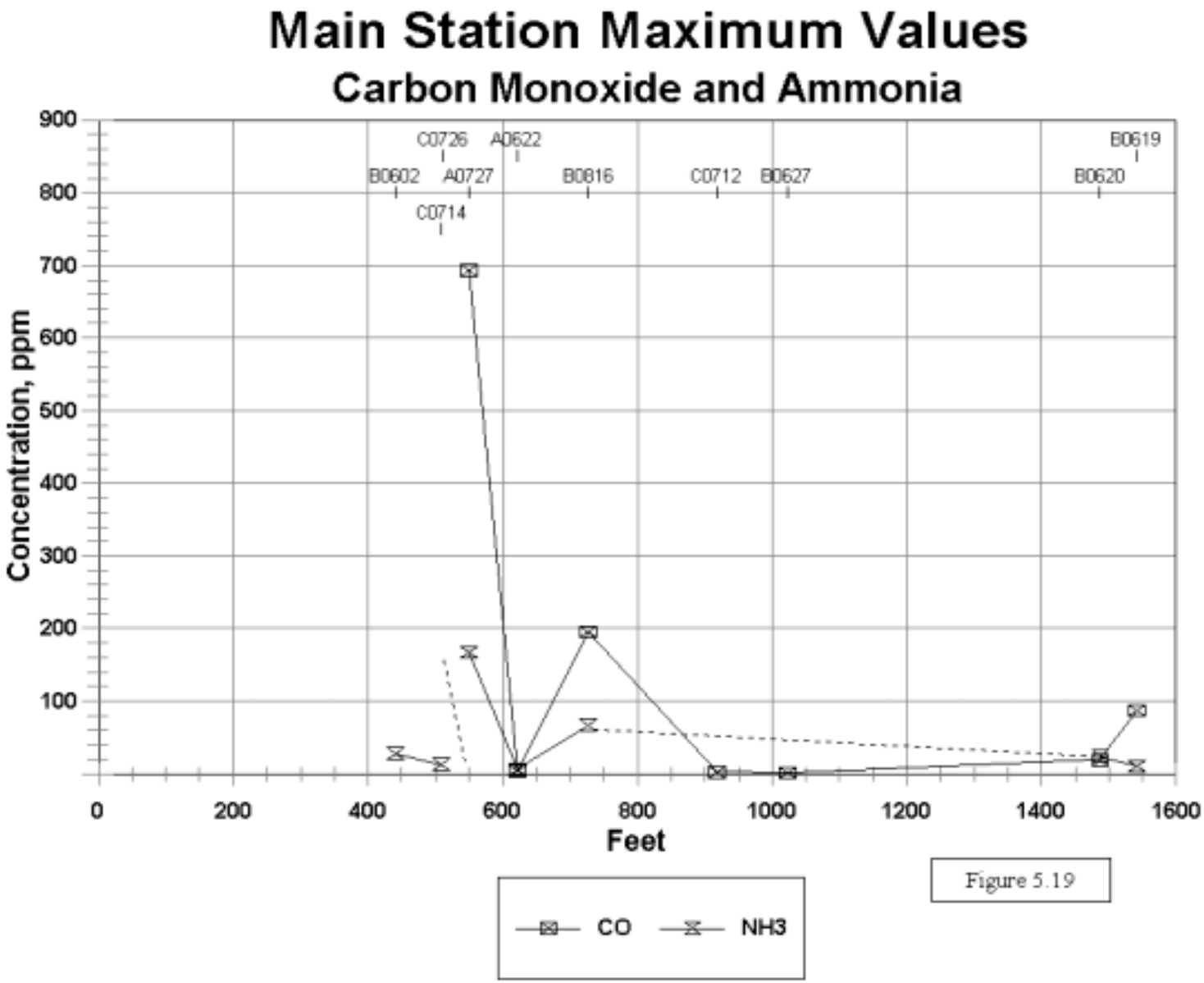

Main Station Maximum Values
Carbon Monoxide and Ammonia
Concentration, ppm
Feet
C0726
A0622
B0619
B0602
A0727
B0816
C0712
B0627
B0620
C0714
CO
NH3

Figure 5.19

5.3 Assessing the Data by Comparison of Individual Events

Up to this point, all of the data have been combined and looked at as a body. There are a number of things that are unique to each individual event and would impact all of the monitoring station readings in similar fashion. Some of them are not easily quantifiable, such as geology, spacing irregularities, accrued damage from adjacent, prior shots. Others are difficult to assess in a useful fashion, such as weather (wind velocity in particular), adjacent terrain, and so forth. And there are differences that are well quantified, including powder factor, total weight of explosives used, delay pattern, and more. Here we have examined the individual events versus powder factor, weight of explosives used, and humidity. The values for each variable were averaged for each event.

As discussed on page 5.11 concerning NO_2, there were stations with zero values for total dust, respirable dust and for NO_2. Also as discussed, it is difficult or impossible to separate the legitimate zeros, ie those in the cloud path, from those that were zero because they were outside of the cloud path. Therefore all three values were averaged both ways, with and without zeros, for all events. Thus there are six sets of data for each variable examined, with 10 points in each set. Then each set was analyzed for best fits using the same 7 models used in section 5.5, and the correlation for each method was determined. Finally, the correlations were compared.

5.3.1 Powder Factor

Figure 5.20 shows total and respirable dust versus powder factor, and Figure 5.21 shows NO_2 versus powder factor. Any potential trend is not obvious. Figure 5.22 compares the correlations, and it is easily noticeable that the best is for respirable dust vs. powder factor, and the worst is total dust vs. powder factor, more than a little surprising. However, eliminating the zero values from the total dust data elevates it to second-best. Eliminating the zeros from the respirable dust data actually worsens the correlations!

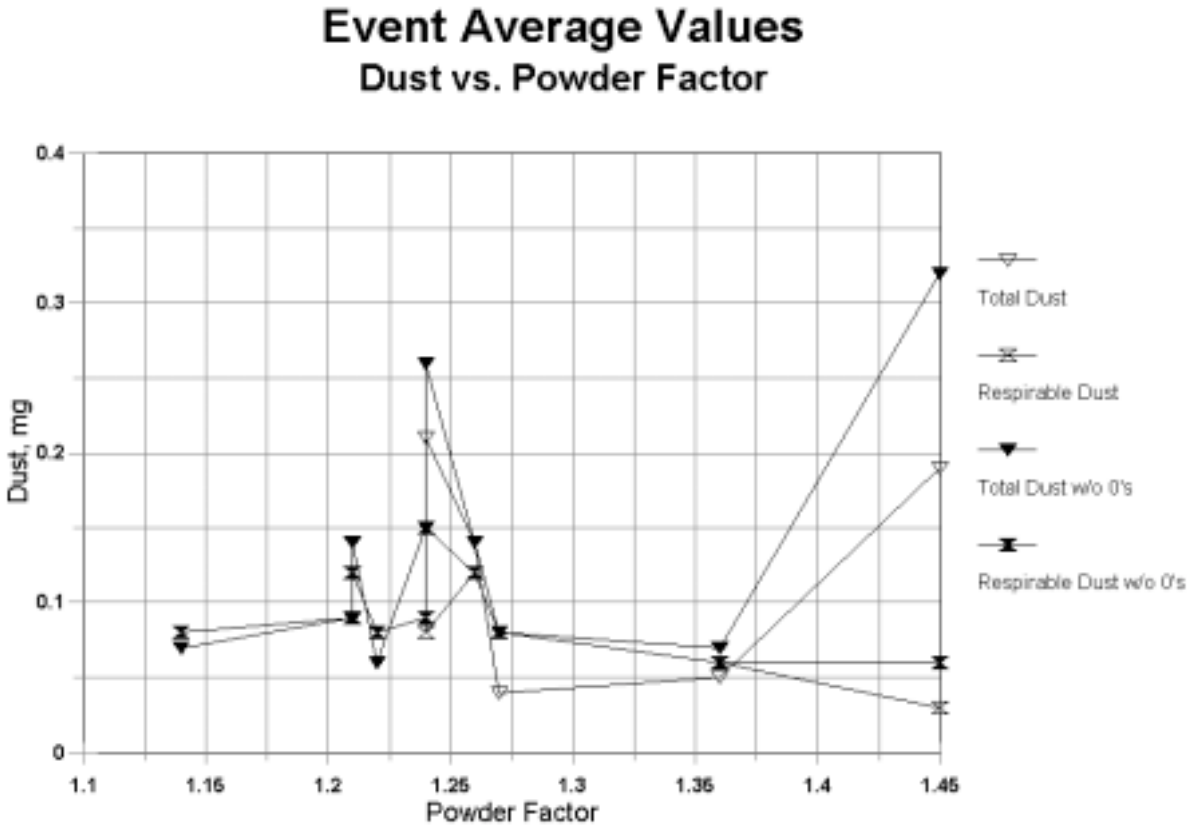

Event Average Values
Dust vs. Powder Factor
Dust, mg
0.4
0.3
0.2
0.1
0
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
Powder Factor
Total Dust
Respirable Dust
Total Dust w/o 0's
Respirable Dust w/o 0's

Figure 5.20

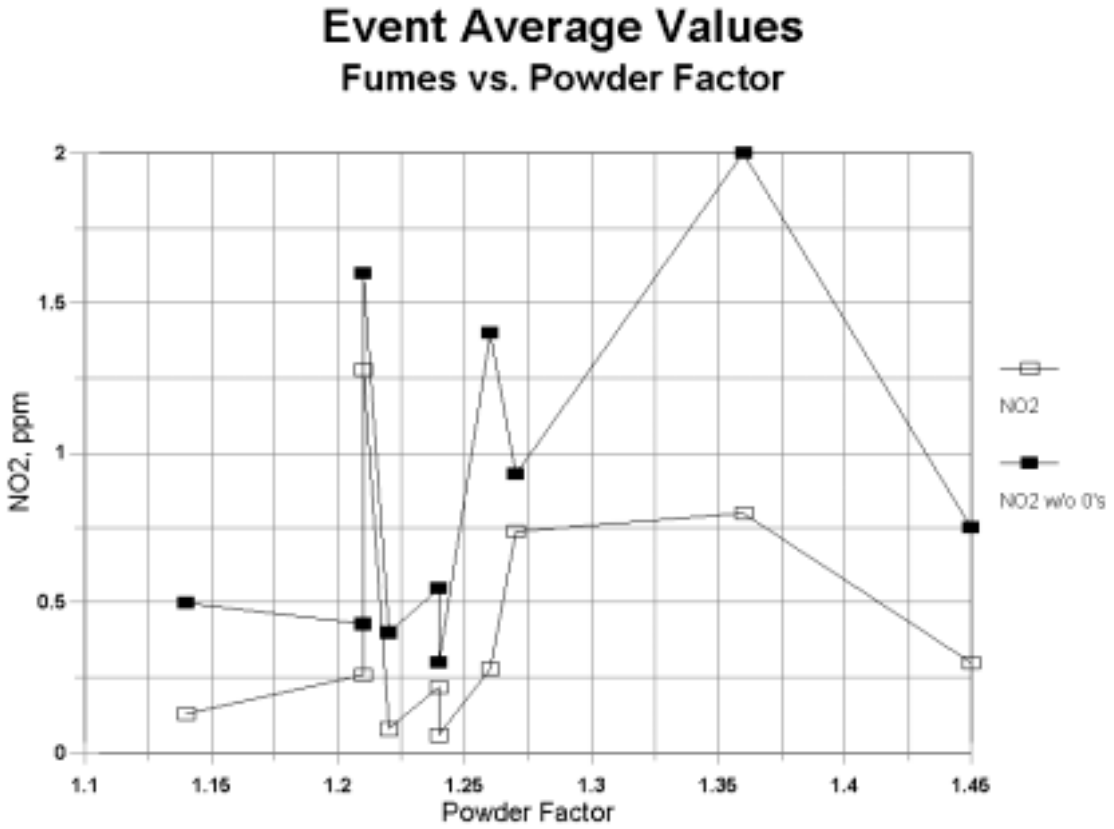

Event Average Values
Fumes vs. Powder Factor
NO2, ppm
2
1.5
1
0.5
0
1.1
1.15
1.2
1.25
1.3
1.35
1.4
1.45
Powder Factor
NO2
NO2 w/o 0's

Figure 5.21

Correlations

Fumes and Dust vs. Powder Factor

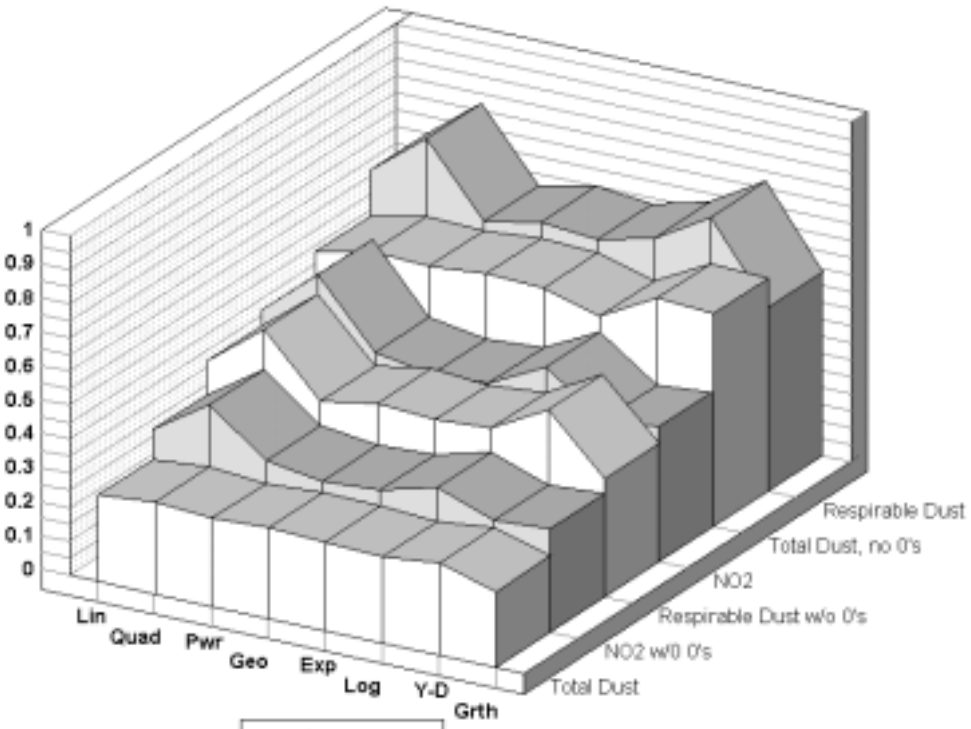


Figure 5.22

5.3.2 Weight of Explosives

Figures 5.23 and 5.24 compare total dust, respirable dust, and NO_2 versus the total weight of explosives used.[1] Once again, there is no real visible trend. A look at the correlations justifies this initial opinion; the correlations are very poor. The respirable dust correlations are the best, the NO_2 the worst.

[1] We originally wanted to separate this category into two parts, shots of less than 500,000 pounds, and shots of more than 500,000 pounds. As it turned out, only two of the measured events would have fallen into the second category, and such a division would not have been meaningful.

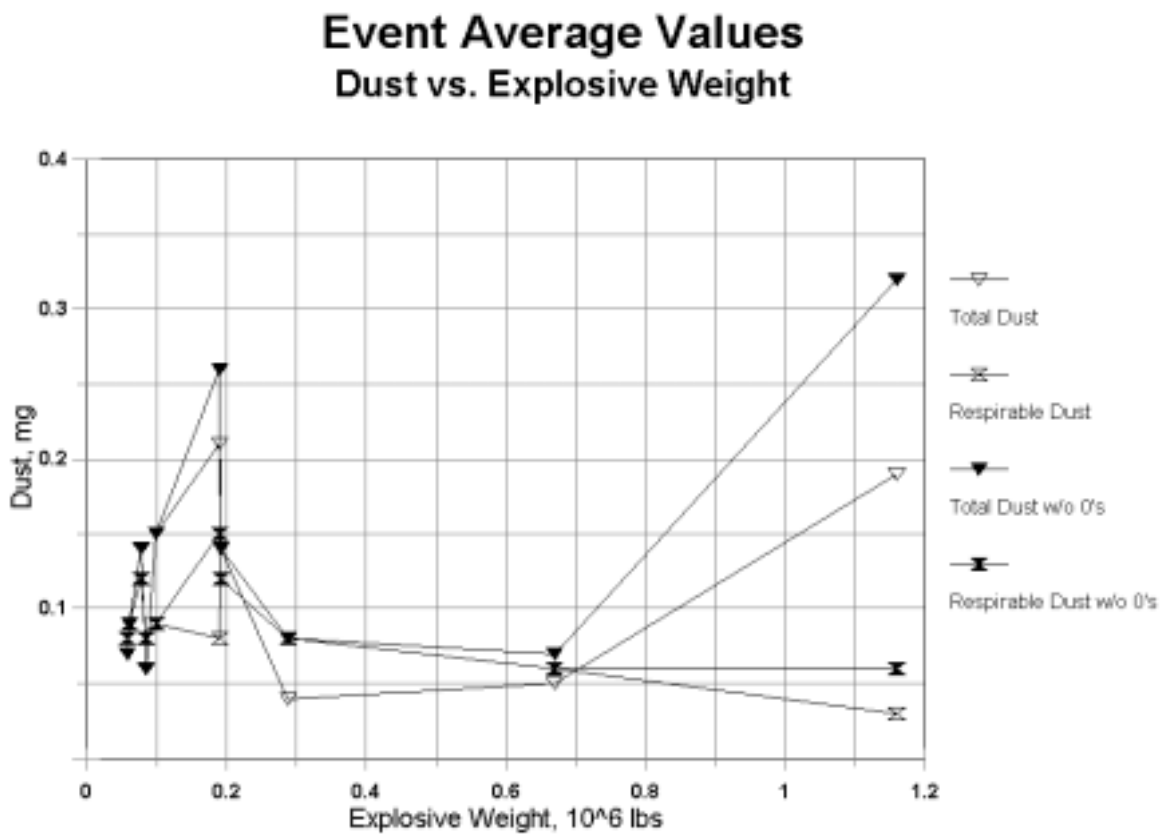

Event Average Values
Dust vs. Explosive Weight
Dust, mg
0.4
0.3
0.2
0.1
0
0.2
0.4
0.6
0.8
1
1.2
Explosive Weight, 10^6 lbs
Total Dust
Respirable Dust
Total Dust w/o 0's
Respirable Dust w/o 0's

Figure 5.23

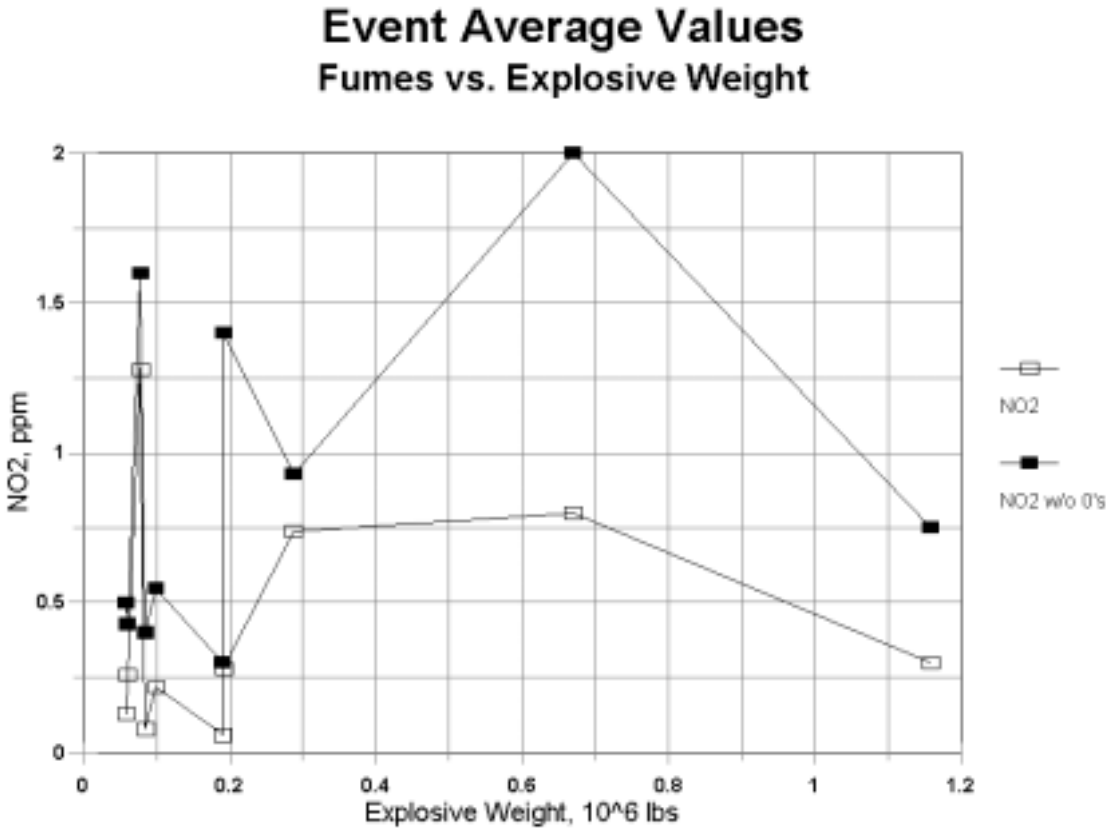

Event Average Values
Fumes vs. Explosive Weight
NO2, ppm
2
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
1.2
Explosive Weight, 10^6 lbs
NO2
NO2 w/o 0's

Figure 5.24

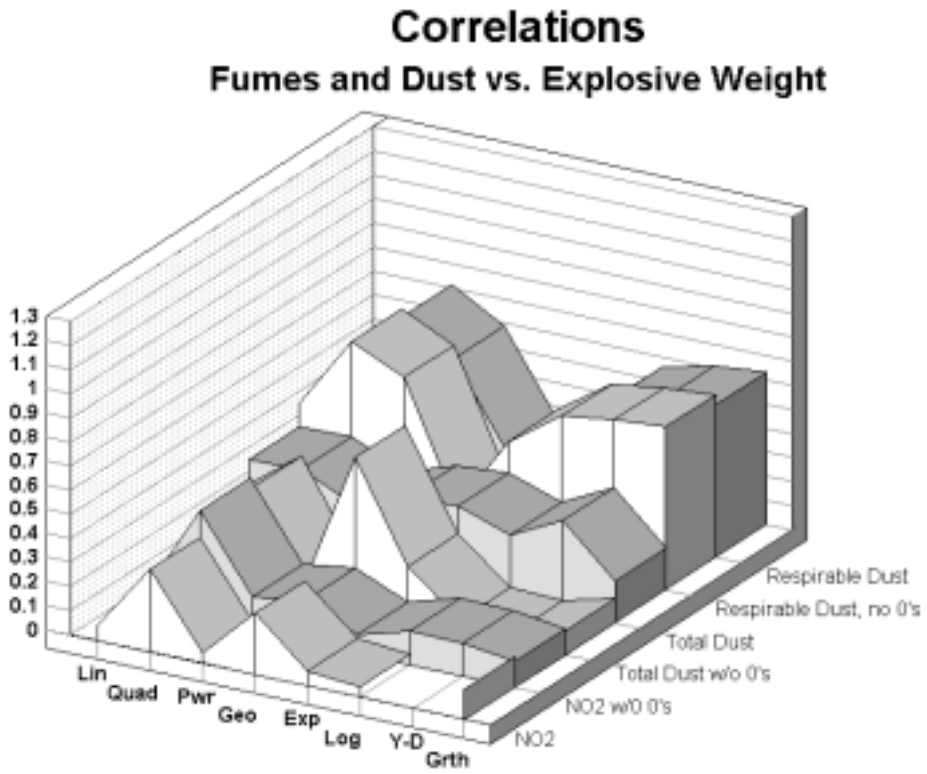

Correlations
Fumes and Dust vs. Explosive Weight
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Lin
Quad
Pwr
Geo
Exp
Log
Y-D
Grth
Respirable Dust
Respirable Dust, no 0's
Total Dust
Total Dust w/o 0's
NO2 w/0 0's
NO2

Figure 5.25

5.3.3 Humidity

This correlation was run primarily because the investigators expected to see a correlation with dust, especially on those days where a higher humidity was associated with precipitation. Not only does Figure 5.26 not show such a correlation, the high dust measurements were taken on the second most humid day. The real surprise was Figure 5.27, NO_2 versus humidity. Even though several experts assured the investigators the weather would have no impact on NO_2, the trend in Figure 5.28 is clear and strong, an inverse relationship between the fumes and the humidity. The comparison of correlations in Figure 5.28 is superb for NO_2, especially with the zero values removed. The correlations for dust are uniformly bad (except for one quadratic fit which is most likely an artifact).

This deviation from common knowledge highlights the lack of work in the area of transient blasting fumes. The experts are most likely right if one is discussing the initial quantity of fumes generated by the blast. However, they have no experience in identifying changes that occur after initial generation as the fume cloud travels, and do not make allowances for it beyond recognizing the dispersion and diffusion occur. Even the conversion rate of NO to NO_2 is not well quantified, especially in regard to ambient conditions, although the process is well known.

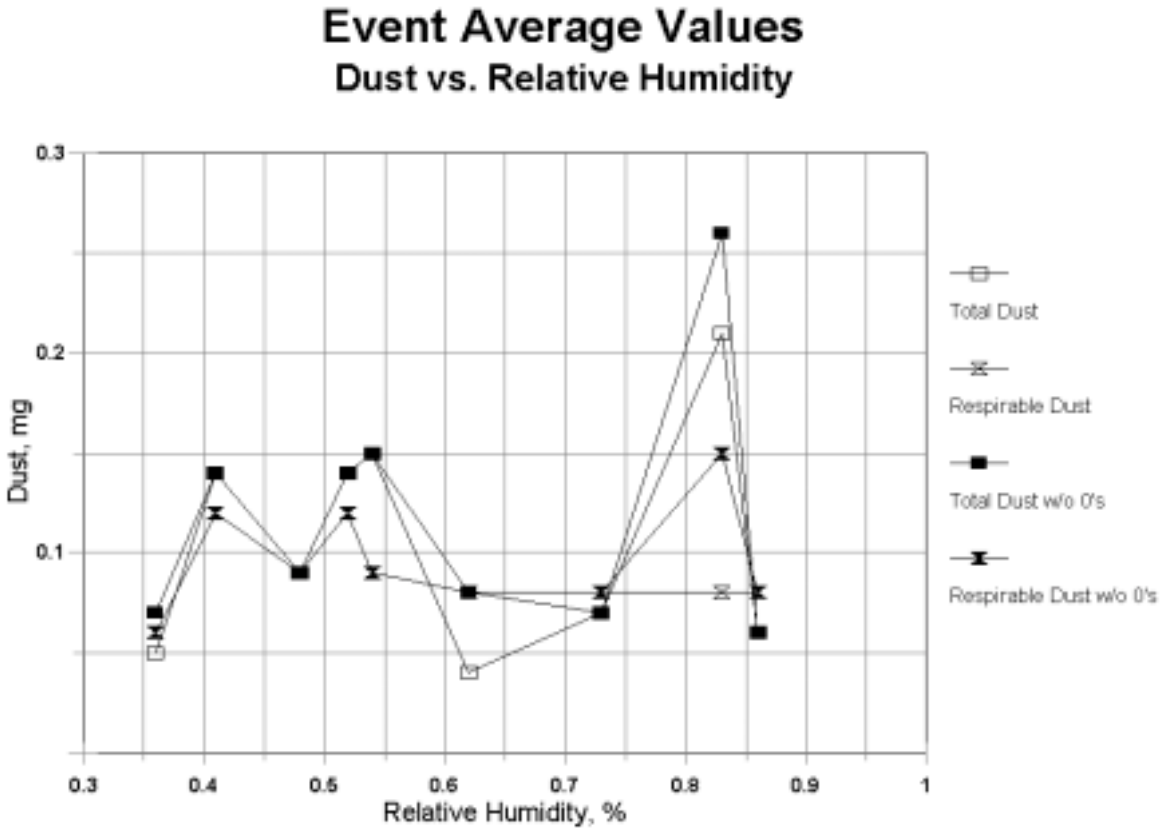

Event Average Values
Dust vs. Relative Humidity
0.3
0.2
0.1
Dust, mg
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Relative Humidity, %
Total Dust
Respirable Dust
Total Dust w/o 0's
Respirable Dust w/o 0's

Figure 5.26

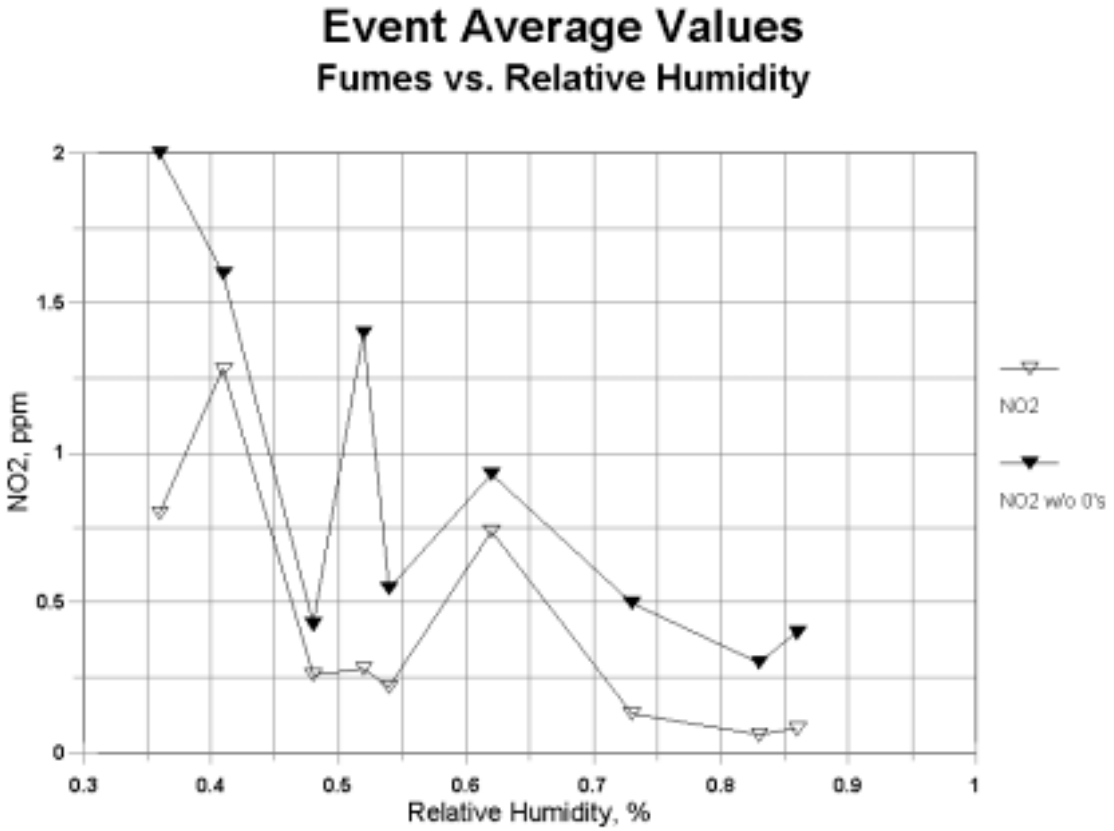

Event Average Values
Fumes vs. Relative Humidity
NO2, ppm
2
1.5
1
0.5
0
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Relative Humidity, %
NO2
NO2 w/o 0's

Figure 5.27

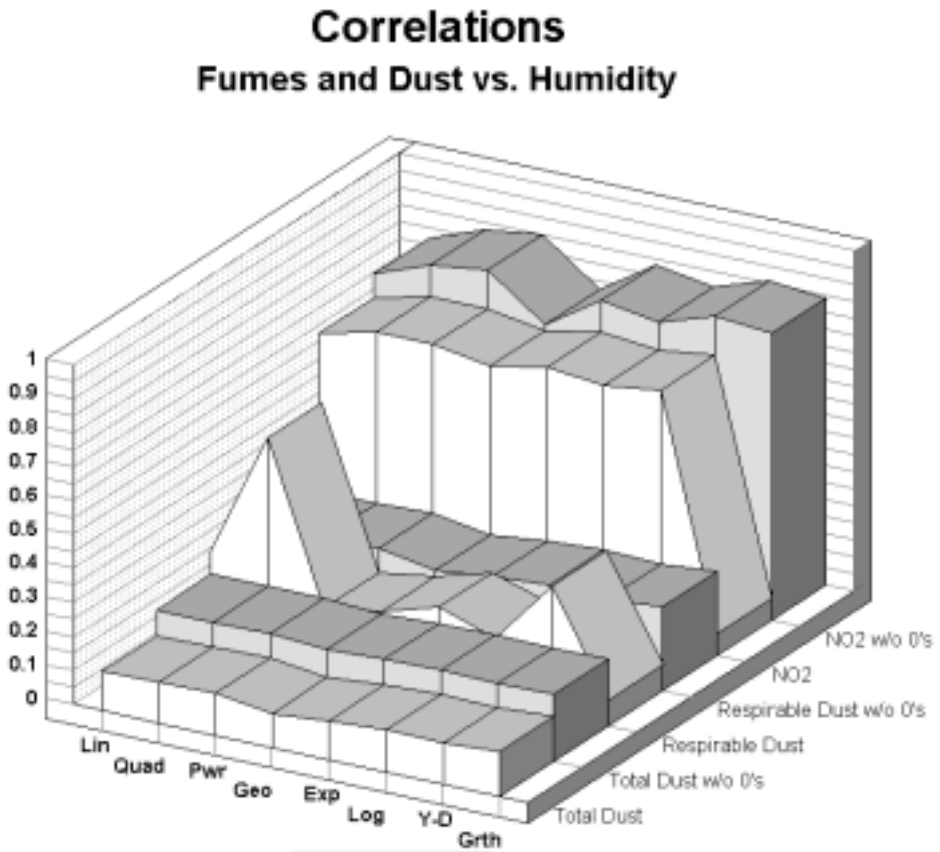

Correlations
Fumes and Dust vs. Humidity
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Lin
Quad
Pwr
Geo
Exp
Log
Y-D
Grth
NO2 w/o 0's
NO2
Respirable Dust w/o 0's
Respirable Dust
Total Dust w/o 0's
Total Dust

Figure 5.28

5.3.4 Summary of Correlations

The following tables (5.2 through 5.4) summarize all of the correlations illustrated in the graphs. For each variable, the correlations themselves are analyzed at the bottoms of the tables, listing the best, the worst, and the standard deviation of the correlations. This is a different way of examining the correctness of the correlation values themselves. The tighter the spread, the more valid those correlations are likely to be for that data set; the wider the spread, the less valid. It is worth noting that the values for NO_2 without zeros change to an average correlation of 0.726 with a standard deviation of 0.017 (2.31%) if the growth model is neglected.

	Total Dust	Total Dust, 0 values disregarded	Resp. Dust	Resp. Dust, 0 values disregarded	NO_2	NO_2, 0 values disregarded
Linear	0.2547	0.5556	0.6910	0.4410	0.4863	0.3434
Quadratic	0.2694	0.5916	0.8199	0.5702	0.6270	0.4506
Power	0.2577	0.5849	0.6128	0.3946	0.4335	0.3226
Geometric	0.2657	0.5998	0.6482	0.4245	0.4047	0.3010
Exponential	0.2622	0.5934	0.6316	0.4115	0.4175	0.3106
Logarithm	0.2520	0.5475	0.6736	0.4260	0.5008	0.3538
Yield-Density	0.2697	0.6335	0.7697	0.5138	0.3803	0.2931
Growth	0.2226	0.6249	0.5394	0.3479	0.3953	0.3051
Best Correlation	*0.2697*	*0.6335*	*0.8199*	*0.5702*	*0.627*	*0.4506*
Avg. Correlation	*0.257*	*0.591*	*0.673*	*0.441*	*0.456*	*0.335*
Standard Deviation	*0.014*	*0.028*	*0.083*	*0.065*	*0.076*	*0.048*
Std. Dev. as % Avg:	*5.56%*	*4.71%*	*12.32%*	*14.82%*	*16.68%*	*14.29%*

Table 5.2 Correlations: Dust and Fumes vs. Powder Factor

	Total Dust	Total Dust, 0 values disregarded	Resp. Dust	Resp. Dust, 0 values disregarded	NO_2	NO_2, 0 values disregarded
Linear	0.3449	0.2439	0.3395	0.4458	0.0666	0.0844
Quadratic	0.3524	0.4082	0.7135	0.7467	0.3413	0.4526
Power	0.2534	0.0453	0.5905	0.6449	0.0405	0.1392
Geometric	0.3292	0.6293	0.2538	0.1597	0.2537	0.1704
Exponential	0.3429	0.2230	0.3735	0.4751	0.0593	0.0763
Logarithm	0.2686	0.0511	0.5580	0.6252	0.0447	0.1394
Yield-Density	0.3785	0.0405	0.6100	0.6560	No Fit	0.1368
Growth	0.1718	0.1005	0.6326	0.6724	0.1246	0.1084
Best Correlation	*0.3785*	*0.6293*	*0.7135*	*0.7467*	*0.3413*	*0.4526*
Avg. Correlation	*0.305*	*0.218*	*0.509*	*0.553*	*0.133*	*0.163*
Standard Deviation	*0.064*	*0.197*	*0.154*	*0.176*	*0.110*	*0.113*
Std. Dev. as % Avg:	*21.04%*	*90.27%*	*30.17%*	*31.84%*	*82.50%*	*69.23%*

Table 5.3 Correlations: Dust and Fumes vs. Weight of explosives, 10^6 lbs

	Total Dust	Total Dust, 0 values disregarded	Resp. Dust	Resp. Dust, 0 values disregarded	NO_2	NO_2, 0 values disregarded
Linear	0.1158	0.1934	0.2618	0.2294	0.6959	0.7671
Quadratic	0.1201	0.1934	0.6310	0.2323	0.7362	0.8293
Power	0.1230	0.1949	0.1664	0.2365	0.7347	0.8493
Geometric	0.1010	0.1859	0.1919	0.2102	0.7078	0.7255
Exponential	0.1150	0.1934	0.2408	0.2286	0.7404	0.8310
Logarithm	0.1256	0.1960	0.1854	0.2391	0.7214	0.8039
Yield-Density	0.1208	0.1939	0.3743	0.2319	0.7441	0.8566
Growth	0.1319	0.1959	0.0744	0.2457	0.0634	0.8430
Best Correlation	*0.1319*	*0.196*	*0.631*	*0.2457*	*0.7441*	*0.8566*
Avg. Correlation	*0.119*	*0.193*	*0.266*	*0.232*	*0.643*	*0.813*
Standard Deviation	*0.009*	*0.003*	*0.160*	*0.010*	*0.220*	*0.043*
Std. Dev. as % Avg:	*7.15%*	*1.55%*	*60.12%*	*4.18%*	*34.16%*	*5.24%*

Table 5.4 Correlations: Dust and Fumes vs. Humidity

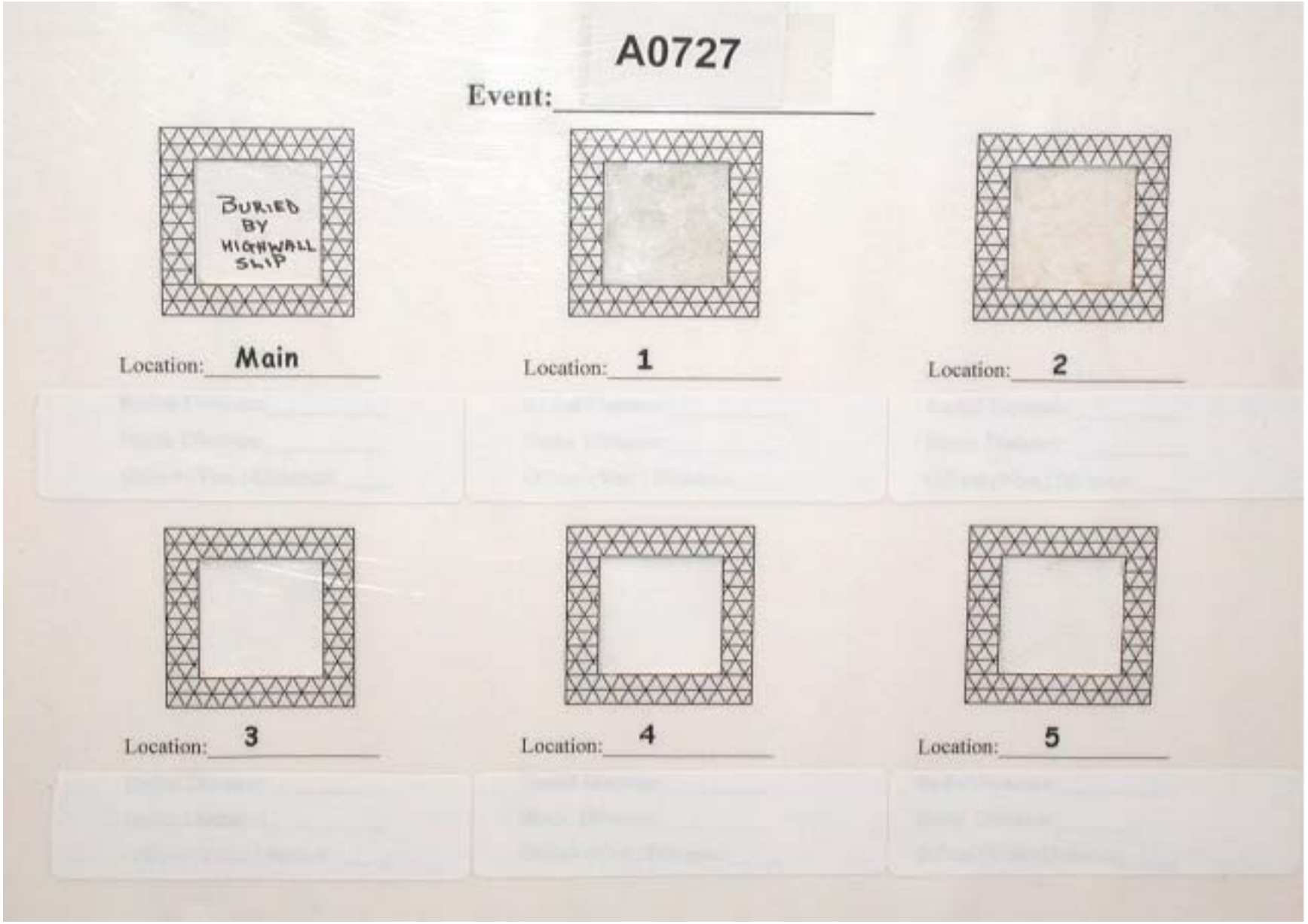
5.4 Visual Dust

It is hard to quantify the impact of dust as a nuisance. This is a subjective criterion based upon personal expectations. What bothers some may not bother others. It was not until relatvely late in the investigation that the investigators decided to try to record, if not measure, the visual impact if the passing of blasting clouds.

Complaints about blasting dust center around the residual dust left behind after the clouds pass. They normally involve things like having to wash cars, rewash laundry, the coating that they leave upon structures, and so forth. At four events, we placed white filter papers exposed on the ground beside all monitoring locations. After the blast, these filters were sealed with clear tape, placed into holders, and photographed under the same conditions. Figures 5.29 through 5.33 show those photographs. The main station filter paper at event A0727 was place to close to a highwall and was buried by 5 to 10 pounds of dirt that slipped because of blast vibration.

These photos indicate that the heaviest visible dust deposits occurred on filters within 1000 feet of the blast, and frequently not then. The exceptions are stations 2 and 3 for event C0714, which show some speckling, Of the five filters beyond 1000 feet, only these showed dust, and these were light amounts. Station 1 for this event, at 228 feet the closest station of any blast, actually caught some large pieces physically thrown from the blast.

On caveat is that some of the dust caught may have come from local activities other than blasting. There is truck traffic in the area as the workers finish final preparations and depart the area. The investigators set out these filters at the last possible minute, but in order to control the timing as much as possible we, too, frequently had to travel by truck between stations. We took as much care as possible. If such impacts were made on the measurements, they would be conservative errors; in other words, they can only adversely affect the filters, not favorably.


A0727
Event:
BURIED BY HIGHWALL SLIP
Location: Main
Location: 1
Location: 2
Location: 3
Location: 4
Location: 5

B0816

Event:

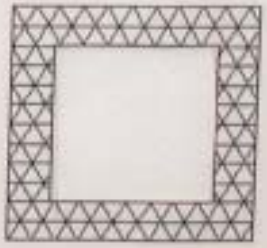
Location: Main

Location: 1

Location: 2

Location: 3

Location: 4



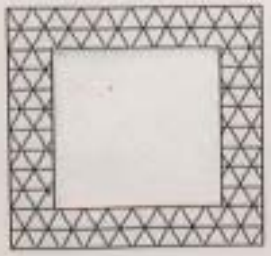
Location: 5

Event: C0714

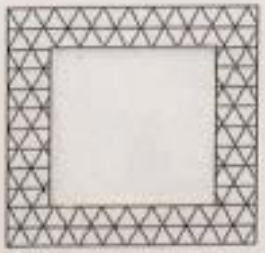
Location: Main

Location: 1

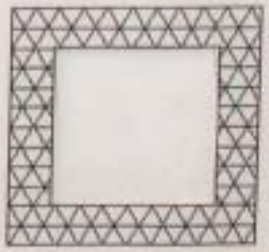
Location: 2



Location: 3



Location: 4

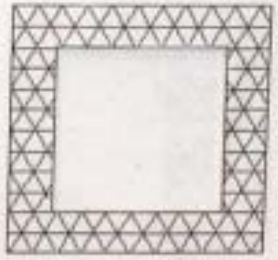


Location: 5

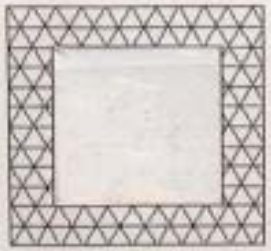
Event: C0726

Location: Main

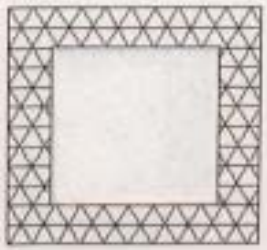
Location: 1



Location: 2



Location: 3



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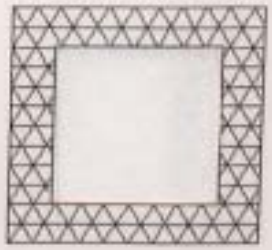

Location: 5

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5.5 Measurement Durations

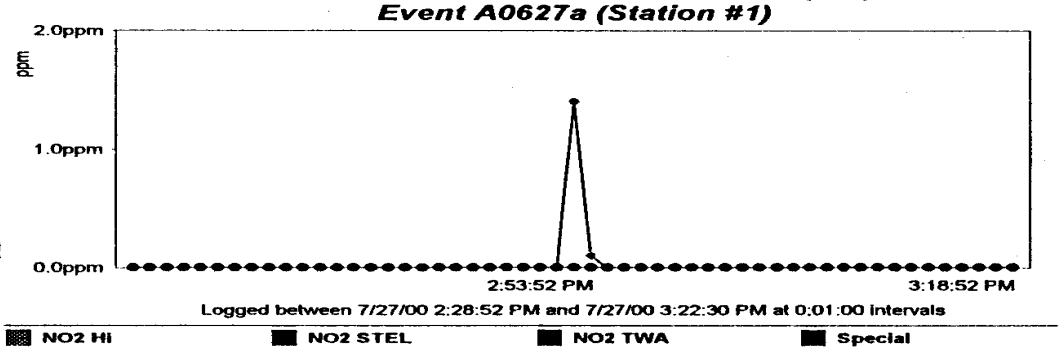
The nine pages that follow (5.48 through 5.56) show the durations of the measurements indicating the presence of fumes. Pages 5.48 to 5.53 are graphs from every montitoring station that recorded nitrogen dioxide. With the exception of stations 2 and 4 at event B0602, all of the events are of very short duration, usually less than two minutes. Event B0602 stations 2 & 4 show longer and more frequent exposures, but at levels less than 1 ppm (pages 5.48 and 5.49). The highest single measurement, 4.2 ppm at event C0714 station 1, the peak was for one measurement cycle only (1 minute duration), followed immediately by a reduction to below 1 ppm (page 5.51). Page 5.53 shows a sample illustrating a main station NO_2 measurement and why we were reluctant to use them. Even though the highs tended to be in accordance with highs from neighboring stations, the unstable baseline with the frequent less-than-zero readings indicated a problem with the unit we were never able to define or correct.

Pages 5.54 and 5.55 are graphs of carbon monoxide readings. Five events had main station readings of 2, 3, 5, 8, and 9 ppm, respectively, only one of those is reproduced here for purposes of illustration. Once again, although the readings are high in several cases, they are of exceptionally short duration.

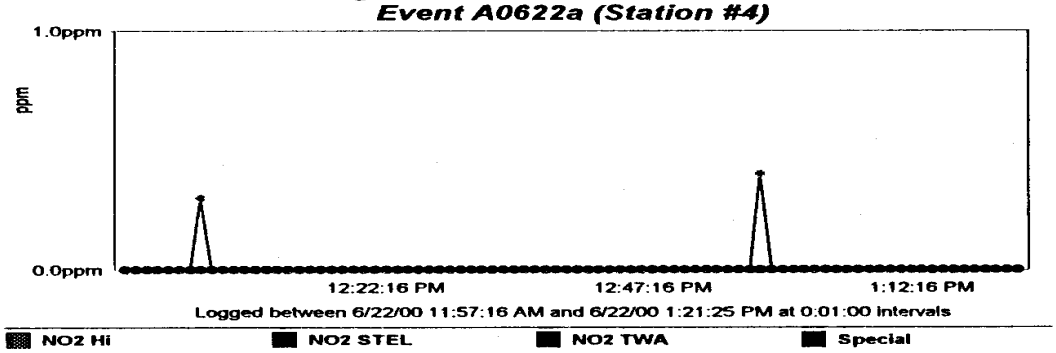
Finally, page 5.56 provides one graph each of an ammonia reading and a nitric oxide reading. These readings tended to follow the form of the other fumes where they occurred as can be seen by comparing these two graphs with the carbon monoxide graphs from the same events.

No readings indicate the possibility of prolonged exposure to unhealthy levels of fumes. Those readings that are high enough to be concerned for long-term exposure are of very brief duration, in the neighborhood of one minute.

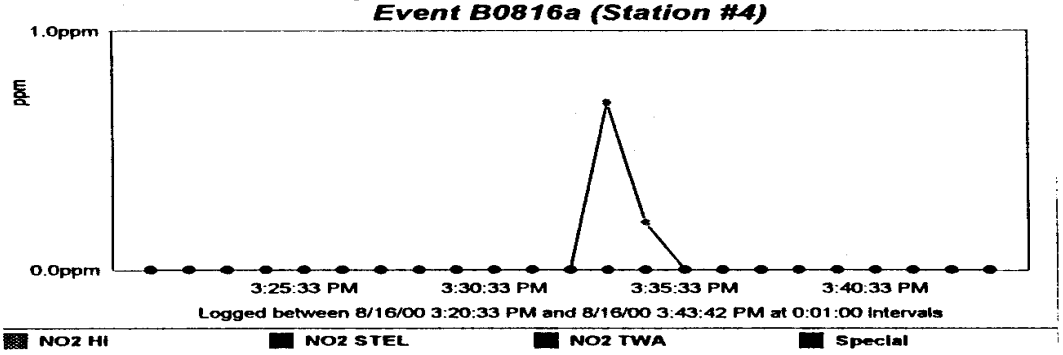
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event A0627a (Station #1)



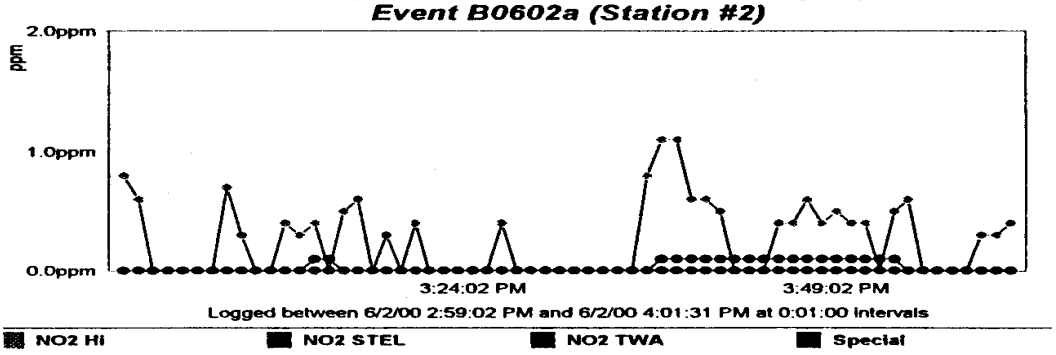
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event A0622a (Station #4)



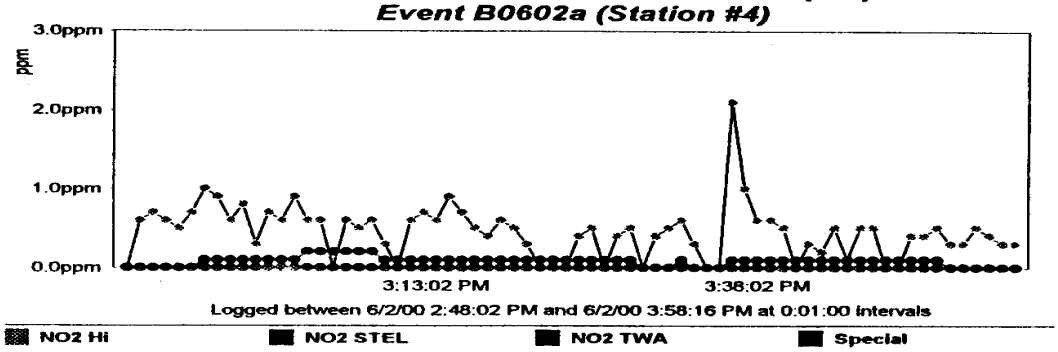
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0816a (Station #4)



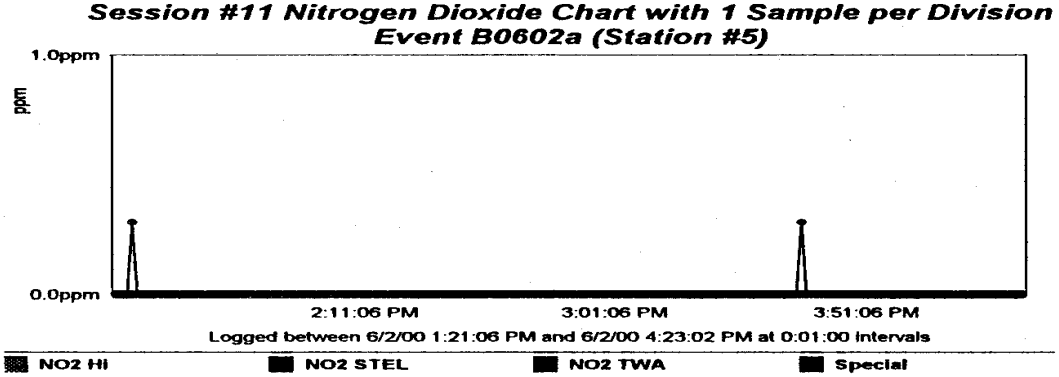
Session #3 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0602a (Station #2)



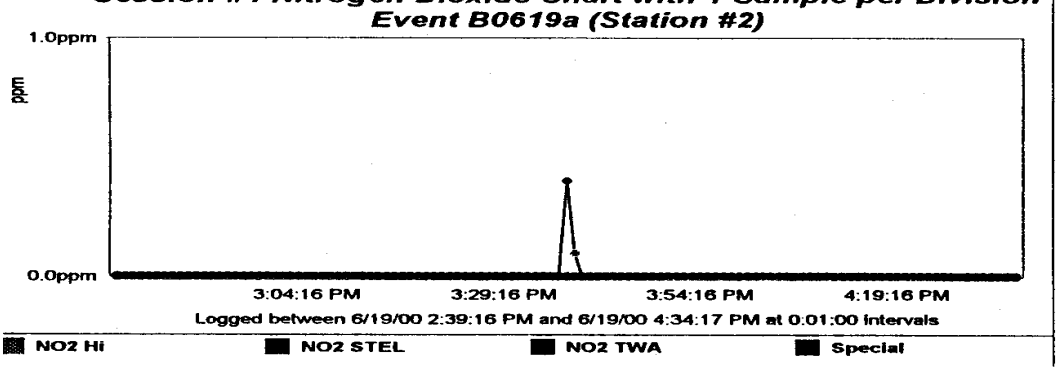
Session #7 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0602a (Station #4)



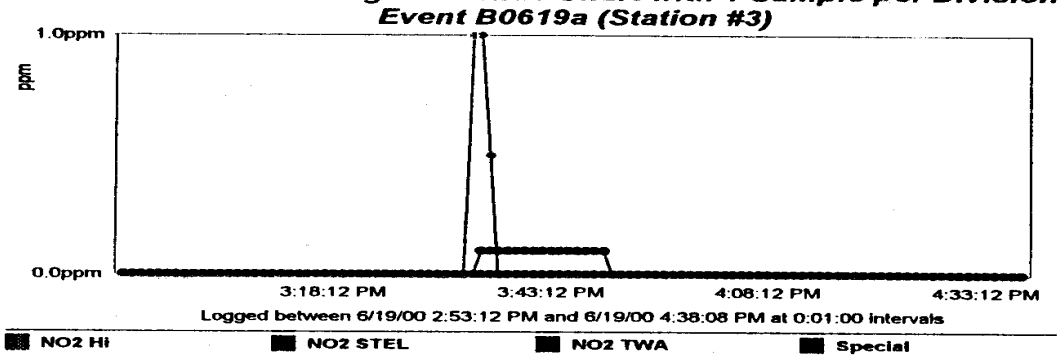
Session #11 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0602a (Station #5)

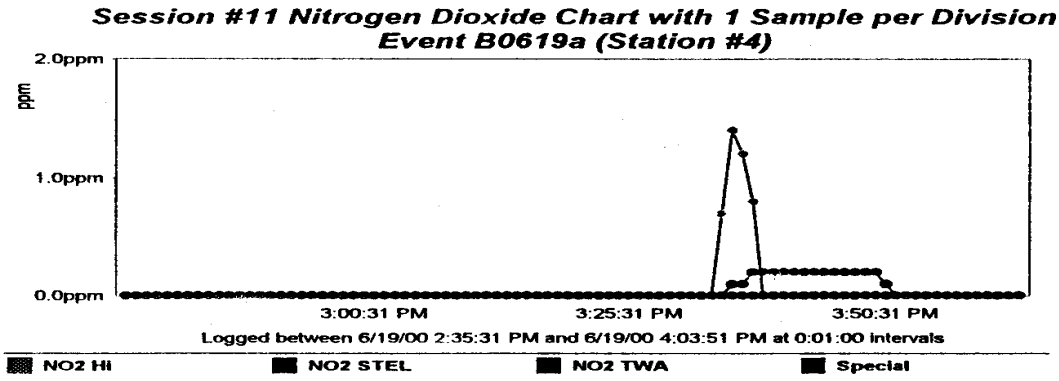


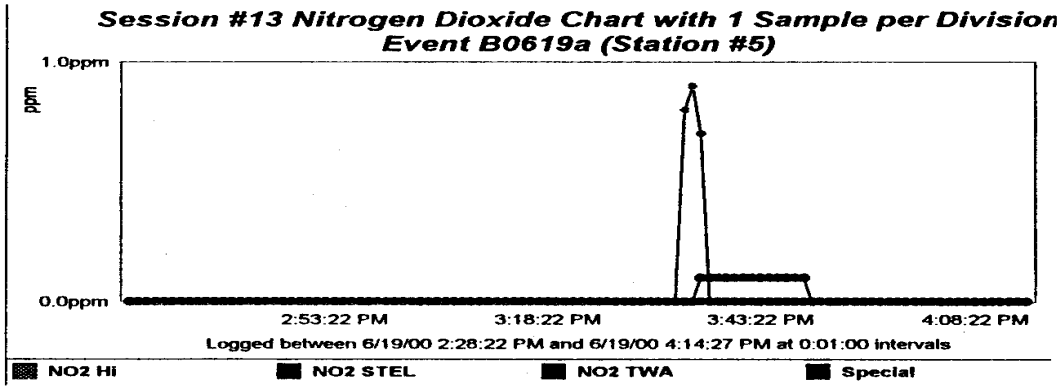
Session #4 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0619a (Station #2)

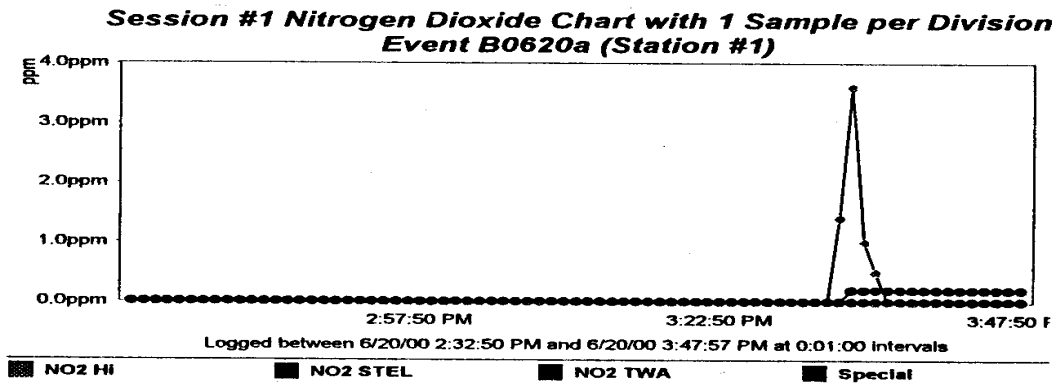


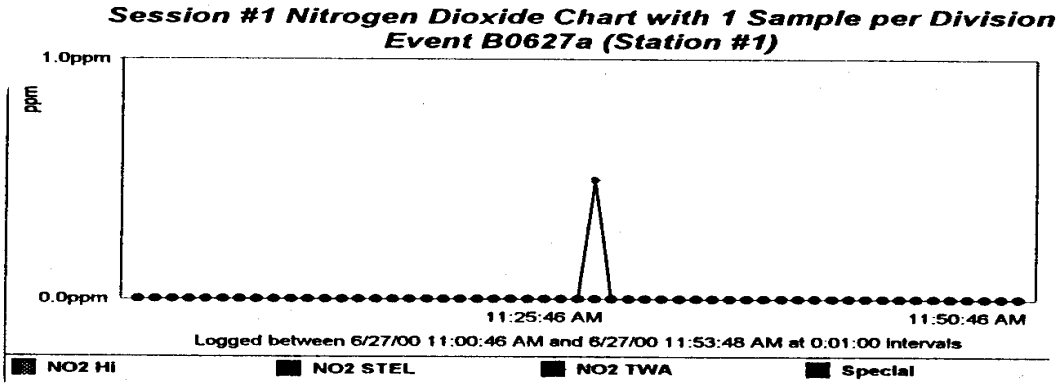
Session #14 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0619a (Station #3)



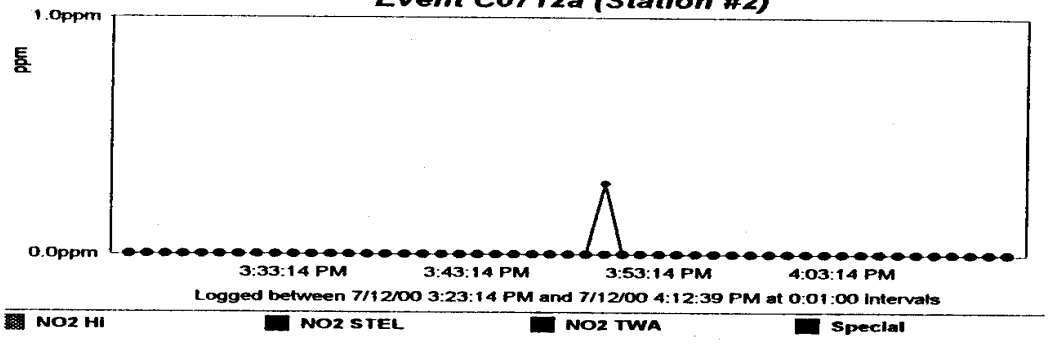

Session #11 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0619a (Station #4)
2.0ppm
ppm
1.0ppm
0.0ppm
3:00:31 PM
3:25:31 PM
3:50:31 PM
Logged between 6/19/00 2:35:31 PM and 6/19/00 4:03:51 PM at 0:01:00 intervals
NO2 Hi
NO2 STEL
NO2 TWA
Special


Session #13 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0619a (Station #5)
1.0ppm
ppm
0.0ppm
2:53:22 PM
3:18:22 PM
3:43:22 PM
4:08:22 PM
Logged between 6/19/00 2:28:22 PM and 6/19/00 4:14:27 PM at 0:01:00 intervals
NO2 Hi
NO2 STEL
NO2 TWA
Special

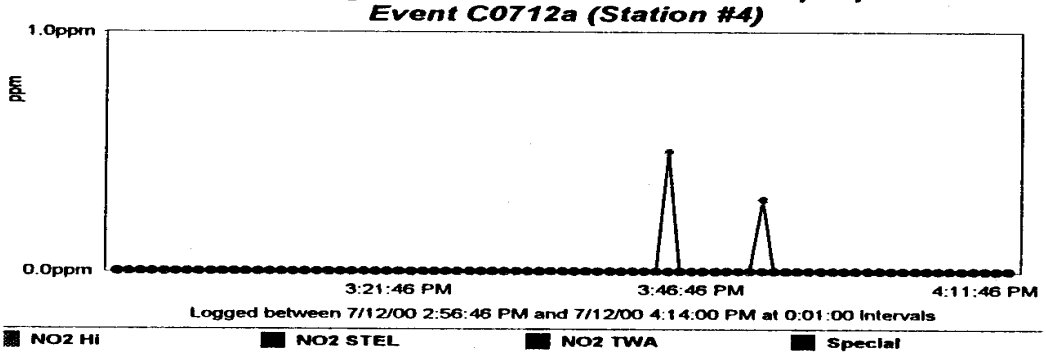

Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0620a (Station #1)
ppm
4.0ppm
3.0ppm
2.0ppm
1.0ppm
0.0ppm
2:57:50 PM
3:22:50 PM
Logged between 6/20/00 2:32:50 PM and 6/20/00 3:47:57 PM at 0:01:00 intervals
NO2 Hi
NO2 STEL
NO2 TWA
Special


Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event B0627a (Station #1)
1.0ppm
ppm
0.0ppm
11:25:46 AM
11:50:46 AM
Logged between 6/27/00 11:00:46 AM and 6/27/00 11:53:48 AM at 0:01:00 intervals
NO2 Hi
NO2 STEL
NO2 TWA
Special

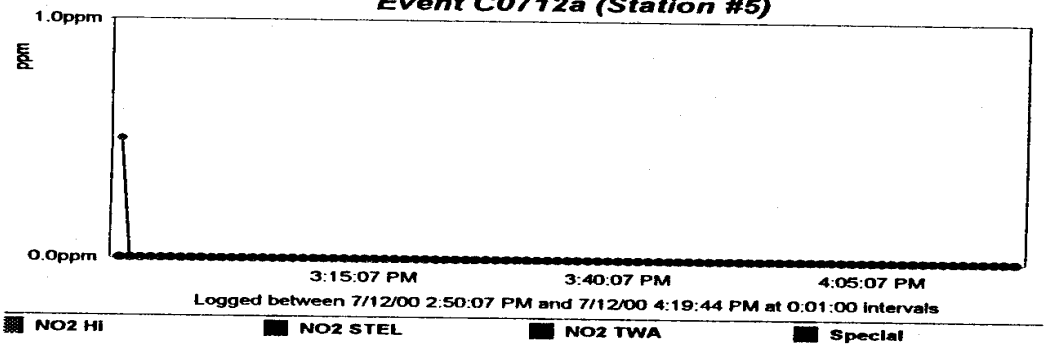
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0712a (Station #2)



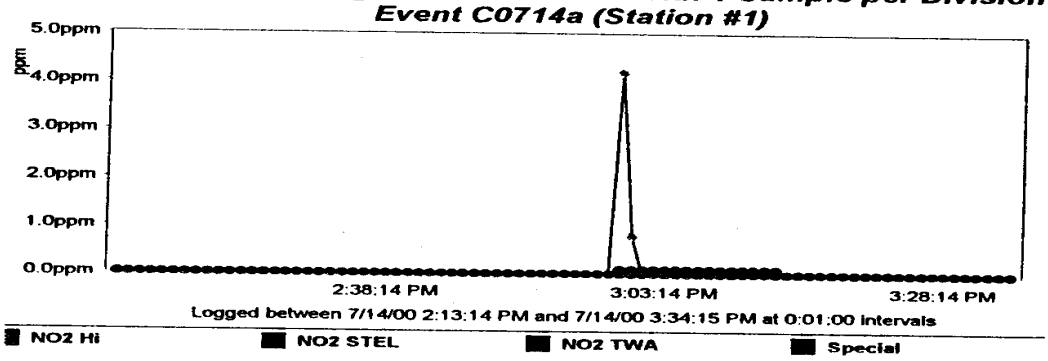
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0712a (Station #4)



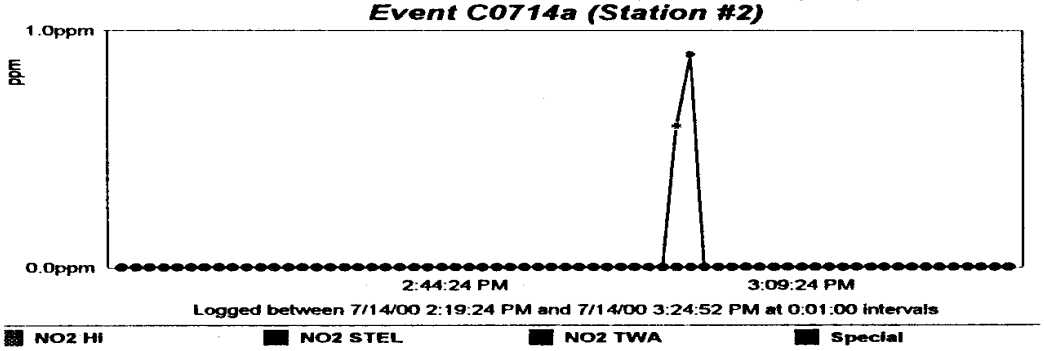
Session #2 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0712a (Station #5)



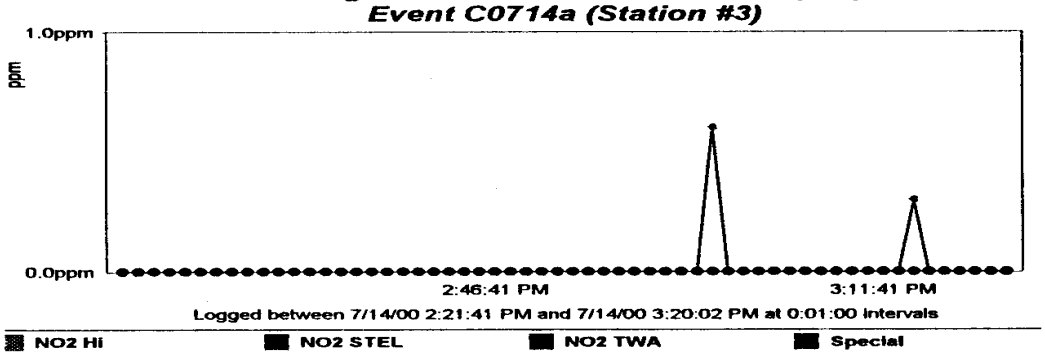
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0714a (Station #1)



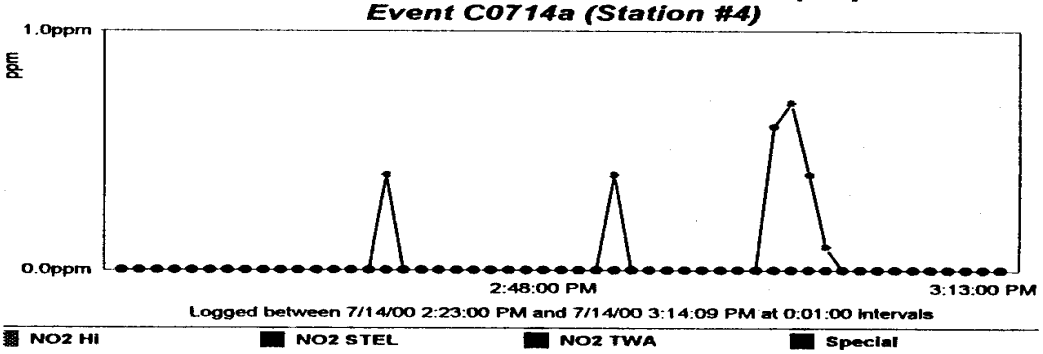
Session #2 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0714a (Station #2)



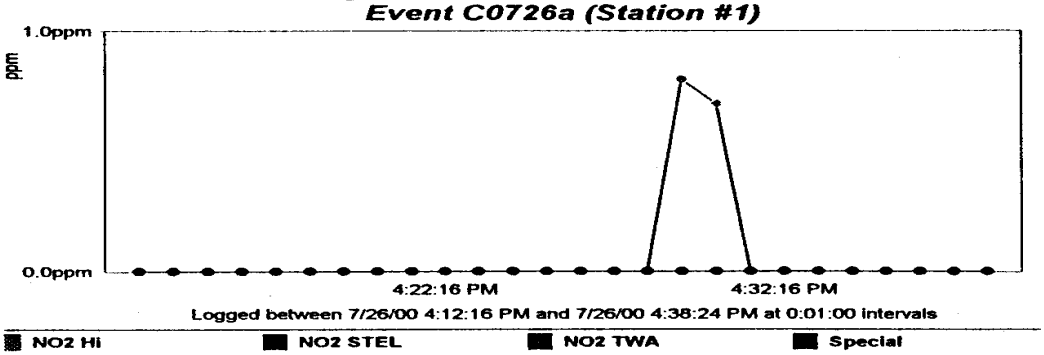
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0714a (Station #3)

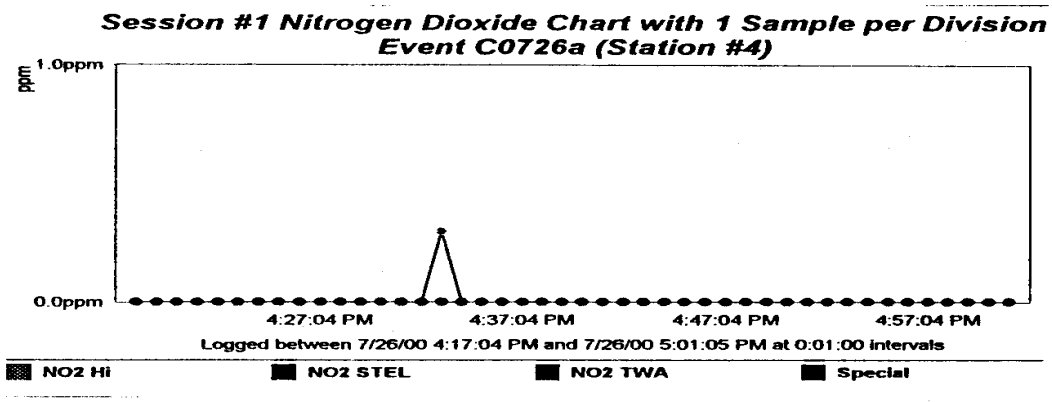


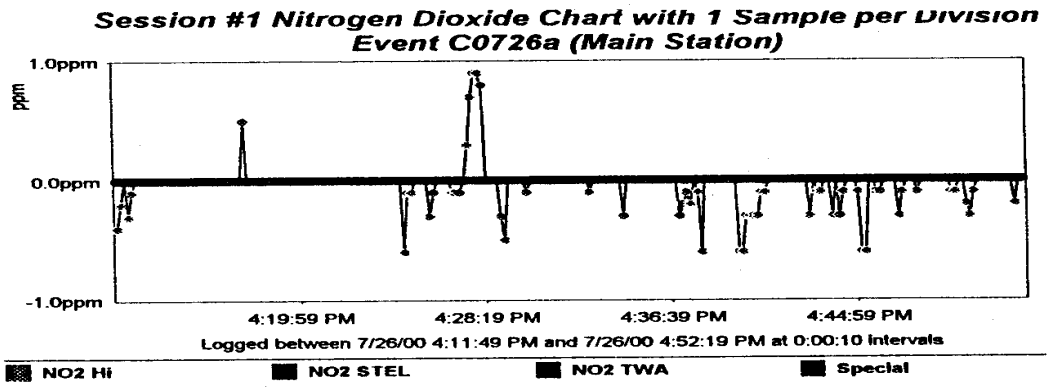
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0714a (Station #4)



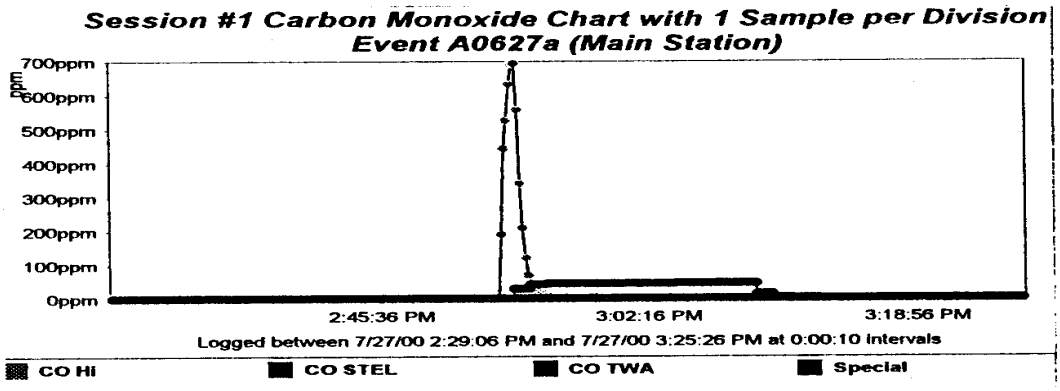
Session #1 Nitrogen Dioxide Chart with 1 Sample per Division
Event C0726a (Station #1)

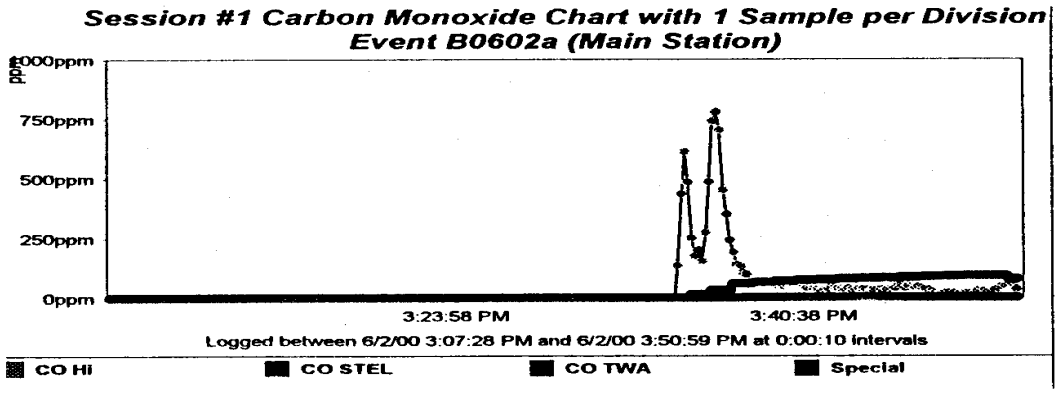


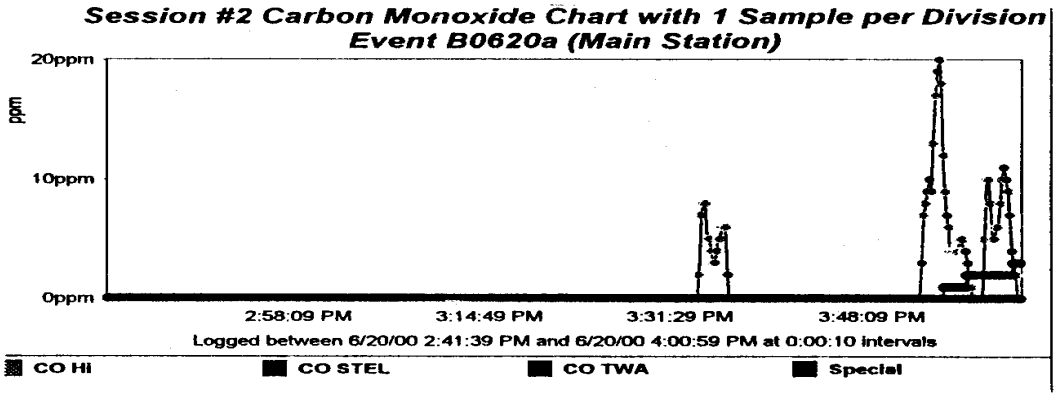


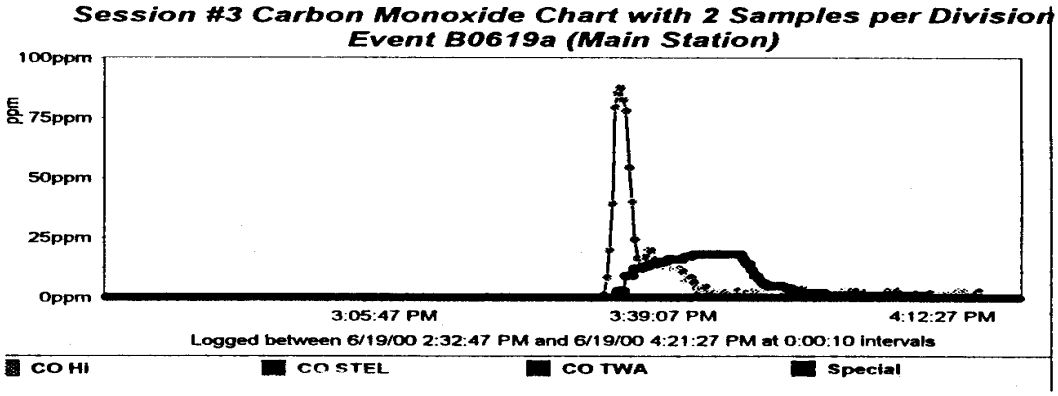


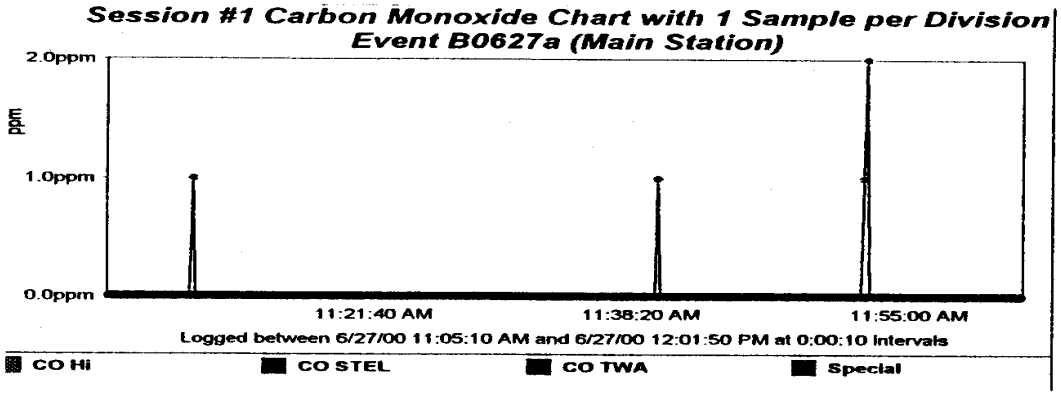
Example of bad main station output for nitrogen dioxide.
Even though the highs are in the expected range, the inconsistencies in the baseline make this data suspect.

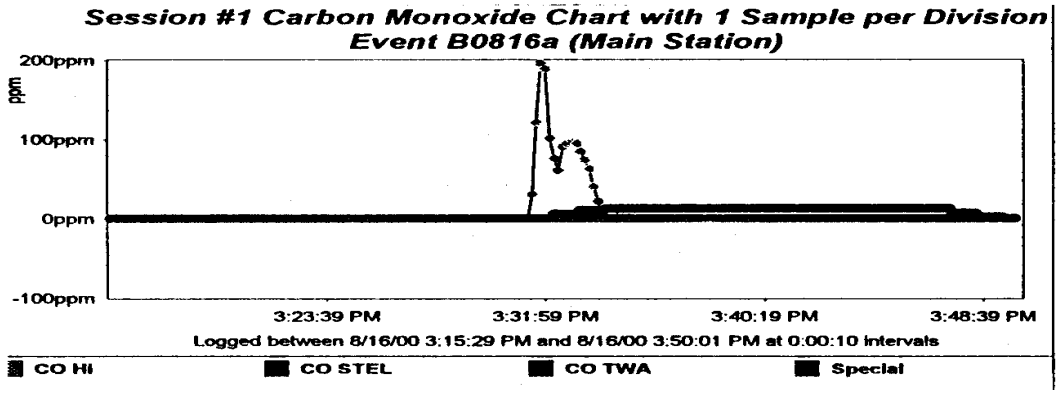

Session #1 Carbon Monoxide Chart with 1 Sample per Division
Event A0627a (Main Station)
ppm
700ppm
600ppm
500ppm
400ppm
300ppm
200ppm
100ppm
0ppm
2:45:36 PM
3:02:16 PM
3:18:56 PM
Logged between 7/27/00 2:29:06 PM and 7/27/00 3:25:26 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special

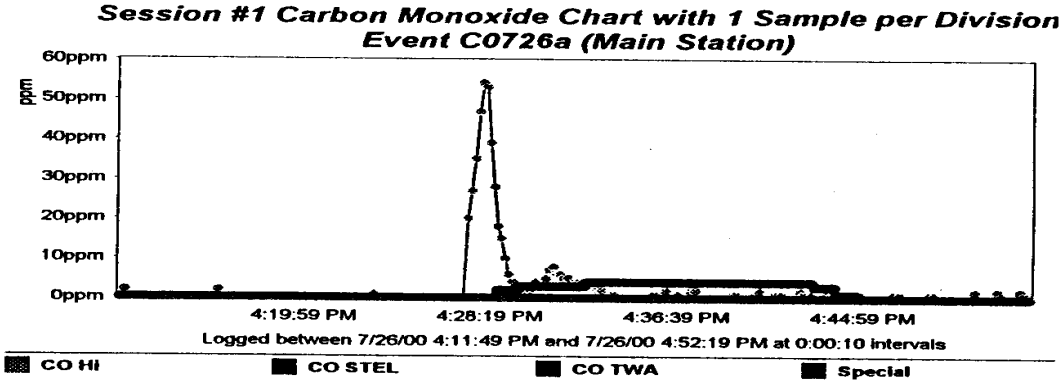

Session #1 Carbon Monoxide Chart with 1 Sample per Division
Event B0602a (Main Station)
ppm
1000ppm
750ppm
500ppm
250ppm
0ppm
3:23:58 PM
3:40:38 PM
Logged between 6/2/00 3:07:28 PM and 6/2/00 3:50:59 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special

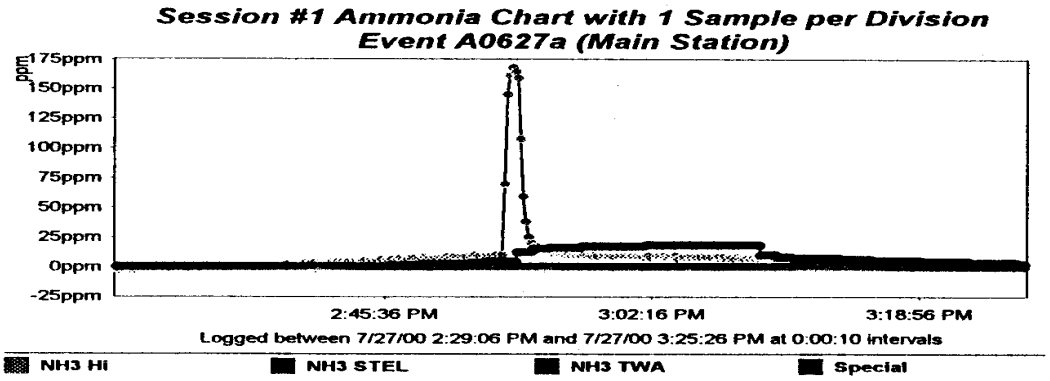

Session #2 Carbon Monoxide Chart with 1 Sample per Division
Event B0620a (Main Station)
ppm
20ppm
10ppm
0ppm
2:58:09 PM
3:14:49 PM
3:31:29 PM
3:48:09 PM
Logged between 6/20/00 2:41:39 PM and 6/20/00 4:00:59 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special


Session #3 Carbon Monoxide Chart with 2 Samples per Division
Event B0619a (Main Station)
ppm
100ppm
75ppm
50ppm
25ppm
0ppm
3:05:47 PM
3:39:07 PM
4:12:27 PM
Logged between 6/19/00 2:32:47 PM and 6/19/00 4:21:27 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special

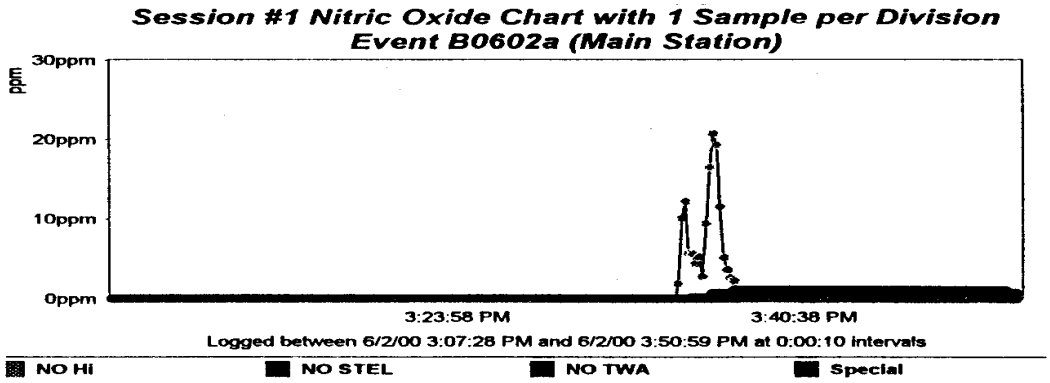

Session #1 Carbon Monoxide Chart with 1 Sample per Division
Event B0627a (Main Station)
2.0ppm
ppm
1.0ppm
0.0ppm
11:21:40 AM
11:38:20 AM
11:55:00 AM
Logged between 6/27/00 11:05:10 AM and 6/27/00 12:01:50 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special


Session #1 Carbon Monoxide Chart with 1 Sample per Division
Event B0816a (Main Station)
200ppm
ppm
100ppm
0ppm
-100ppm
3:23:39 PM
3:31:59 PM
3:40:19 PM
3:48:39 PM
Logged between 8/16/00 3:15:29 PM and 8/16/00 3:50:01 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special


Session #1 Carbon Monoxide Chart with 1 Sample per Division
Event C0726a (Main Station)
60ppm
ppm
50ppm
40ppm
30ppm
20ppm
10ppm
0ppm
4:19:59 PM
4:28:19 PM
4:36:39 PM
4:44:59 PM
Logged between 7/26/00 4:11:49 PM and 7/26/00 4:52:19 PM at 0:00:10 intervals
CO Hi
CO STEL
CO TWA
Special



Compare form of curve to same event curve for carbon monoxide.



Conpare form of curve to same event curve for carbon monoxide.

5.6 Conclusions

Dust and fume emissions from 11 blasting events at three mines were measured, 10 of which were useable. Both respirable and non-respirable dust was measured, as well as nitrogen dioxide (NO_2), nitric oxide (NO), carbon monoxide (CO), and ammonia (NH_3). Nitrogen dioxide, total dust, and respirable dust were measured at 10 points for each event; the remaining fumes were measured at only one. At four events, settled dust at the monitoring stations was caught on filter paper and photographed. Results are consistent, but the statistical correlations are poor. The suspected primary reason for poor correlations is the inability to account for wind velocity across the measurement sites close to ground level. Surprisingly, the best correlation (r = 0.86) was an inverse relationship between NO_2 and humidity. The CO and NH_3 highs were also a surprise. Topographical constraints, although expected, were worse than expected. Topographical constraints were such that all sites were within 1900 feet, with an average distance of 943 feet. This was actually a fortuitous turn of events because of the very low levels of anything that were detectable as the stations approached 2000 feet.

The basic results are presented in Table 5.5:

Dust, Respirable::	**Max:**	**0.34 mg**	**Min:**	**0 mg**
	Max over 1000 ft:	**0.21 mg**	**Min over 1000 ft:**	**0 mg**
Dust, Total:	**Max:**	**0.66 mg**	**Min:**	**0 mg**
	Max over 1000 ft:	**0.10 mg**	**Min over 1000 ft:**	**0 mg**
Nitrogen Dioxide:	**Max:**	**4.2 ppm**	**Min:**	**0 ppm**
	Max over 1000 ft:	**1.0 ppm**	**Min over 1000 ft:**	**0 ppm**
Nitric Oxide:	**Max:**	**48.7 ppm**	**Min:**	**0 ppm**
	Max over 1000 ft:	**9.8 ppm**	**Min over 1000 ft:**	**0 ppm**
Carbon Monoxide:	**Max:**	**780 ppm**	**Min:**	**2 ppm**
	Max over 1000 ft:	**88 ppm**	**Min over 1000 ft:**	**2 ppm**
Ammonia:	**Max:**	**168 ppm**	**Min:**	**0 ppm**
	Max over 1000 ft:	**25 ppm**	**Min over 1000 ft:**	**0 ppm**

Table 5.5 Summary of collected data
(Compare these to the ACGIH TLV's in Table 1.1)

Maximum measurements were of very short duration. Even where measurements exceeded thresholds for the workplace, they were 1) of exceptionally short duration and 2) located within a zone where no individual would be permitted during blasting. There were some equipment difficulties, the primary one being the failure to achieve proper operation of the main station NO_2 monitor. Therefore the ratio calculations that we had anticipated being able to do are not possible. Still, where the main station is close to another monitoring station and the distances are equivalent, inferences may be made.

We find no indication that there are any significant health risks due to exposure to large blasts when no personnel are in close proximity to the blast zone. This is the standard procedure for safety purposes anyway; as the blasts become smaller, the safety zone may decrease. Vibration limitation requirements result in very small blasts when as the distance to off-site structures is reduced . Even within 1,000 feet of a large blast, measurements of adverse levels of fumes and dusts are infrequent and of short duration.

This investigation is concerned with fugitive dust and fumes, meaning that which escapes the confines of the mining property. This investigation indicates that these emissions present no potential health problem for the following reasons.

- No event produced any harmful levels of any duration at distances exceeding 1,000 feet, except one measurement of 3.6 ppm NO_2 at 1251 feet.
- This measurement, and all others were of very short duration.
- Fugitive emissions are those that leave the property; if the property boundary is closer than 2,000 feet, persons within this area are evacuated.

Quality of life issues other than health, that is the enjoyment of life and the potential of reducing that enjoyment, is harder to define because of its very subjective nature. Photographs of dust settling out of blasting clouds do not show significant deposition beyond 1000 feet.

6.0 RECOMMENDATIONS

6.1 A Word About Approach

When is enough enough? Buried in this cliché is a very real problem. Just because it is possible to measure something, or measure it more accurately, does not mean it is best to do so. There were a lot of expectations coming into this project, not all of them reasonable. Would we be able to determine dispersion and diffusion factors? Could we pick out the quartz? Could we separate the gases? Some of these expectations were ours, some from others. Limiting factors on these expectations were resources: time, manpower, budget. Ultimately, of course, multiple times, we had to return to two basic controlling guidelines: What was the scope of work, and what were the resources? The two questions in the scope of work were to determine if hazardous levels of dust and fumes traveled far enough from the blast site, and if they represented an annoyance that impacted the quality of life. The first is a simple yes-or-no question, not requiring information in enough detail to model. Simply put, has a threshold been crossed? The second is a value judgement, much more difficult to answer and even more difficult to obtain objective input for. And the budget was $63,000.

For much of my professional life I have used Occam's Razor[1] as a guide. When I share this with someone, the most frequent response I receive is, "Ah, yes, the Law of Parsimony!" This is absolutely wrong, but understandable since many references themselves make the same mistake, especially internet sources. The difference is crucial. The Law of Parsimony (also known under several other names) states that when multiple explanations are available for a cause or event, the simplest is most likely true and should be used. Occam's Razor states, "Thou shalt not multiply complexities unnecessarily," an instruction to avoid adding unnecessary components. The first is a statement about the nature of reality, the second is a directive governing the observer's behavior.

In the scientific and engineering community there is a great tendency to use tools just

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[1]Also known as Ockham's Razor -- first expressed circa 1358.

because we have them. Why measure to an inch when we can measure to a micron? Why weigh an once when we can weigh a microgram? And more. The broad general assumption is that more information is better. If this information cannot be used now, perhaps in the future. But by analogy, it is easily seen not to be the case. Does an individual buying a fifty-foot piece of rope really need to know that it is 50.002364 feet long? No. Does the mechanical engineer really need to know that the piston is 5.0000±0.0001 inches? Yes. So the answer is based on a need to know, the application, and the question to be answered.

I have seen more than one project where basic information, the really important stuff, was lost in a flood of extraneous information. (And don't forget that added resources were expended to obtain that extraneous information.) The resulting clutter of data can bury or obscure the simple underlying principle. There is *so much* to look at that the simple relationships just aren't discernable. This is especially true in initial work. Often orders-of-magnitude for variables of interest are not even known, and thus a good choice of instruments is difficult. In practice, budget withstanding, the "best" instruments are chosen. However, in a case such as this, a "tape-measure" approach is best; obtain a general measurement as a starting point. A decision on whether a micrometer, a vernier, or a theodolite is needed can be made afterwards with some assurance. This is the situation we found ourselves in for this project.

Occam's Razor has long been an indispensable item tool in my toolbox. If an approach, an instrument, or a technique does not add either understanding or increased accuracy to the answer, I do not use it. What is the point of creating a differential model if the rate functions that should drive it are not known? It helps me avoid this tendency to over-use tools, especially mathematics, when the underlying principles are neither defined nor understood. Many models are created that do not produce useable output for this reason.

So was Occam's Razor used here? First, limited funding meant limited instruments. Either we could learn a lot about a single point, or learn less about multiple points. Knowing that we would have difficulty in placing a single point in context, we chose to measure multiple points. With the uncontrolled variables of weather, wind speed and direction, shot confinement and efficiency, and more, it would have been impossible to place one point in context, and it would have been at least difficult and probably impossible to compare two points from two different shots in any meaningful way with all of those variables operating. Multiple points at least provided multiple measurements within each blasting event. In this initial investigation of

an eastern blasting cloud we did not even know what magnitudes to expect, an important criterion for selecting instrument sensors. None of the experts we consulted could even suggest a starting point. So we opted to purchase as many basic instruments as we could afford that had the option of changeable sensors. For determining station locations, what accuracy was needed? Again, with the distances involved, with the rapid changes of terrain within the measurement areas, and with the variations in plume movements that we expected, we decided that surveying-precision and the attendant cost and labor involved were not warranted, especially in light of the time available for station set-ups. Global Positioning Surveys would be adequate; measurement errors are a small fraction of the distances involved. (We were also fortunate in that the government ended GPS scrambling just weeks before our first field trip.) How do we measure the impact of dust on the quality of life? In other words, with real data, weights-and-measures, just how would one judge these dust weights or size distributions as perceived nuisances? Late in the project we decided that nuisance essentially meant visible dust (health is another matter, of course). After all, this is the basis of most dust complaints. Therefore we decided to set up large filter papers to collect dust and actually *see* what the dust deposition *looked* like. And there are other examples as well. The point is that a simple question was asked about a phenomenon that has not really been investigated before, and ultimately we translated a limited budget and a very specific question in the most useful approach possible. Occam's Razor pointed the most direct path.

This is a very detailed explanation to arrive at the next point I wish to make. We strongly recommend that a similar but much broader approach be used in any follow up activity. For example, the largest variables of concern are time, wind, and distance. Rather than setting up six more sophisticated instruments, setting up fifty or a hundred simpler instruments in a plume path. This would add immensely to the ability to define the plume, whereas a couple of detailed points would not This approach would require a lot of sensors, and a field team, not just two investigators in a single vehicle. But this approach could very well help produce data leading to the definition of dispersion and diffusion factors. It is our current belief that each individual shot is so unique that it will be very difficult to combine individual data points from different blasting events in a meaningful, trustworthy way without a substantial database. Comparing dispersions, however would be easier. It would take a large number of stations to do this. Fortunately, personal monitoring devices would be accurate enough to do this and represent a

real value over research-level instruments. In this case the difference between 2. 4 and 2.8 milligrams or parts per million is important. The difference between 2.44 and 2.46 probably is not; it is the difference of moving a station 20 or 30 feet one way or another, or difference turbulence makes in moving one portion of a cloud this way or that.. More than one individual expressed concern when we indicated that we were using personal monitoring devices instead of research-level instruments. However, these instruments *are* accurate enough to entrust individual safety and health to them and have thus already passed regulatory scrutiny for accuracy within their stated limits. And the required added research *is still* in the mode of having to measure fifty-foot pieces of rope.

6.2 Recommendations for Future Work

This investigation gives an insight into the hazards and nuisances to be expected from blasting. It is based on a small number of blasts, ten, and data points, six per blast, plus a photographic record. It is enough to show that fugitives from blasting are minimal, but not enough to accurately define cloud movement, dispersion, or diffusion of clouds from blasting. Additional work needs to be done

6.2.1 Information to Obtain

6.2.1.1 Blasting-Related Information

More information points need to be obtained, and not only more blasting events, but more data points per event. More information on wind velocity needs to be obtained. The strong correlation between fumes and humidity indicates that there may be greater weather impacts than originally suspected; data needs obtained under a wider range of weather conditions, including extreme cold, heavy precipitation, and stronger winds. None of the measured events occurred during a wind strong enough to move a blasting cloud at a high velocity.

6.2.1.2 Non-Blasting Related Information

To answer the quality-of-life issue regarding fugitive emissions for residents near MTR blasting (or all MTR operations for that matter), the dust in these residential areas needs to be assessed by source. In other words, the dust that does exist needs to be identified by source: What comes from mining operations, and what comes from local road traffic and agricultural and recreational activities. (Several times during this investigation, the PI observed local residents running on the back roads and trails on ATV's, twice trespassing on mine property.)

6.2.2 Potential Methods

If the investigators had this work to perform again, they would make at least two substantial changes.

First, we would use helium balloons to determine wind direction. Such balloons would be relatively inexpensive, and if launched from a blast site would travel in the same direction as the average cloud movement until an altitude was reached that was above ground effects. Launching of several balloons from different locations or from one spot at different times would identify local variations.

Second, we would make much fuller use of the large filter disks to catch settled dust. These are inexpensive, and a large number could be place in the area of expected cloud travel. The use of a GPS system greatly simplifies locating them in relation to the blast site. With some advance design work, perhaps a better way to use these filters, or an alternative method for obtaining the same information might be developed. An adhesive surface sounds attractive, but we tried them and they were disappointing; once a thin covering develops, subsequent dust does not adhere.

We are of the opinion that this work is still at the level where there is a larger payback for using more less expensive monitors than fewer more expensive ones. Ultimately, the success of any follow-up work will depend upon having many more points at many more events. Specific recommendations would include:

- The use of more dust pump placed more broadly around the blast, covering a larger area.
- The use of more gas monitors, not only at more sites, but more per site to cover more gases. (Our experience is that the individual monitors were more dependable than the

larger multi-gas unit.)

- Use of a method to measure the visual impact of settled dusts, and using this method as broadly as possible.
- Use the same methods around other dust sources, such as haul roads, drilling, draglines, etc. It is important to map these values over distance, not just to find single-point values.
- Use the same methods off-site in the area of received complaints.
- Use the same methods off-site and in an area substantially removed from MTR mining, but with similar roads and similar agricultural and recreational activity.
- Use the same methods during weather extremes.

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