

**CO Migration from Trench Blasting in Amherst, New York**  
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**Abstract**

The New York State Department of Transportation recently commenced highway widening and drainage improvement projects in Clarence and Amherst, NY. Drainage improvements including the installation of storm sewer lines required excavation to a depth of 2.5 m (8.2 ft).

In September 2002, NYSDOT stopped further blasting when 800 ppm CO was detected in the basement of a house near the blasting site. At the insistence of NYSDOT, the general contractor developed a new blast plan with the assistance of an environmental consultant. The plan provided for the installation of multi-gas monitors in buildings of special concern and/or with basements and residential type CO monitors in all other buildings within 100m (330 ft) of the blast. The multi-gas monitors would be remotely monitored. The plan provided action levels which would ensure public safety. The blast design was also modified to allow for better venting of CO. Blasts were limited to 20 ft lengths. The overburden was to be removed from the rock and blasting mats put in place to prevent flyrock. Approximately twenty feet of trench adjacent to the blast was left open to allow ground movement and gas release.

The use of CO monitors was effective to alert occupants of a building to the presence of CO. The most effective appeared to be the residential type CO alarms with digital readouts. They were simple and easy to use and allowed the public to participate in the process. False alarms were repeatedly received with the more sophisticated instrumentation. Residential type CO monitors are preferable to warn people near blast sites. More sophisticated instrumentation should be avoided unless personnel are experienced in its use.

A general overview of the blasting and monitoring is presented and discussed. The use and effectiveness of residential type CO monitors and multi-gas monitors are discussed.

## Introduction

Toxic gases such as carbon monoxide (CO) and nitrogen oxides (NO<sub>x</sub>) are produced by the detonation of explosives. The implications and minimization of such products have been studied for decades. Over the past decade there has been an increased interest in the toxic gases that are released during some large surface mine blasts. More recently, the mining and construction industry has been concerned with toxic detonation products that may travel laterally through the earth rather than vent to the atmosphere.

The NYSDOT has recently commenced two consecutive reconstruction projects on the same highway corridor. The contracts were awarded to two different prime contractors. Both projects included the installation of new storm sewer lines, requiring removal of bedrock and both prime contractors hired the same blasting subcontractor to break up the limestone bedrock. Beginning in April of 2002, carbon monoxide (CO) was detected in homes and businesses near the blast site in Clarence, NY. NYSDOT contacted their consultant to screen the structures in the vicinity of the blasting operations and assist in determining the possible cause and migration routes of the CO. In May of 2003, NYSDOT asked NIOSH for assistance with this problem. NIOSH personnel traveled to Amherst on several occasions to view the incident site, study the data, and advise NYSDOT personnel on techniques for minimizing the movement of CO. NIOSH personnel plan to combine the information collected at this and similar sites with the results of NIOSH research to develop guidelines to minimize the possibilities of workers or the public being injured by CO from blasting. Migration of CO from a blast into nearby structures is not a common occurrence but has been observed and reported.<sup>1,2,3,4,5</sup>

Excavations for installation of sewer lines along the street required that a trench be excavated to a depth of 2.5 to 4.5 m (8.2 to 14.8 ft). Hard Onondaga limestone was encountered at a depth of about one meter (3.3 ft). The hardness of the limestone was one of the reasons the contractor chose to use blasting as the primary method of breaking up the rock. Mechanical means of breaking the bedrock were also employed, but were less effective and efficient in some areas.

## Background

NYSDOT first became aware of the occurrence of CO migrating into homes and businesses on a Clarence, NY, Erie County project in April 2002. On April 9, a homeowner near the excavation site reported that a CO alarm indicated elevated levels of CO were present in his two-story frame house. The homeowner and the NYSDOT Engineer in Charge (EIC) of the project suspected that blasting may have caused the elevated CO readings. Later in the day, NYSDOT's environmental consultant visited the home and detected 57 ppm CO in the basement. Further investigation was inconclusive as to the cause of the elevated CO in the residence. On April 10, another nearby resident in close proximity to the blast site reported that a CO monitor in the basement had alarmed. The consultant visited the home and five others nearby and measured for CO. Although no significant CO was detected, the NYSDOT EIC and the Construction Environmental Coordinator (CEC) asked the consultant to purchase and install CO monitors in the six homes. The following day, five more CO monitors were purchased and installed. Blasting and CO monitoring continued through April, May, and June 2002. The highest CO levels detected were 318 ppm and 111 ppm on May 30 and 31 in the basement of one business.

The building was ventilated by opening doors and windows. No CO was detected in any of the other homes or businesses monitored during this time period. However, awareness of blasting related CO was raised.

In August 2002, the NYSDOT commenced a second reconstruction project involving another area of the same highway corridor, in the town of Amherst, NY, Erie County. Due to the concerns on the previous project regarding the possible generation and migration of CO, the NYSDOT EIC and CEC requested the NYSDOT's environmental consultant to install CO monitors in basements or crawl spaces in nearby structures. Initially three CO monitors were employed, with five more being purchased the next day. The monitors were installed in basements or crawl spaces of eight nearby homes. The monitors were moved as the blasting progressed. NYSDOT's environmental consultant checked the monitors on a daily basis, simultaneously taking readings with a real time quad-gas monitor. Table 1 contains summary information on the CO incidents.

**Table 1 – Summary information on CO detected.**

<b>Date</b>	<b>Location Of CO Monitor</b>	<b>Peak CO Reading</b>	<b>Time Elapsed Since Last Blast</b>	<b>Last Blast Total Explosive Weight</b>
8/28/02	Basement, adjacent to sump pit	213 ppm	Approximately 14 hours	1030 lb (467.2 kg) dynamite
9/12/02	Basement, adjacent to foundation crack	67 ppm	Approximately 12 hours	165 lb (74.8 kg) dynamite 400 lb (181.4 kg) ANFO
9/12/02	Residence beyond 100 Meters from blast zone	90 ppm	Approximately 16 hours	
9/20/02	Basement, adjacent to sump pit	800 ppm	Approximately 18 hours	110 lb (49.9 kg) dynamite 275 lb (124.7 kg) ANFO

The first occurrence of CO on this project, took place August 27, 2002, see Figure 1, and was attributed to an automobile running in the garage. The first definite sign that CO was migrating from the blasting occurred on August 28, 2002, when 213 ppm was recorded in a basement. This incidence was followed by two occurrences of elevated CO recorded on September 12. In the first instance, the CO alarm located in the basement adjacent to a crack in the foundation alarmed when the concentration of CO peaked at 67 ppm. In the second instance on September 12, a resident living just beyond 100 meters from the blasting area contacted the EIC to report their own CO monitor had been periodically alarming. They initially disregarded the alarm. An investigation disclosed that CO was present in an unlined sewage ejection pit in the basement at 90 ppm. This appeared to be the avenue by which the CO entered the home. No other source of CO was identified.

At 2:00 AM on September 20, 2002, the CO monitor in a group home located along the project corridor sounded. A CO reading of 800 ppm was present in the basement at that time. The fire department was contacted and the building was evacuated. The NYSDOT environmental

consultant later surveyed the home for CO. The only CO detected was near the sump in the basement. The sump was covered with plastic and the environmental consultant measured 70 ppm in the vicinity of the sump several hours later. The NYSDOT and their environmental consultant were able to positively identify the sump as the point of entry. No other sources of CO were evident.

These occurrences of blasting-generated CO migration revealed a pattern of CO building in the ground and then migrating to a point of escape, such as a sump pit. The inability to force people living along the project corridor to react to the CO monitors, or in some cases, to initially accept the monitors, concerned NYSDOT personnel. Concerns were also raised regarding the 100 meter threshold for CO migration.

On September 23, 2002, NYSDOT told the construction and blasting contractors that blasting could not resume until a new blasting plan was developed that better addressed the issue of CO migration. During late September and October, three proposed blasting plans were reviewed and rejected by NYSDOT. The plans were rejected due to lack of clarity, comprehensiveness, and likelihood of controlling the generation and migration of CO. The project work slowed at this time due to winter shutdown. In the spring of 2003, the contractor used mechanical means to break the rock for removal. This practice worked well in some areas but proved highly inefficient in others.

Because blasting of the bedrock was the method chosen by the contractor, the NYSDOT emphasized that the contractor needed to take a more active role in the monitoring process and in the risks and uncertainties associated with blasting and CO migration. This request was granted. The contractor submitted a new blasting plan in early May 2003, that included taking on responsibility for monitoring. After significant discussion and revisions, it was approved on May 14, 2003. The blasting plan specified that prior to a blast, the contractor's environmental consultant would survey each building within 100 meters (330 ft) of the blast. This survey would:

- 1) indicate whether each house had a basement or was built on a slab,
- 2) identify potential pathways for toxic gases to migrate into the structure (e.g. gas lines, water lines, sewer lines, telephone lines, etc),
- 3) provide each owner/resident with a notification letter,
- 4) contact the owner or resident of each structure, conduct an internal inspection to identify the locations where toxic gases could enter the structure (e.g. sumps or dry wells), and identify any special conditions/uses,
- 5) determine the type(s) of air monitoring equipment that should be installed in each structure and the location(s) where the monitoring equipment should be installed, and
- 6) identify other potential sources of toxic gases.

Identification of a slab or basement construction was thought to be an indication of susceptibility to CO migration. Typically, potential entry points such as sumps or drains are located in a basement. Slab construction would not have these potential entry points. Previous blasting revealed 4 out of 5 high readings occurred in homes with basements. Routes of entry included sumps and a sewage ejector pit.

The blasting plan also required that toxic gas monitoring instrumentation be employed. The contractor's environmental consultant set up five AreaRAE monitors (<http://www.raesystems.com/area.html>) in five buildings of special concern for continuous remote monitoring of CO, nitrogen dioxide (NO<sub>2</sub>), and oxygen (O<sub>2</sub>) concentrations.♦ The AreaRAE monitors are electrochemical-cell based instruments that sample every 2 minutes and radio transmit the data to a central laptop computer. Nighthawk CO monitors were also placed in each home and business within 100 m (330 ft) of the blast.♦ The Nighthawk CO monitors were intended to alert residents in the event that the CO concentration reached levels of concern. These units were designed to alarm within 90 min at 100 ppm CO, 35 min at 200 ppm CO, and 15 minutes at 400 ppm CO.<sup>6</sup> The Nighthawks also recorded the peak CO level occurring since the last time they were reset. Periodically, the consultant's personnel would check the Nighthawks and reset them. The NYSDOT environmental consultant continued to act in an advisory and backup monitoring capacity. The AreaRAE multiple gas detectors were to be put in place at least 24 hours prior to blasting. Action levels were set at 9 ppm for CO and 0.25 ppm NO<sub>2</sub>. If concentrations exceeded the action levels, the person monitoring the instrumentation was to notify a contact person in the affected building, the fire department, the contractor, and NYSDOT. The instrumentation is illustrated in Figure 2. Figure 3 shows the placement of toxic gas monitoring instruments and the location of the first blast.

The first blast was scheduled for the morning of May 15, 2003 (see Figure 7). On the evening of May 14, the environmental consultants for the contractor and NYSDOT set up the AreaRAE and Nighthawk monitors. The consultant for NYSDOT also spoke with the residents and explained the functioning and purpose of the monitors; he reported that all the residents were receptive and cooperative. In the early morning hours of May 15, the AreaRAE at the Youth Center alarmed when it detected 0.4 ppm NO<sub>2</sub>. Following an investigation it was determined this was a false alarm and the NO<sub>2</sub> alarm level was reset to 1 ppm.

The first blast was conducted at approximately 11:00 AM on Thursday, May 15, 2003. The blast consisted of ten holes, twelve to fourteen feet (3.7 to 4.3 m) deep, each loaded with four or five 2.25- x 16-in. cartridges of dynamite and seven feet (2.1 m) of stemming. Interval blasting involving the removal of the overburden from the rock and the blasting of 20 feet (6 m) sections into an open trench was employed to allow for easier release of explosive fumes. Blasting mats were placed on the shot to prevent flyrock. Steel plates were also placed over the open trench end to minimize flyrock. All shot rock would be excavated immediately following detonation of the blast. The excavation would be left open to allow the toxic gases generated from the blasting operations to vent. Figures 4, 5, and 6 illustrate the setup for the blast. A total of four blasts were conducted on May 15, followed by four blasts on May 16.

Over the weekend of May 17-18, the AreaRAEs alarmed several times for NO<sub>2</sub> but an investigation of the alarms attributed them to either response of the NO<sub>2</sub> sensor to chlorine bleach in a laundry room, a software setup error, or a calibration error. No significant CO was detected. Blasting resumed on Monday, May 19.

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♦ Use of brand names is for informational purposes only and does not imply endorsement by NIOSH.

Blasting continued without incident until May 28 when 6 ppm CO was detected in the youth center. An investigation revealed that CO was entering the building through a basement sump pit in a storeroom and through cracks in the floor under a sink. A window fan was installed to help ventilate the storeroom area.

In the early morning hours of May 29, a check of the youth center revealed 35 ppm CO in the sump pit. In an effort to keep CO out of the building, plastic was taped over the sump and the cracks under the sink were sealed with duct tape or caulk. At about 10:00 that morning, 400 ppm CO was detected in the sump pit. By noon the CO in the sump pit had risen to more than 1,500 ppm. NYSDOT suspended blasting operations because the blasting plan had failed to prevent migration of CO into the youth center. A vent pipe and additional fans were employed to reduce the levels of CO in the basement.

On May 30, a meeting was held to discuss revisions to the blasting plan that would aid in preventing future CO migration. The participants at the meeting believed that CO migration had become a problem because the blaster gradually raised the number of shots from four a day (165 – 200 lb [74.8 – 90.7 kg] dynamite per shot) to six a day (170 – 300 lb [77.1 – 136.1 kg] dynamite per shot), and possibly leaving insufficient time to vent the CO between blasts. To address this, the blasting plan was revised to provide for shooting alternately at two different locations, allowing the CO more time to vent between blasts. The revised plan required at least three hours between each blast in one area. Each area was to be a minimum of 300 meters apart. No more than 4 blasts in one day were to be allowed. Additionally, ventilation holes were dug down to any utility lines along the right-of-way within 100 m (330 ft) of the blast. These vent holes were intended to both provide venting of the CO and track the migration of the CO. Other parts of the blasting plan were also revised based on the experience gained during the previous month.

The blast plan was revised and blasting resumed on June 17, 2003. Blasting continued with low level CO migration occurring. CO readings were recorded ranging from 0.4 ppm to 1.1 ppm. On June 21, 2003, the contractor's operations were suspended in one of the two blasting areas, by National Fuel Gas, due to elevated seismic displacement. The contractor requested that blasting be increased in the remaining area. NYSDOT denied this request. The current approach of blasting in two alternate areas appeared to be keeping CO migration to a minimum.

It was agreed to allow the contractor to blast in one area with the condition that they install standpipes at routine intervals in the previously blasted trenches to allow any trapped CO to vent. The standpipe was a 24 inch PVC pipe surrounded by pea gravel. The pipe was placed in previously blasted and broken up rock at a depth equivalent to the bottom elevation of the blast. The standpipe was placed as close as possible to the area being blasted. See Figure 8 for details. The standpipe appeared to allow the CO a direct venting pathway. Levels ranging from 30 ppm to 1500 ppm were recorded at the standpipe. At the urging of NYSDOT and their environmental consultant, the contractor began ventilating the standpipes after blasting, to attempt to remove the CO *before* it migrated. At one point, in an effort to reduce CO levels faster in the trench, the contractor excavated a vent pit next to the standpipe.

The level of CO was monitored at both utility lines and the standpipes. When the level of CO was below 200 ppm, and at least three hours had passed, blasting would resume. If 200 ppm or more CO was measured at any monitoring point (house, office building, utility line, standpipe, etc.), or the three hours had not elapsed, no blasting was allowed. Utilizing the standpipe, vent pit and ventilation strategies continued even after blasting in two different areas resumed.

## Discussion

In an effort to prevent CO migration from the blasting site to the nearby structures, NYSDOT, the general contractor, and the environmental consultants agreed upon a blast plan that detailed not only the blasting activities, but the pre-blast excavation preparations, toxic gas monitoring efforts, and necessary emergency response and notifications. Information collection activities were detailed in the blast plan. This included pre-blast surveys of all buildings within 100 m that would identify potential sources of entry. Internal inspections of the potentially affected structures would be performed. Potential pathways such as utility lines would be identified. The blasting approach was defined as interval blasting and the explosives to be used were required to be IME Fume Class 1. The removal of overburden and use of blast mats was specified in the blast plan. Immediate excavation of shot rock was also required. Utilizing a standpipe as a venting mechanism was also later employed. In the event of high readings or an alarm on the gas monitoring equipment, an action plan for the occupant and the remote monitoring person was also developed.

Some valuable lessons were learned from the blasting discussed here. A major difficulty in the May, 2003 blasting was false alarms by the instrumentation. There were several causes for this.

- Failure to install the AreaRAE units 24 hours prior to the first blast. This may have revealed some of the non-blasting related causes for the NO<sub>2</sub> sensor alarm, which would have aided in preventing false alarms.
- The alarm levels for the NO<sub>2</sub> and CO measured using the AreaRAE units were set too low.
- Difficulties in the use of the AreaRAE units.

The AreaRAE instrumentation is based on electrochemical cell science. Users of the instrumentation should have experience with the instruments. The accuracy of the instrumentation should be known, any chemical interactions that may trigger a false reading should be known, and the instrument capabilities in general should be well understood.

Typically, household CO monitors are designed to alarm when exposed to a given CO concentration for a set period of time. The alarm level is set to provide adequate protection while minimizing false alarms. Underwriter Laboratory (UL) recommendations for CO alarm levels for home CO monitors are detailed in UL2034.<sup>7</sup> This philosophy should also apply to CO produced by blasting. Once CO migrates into a home, it is no different from CO produced by a faulty furnace or gas appliance. Rather than developing alarm levels to apply to the detection of CO from blasting, it would seem reasonable to use UL's standard, as detailed in Table 2. In short, commercial home CO monitors seem to be the most appropriate instrumentation for protection from CO migrating from a blast into a nearby structure. Use of more sophisticated

instrumentation by persons who are not experienced in their use may lead to errors and confusion that mask dangerous CO levels.

**Table 2 - Underwriter Laboratory's recommended alarm levels for home CO monitors.<sup>7</sup>**

CO Concentration, ppm	Time Until Alarm Sounds
15	30 days
70	189 min (minimum 60 min)
150	50 min (minimum 10 min)
400	15 min (minimum 4 min)

For the project reported here, NO<sub>2</sub> was monitored along with CO because it is theoretically possible that NO can migrate through the ground along with CO and oxidize to NO<sub>2</sub> when it enters a confined space. Small yellowish-orange clouds were observed after some of the blasts. This is confirmation that NO and NO<sub>2</sub> were being produced in the detonation production gases.<sup>8,9,10</sup> Monitoring appears to confirm, in this instance, the migration of NO<sub>x</sub> was not an issue of concern within the structures.

A factor that can be controlled and can contribute significantly to the CO produced by the blast is the oxygen balance of the explosive used. Figure 9 shows that the CO production of ANFO increases significantly as the oxygen balance becomes more negative.<sup>11</sup> This is confirmed in Explosives and Rock Blasting which states "An excess of oxygen in the explosives can result in the formation of nitrogen oxides (NO and NO<sub>2</sub>) and a deficit of oxygen can cause carbon monoxide (CO) to form."<sup>12</sup> This means that an explosive formulated with too much fuel will produce excessive CO. An explosive formulation with too little fuel will generate excessive nitrogen oxides.

The ISEE Blaster's Handbook recommends, "Where fumes can be a problem, proper formulated and manufactured explosives and blasting agents will give minimum quantities of toxic gases."<sup>13</sup> If ANFO is mixed on site, the blaster should ensure that the ratio of fuel oil to ammonium nitrate is correct. However, the blaster has no control over the formulation of premixed explosive products. For premixed products, only the manufacturer can control the formulation. The manufacturer must ensure that the explosive is properly formulated to minimize toxic fumes production.

At Amherst, a number of techniques were employed to help minimize CO migration. These included:

- shooting into an open pit to allow the broken rock to expand and vent toxic gases,
- removing the overburden prior to blasting and the shot rock after blasting,
- alternating blasting areas to allow sufficient time in between blasts for CO to vent and dissipate (limiting the amount of explosives used at any one site and in any one day), and
- installing standpipes in close proximity to the blast site and ventilating these standpipes until a lower level of CO was measured.



These methods seem to have allowed the continuation of blasting with minimal CO migration occurring and with minimal public involvement. Two instances show the complexity and the possible necessity of each of the involved factors.

1. On June 30, 2003, the concentration of CO in a standpipe prior to loading the shot holes for the second blast of the day, was 16 ppm. The concentration of CO rapidly rose to over 700 ppm as soon as ventilating activities were discontinued. This is when the contractor began excavating a vent pit next to the standpipe.
2. The last two blasts of the Amherst project contained deviations from these procedures. The area being blasted was across the roadway. Therefore, to minimize the impact on traffic, the overburden was not removed prior to blasting. The roadway location also lacked the area needed for a standpipe or vent pits. It was determined that the storm sewer manholes, installed on both sides of the roadway, would be monitored for CO. It was also decided that the number of shot holes would be limited to reduce CO generation. CO in the storm sewer prior to blasting was 0 ppm. CO readings about 1 ½ hours after the blast exceeded 1500 ppm. The contractor began ventilating the storm sewer. Ventilation brought the levels of CO in the storm sewer manholes down to 425 ppm on the north side and 580 ppm on the south side of the roadway within the next half hour.

The two instances illustrate how the CO may be produced and travel to the point of least resistance.

Another factor that seems to have impeded the migration of CO is the limitation of explosives used within a day in any one area. CO appeared to migrate again, at low levels, when the contractor went back to blasting in one area. The use of standpipes also appeared to have mitigated CO in the ground before it could potentially migrate to an enclosed space.

For the blasting discussed here, factors seemed to gradually change from shot to shot. The prevention techniques employed appeared to curtail the CO migration successfully in this case. However, one cannot say for certain which contributed to or minimized CO migration. One cannot say that the changes to the blast plan prevented CO migration for a given shot because the blaster had probably used the original blast plan previously for hundreds or thousands of shots without a known case of CO migration.

## Summary

The use of CO monitors was effective to alert occupants of a residence to the presence of CO. The most effective appeared to be the residential type CO alarms with digital readouts. They were simple and easy to use. False alarms were received with the more sophisticated instrumentation related to lack of in-depth experience in its use in this application. Residential type CO monitors have provided the best early warning to people near blast sites. More sophisticated instrumentation should be avoided unless personnel are experienced in its use.

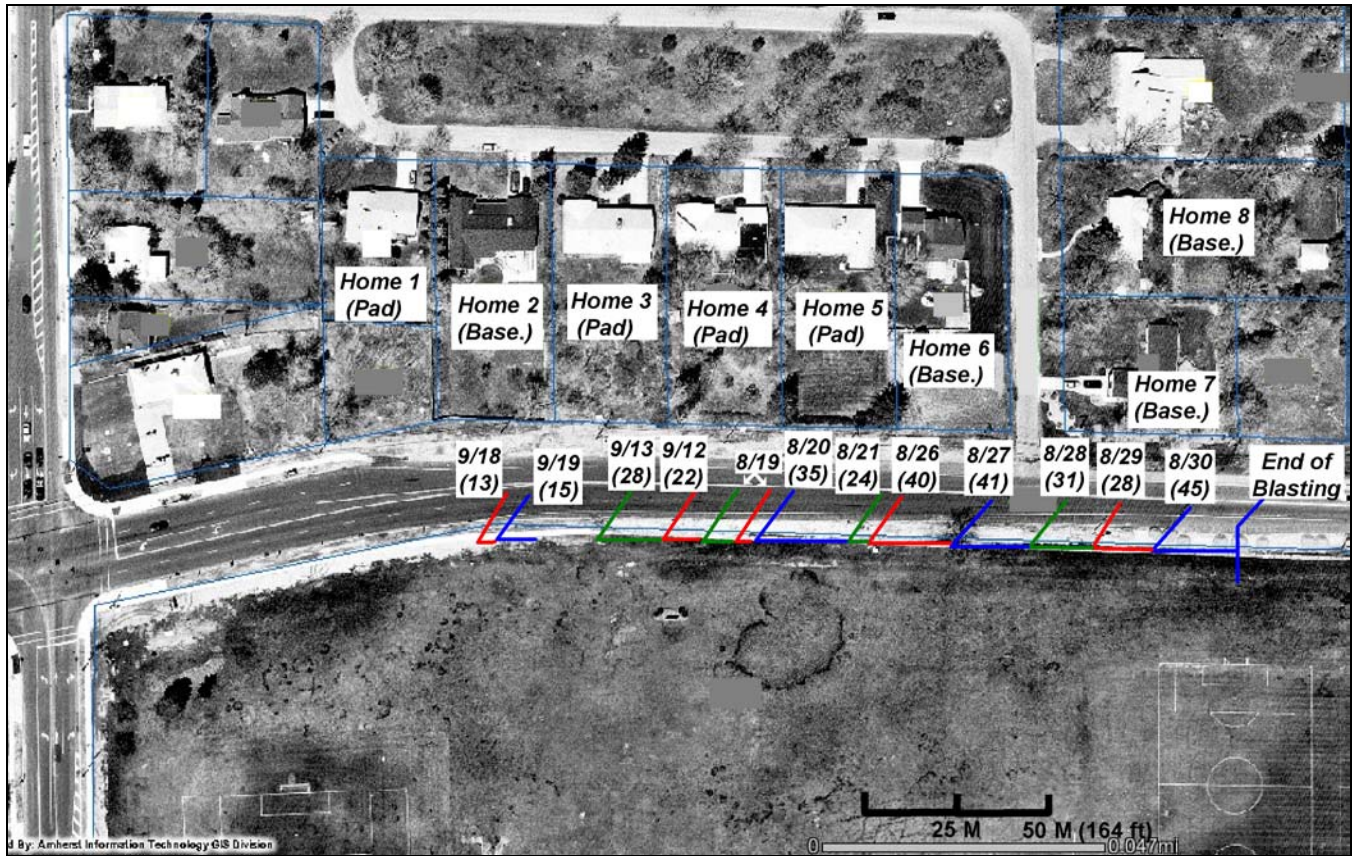
Although many factors changed over the course of the project in Amherst, NY, it appears that the following factors contributed to minimizing the buildup and migration of CO in this location, in this type of bedrock:

- researching the characteristics of the bedrock and the overburden in the area;
- surveying and monitoring all structures within 100 meters of the blast;
- limiting the amount of explosives and the frequency of blasting in any one area within a day's time;
- removing the overburden prior to blasting and using blast mats;
- excavation of the shot rock after detonation;
- utilizing standpipes in close proximity to the blast area; and
- ventilation of the standpipe when CO was detected.

As the blasting continued, the location and circumstances changed. When numerous factors are changing simultaneously, it is not possible to say which one caused a given outcome. This is a complex issue and circumstances in a particular area need to be handled individually.

### Acknowledgements

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**Figure 1 - Area blasted during August and September, 2002. Pad and Base indicate whether the corresponding home is built on a pad (slab) or has a basement. The dates and the number of blast holes are indicated. Each blast hole was loaded with three to four pounds of ANFO.**



**Figure 2 - AreaRAE and Nighthawk gas monitors.**

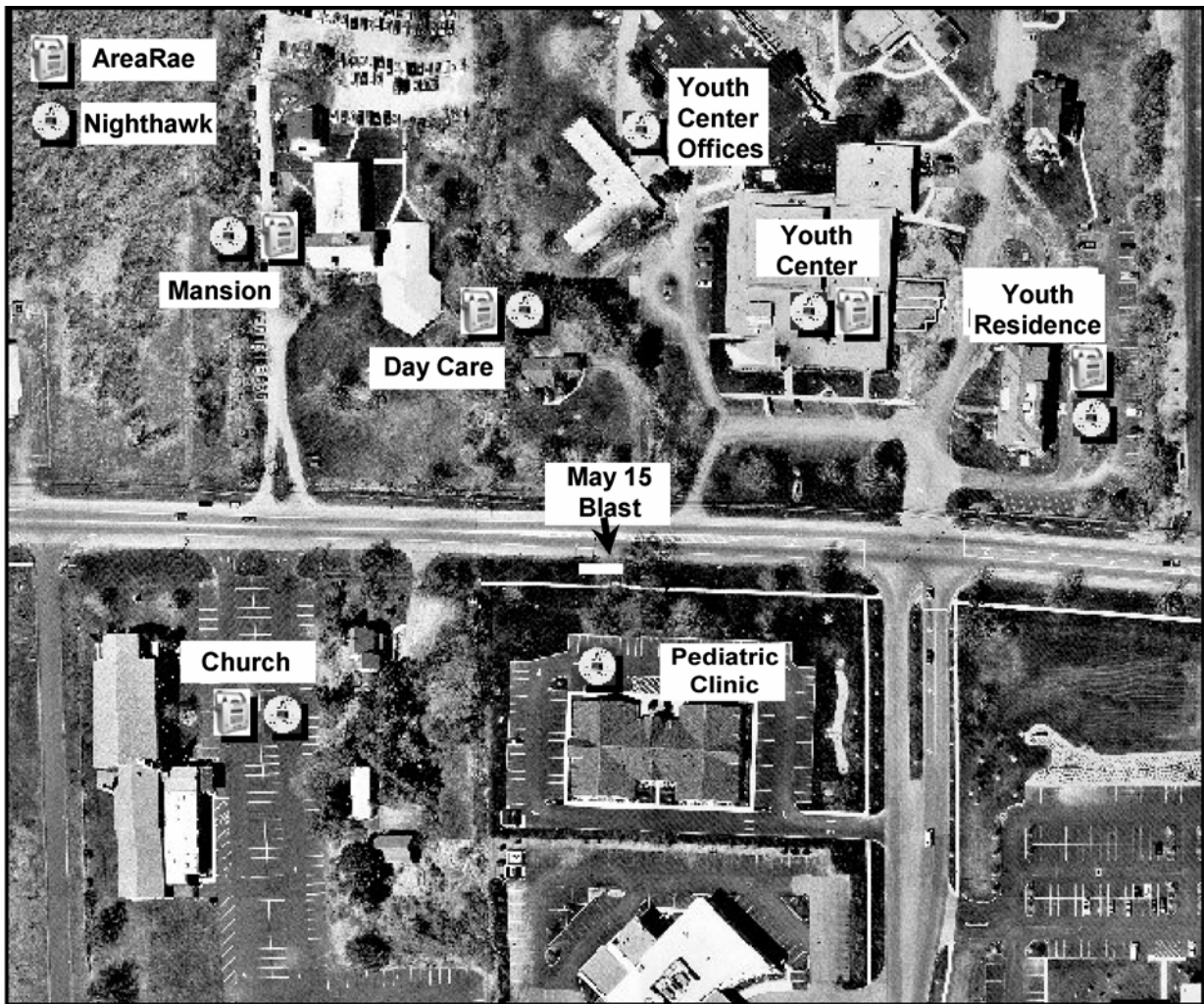


Figure 3 - Locations of instrumentation for May 15, 2003 blast.



Figure 4 - Steel plates cover the open trench area.



Figure 5 - Overburden is removed from the rock.

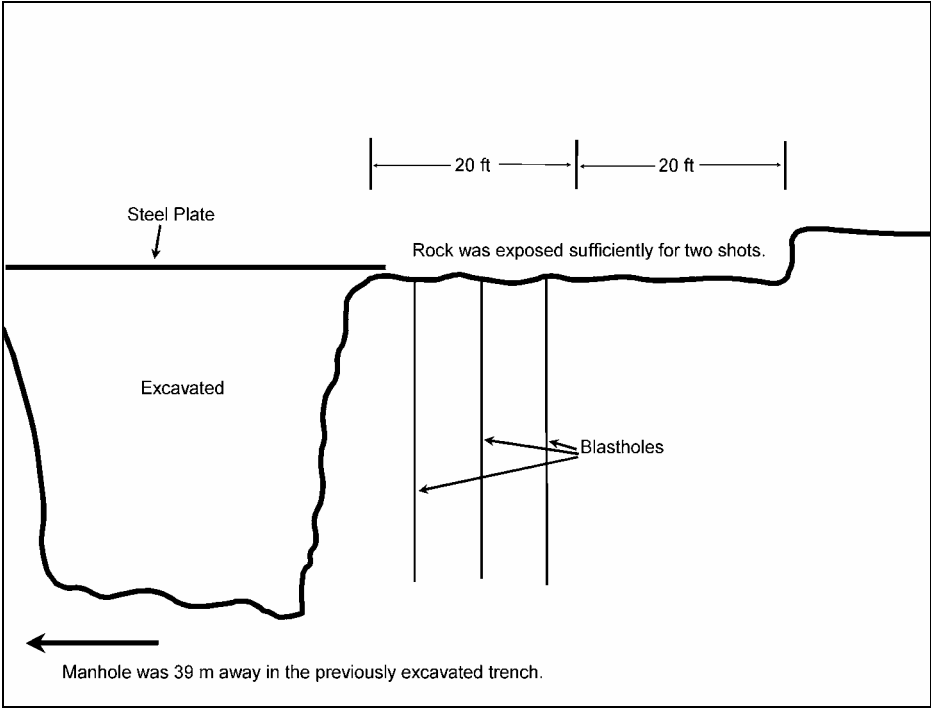


Figure 6 - The blast was designed so the broken rock could move into the excavated space, allowing the gases to vent.

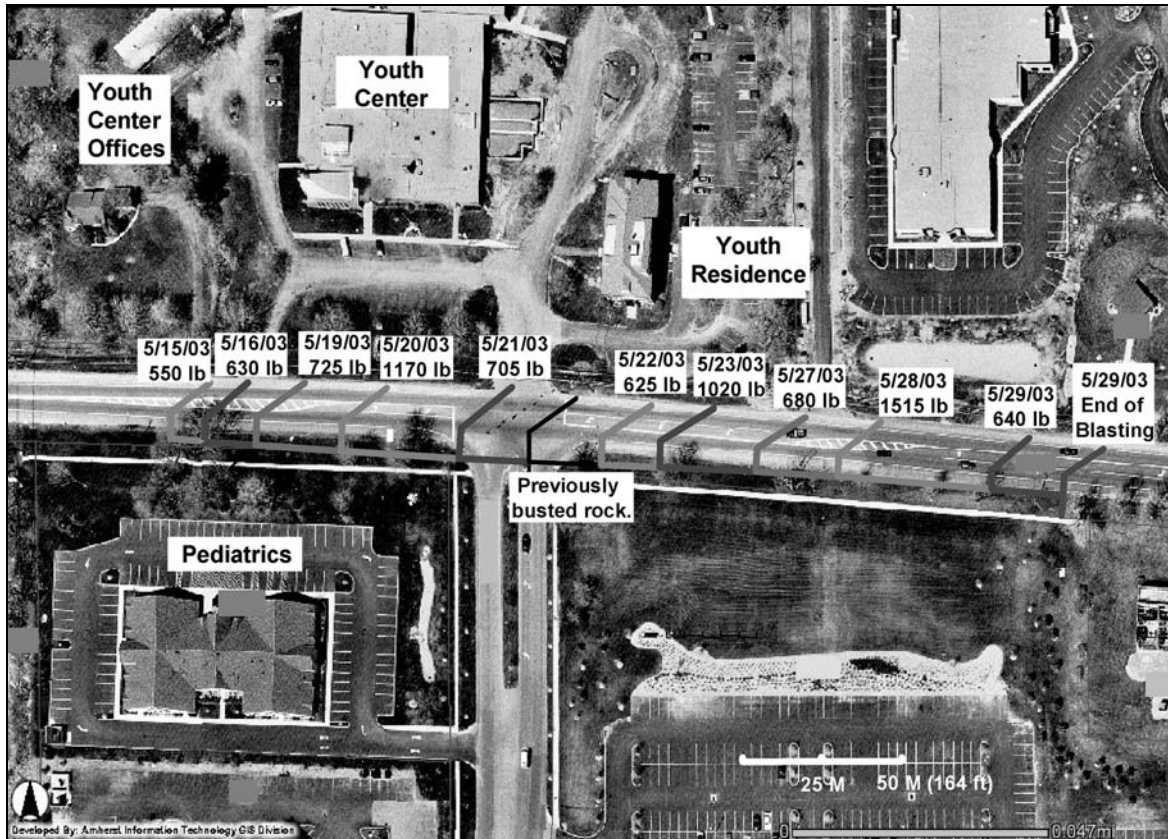


Figure 7 - Locations of blasts during May, 2003.

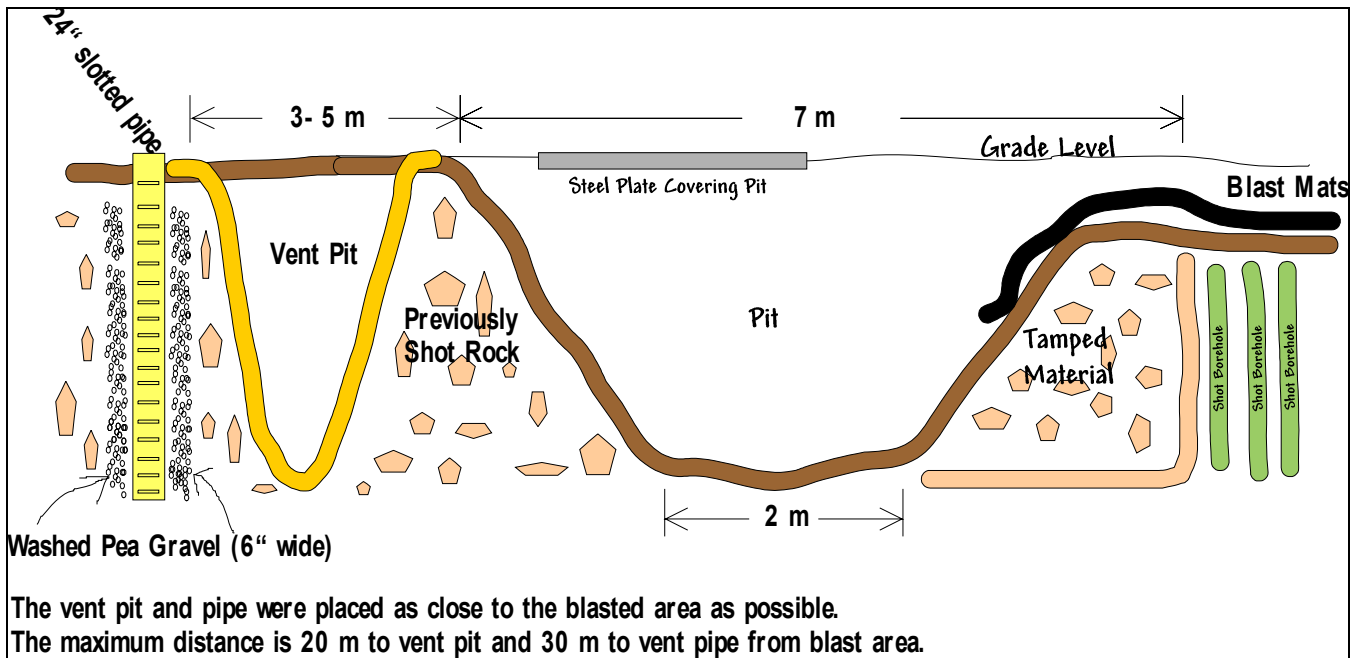
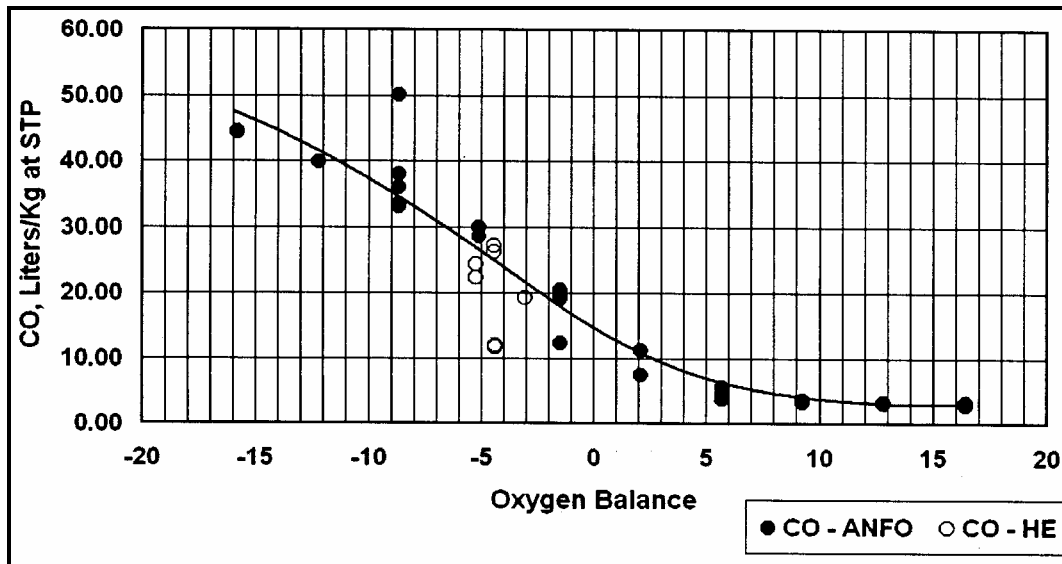


Figure 8 - Final Blast Layout.



**Figure 9 - Effect of Oxygen Balance on carbon monoxide production for 94/6 ANFO and high explosives (cap-sensitive explosives).<sup>7</sup>**

## References

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<sup>8</sup> Agreda, C, Rock Blasting Environmental Impacts. International Society of Explosives Engineers, 1995 v1 G, 2000, p. 143.

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<sup>9</sup> Turcotte, R., R Yang, MC Lee, B Short, and R. Shomaker, Factors Affecting Fume Production in Surface Coal Blasting Operations. International Society of Explosives Engineers, 2002G, Volume 2, p. 307.

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<sup>12</sup> Explosives and Rock Blasting, published by Atlas Powder Company, Field Technical Operations, 15301 Dallas Parkway, Colonnade Suite 1200, Dallas, TX 75248-4692, 1988, p 25.

<sup>13</sup> ISEE Blasters’ Handbook, Seventeenth Edition, International Society of Explosives Engineers, Cleveland, OH, 1998, p 48.