

Blasting-Related Carbon Monoxide Incident in Bristow, Virginia
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Abstract

In the past several years, there have been a number of blasting-related carbon monoxide migration incidents. In each case, there have been some common factors that appear to be related to carbon monoxide migration. Geology, heavy confinement of the blast, close proximity to the affected structure, and open pathways into the affected structure are just a few.

Prince William County, VA is an area undergoing a boom in suburban development. In the year 2001, more than 4,050 new homes were constructed within the county.¹ In the new housing development located in Bristow, VA, trench blasting was utilized to excavate proposed sewage and utility lines. On November 8, 2002, a trench blast was conducted for the installation of utility lines. Later that evening a carbon monoxide detector alarmed in a nearby house. The gas company and fire department sampled for carbon monoxide and measured 100 ppm and more than 200 ppm on the first floor and in the basement respectively. Subsequent efforts to prevent migration of CO into the nearby homes met with mixed results. The only reliable technique for protecting neighbors from CO appears to be the placement of CO monitors in the homes. The events are presented and discussed.

Introduction

Toxic gases such as carbon monoxide (CO) and nitric oxide (NO) 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 industries have been concerned with toxic detonation products that may travel laterally through the earth rather than vent to the atmosphere. Since 1988, there have been 17 reported incidents in which explosive-generated CO moved through the earth and accumulated in nearby underground enclosed spaces.^{2,3} The reported incidents involved 39 suspected or medically verified CO poisonings and one fatality. In each case, overburden heavily confined the explosive in the blasts, restricting the venting of explosive gases to the atmosphere. All the blasts were in or near residential areas and none of the areas was excavated immediately. Five of the blasts were within 20 to 50 ft (6 to 15 m) of the enclosed underground spaces, three were 100 to 150 ft (30 to 46 m) away, and one was 400 to 500 ft (120 to 150 m) away. Likely pathways included old trenches filled with porous material intersecting the blast site, horizontal sedimentary bedding, unconsolidated material in a horizontal plane, and hill seams together with sumps, drains, the gap between a basement floor and wall, and direct openings in structure walls.

Background

On Friday, November 8, 2002, in the late afternoon, a trench blast was shot by the development contractor for utility lines in a new housing development in Bristow, Virginia. For this particular shot, 3.5 in (8.9 centimeter [cm]) diameter boreholes were loaded with a bulk emulsion blasting agent to break diabase intrusive bedrock. Three-quarter pound (lb) (0.34 kilogram [kg]) boosters were used to initiate the blasting agent. A total of 2,581 lbs (1,170 kg) of bulk emulsion and 116 lbs (52.6 kg) of primer were used in the blast. The trench was approximately 320 ft (97.5 m) long and the stone to be excavated, which consisted of diabase bedrock (hard limestone), ranged between 4 and 8 ft (1.2 and 2.4 m) in depth.

During the evening of November 8, a CO monitor in a home located approximately 90 ft (27.4 m) from the blast (see Figure 1) alarmed. The residents called the gas company and the local fire department of Prince William County. The gas company measured in excess of 800 parts per million (ppm) of CO near the water sump in the basement of the house. The fire department also took CO readings on the first floor of the house and in the basement. The CO readings were 100 ppm on the first floor and more than 200 ppm in the basement. Exposures for long periods of time at these levels can be hazardous to a person's health. The NIOSH recommended exposure limit (REL) is 35 ppm time weighted average (TWA) for an 8-hour period.⁴ In the range of 200 ppm, slight headaches, tiredness, dizziness, and nausea (after 2-3 hours) may be experienced. A person could experience frontal headaches within 1-2 hours when the CO is in the 400 ppm range. In the 800 ppm range, dizziness, nausea and convulsions may occur within 45 minutes of exposure. If exposed to 800 ppm for 2-3 hours, death will occur.⁵

The house was ventilated (by opening doors and windows) to remove the CO. The homeowners were able to return to the house later that evening. The next morning, November 9, 2002, around 7:00 A.M. the fire department returned to the house to take more CO measurements. In the basement, the CO reading was greater than 300 ppm. At the water sump, the fire department measured 680 ppm. Three neighboring homes were checked for CO at this time. The CO readings in these homes ranged from 23 to 370 ppm. These

homes were not equipped with their own CO detectors.

It was determined that blasting was the source of CO. This conclusion was based on the number of homes affected, the distance between the homes and the blast, the apparent entry routes, and the short time delay between blast and first detection of CO. The gas company had initially responded and determined the utility was not the source. No other source for the CO was identified.

The second trench blast (see Figure 1) occurred on November 14, 2002. The blast consisted of 82.5 lbs (37.4 kg) of boosters and 770 lbs (349.3 kg) of packaged cap sensitive emulsion. To reduce the possibility of CO entering the four affected homes, the fire department covered the water sumps in the homes with plastic and sealed the plastic with duct tape. CO monitors were also purchased and placed in each of the homes. After the shot, the CO monitors did not alarm in any of the houses.

The third trench blast (Figure 1) was shot on December 3, 2002, at 11:30 a.m. The trench was 120 ft (36.6 m) long with boreholes 20 to 27 ft (6.1 to 8.2 m) deep. The shot consisted of 3,504 lbs (1,605.7 kg) of bulk emulsion blasting agent primed with 167.75 lbs (76.1 kg) of booster. Immediately after the shot, four venting pits approximately 6 ft x 6 ft x 5 ft (1.8 m x 1.8 m x 1.5 m) deep were excavated along the length of the shot to release the trapped gases into the atmosphere. Following the shot, the home CO monitor alarmed in house # 2. The fire department was called to take measurements. In the basement near the water sump, the CO reading was 370 ppm, while in the living area the CO reading was 55 ppm. The levels measured in the living areas of the other three homes ranged from 55 ppm to 182 ppm. The next day, CO readings taken in the living area of each home ranged from 27 ppm to 226 ppm. Every home except one was evacuated. Two days later on December 5, 2002, no CO could be detected at house #3. None of the other home owners were available for access to their homes. At this point, the fire department voided the blasting permit and would not reissue the permit until the department was confident that measures had been put in place to protect the homeowners from CO poisoning.

Several parties agreed to meet on Friday, December 6, 2002, in Bristow to discuss possible actions to prevent CO migration into the homes in future shots. Also, by this time, concern had spread throughout the neighboring housing development and most residents purchased their own home CO monitor.

All parties agreed that the best solution to prevent CO from migrating into nearby homes was to excavate the entire length of the trench down to and into the bedrock immediately after the blast. It was agreed that the present utility line trench would be left open to allow for venting of future shots, as well as providing a barrier to the movement of gases toward the homes. The blaster also directed his contractor to note the existing sumps, type of foundation/concrete slabs, and existing CO monitors in each home in future pre-blast surveys. This was incorporated into the new blast plan with other precautions listed below:

1. All structures within 200 ft (60.96 m) of blasting must be surveyed, have CO monitors installed if they have open sumps or plumbing, and must be monitored for 48 hours after each shot.
2. In front of each shot, approximately 6 to 8 ft (1.8 to 2.4 m) will be excavated all the way to grade and then back filled, to provide proper relief of rock and gas movement.
3. The Fire Marshals= office will be notified 24 hours prior to each blast.

After submitting a revised blasting plan, a blasting permit was reissued. On December 13, 2002, a shot was fired to break up rock for excavation of a house foundation pad (Figure 1). The blast pattern consisted of about 120 holes, each 7 to 8 ft (2.1 to 2.4 m) deep, loaded with 4.6 lb (2.1 kg) of explosive primed with ¾-lb (0.34 kg) boosters. The total 630 lbs (285.7 kg) of bulk emulsion blasting agent was primed with 101.5 lbs (46 kg) of boosters. To prevent migration of CO to the homes that were affected previously, the shot was excavated immediately following the blast as required in the new blasting permit. Additionally, the 15 to 25 ft (4.6 to 7.6 m) deep storm sewer trenches between the shot and the homes were left open to ventilate any CO to the atmosphere before it could migrate away from the blast.

On Saturday, December 14, 2002, at 5:00 a.m. CO was detected in homes 1 and 2. This result was totally unexpected considering that there was an open 15 to 25 ft (4.6 to 7.6 m) deep trench between the pad and the homes and the shot was excavated immediately after the blast. After this incident, the county would not reissue a blasting permit until a guarantee could be made that CO would not enter the homes. No guarantee could be given with the current knowledge and information. The blasting company would no longer conduct blasting at this site. This decision was encouraged by the blaster's insurance company.

Discussion

Several factors must be present for CO to migrate through the ground and enter an underground enclosed space. First, there must be a source. It was determined that blasting was the source of CO. This conclusion was based on the number of homes affected, the distance between the homes and the blast, the apparent entry route, and the short time delay between blast and first detection of CO. Nothing else was identified as a source for CO.

The composition of explosive detonation gaseous products depends upon the formulation and the conditions surrounding the explosive's use. Carbon dioxide, water vapor, and nitrogen are the main products and are always produced. In addition, CO, NO, methane (CH₄), and hydrogen (H₂) may form in large or small quantities. All explosives generate CO and NO.^{6,7} Using an oxygen balanced explosive is important. The less CO produced, the less CO there is to possibly migrate into underground spaces. Also, using the appropriate explosive in each blast for the conditions present is important. The explosives used were an emulsion blasting agent that was supplied in bulk and pumped into the blastholes and a packaged product. The bulk blasting agents were used on shots 1, 3, and 4 and were supplied by two different manufacturers, according to blasting reports. The explosive is assumed to be oxygen balanced in the production process by the manufacturers. If the explosive is used in the manufacturer-recommended fashion, then the CO generated should be minimized.

Another factor affecting CO migration is the available venting of the fumes to the atmosphere. In open-pit blasting operations, wind rapidly dilutes the vented gases during the fragmentation process and continues to dilute the gases slowly emanating from the muck pile. Generally, trench blasting near occupied dwellings is done with heavy explosive confinement, with a focus on preventing flyrock and minimizing air blast damage. Consequently, there is little or no surface heave or venting for most of the shots. The Institute of Makers of Explosives recommends the excavation of muck piles as soon as possible after the shot.⁸ Past CO incident investigations have determined that the muck piles were not immediately mucked out after the shot.^{2,3}

In this study, the first shot was not immediately mucked out, which may have contributed to CO migrating through the ground into the homes. Four excavated pits measuring 6 ft x 6 ft x 5 ft (1.8 m x 1.8 m x 1.5 m) were installed on the second and third shots to vent any generated fumes. No CO accumulated in the nearby homes after the second shot. However, the venting pits still were not sufficient to ventilate the detonation fumes of the third shot. CO appeared in the homes the same day as the shot.

Obviously, a pathway must be present. However, the pathway may not be obvious. It is hard to discern or predict fractures in the material to be shot. Currently, there is no practical way to characterize the ground strata and be able to predict possible routes of migration. If knowledge is available on locations of current and previous utilities, trenches, drains, etc., then those may be considered as possible routes. Suspected pathways from blast sites to structures have been cited as old trenches, fracture zone, hill seams, horizontal bedding plane, unconsolidated material, and a water path.^{2,3}

Before the meeting on December 6, the blaster took NIOSH personnel to the construction site where the incidents occurred to assess the geology and their blasting operation. In the venting pits, fractures with an orientation of approximately 20 degrees east of north were observed in the bedrock; this orientation lines up perfectly to intercept the homes affected by the CO migration after the blast shots 1 and 3 (Figures 2 and 3). Another observation was that the fractures appeared to be naturally occurring and not caused by blasting. It was not determined how deep the fracture system may extend. It may be entirely possible the fracture system may extend below the blast site and trenches. Also, the elevation of the bedrock in the pits excavated after blast shot #3 visually appeared to be at the same elevation as the basements of the houses affected by the CO migration. It appears that a fracture system is in place that is positioned just right to result in a strong conduit from the blasted material to the homes.

A route of entry into the enclosed space must be present. In the past, routes of entry have included sumps, drains, and cracks in the foundation.^{2,3} In the case discussed here, the existence of sumps in full basements was considered to be the route of entry into the homes. Most of the other homes surrounding the affected homes did not have full basements; they were constructed on a concrete slab without openings to the strata beneath them. CO monitors did not alarm in these homes. Even though the sumps were covered and taped, CO was still able to enter the homes with basements. It is not possible to completely seal the sump using plastic sheet and duct tape. It is also possible that a crack existed in the foundation that was not accounted for.

In past CO migration incidents, the people affected were victims of CO poisoning. In the published case summaries, there have been 39 suspected or medically verified CO poisonings (9 with recuperation in a hyperbaric chamber) and 1 fatality. Fortunately, in this instance, no one experienced any symptoms or had to seek medical treatment because commercially available, home-type CO monitors had been purchased and installed by homeowners. The initial home that was affected had a home CO monitor installed. Once the problem was identified, the other affected homes were equipped with these inexpensive monitors.

Even after the modified blast plan was put into effect, CO had appeared in the homes after the fourth shot. This is puzzling because there was an open trench 15 to 20 ft (4.6 to 7.6 m) deep between the affected homes and the location of the blast. One possible explanation is that the CO may have been present in the ground from previous blasts and pressure from the last blast forced the CO into the homes. Another explanation may be that the trench did not intersect the conduit of migration.

In many past cases of blasting related CO migration incidents, the problem was not recognized until after symptoms of CO poisoning were experienced and reported.^{2,3} In some cases, recovery from CO poisoning required medical treatment and hyperbaric chambers. In this case, medical treatment was not required. CO poisonings were most likely prevented by early warning provided by a homeowner's installed CO detector.

Summary

During pre-blast surveys, the blaster should determine where the likely or open pathways exist for potential gas entry into nearby homes. Possible entries may include, but are not limited to, sumps, open plumbing, an open wall (dirt floor or unsealed stone wall), an uncased well, or cracks in a basement floor or wall. The CO monitor should be located at the most likely point of entry.

Each CO migration occurrence is unique and depends on the route of entry, distance of site from CO generation source, and geology. Therefore, possible monitoring of nearby underground enclosed spaces may continue for an extended period of time from several hours to a few days.

It is imperative for construction personnel to coordinate their efforts closely with the blaster. Shots should be excavated as soon as possible following detonation. Venting is important for relief of potentially harmful toxic gases.

CO poisonings were most likely prevented by early warning provided by a homeowner's installed CO detector. Because of early warning, the source of CO was determined and affected homes were evacuated and closely monitored. Fortunately, no one had to be treated for CO poisoning.

In any accident, there are multiple contributing factors. Any action to prevent or minimize should address each of these factors. A blast plan should be developed and implemented in situations where possible CO migration is anticipated. It should include methods, materials, and sequence of blasting to complete the job safely. Everyone involved with the project should understand the plan. The blast plan should specify actions to take if CO migration should occur.

It is important to understand that techniques may help reduce the chance for CO migration into a home, structure, or building, but they do not always work, as in these Prince William County events.

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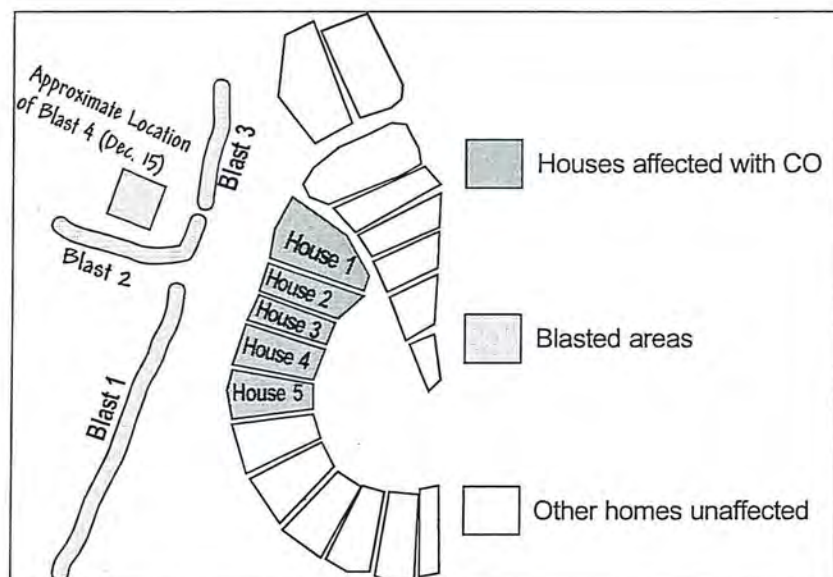


Figure 1 - Locations of houses and blasts.



Figure 2 - The first of four pits dug at the location of the trench blast in an effort to vent CO. Homes 1 and 2 can be seen in the background.

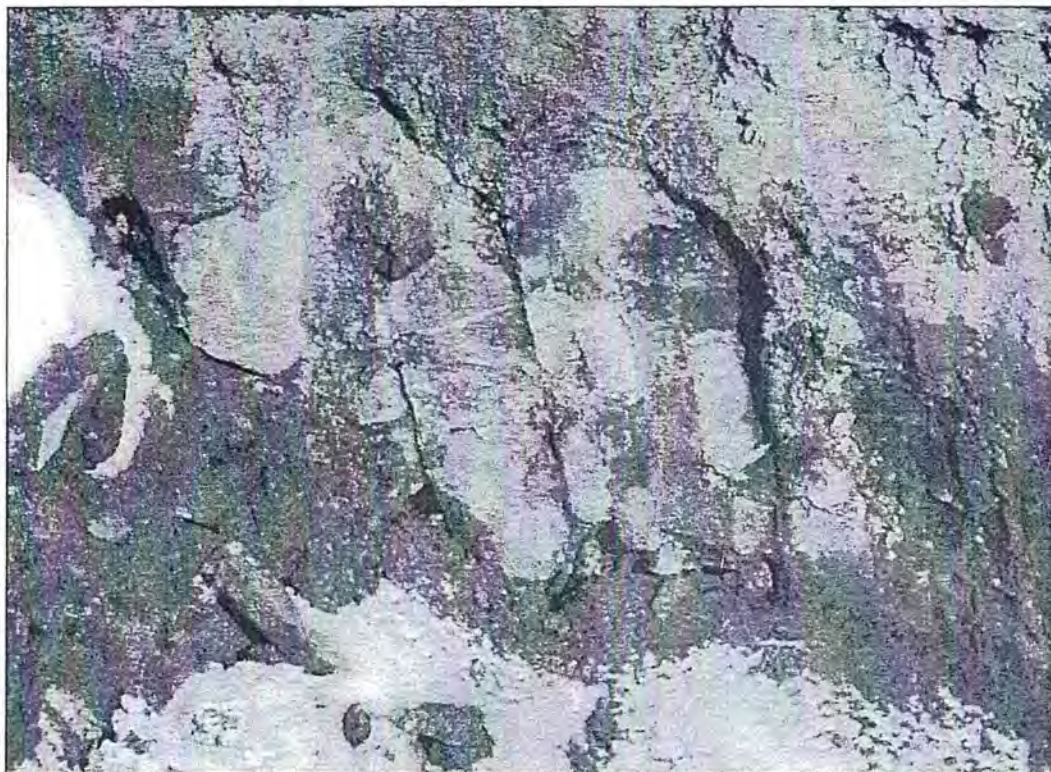


Figure 3 - A close-up of the bedrock seen in Fig. 3. Note the fractures are oriented towards nearby homes.

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