Carbon Monoxide Poisoning at a Surface Coal Mine .... A Case Study

Kenneth K. Eltschlager
Office of Surface Mining Reclamation and Enforcement
Pittsburgh, Pennsylvania

William Shuss and Thomas E. Kovalchuk
Pennsylvania Department of Environmental Protection
Greensburg, Pennsylvania

Abstract: In April of 2000, two adults and their newborn infant, were poisoned by carbon monoxide in their home and received medical treatment at a Pennsylvania hospital. Carboxyhemoglobin levels were; child - 31%, father - 28%, and mother - 17%. Initially the furnace was blamed but after further review, blasting at a nearby coal mine was determined to be the source. All other sources of carbon monoxide were ruled out. The blasting was about 400 feet from the house. The conditions that led to the migration of gas include: the blasts were highly confined, the geologic structure contained fractures that served as conduits for the carbon monoxide to reach a hand-dug well outside the house, and the well was atmospherically connected to the basement floor drains.

Introduction

State Industries, Inc. began mining the Upper Freeport coalbed at the Milliren Mine, SMP 03910107 in Armstrong County, Pennsylvania in February 2000. The mine property is owned by Mr. and Mrs. Milliren and their garage is within 50 feet of the nearest blast site. Figure 1 shows the mine and nearby structures.

Residence #1 is about 430 feet from the nearest blast and topographically sits at an elevation of 1370'. A hand-dug 36-inch diameter, cobble lined, well that is about 28 feet deep serves as the primary source of water. The well is located on the east side of the house nearest the mine (Figure 2). The Millirens and residence #2 have drilled wells.

On Monday, April 11, 2000, the family of residence #1 contacted the Pennsylvania Department of Environmental Protection (DEP) with a complaint of muddy water from blasting. During the initial site visit, the DEP inspector discovered that the family had suffered carbon monoxide poisoning on April 1, 2000. The family's carboxyhemoblogin levels from that exposure were reported by the Presbyterian Hospital in Pittsburgh to be: wife - 17%; husband - 28%; and infant (11 days old) - 31%.

Chronology

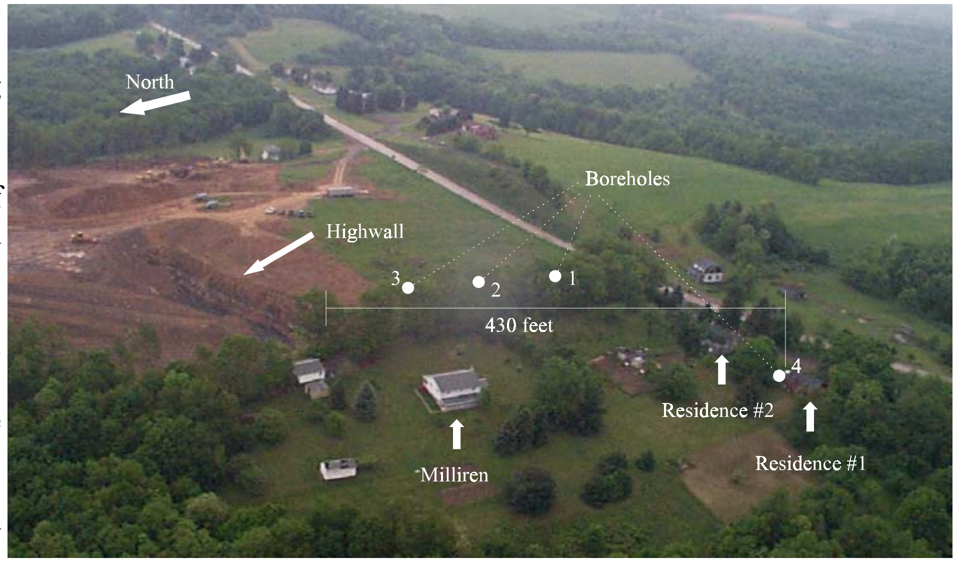

Figure 1 Mine site and nearby structures.

February 2000 - mining began.

March 7, 2000 - the first of twenty blasts was conducted at the mine.

March 31, 2000 - two blasts are detonated in the afternoon, the first is within 25 feet of the Milliren garage.

April 1, 2000 - in the early morning the child is restless and the parents feel lightheaded. They seek medical attention and are diagnosed with carbon monoxide poisoning. The infant is placed in a hyperbaric chamber to reduce its carboxyhemoglobin level. All family members are released later that day.

April 2, 2000 - the contractor who had installed a new furnace in September 1998, was called to check the furnace for fumes. They found 650 ppm in the basement, 450 ppm on the first floor, and 400 ppm on the second floor. The contractor informed the family that the carbon monoxide buildup in their home was a result of an inadequate furnace draft. They reworked the furnace flu and installed a power vent to ensure adequate draw. Furthermore, one of the basement windows was removed to provide fresh air to the basement. At this time the gas hot water heater was also replaced with an electric heater. As a future safeguard, the residents purchased two carbon monoxide detectors; one for the basement and one for the bedroom.

Figure 2 Residence #1 setting.

April 2-7, 2000 - The family of residence #1 stay at their parents' home.

April 17, 2000 - two blasts are detonated. The first blast, at 11:51, located approximately 430 feet from the home was followed by another blast at 14:02, approximately 475 feet away from the home.

April 20, 2000, one blast was detonated at 13:45. About an hour later, the carbon monoxide detectors in the home sounded an alarm and reported carbon monoxide levels of 73 ppm in the basement and 46 ppm in the upstairs of the home. The family left the house.

The local volunteer fire department was alerted of this incident. They arrived at 16:00 and found 72 ppm at the furnace. After venting the house, they restarted the furnace and got readings of 144 ppm at the furnace. Unaware of any other source of carbon monoxide in the area, they focused on the furnace because their training had taught them that the furnace is the most likely source of carbon monoxide in homes. As a precautionary action, the DEP inspector, requested that State Industries voluntarily cease blasting until an investigation could be conducted.

On April 21, 2000 - the DEP Emergency Response Team (ER) was called in to assist. ER personnel sampled the air quality inside the house and from a 36" diameter, cobble lined, well. The investigators found that the highest concentrations were inside the home at the floor drains, the highest being 200ppm. The well had 160 ppm. The Milliren's house and residence #2 were also checked for gas. The only CO observed at any other residence was 3 ppm on the top of the residence #2 drilled well.

ER vented the well with a high volume fan. They observed a negative air pressure in the basement floor drains. They concluded that the air coming out of the well was supplied from the basement and that the furnace could draw air from the well. Their investigation led them to believe that blasting was the source of the carbon monoxide. The fan remained on the well for a few days until CO was no longer detected.

April 24, 2000 - DEP Blasting and Explosives Section inspectors inspect the mine. They find that the two blasts of April 17 and the one of April 20 had not been excavated. The material from all three blasts was to be removed at the same time. A review of the blast records showed that the operator was under-shooting the overburden to protect the Milliren residence located within 200 feet of the pit. They also found an old country bank mine opening below residence #1. This discovery was not consistent with the data provided in the permit application, the coal seam was shown on the geologic maps to crop out above the affected home.

Furthermore, the inspectors looked for other potential sources of carbon monoxide in the area. There was no field evidence of a mine fire; no smoke, fumes or hot spots. The affected family had no internal combustion engines in the basement area, no wood stove, and no integral garage. The furnace is a relatively new oil fired unit and power vent and hot water heater (electric) were newly added after the first event. Finding no other readily explainable source, the Explosives Inspector ceased blasting on the mine.

April 26, 2000 to May 11, 2000 - numerous meetings among DEP, Office of Surface Mining (OSM), Mine Safety and Health Administration (MSHA), and National Institute of Occupational Safety and Health (NIOSH) were held on site.

May 9, 2000 - A survey crew obtains site location information which includes the elevations of the pit floor, the top of the dug well, the water level in the dug well, and the country bank mine opening.

May 31, 2000 - DEP and OSM jointly conduct geologic profiling of the site by drilling bore holes between the home and the mine. This confirms that the coal seam cropped out below the home. After each hole was drilled and for the next three days, NIOSH representatives sampled for gasses. Drill hole 2 penetrated a sandstone fracture and consistently produced carbon monoxide, up to 23 ppm.

July 7, 2000 - DEP writes an order for failure to prevent injury to people outside the permit area and requires blast plan modifications. State Industries decides to reclaim the mine site.

Carbon Monoxide Characteristics

Carbon monoxide is a colorless, odorless, and tasteless gas with a vapor density (air) of 0.97. It results from the incomplete oxidation or combustion of carbon. Very few natural sources exist.

The most common source of CO is automobile exhaust. Appliances which can contribute carbon monoxide into the home include gas cook tops, gas heaters, furnaces, wood stoves, or even hot water heaters. Inadequate maintenance, broken parts, or back drafting, because of the design and construction of a house, can make these devices dangerous.

According to NIOSH, 1,200 ppm is Immediately Dangerous to Life and Health (IDLH) and 35 ppm is a safe exposure over an 8-hour time for healthy workers in the workplace. Adverse health effects from carbon monoxide (an asphyxiant gas) are due to the formation of carboxyhemoglobin in the blood, which inhibits oxygen uptake. Normal carboxyhemoglobin concentrations are <2% for nonsmokers and 5%-9% for smokers. At moderate concentrations, early symptoms may be nonspecific (e.g., headache, dizziness, weakness, nausea, visual disturbances, and confusion). At higher concentrations (>30%), carbon monoxide exposure may be fatal.

The byproducts of the detonation of ammonium nitrate and fuel oil (ANFO) are primarily water (H_2O), Nitrogen (N_2) and carbon dioxide (CO_2), all nontoxic to people. In an ideal reaction:

$$3NH_4NO_3 + CH_2 \Rightarrow 7H_20 + CO_2 + 3N_2 \quad \text{(Dick,1983)}$$

When the fuel oil proportion is incorrect, water is introduced into the ANFO, or optimum detonation velocities are not attained due to inadequate priming, noxious fumes are generated. Generally, whenever the reaction becomes less efficient, toxic gases, fumes or "smoke" are produced. These secondary byproducts are carbon monoxide (CO) and oxides of nitrogen (NO_x). According to the ISEE Blaster's Handbook, factors that increase fume production are:

1. Poor product formulation
2. Inadequate priming
3. Insufficient water resistance
4. Lack of confinement
5. Reactivity of the explosive with the rock
6. Incomplete product reaction.

CO Poisoning in Residential Structures

Explosives generate fumes during detonation including carbon monoxide. Gases are produced as a normal by-product of blasting operations regardless of the types of explosive materials used. Normally, in open pit blasting or outdoor construction blasting, any gases generated are readily diluted by the atmosphere and rapidly dissipated by prevailing winds or air currents. However, over the past few years, there have been reports of incidents where carbon monoxide from outdoor blasting operations, has migrated into inhabited buildings (Decker, 1997) .

Carbon monoxide in homes due to blasting is rare, occurring at seven residences nationally since 1988. In each of these cases, either CO was detected indoors or one or more occupants of the house were diagnosed with elevated levels of carboxyhemoglobin (carbon monoxide blood levels).

Table 1. Carbon Monoxide poisoning from blasting.

Location/ Year	Project	Max. Hole Depth (ft)	Distance to Residence (ft)	Maximum CO (ppm)	Explosives
North Hampton Twp., PA/1988	Sewer	33	100	2,000	Nitropel/ ANFO
Harford Co, MD/1994	Adjacent Home Foundation	11	35	1,000	Ireco Unimax
Millheim, PA/1995	Ditch Line	15	35	400	ICI Nitropel
Quebec City, Canada/1995	Road Trench	27	20	1,500	APEC Ultra40 Power Frac
Dunmore, PA/1997	Road Trench	27	100	1,500	Blastex Plus/ANFO
Baltimore Co., MD/1998	Adjacent Home Foundation	12	20	>345	ETI Trenchrite
Lake Mills, WI/ 1999	Sewer and Basements	10	150	2,600	ANFO and Dynamite

Common to all these incidents is the closeness between the activity and the home. The blasting industry has recognized since 1988, with the incident in North Hampton Township, that carbon monoxide can migrate into homes at short distances. Given some means to efficiently transfer fumes to the home, migration of carbon monoxide at dangerous levels could be expected. Elevated carbon monoxide levels have not been documented at distances greater than 150 feet before this incident.

The Institute of Makers of Explosives (IME) and NIOSH subsequently have noted that the distance from the blast area, the amount of confinement of the explosive charge, the timely evacuation of the shot material, openings into the homes where the fumes can enter, and lack of adequate fresh air make up within the home, appear to be five common factors of these incidents. The fume characteristics of the explosives can also play an important role.

Blasting Operations

The blasting contractor on this site used bulk ANFO and a high explosive booster. Initiation was by non-electric means. Burden and spacing were relatively consistent, with a 16' x 16' pattern. Blast holes were 6 1/4 inches in diameter. Blasts ranged from 16 to 89 holes, with charge weights ranging from 17 to 170 pounds. The closest distance to the residence #1 was 430 feet on April 17, 2000. The distance was 500 feet

on March 31, 2000 when carbon monoxide was first reported.

Twenty blasts were detonated from March 7, 2000 to April 20, 2000. The overburden above the coal (12-36") is predominately shale with a 4 to 6-foot thick sandstone two or three feet above the coal. A typical blast hole would penetrate about 20 feet of shale, 6 feet of sandstone and 3 feet of shale before reaching the coal. The shale is ripable with a dozer. The sandstone needs to be explosively broken before it can be removed (Figure 3).

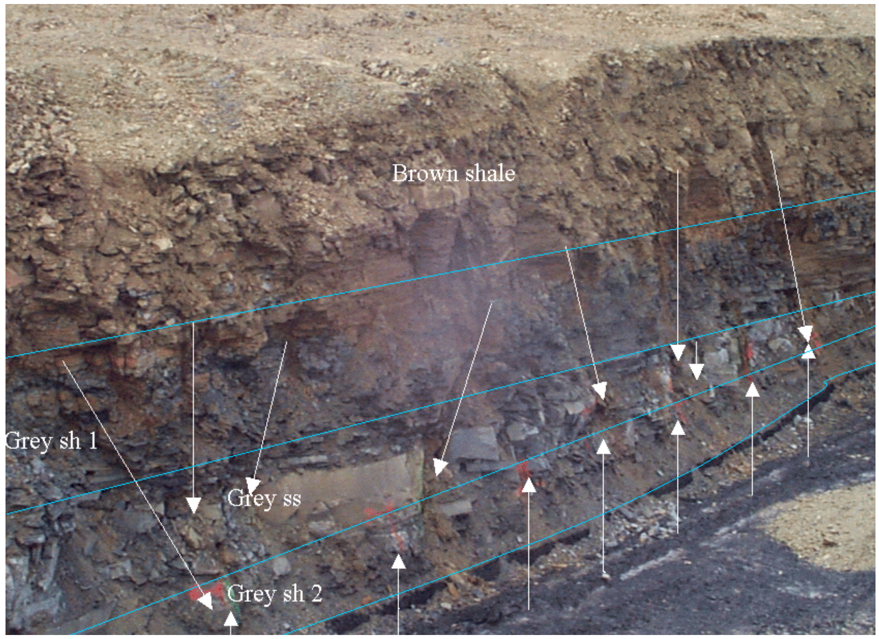

Figure 3 Milliren mine highwall, fracture traces and blasthole locations.

Problem Blasts: The blasts on March 31 and April 20 coincided with elevated levels of CO at the residence #1. The blasts of March 31 (#13 and #14), April 17 (#18 and #19) and April 20 (#20) were the closest to all the homes and are the focus of this discussion (Figure 4). Blasts between these dates occurred when either no one was living in the house or when blasting was further away. The primary concern of the blaster for these blasts was protection of the Milliren property from flyrock. Table 2 shows all the blasts at this mine.

Table 2. Blast data: row 1, blast number; row 2, date; row 3, charge per hole; row 4, powder factor.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
3/7	3/8	3/9	3/14	3/15	3/16	3/21	3/22	3/22	3/24	3/24	3/31	3/31	4/5	4/5	4/6	4/7	4/17	4/17	4/20
52	17	85	68	170	80	50	83	83	120	120	80	50	82	104	152	124	51	121	120
0.39	0.33	0.42	0.29	0.64	0.64	0.33	0.42	0.42	0.44	0.44	0.34	0.24	0.32	0.37	0.73	0.62	0.22	0.43	0.55

Stemming: Rules of thumb to prevent flyrock are to reserve 50% of the upper hole depth for stemming or provide stemming greater then 7/10 the burden. This ensures that the weight of the inert material will contain the force of the explosive material. Hole depths ranged from 19 to 27 feet with 13 to 24 feet of stemming. All holes were backfilled about 3 feet to protect the coal and put the explosive column at the sandstone interval.

Powder Factor: Powder factor values for these five blasts were 0.22, 0.24, 0.34, 0.43 and 0.55 lb/yd^3. The lowest were for blasts #13 and #18. Lower powder factors increase confinement, reduce flyrock potential and reduce fume dispersion into the open air. Fume storage capacity in the overburden can be increased because of the material bulking.

Blast Sequencing: Mining operations were advancing toward the Milliren property and, by mid-April, were within 200 feet. On the last two cuts, the blaster generally directed relief away from the Milliren garage to protect the structure. The arrows in each blast on Figure 4 show where the first hole was initiated. Blast #12 was initiated in the center as a typical box cut. Blast #13 was corner initiated prior to excavation of the blast #12 and was the first blast confined with a low-wall to the west. Blast #18 was initiated in the center as a typical box cut. Blast #19 was initiated on the west side adjacent to blast #18 in the center and progressed in a zig-zag pattern to the east (lift shot). Blast #20 was similar. Both #19 and #20 would have a tendency to generate higher internal gas pressures within the muck pile due to lack of face movement and subsequently force gases into the bedrock. Blasts #15, #16 and #17 were center initiated and also had a potential to contain the fumes. The mine superintendent remarked that most blasts heaved about 8 feet.

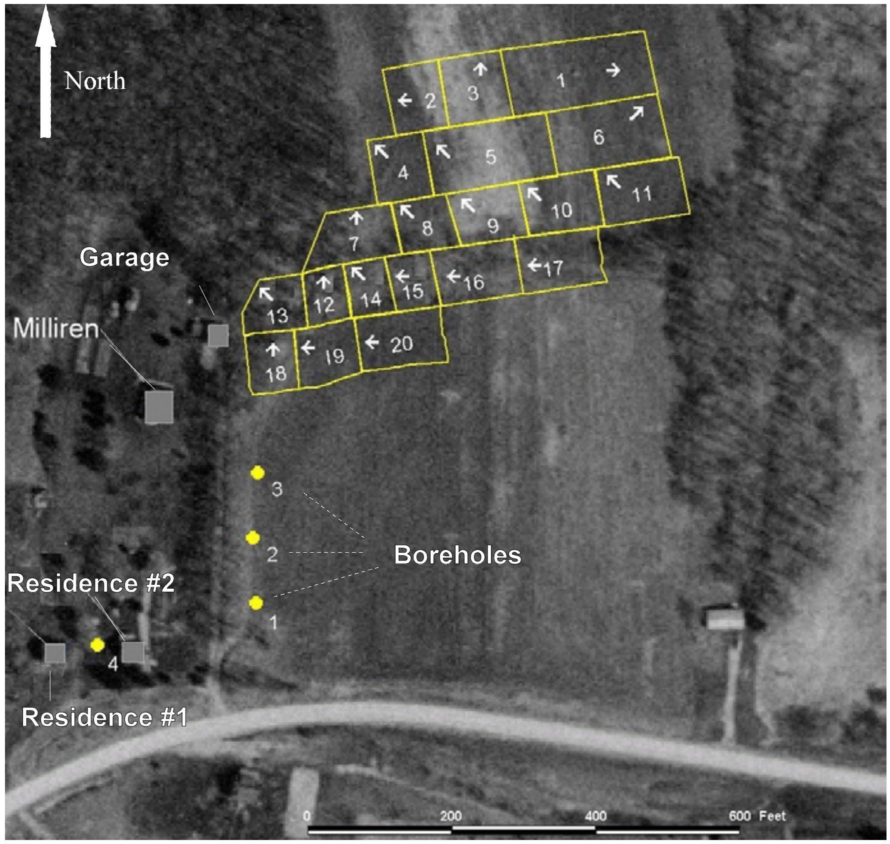

Figure 4 Areal photograph with blast locations in sequence.

Blast Excavation: Immediate excavation of material allows for the fumes to dissipate into the atmosphere. States Industries did not immediately excavate the muck pile and frequently left it in place to buttress the adjacent blast. The blast # 12 muck pile was left for blast #13 and blasts #18 and 19 muck piles were left for blast # 20. The storage capacity of fumes in the previously blasted overburden was enhanced, due to the increased porosity of the material.

Detonation Velocity: The detonation velocity is important to ensure efficient detonation of the explosive material and satisfactory performance. At this mine the blaster used ANFO in 6 1/4 inches blast holes. The powder column length was typically from 4 to 10 feet. Blasts #12 and #18 had only 4 feet of ANFO (50 pounds per hole). A one-pound cast booster in a 6-1/4 inch diameter hole provides marginal priming for a short column of ANFO. Detonation velocity will be lower than optimum for about the first 1 ½ feet (ISEE, 1998), thus the blast will be less efficient. In this case, about 30% of the ANFO in these two blasts detonated inefficiently and were likely to cause excessive fumes.

While blasts at this mine were designed to prevent flyrock and did not produce flyrock, they also promoted the generation of fumes and inhibited the release of the fumes to the atmosphere.

Geology

The Upper Freeport coal dips southwest toward residence #1. Permit maps show the coal outcrop above the affected home. However, during the field review a small country bank mine was observed below the affected home, which made the reported coal crop suspect.

Four boreholes were drilled on May 31, 2000, five weeks after the last CO recording (Figure 1 and 4). The fourth was adjacent to residence #1 (Figure 2). Drill hole 4 confirmed that the coal cropped below the house and that the stratigraphy between the mine and house were the same. Drill hole 2 lost air circulation when a fracture was encountered at the depth of the sandstone.

The stratigraphy could also be viewed in the highwall (Figure 3). Mineralization and staining is obvious on the rocks and is physical evidence of groundwater flow paths. The downward arrows of figure 3 are the defined flow paths based on rock weathering. The joints measured and documented in the highwall and encountered during drilling were both prominent, numerous and open. Clearly, most of the blast holes (the upward arrows of Figure 3) were in or immediately adjacent to the sandstone joints.

Within the sandstone on broken samples, mineralization was found as much as six inches from the joint fracture face as a result of the wet and dry cycling of these fractures. Joints are oriented at slightly different angles in the shales overlying and underlying the sandstone unit blasted, indicating the different rock deformation characteristics and creating conditions that limit atmospheric connection when the aquifer is pressurized.

Topographically, the Upper Freeport coalbed truncates the hilltop or crops out around the perimeter of the hilltop. This defines the areal extent of the perched aquifer that feeds the residence #1 well (Figure 5). The aquitard below is the underclay of the coal seam. The sandstone and gray shale immediately above the coal is the saturated zone. The vadose zone (area above the water table through which water percolates from the surface) consists of gray fractured shale and sandstone. From the mineralization evident in the joints of the highwall, the fractured gray shale and sandstone units act as the conduits draining the surface water to the water table. These joints are discontinuous in the brown shale and are poorly developed or partially healed in the weathered rocks in the near surface. Sandstone and shale layers owe much of their permeability and water-bearing capacities to the presence of developed joint sets. Joints generally become less open with depth, this being a low cover site, joints are open.

The fractured joint system should be visualized as a three dimensional grid where the joints are vertical or nearly vertical and horizontal along bedding planes interconnected with varying openness in three dimensional flow paths. They can be described as passageways or conduits where ground water flows in unsaturated aquifers. The strength of the rock is reduced in these areas and the rock is most susceptible to attack by erosional processes and percolating groundwater. These passageways through which water can move freely, increases effective permeability and water/gas-bearing capacity of the stratigraphic unit.

The well of residence #1 is connected to the Upper Freeport aquifer. The Milliren and residence #2 wells are deeper and tap a different aquifer.

Figure 5 illustrates how the well relates to the aquifer and residence #1. The well is a sump that collects water and can do the same for gases. The drawing does not show the well cap that covered the well and prohibited it from venting to the atmosphere. Based on the ER observations the floor drains, through the under drain system of the home, are connected to the well.

Borehole Gas Levels

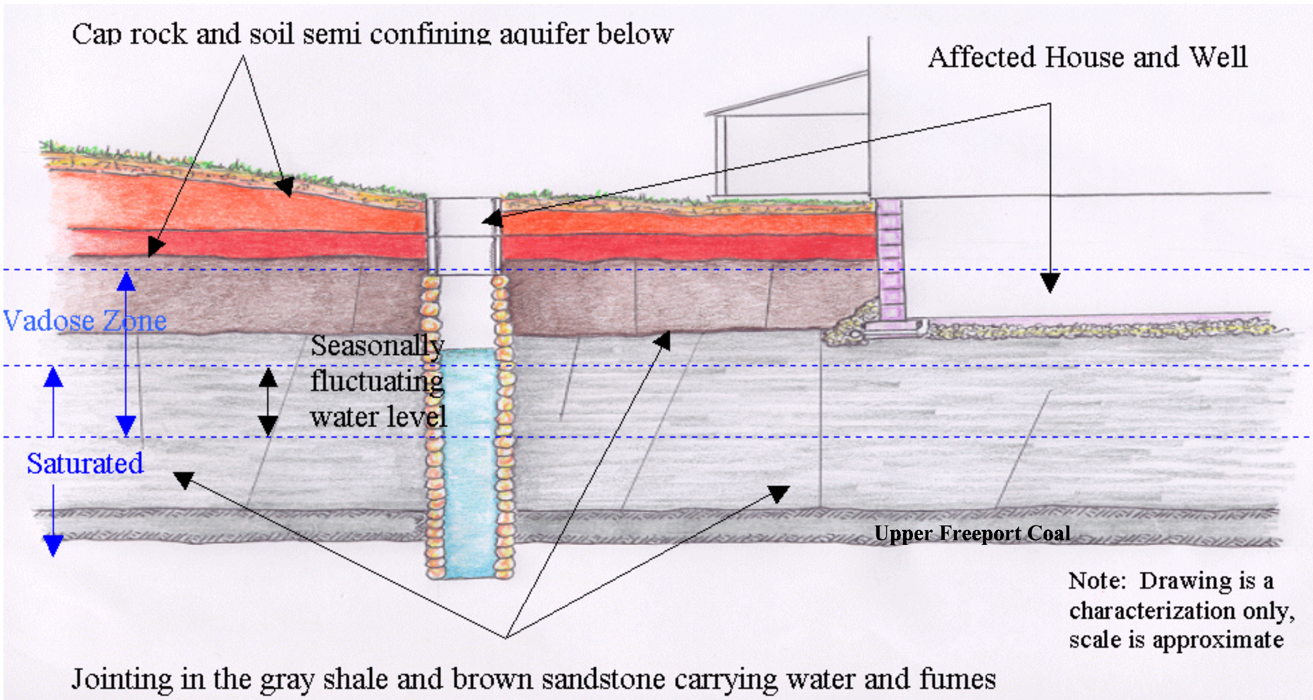

Figure 5 Residence #1 well and basement.

Blasting fractures rock by shock waves and high pressure gases imparting a stress around the blast hole that expand the hole, extend radial cracks, and jet into any discontinuity. Gases will take the path of least resistance. When heavily confined, the gases will migrate into existing cracks, joints, faults, and discontinuities until equilibrium is established.

NIOSH personnel sampled the ambient air in the four boreholes the day of drilling, and the following two days. Each borehole was covered with plastic to retard atmospheric air from entering and mixing with the borehole air as barometric pressures changed. Plastic tubing was inserted into each hole down to immediately above the water. Portable air pumps drew air until the gas levels stabilized whereby purging the lines. The portable gas detection instruments included the MSA Passport, the Crowcon Triple Plus, and the MiniWarn. Once the levels stabilized, NIOSH also took vacutainer samples to confirm field results. Vacutainer data agreed with the readings of the portable instruments and are shown in Table 2.

Table 3. Borehole atmosphere levels.

Gas	Air	Hole #1			Hole #2			Hole #3			Hole #4		
		1	2	3	1	2	3	1	2	3	1	2	3
N_2	78.08	76.97	77.72	78.13	83.32	84.97	89.29	79.10	78.13		78.06	78.17	78.15
O_2	20.96	19.62	19.79	19.67	13.64	12.23	5.78	19.53	20.66	18.70	20.71	20.32	20.39
CO_2	0.03	2.49	1.56	1.26	2.04	2.68	3.86	0.43	0.27	.0012	0.30	0.57	0.52
AR	0.93	0.92	0.93	0.93	0.99	1.02	1.07	0.95	0.93		0.93	0.93	0.93
CO	0.00	.0004	.0004	.0006	.0036	.0013	.0023	.0012	.0004		.0006	.0006	.0006
CH_4	0.00	.0004	.0004	.0004	.0003	.0003	.0003	.0004	.0003		.0004	.0003	.0004

Given the shallow perched nature of the aquifer, gases contained in the fracture system should closely resemble atmospheric proportions. The samples taken in the field confirm that carbon monoxide was present in the formation six weeks after blasting ceased. In addition, carbon dioxide and nitrogen levels, the two principle byproducts of ANFO detonation, are elevated from normal air in hole #2 that intercepted the fracture system. Under the blasting conditions here, the closed jointing near the surface impaired venting through the joint system to the surface and the large amount of stemming used. Blast gases were forced into the joint system.

Residential Settings

None of the houses are founded on the sandstone above the coal, however residence #1 is the closest. All three have basement rooms. Residence # 2 and the Milliren residence basements contained no CO. Residence #1 has a 36" diameter well and the other two have drilled wells that reportedly exceed 100 feet in depth.

The residence #1 well has the largest interior surface area and a lining that is roughly textured and permeable to allow water from the perched aquifer to enter for storage. The same would be true for any pressurized gases within the aquifer. The well could be likened to a gas sump. Since the aquifer is perched and the crop of the sandstone is capped with relatively impermeable soil, the path of least resistance for gas flow would be the well.

The underdrain system and the well are in contact and connected to the joint system in the underlying and surrounding formation. In this case, they both functioned as a collection system for fumes in the unsaturated portion of the gray shale aquifer. The airflow, when the well was purged of fumes by ER, revealed a connection between at least two of the floor drains and the well.

Carbon Monoxide Generation and Transmission

The family of residence #1 has lived in their home for nine years, with no recorded carbon monoxide incidents. The timeliness of the two incidents of April 1 and April 20, indicate a more than casual relationship between blasting and carbon monoxide in the home.

All blasting creates fumes including carbon monoxide. Blasting practices to control flyrock at the mine fostered the generation, storage and propagation of the fumes. The blasts were heavily confined to protect the nearby Milliren residence and garage. The blast pattern was spread out to lower the powder factor and heavily stemmed to focus the explosive energy on the sandstone near the coal. The center initiation sequence helped to create higher internal gas pressure that was not allowed to dissipate to the atmosphere. A series of blasts at the west end of the pit (on two occasions) not only minimized the potential for flyrock but also increased the cumulative gas reservoir in the ground.

The sandstone being blasted has fracture zones on about 16-foot centers that were mineral stained and open. Blastholes were drilled in or near these fractures on the same spacing. The high gas pressure generated in each hole would charge the fracture system in the surrounding rock units (aquifer). The likely path of gas transmission was the fracture system in the sandstone. Each successive blast effectively pumped the gas further into the aquifer through the open fracture system above the water level. The reservoir contained CO and elevated levels of nitrogen and carbon dioxide up until drilling was conducted on May 31, 2000. The finite areal extent of the perched aquifer may have contributed to the gas migration.

The distance to the home from the blasts on March 31, 2000, when the first CO incident occurred was about 500 feet and about 430 feet away for the second event. The house is founded in close proximity to the coalbed and the same stratigraphic unit being blasted. As the blasting pumped gas into the aquifer, the 36-inch diameter 28-foot deep well acted as a sump to collect the CO. Other than the highwall, this may have been the only other exit point available to the fumes since perched aquifer would be flanked on all sides by a less permeable surficial soils.

Once into the well, the CO could migrate into residence #1. The floor drains are atmospherically connected to the well and the gas would follow the path of least resistance. ER reported that while venting the well, air was drawn from the basement through the floor drains. ER hypothesized that the reverse occurred, i.e. negative pressure was created within the well when the furnace started and began to draw combustion air. The basement had the highest CO concentrations at the floor drains where air from the well was entering the basement. Once into the basement, CO could easily migrate into the other areas of the house.

In surface coal mining, explosive fumes usually dissipate rapidly into atmosphere. However when the March 31 and April 17 and 20, 2000 series of blasts were detonated, fumes containing CO were contained in the ground, blasting fumes were forced through the open fractures in the aquifer, over many blasts the fumes filled the open fractures above the water table, and eventually under pressure entered the 36" well of residence #1. The CO then flowed into the basement through the floor drains where it eventually spread throughout the house.

Conclusion

While the blaster was concentrating on controlling flyrock to protect a structure less than 50 feet away, he inadvertently created a situation where the gas could be contained in the ground under pressure. Unique site geology and an unfortunate alignment of blast holes with the sandstone fracture system allowed for the gas to accumulate in the fractures of the aquifer and migrate into the residence. Thus, combining all the factors which includes geologic conditions, blasting practices, mining practices, well type and foundation construction, blasting at the Milliren mine generated the carbon monoxide that entered the home and caused the family to become ill.

Noteworthy are the Guidelines and Recommended Practices for blasting issued by the Institute of the Makers of Explosives (IME). One of their guidelines entitled Fumes from Blasting Operations lists 5 circumstances that have existed in previous incidents of carbon monoxide poisoning. At this site 4 of 5 circumstances existed:

1. Blasting was conducted to minimize displacement,
2. Broken overburden was not immediately excavated,
3. Carbon monoxide had a pathway to enter the basement, and
4. Adequate or positive ventilation was not provided.

The only IME circumstance not existing at this site was that the blasts be "very close" to the residence.

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