A Modeling Study on Longwall Tailgate Ventilation

Conference Paper · June 2012

2 authors:

Jurgen Brune
Colorado School of Mines

Michael J. Sapko

A modeling study on longwall tailgate ventilation

Jürgen Brune,
Colorado School of Mines, Golden, Colorado, USA

Michael Sapko,
Sapko Consulting Services, Finleyville, Pennsylvania, USA

ABSTRACT: In the United States longwall gobs are usually ventilated with bleeder systems. These bleeders are designed to dilute, render harmless, and carry away flammable, explosive, noxious, and harmful gases, dusts, smoke, and fumes from the active mining areas.

One of the most critical areas for longwall ventilation is the tailgate corner. This paper uses computational fluid dynamics (CFD) simulations using the Fire Dynamics Simulator (FDS) by the National Institute of Standards and Technology (NIST) to analyze the ventilation and potential methane accumulation and mixing patterns in the tailgate corner area. Ventilation airflow in the longwall tailgate is essential to proper methane dilution and helps prevent methane-rich air from being drawn from the gob. Positive ventilation may be obstructed if the tailgate entry immediately inby the longwall face cannot be kept open due to caving of the roof and/or floor heaving.

CFD simulation results illustrates the impact of various ventilation patterns and suggest improved ventilation and ground control practices to reduce the hazardous accumulations of methane in the tailgate areas of longwall sections. Simulations also suggest re-evaluation of the locations of methane monitoring approaches to detect and warn of potential methane accumulations in the tailgate before the shearer cuts into the tailgate.

1 Introduction

Longwall ventilation in Unites States underground coal operations is governed by title 30 of the Code of Federal Regulations (30 CFR), §75.334(b)(1) which mandates the use of a bleeder system "to control the air passing through the area and to continuously dilute and move methane-air mixtures and other gases, dusts, and fumes from the worked-out area away from active workings and into a return air course or to the surface of the mine. Figure 1 shows a typical longwall ventilation pattern using bleeders.

A concise definition of the terms "bleeder" and "gob" is given by the U.S. Mine Safety and Health Administration MSHA (MSHA 2002):

> *Bleeder systems are that part of the mine ventilation network used to ventilate pillared areas in underground coal mines. Bleeder systems are designed to protect miners from the hazards associated with methane, oxygen-deficient air, and other gases which may accumulate in these mined-out areas. Bleeder systems include any area from which pillars are wholly or partially extracted, any combination of bleeder entries, bleeder connections, and all associated ventilation control devices.*
>
> *Gob areas, or pillared areas, are those in which pillars have been wholly or partially removed.*

It should be noted that a longwall panel is considered a "pillar" in the context of this definition.

Modern longwall faces are 1,200 to 1,500 feet wide and panel lengths exceed 10,000 feet in many cases.

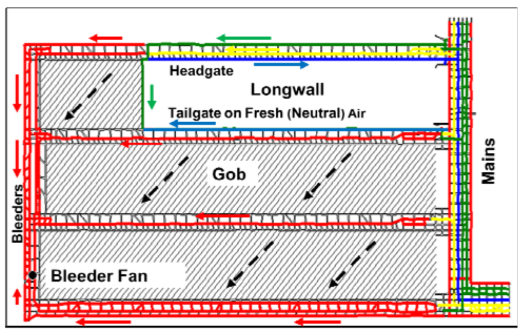

Figure 1: Longwall mine ventilation scheme. Arrows indicate direction of air flow. Colors indicate fresh air (intake): green, track: yellow, belt and neutral: blue and return or bleeder air: red. Black dashed arrows indicate general air flow tendencies in the gob. Not to scale.

The ability to dilute and render harmless any accumulations of methane in and near the active areas of the longwall depends on the ability to ventilate the bleeder entries as well as the gob with sufficient quantities of fresh air. U.S. regulations limit the methane concentration in bleeder entries to 2% (30 CFR § 75.323(e)). The need to have enough air in the bleeders to meet this criterion sometimes reduces the pressure on the gob.

Historically, longwall mines have suffered ignitions in the longwall face and adjacent gob areas, in many cases causing multiple fatalities. Beiter (2007) has summarized several examples where longwall bleeder systems failed:

- Greenwich Collieries No. 1 Mine, Fatal Mine Explosion and Fire, 1984: Three miners killed, 11 injured due to an ineffective bleeder system for a longwall. The bleeder entries were partially inundated with water, restricting airflow. The longwall panel was worked out, and pumpers were assigned to pump, entered with locomotive, did not test for gas which accumulated in roof cavity and ignited when locomotive ran under it. Water was impounded in the rear of the longwall panel which went down-dip.
- Williams Station (Pyro) No. 9 mine, Fatal Mine Explosion, 1989: 10 miners killed, 4 injured. Mine operator made ventilation changes that rendered the longwall bleeder system ineffective.
- Unspecified Mine Explosion 1997, no injuries: A longwall mine had a fire in the gate entries but it was believed to have been extinguished. Later, miners felt two light airblasts that made their ears pop. The investigation concluded that an explosion had occurred in the gob.
- Big Branch Mine Explosion 1997, no serious injuries: An explosion occurred in the longwall gob behind the tailgate shields. Miners reported seeing an orange glow and saw smoke coming from behind the shields. Several small explosions followed after the miners had escaped; destroying stoppings in the tailgate entry.

Well-known examples are the ignitions, subsequent explosions and/or fires that occurred at the Willow Creek mine (1998 and 2000) and at the Buchanan mine (2005 and 2007). These events were detailed in MSHA and State investigation reports:

- On November 22, 1998 an explosion and subsequent fire occurred at the Willow Creek mine in Utah (Elkins, 2001). No injuries resulted from this incident but a large airblast knocked down four miners at the longwall face and reversed the airflow at the longwall face. Miners observed an orange colored flame in the gob behind the shields that appeared to move towards the face and then back into the gob. According to the investigation report, the orange glow was pulsing back and forth along the tailgate entry from about 15 ft to 100 ft inby the shields ("inby" indicating the direction into the gob as viewed from the face). MSHA learned from interviews with the longwall crew that an ignition had not been seen at the face. Also, none of the miners received burn injuries, indicating a high likelihood that the fire was ignited within the gob and did not reach the face before the miners had evacuated the area.
- A series of four explosions occurred in 2000 at the Willow Creek mine that killed two miners and injured eight more, some of them severely burned. The first explosion shortly before midnight on July 31 was followed by two closely spaced explosions about seven minutes later. The fourth explosion occurred approximately 30 minutes later on August 1. According to the MSHA investigation report (McKinney et al., 2001) "Most likely, a roof fall in the worked-out area of the D-3 longwall panel gob ignited methane and other gaseous hydrocarbons." Like in the 1998 explosion, the ignition source was most likely friction from falling rock in the gob "causing either a piezoelectric spark or a spark against a metal object".
- The first of two gob explosion events at the Buchanan mine in Virginia happened in 2005, resulting in no serious injuries. According to the MSHA investigation report (Ratliff, 2005) the breaking of a thick sandstone bed overlying the coal seam caused a rush of gob air containing methane into the 6 Right longwall face. This initial roof fall in the gob was recorded as a seismic event of magnitude 3.3. Four seconds later flames were visible at the tailgate of the longwall where the shearer had been cutting, as depicted in Figure 2.

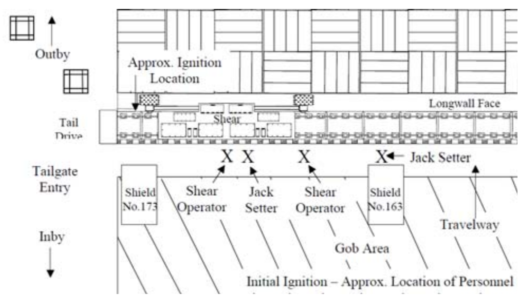

Figure 2: Location of 2005 ignition at Buchanan Mine, modified after Ratliff (2005)

One miner described the flames as "red in color" and observed their extent as about 8 feet. He saw them for only about two seconds until a thick cloud of dust obscured his view.

- The 2007 gob ignition at the Buchanan mine was found to have similar causes as the 2005 ignition, triggered by a violent break of the sandstone overlying the coal bed. No injuries were reported. Two separate seismic events were registered having magnitudes of 2.9 and 3.4. The MSHA investigation report (Woodward and Sheffield, 2007) states that the initial roof fall "ignited methane within the gob".

These events demonstrate that methane accumulations in longwall gobs are common and that explosive methane-air mixtures can form near the longwall face. If these mixtures ignite (frequently due to caving of quartzitic sandstone), flames, explosion pressures and hot, toxic combustion gases can reach into the active mining areas where they present a potentially deadly hazard to the miners. MSHA's investigation report of the 2005 Buchanan mine ignition (Carico, 2005) states:

> *The width and location of the elevated methane/air mixture along the gob periphery is variable dependent upon the permeability of the periphery and the proximity of the diluting air currents. An ignition of the methane within this zone can result in*

flame/explosion propagation along that periphery to other areas of the mine. Where sufficient volumes of these mixtures are present and those volumes are sufficiently confined, the resulting explosions will be evidenced at the closest pressure relief point into adjacent open areas of the mine such as regulated gate entry gob connectors, active gate roads, or active faces.

2 Longwall Tailgate Ventilation

There are two fundamental ventilation patterns for longwall bleeder ventilation. The first is the "H" pattern as shown in Figure 1, where fresh air is brought up along the tailgate to the intersection with the face. The second variant is the "Y" or "T-split" pattern where the return air coming from the face splits at the tailgate intersection and part of this air is ventilated towards the bleeders while the remainder is routed towards the main return through the immediate tailgate entry (entry adjacent to the solid block, "no. 3 Tailgate" in Figure 3). The T-split method usually provides a much higher air quantity at the longwall face but requires that an intact stopping line must be maintained between the center entry (no. 2 in Figure 3) and the no. 3 so that the center entry can serve as a fresh air escapeway.

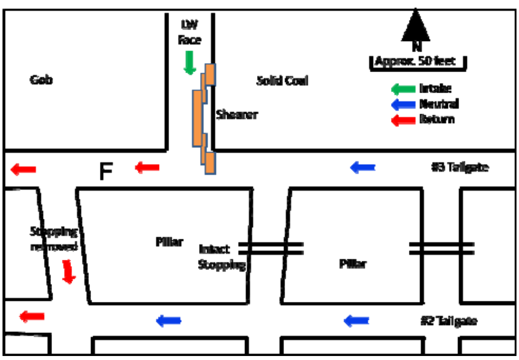

Figure 3: Tailgate ventilation detail

3 Typical Ventilation Problems in the Tailgate Area

Figure 3 shows a detailed map of a typical longwall tailgate area ventilated in the "H" pattern. Neutral air coming from the mains mixes with the air coming from the face and flows into the bleeder.

Stoppings between the no. 3 and the no. 2 tailgate entries are removed as soon as the longwall face passes the respective crosscut. This creates a common airway between no. 3 and no. 2 entries inby the face which is necessary to ensure sufficient bleeder capacity as the no. 3 entry frequently caves shortly inby the face. The ventilation may become problematic if this caving process sets in immediately behind the face (indicated by the letter "F" in figure 3), creating a blockage for the bleeder flow that can significantly reduce the longwall face ventilation quantity. If this happens, mine operators resort to removing the next stopping outby (marked as "intact stopping" in figure 3). This measure creates a quasi - T-Split as some or most of the air from the face is forced outby for a short distance before it reaches the nearest open crosscut to the no. 2 entry. This scenario is shown in figure 4.

This situation creates a potential explosion hazard as explosive air from the gob fringe may be pulled from behind the shields into the cutting area of the shearer where it may be ignited by hot metal smears created especially when cutting quartzitic sandstone. The face air mixes with methane emitted from the exposed face as well as from the coal on the face conveyor. Also, portions of the face air pass behind the shields where they may mix with additional methane from the gob. In an effective bleeder system, the location of the lowest pressure (the pressure sink) should be inby (on the gob side of) the longwall face so that all air contaminated with methane tends to flow away from the face and into the bleeder system. Under certain ventilation conditions such as the one shown in Figure 4, it is possible that the point of low pressure in the tailgate area moves outby towards the face. This hazard scenario has been investigated in detail by modeling with computational fluid dynamics (CFD) software.

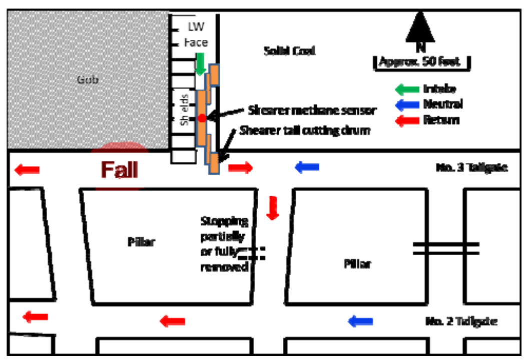

Figure 4: Fall in no. 3 tailgate inby face requires changed ventilation pattern

4 Numeric Simulation of Ventilation Flows in the Tailgate Area

Numeric modeling of ventilation airflows in the tailgate area was carried out using the Fire Dynamics Simulator (FDS). The FDS is a computational fluid dynamics (CFD) software package designed to model fire-driven fluid flow published by the National Institute of Standards and Technology (NIST). The FDS program solves the Navier-Stokes equations for thermally-driven flow, predicting smoke and heat transport from fires. Although primarily designed for simulating and analyzing gas flows in a building or structure fire, the FDS is also useful to model gas concentrations, turbulent inflow and outflow scenarios, flow around obstacles and gas mixing due to buoyancy and flow.

Figure 5 shows an oblique view of the three-dimensional model created in FDS. Simulations were carried out with various quantities of methane emanating from the gob area behind the shields. These simulations show that a partial or total blockage of the no. 3 entry immediately inby the longwall face may cause explosive air mixtures from the gob behind the shields to be drawn into the face area where they may be ignited by the shearer cutting drum.

Figure 4 also shows the typical location of the built-in methane sensor on the body of the shearer. The following assumptions and parameter selections were made for the CFD modeling effort:

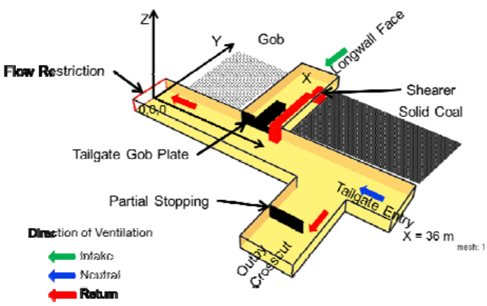

Figure 5: Three-dimensional FDS model for a typical longwall tailgate.

At the tailgate, as is typical for most longwalls, the face is partially restricted by a gob plate and the shearer cutting out the tailgate. The outby crosscut is partially restricted by a partial stopping covering about 2/3 of the cross section. The longwall face flow was held constant at 80,000 cfm (38 m^3/s), which are typical face quantities for Appalachian longwalls.

The air approaching the tailgate, flowing inby from the mains along the tailgate entry, was held constant at 10,000 (4.7 m^3/s) cfm. The open area of the caved tailgate inby the face was varied to investigate different degrees of closure in the tailgate entry and their consequences for clearing methane from the tailgate area. Simulations were conducted using 250 to 1000 cfm (0.12 to 0.47 m^3/s) of methane entering the tailgate entry from behind the shields.

The results are shown in figures 6 through 10, respectively. Each image was captured at a point into the simulation when the methane distribution had achieved a quasi-static state and did not show any significant changes at later times. In the figures, the rainbow pattern shows methane concentrations. Dark to light blue indicates a concentration below the lower explosive limit (1 to 5%), green indicating the lower explosive limit of 5% and red indicating a concentration of 14%. Black colors show concentrations above 14 %, the upper explosive limit. Grey colors indicate concentrations below 1%

Figure 6 shows the flow status for model run no. 134. The tailgate is wide open with a quantity of about 56,000 cfm (26 m^3/s). An eddy is formed in the shadow of the gob plate/windrow, confining the flammable mixture to a limited area behind the gob plate. The simulation shows that, although a significant amount of methane (1,000 cfm, 0.47 m^3/s or 1.25% of the face quantity) flow from behind the shields, the explosive cloud gets diluted quickly below the explosive range as it flows down the tailgate. There is no explosive methane (green to red color range) near the shearer tail drum where it might be ignited in the cutting process. Note that no explosive methane is near the shearer body where it might trigger a CH4 monitor alarm, either.

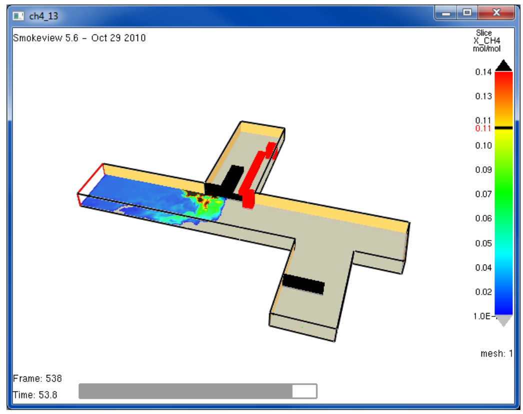

Figure 6: Methane cloud in run 134, 1000 cfm CH4 (0.47 m^3/s), fully open tailgate

Figure 7 shows the results for run no. 135, using the same methane quantity (1,000 cfm, 0.47 m^3/s), with the opening to the gob reduced to 1 m^2 (11 ft^2), equivalent to restricting the flow in the tailgate to about 26,000 cfm (12 m^3/s) or about half of the original flow. Here it is clearly visible that explosive methane concentrations (green colors) build up close to the tail drum, creating an acute explosion hazard.

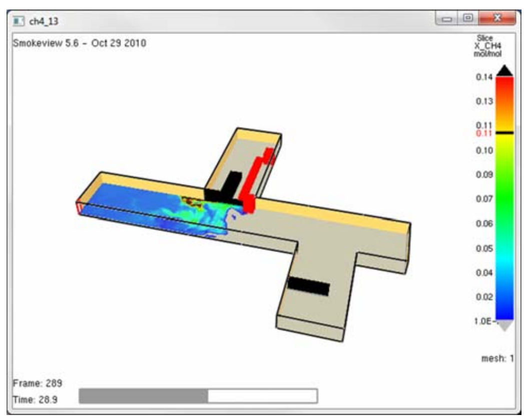

Figure 7: Methane cloud in run 135, 1000 cfm CH_4 (0.47 m^3/s), tailgate opening reduced to 1 m^2 (3.3 ft^2)

Figure 8 shows the gas cloud for model run 140. In this run the methane quantity was reduced to 250 cfm (0.12 m^3/s), with the gob opening left at 1 m^2 (11 ft^2). The gas cloud shows concentrations in the explosive range only inby the face (green colors), but concentrations between 1 and 5% may accumulate behind the gob plate and reach all the way to the shearer.

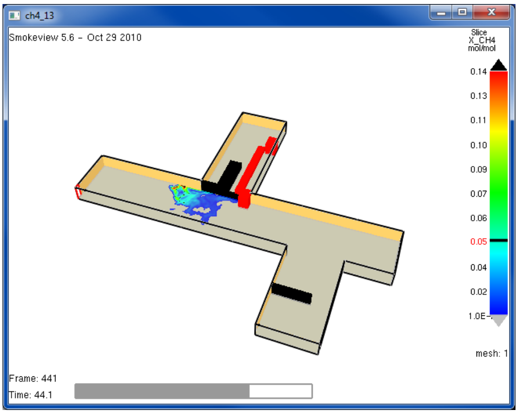

Figure 8: Methane cloud in run 140, 250 cfm CH_4 (0.12 m^3/s), 1 m^2 (3.3 ft^2) tailgate opening

Figure 9 represents model run 142, where the tailgate opening was further reduced to 0.25 m^2 equivalent to about 7300 cfm (3.4 m^3/s). Methane inflow was left at 1,000 cfm (0.47 m^3/s). Modeling shows that a significant methane cloud now develops outby the longwall face. Although this cloud appears to be below the explosive range, the modeling succession clearly demonstrates that tailgate restrictions will eventually drive methane accumulations into the tailgate outby the face, where they will enter the nearest outby crosscut.

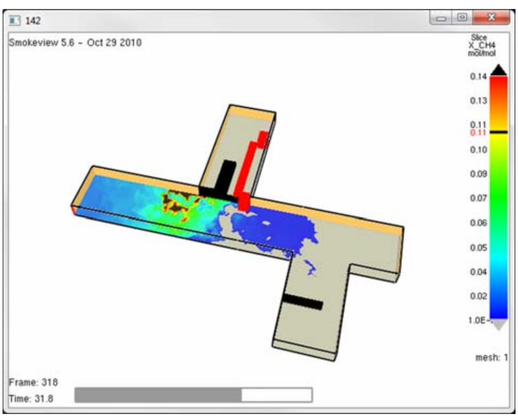

Figure 9: Methane cloud in run 142, 1,000 cfm CH_4 (0.47 m^3/s), 0.25 m^2 (0.8 ft^2) tailgate opening

Figure 10 shows model run 143 with the tailgate fully closed and a methane release of 1,000 cfm (0.47 m^3/s). Compared to figure 9, there is a more significant methane accumulation in the dead-ended tailgate with explosive concentrations close to the shearer drum. Concentrations outby the face are shown to be below the explosive range. It should be noted that, in all simulated cases, a methane sensor mounted on the body of the shearer (see figure 4) would not pick up any methane since it is always in fresh air.

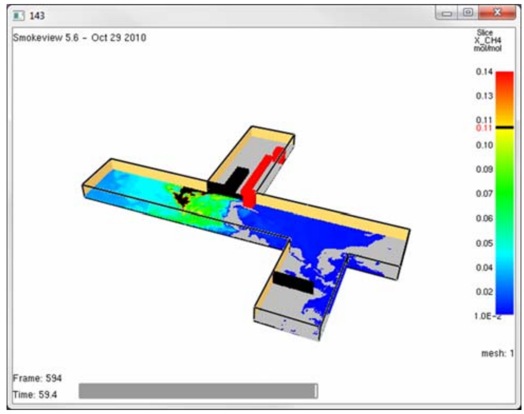

Figure 10: Methane cloud in run 143, 1,000 cfm CH_4 (0.47 m^3/s), tailgate opening closed

5 Conclusions and Recommendations

The CFD modeling work using the NIST Fire Dynamics Simulator (FDS) to simulate gas flows in the longwall tailgate area leads to the following conclusions and recommendations:

- A significant release of methane from the gob behind the longwall tailgate shields can lead to accumulations of methane-air in explosive concentrations.
- If the immediate tailgate entry caves tightly shortly inby the face, this methane release will not be diluted and carried away but will present an acute explosion hazard. Modeling demonstrates that explosive methane-air mixtures can reach the tailgate side cutting drum of the shearer, where it could be ignited by hot smears generated by the picks.
- Modeling also shows that, if methane sensors are mounted on the shearer body or on the longwall tailgate drive, it is unlikely to pick up dangerous concentrations of methane and shut off mining equipment.
- Based on the results of these models, the authors recommend to keep the immediate longwall tailgate entry open at least to the nearest inby crosscut so that positive ventilation is maintained inby the face to dilute and carry away any methane released behind the shields.
- Based on these modeling results, the locations of methane monitoring sensors on longwall equipment should be re-evaluated to ensure that dangerous concentrations of methane near the shearer cutting drums will be detected.

6 References

Beiter, D [2007]. Internal Airflow Paths. MSHA Ventilation Summit, National Mine Health and Safety Academy, Beckley WV, February 21-22, 2007, Mine Safety and Health Administration, Arlington VA, 2007.

Carico AD [2005]. Methane Ignition/Explosion/Mine Fire Accident February 14, 2005 at Buchanan Mine #1, Consolidation Coal Company, Mavisdale, Buchanan County, Virginia, ID No. 44-04856, Mine Safety and Health Administration, Norton VA 2005

Elkins DW, Luzik SJ, Lemon JOD [2001]. Report of investigation, underground coal mine fire, November 25, 1998. Willow Creek mine, Cyprus Plateau Mining Corporation, Helper, Carbon County, Utah, ID. No. 42–02113. Arlington, VA: U.S. Department of Labor, Mine Safety and Health Administration.

McKinney R, Crocco W, Tortorea JS, Wirth GJ, Weaver CA, Urosek JE, Beiter DA, Stephan CR [2001]. Report of investigation, underground coal mine explosions, July 31-August 1, 2000. Willow Creek mine, MSHA ID No. 42–02113, Plateau Mining Co., Helper, Carbon County, Utah.

MSHA [2002]. Bleeder and Gob Ventilation Systems. Ventilation Specialists Training Course. Revised Edition, U.S. Department of Labor, MSHA, Arlington VA 2002

Ratliff TA [2005]. Accident Investigation Report, Underground Coal Mine Methane Ignition / Mine Fire Accident, February 14, 2005, Consolidation Coal Company, Buchanan Mine No. 1, Mine Index No. 11912AA, Buchanan County, Virginia, Virginia Department of Mines, Minerals & Energy, Division of Mines 2005

Woodward DN and Sheffield T [2007]. Report of Investigation, Underground Coal Mine Methane Ignition/Explosion/Mine Fire Accident, July 9, 2007, Buchanan Mine #1, Consolidation Coal Company, Mavisdale, Buchanan County, Virginia; ID No. 44-04856, Mine Safety and Health Administration, Norton VA 2007.