Explosions and Refuge Chambers

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Effects of blast pressure on structures and the human body

The following table 1, based on Department of Defense data from Glasstone and Dolan (1977) and Sartori (1983), summarizes the effects of increasing blast pressure on various structures and the human body. This data originates from weapons tests and blast studies to assess the effect of blast overpressure on structures and people. This data provides some guidance on the possible effects of mine explosions on miners.

Table 1 – Effect of various long duration blast overpressures and the associated maximum wind speed on various structures and the human body.

Peak overpressure	Maximum wind speed	Effect on structures	Effect on the human body
1 psi	38 mph	Window glass shatters	Light injuries from fragments occur
2 psi	70 mph	Moderate damage to houses (windows and doors blown out and severe damage to roofs)	People injured by flying glass and debris
3 psi	102 mph	Residential structures collapse	Serious injuries are common, fatalities may occur
5 psi	163 mph	Most buildings collapse	Injuries are universal, fatalities are widespread
10 psi	294 mph	Reinforced concrete buildings are severely damaged or demolished	Most people are killed
20 psi	502 mph	Heavily built concrete buildings are severely damaged or demolished	Fatalities approach 100%

The human body can survive relatively high blast overpressure without experiencing barotrauma. A 5 psi blast overpressure will rupture eardrums in about 1% of subjects, and a 45 psi overpressure will cause eardrum rupture in about 99% of all subjects. The threshold for lung damage occurs at about 15 psi blast overpressure. A 35-45 psi overpressure may cause 1% fatalities, and 55 to 65 psi overpressure may cause 99% fatalities. (Glasstone and Dolan, 1977; TM 5-1300, 1990)

Table 1 also shows the maximum wind speed associated with the given overpressure. In mine explosions, as in war-related explosions, it is the blast wind resulting from the blast overpressure that leads to injuries and fatalities. The human body may be thrown violently into objects and receive blunt force trauma; conversely, large objects may be thrown into persons resulting in crush injuries, or else projectiles launched by the blast wind may penetrate the body. The susceptibility of personnel to blast effects depends on their proximity to nearby objects and possible projectiles. Miners standing in the open and away from projectiles may survive higher blast overpressures than those standing near a solid wall or object. Personnel sitting within the confines of mining machines may receive some protection from both blunt force trauma and projectiles. While it is impossible to determine the exact correlation between blast wave overpressure and fatality rate for personnel in an active underground mine, the data in table 1 above appears to provide useful guidance.

Explosion scenarios for refuge chambers and outby refuge stations

Figure 1 illustrates several possible locations of rescue chambers and outby rescue stations in a typical mining operation with three working sections, 1) a longwall face, 2) a longwall development heading and 3) a mains development heading. Refuge chambers are located near each working face where the greatest concentration of mine workers is expected, and outby refuge stations are located periodically along the primary escape route.

Multiple methane explosions with or without coal dust might occur within a mine. A first explosion might occur 1) on the working face, either longwall or room-and-pillar, 2) within a sealed area or 3) at some location outby the working face such as a shaft bottom, bleeder system or along the mains. This first explosion could disrupt the ventilation system severely and lead to a second and possibly subsequent explosions. These subsequent explosions will most likely occur close to the first explosion, but they could occur at some distance away as well. According to the MSHA investigation reports, the Willow Creek mine disaster in 2000 involved 4 explosions, and the Jim Walters Resources mine disaster in 2001 involved 2 explosions. Most of the fatalities occurred in the second and later explosions.

The areal extent of an explosion depends on many factors, but most important are the amount of methane gas available to fuel the explosion and the extent of coal dust participation. We define a “small” explosion as one with flame travel of less than 100 feet, a “medium” explosion as one with flame travel of several hundred feet, and a “large” explosion as one with flame travel of more than 1000 feet. Small and medium explosions likely affect just one working section, whereas a large explosion could affect the entire mine. Usually, methane explosions at the face or outby range from small to medium explosions traveling hundreds of feet. If coal dust becomes involved, the explosion may become “large” and travel thousands of feet.

With any explosion, the crew’s proximity to that explosion dictates their likelihood of survival and the likelihood they can make it to a refuge chamber, or preferably escape completely. In this analysis, we assume that a medium or large explosion, less than 1000 feet away, will likely kill or severely incapacitate the crew instantly and render the need for the refuge chamber moot. Such a scenario could occur at any working face, longwall or room-and-pillar. If a small to medium explosion occurs far from the crew, defined as more than 1000 feet away, we assume that many of the crew will likely survive to enter the refuge chamber. We are therefore designing for a "survivable" explosion.

With reference to figure 1, table 2 illustrates the relationship between the crew location, the location of a "medium" size explosion, and the likely effect on each work crew, which is either fatal immediately, survivable with rescue chamber and survivable with immediate escape.

Table 2 – Relationship between crew location, the location of an explosion and the possible effect on the work crew.

Crew Location	Location of "Medium" Explosion			
	Longwall (at or near face)	Longwall Development (at or near face)	Mains Development (at or near face)	Other location along primary escapeway
Longwall	Fatal	Chamber or Escape	Escape	Chamber or Escape
Longwall Development	Chamber or Escape	Fatal	Chamber	Chamber or Escape
Mains Development	Chamber or Escape	Chamber or Escape	Fatal	Chamber or Escape
Inby the Explosion	Not applicable	Not applicable	Not applicable	Chamber
Outby the Explosion	Escape	Escape	Escape	Escape

Pressure design criteria for refuge chambers and outby refuge stations

Refuge chambers and outby refuge stations may be designed to resist an overpressure of at least 5 psi. If a miner miraculously survives a 5 psi blast in the vicinity of a refuge chamber, that person is assured that the refuge chamber will also survive.

The state of West Virginia has ruled that refuge chambers will resist a blast overpressure of 15 psi. This pressure design criterion is apparently conservative and errs on the side of safety.

Anchorage requirements for refuge chambers and outby refuge stations

Refuge chambers and outby refuge stations could be anchored to the floor or otherwise rendered immovable in some way. A 6-ft-wide by 5-ft-high refuge chamber has a cross-sectional area of 4,320 square inches. A 5 psi blast overpressure subjects the chamber to a lateral force of 21,600 pounds. Therefore, the chamber requires anchorage or some other means to render it immobile in a mine entry.

To demonstrate the effects of explosion pressure on objects, an LLEM test moved a 1,560 pound object about 79 feet. The explosion pressure on the object was estimated at 3.5 psi and lasted less than 7 milliseconds. The exposed cross-sectional area is estimated at about 900 square inches, and therefore, the total force on the object was about 3,150 pounds for a few milliseconds. Again, this force moved the 1,560 pound object about 79 feet.

Explosion debris protection for refuge chambers and outby refuge stations

Figure 2 shows the debris pattern from a failed seal in a test at the Lake Lynn Experimental Mine. The explosion was initiated in the C drift and reached a maximum pressure of 90-100 psi inby the seal. Debris from the failed seal, from cribs built near the seal, and from a stopping outby the seal extended about 1100 feet from the original seal location.

The most important point to note from this debris pattern is the general lack of debris in the cross-cuts at right angles to the "line of fire" from the explosion. The debris travels in a straight line. In terms of debris protection, there is an advantage to placing refuge chambers in cross-cuts if the debris from blown-out seals is likely to travel out the entries. If the seals are perpendicular to the entries or if there are stoppings in the cross-cuts, then there would be significant debris in the cross-cuts.

Figure 3 shows several possibilities for locating refuge chambers in the vicinity of a typical development heading, such as in cross-cuts or in stub entries in various possible locations. A stub entry requires ventilation for use as a refuge chamber locale.

Design guidelines for refuge chambers located near the working face and outby refuge stations located along primary escapeways

1. The refuge chamber should survive an explosion overpressure of at least 5 psi. A refuge chamber designed for this pressure could provide sanctuary to a miner who survives such explosion pressure.
2. The outby refuge station should survive an explosion overpressure of at least 5 psi. A miner who survives such explosion pressure, should find the outby refuge station intact.
3. Locate refuge chambers less than 1000 feet from the working face or other concentrations of the underground mining workforce.
4. Locate refuge chambers and outby refuge stations in a cross-cut between two intakes, insofar possible. This practice can help protect the refuge chamber from explosion debris.
5. Alternatively, locate refuge chambers and outby refuge stations in a stub entry perpendicular to the main entries and in between crosscuts. See figure 3 to illustrate. Note that the stub entry would require proper ventilation. If the chamber is at the end of a stub entry, another advantage is that it would not be moved by the explosion pressure.

6. Locate refuge chambers and outby refuge stations out of the possible explosion path or “line-of-fire” from sealed areas, insofar possible.
7. Locate refuge chambers and outby refuge stations at least 1000 feet away from seals, insofar possible.
8. Locate refuge chambers and outby refuge stations away from or around a 90 degree corner from major debris sources such as cribs, stoppings, conveyor belt structure or large stores of supplies that could become flying objects, insofar possible.
9. Protect the refuge chamber and outby refuge station doors and other important structures from the possibility of damage from any likely source such as routine moving and any debris from an explosion.
10. Shield refuge chambers and outby refuge stations from possible flying debris with sacrificial structures or some other technique, insofar possible.
11. Anchor refuge chambers and outby refuge stations firmly to the floor or assure that it remains stationary by some means.

References

Glasstone S, Dolan PJ, eds. [1977]. The effects of nuclear weapons. 3rd ed. U.S. Department of Defense and the Energy Research and Development Administration.

Sartori, L. [1983]. The effects of nuclear weapons, Physics Today, March, pp. 32-41.

ARMY Manual TM 5-1300 [1990]. Department of the Army, Washington, DC, 1990

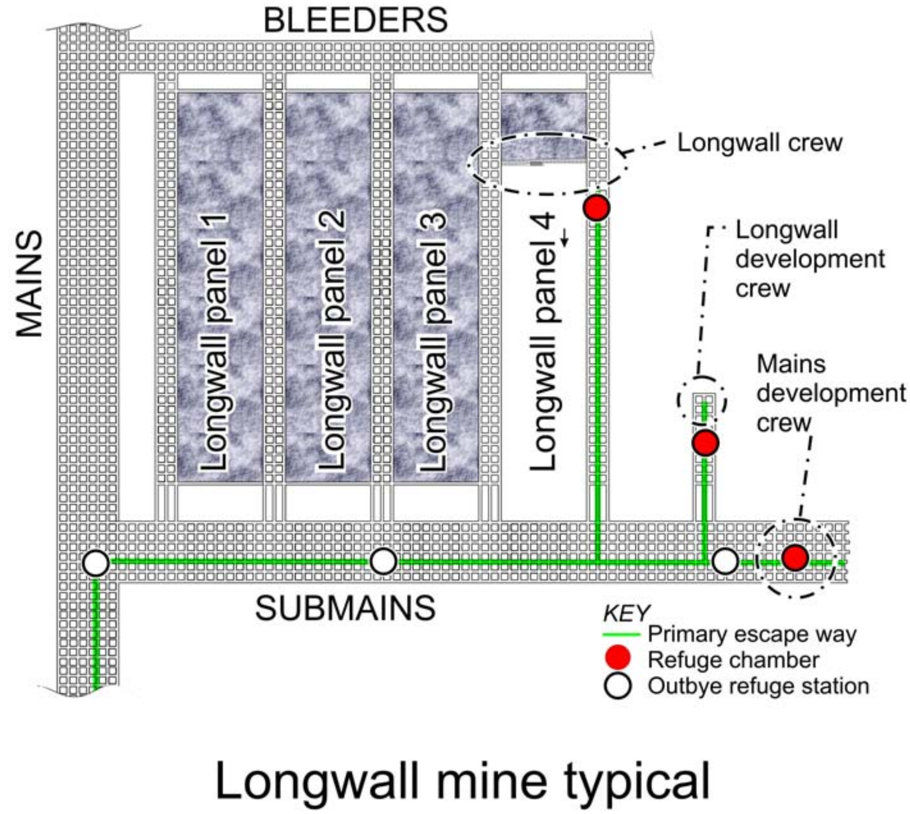

Figure 1 – Typical longwall mine layout showing the likely locations of refuge chambers and outby refuge stations.

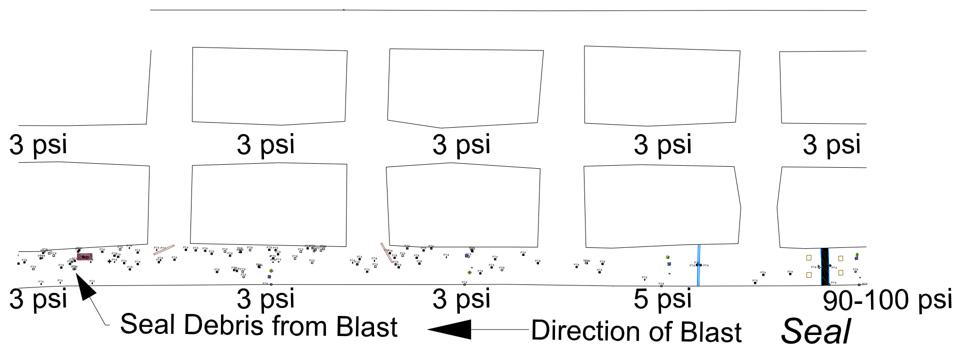

Figure 2 – Most debris from an explosion remains in entries parallel to the direction of the blast. Little debris affects entries perpendicular to the blast. Locate refuge chambers in cross-cuts at right angles to the most likely "line of fire" from an explosion to protect the refuge chambers from projectiles.

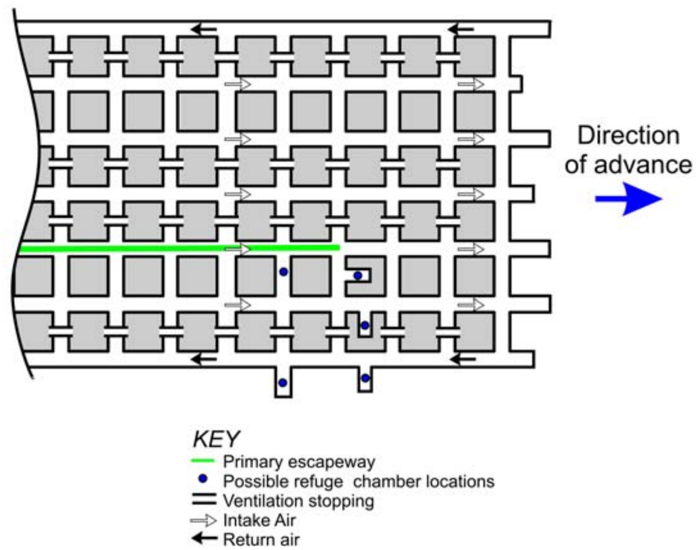

Figure 3 – Possible locations for refuge chambers in a development heading. The main options are a cross-cut or a stub entry. Note that a stub entry would require proper ventilation.