3. Refuge Location Analysis

3.1 Introduction

In the analysis conducted in Phase I of this project, we reviewed a total of forty two (42) past mining disasters and studied the impact refuge stations[1] would have had on the final outcomes of thirty eight (38) of those disasters most applicable to the project. All disasters occurred between 1970 and 2006 and involved fires, explosions, and inundations in which at least one fatality occurred. MSHA reports were reviewed and data collected on the type of incident, number of survivors, and the number and type of fatalities. The potential effect of refuge chambers on both survivors and fatalities was estimated. The amount of data is limited; we provided the best analysis possible within the confines of the information available.

The objective of the ongoing analyses of past mining disasters in Phase II of the project has been to build on the earlier studies to reach final conclusions and recommendations on the placement of stations within underground coal mines to help save miners lives in the event of future disasters. To do this, we engaged in a two-pronged approach:

1. We conducted an additional review of all 42 disasters studied in Phase I to determine if the point of origin of the disaster (fire, explosion, etc.) occurred at a working face or some distance away and how this might correlate with the outcome on miners lives and therefore on the placement of stations.

2. We selected a subset of those disasters studied in Phase I that were most relevant for the potential of stations to save miners lives and studied them in greater depth to more accurately pinpoint how stations might have been used in those cases.

Based on these studies, we were able to reach final conclusions and provide a series of recommendations for the use of stations in coal mines. The following subsections present the results of our Phase II studies and our recommendations for the use of refuge stations. A bibliography listing the resources we used to conduct the analyses on this project is provided in Appendix B. The bibliography also includes contact information for those individuals that either met with us regarding the project or provided us with some of the materials used in the analyses.

3.2 A Study of the Locations of Mine Disasters Within the Mines

An additional review was conducted of all of the forty two (42) disasters studied in Phase I to determine if the point of origin of the disaster occurred at a working face or some distance away. This was expected to shed light on how the point of origin of a disaster might correlate with the outcome on miner's lives. In the case of explosions, for example, it was assumed that an explosion right at the working face would instantly

[1] Throughout this document the term *station* refers to either portable refuge chambers or to bulkhead-based refuge locations.

either kill or severely injure the miners in the area, limiting the potential ability of a refuge station to have a positive impact. Explosions elsewhere in the mine, on the other hand, would be expected to have a less dramatic impact on most of the affected miners.

In the case of mine fires or gas inundations, the reverse could be true. A fire or gas inundation near the working face would likely be discovered quickly and miners on the working section would probably be able to readily escape through an intake escapeway. Fires or inundations in outby areas, on the other hand, might not be discovered and communicated to inby miners in a timely manner and could contaminate intake airways or belt entries leading into working sections.

Table 1, Table 2, and Table 3 below present the basic data from this review. Because of their differing impact on disaster outcomes, explosions and fires/inundations are tabulated separately. For completeness, a third table lists remaining disasters of the total 42 originally studied that are not applicable to this review.

Table 1. Mine Explosions

	MINE	**EXPLOSION AT FACE AREA?**
1	Darby Mine Explosion	No – 1000 ft away; 2 victims near explosion died instantly; 3 in face died later
2	Sago Mine Explosion	No – 2300 ft outby; 1 victim near explosion died instantly; 11 in face died later
3	Pyro No. 9, William Station Explosion (1989)	No – 450 ft inby; 4 victims along longwall face closest to explosion died instantly; 6 further from explosion died later
4a	Scotia Mine Explosion – 1st explosion	No – 800 ft inby; 6 of 15 victims killed instantly; of 9 others near face, 3 likely survived a short time and 6 others died in barricade
4b	Scotia Mine Explosion – 2nd explosion	No – 2500 ft inby; all 11 victims located in an outby area died instantly
5	Oakwood Red Ash Explosion	No – 6000 ft away; 2 victims near explosion were not killed instantly
6	Itmann No. 3 Mine Explosion	No – 1000 ft outby; of 8 miners near explosion, 5 were killed (instantly or nearly so) and 3 were injured
7	Blacksville No. 1 Fire & Explosion (1972)*	No – occurred between mine fire and face area (report is not specific on location); no deaths were related to this explosion
8	Finley 15 & 16 Mine Explosion	No – 150 to 1500 ft away; 33 of 38 affected miners were killed instantly
9	Pyro No. 2 Mine Explosion	No – 1 of 2 men surveying old works died; the other escaped; explosion occurred a considerable distance from active areas (data not provided); no other miners affected
10	Jim Walters Resources, Inc., No. 5 Mine	No - 2 explosions: one (minor) about 400 ft outby the faces; the other (major) about 1,000 ft outby the faces; the major explosion killed 12 of 13 victims instantly, none near faces at the time

	MINE	EXPLOSION AT FACE AREA?
11	Southmountain Coal Co., Inc. - #3 Mine	Yes (or very close); 8 of 9 victims killed instantly
12	McClure #1 Mine	Yes (or very close); 3 of 7 victims killed instantly; others too injured to escape
13	RFH Coal Co., #1 Mine	Yes; 2 of 7 victims killed instantly; others too injured to escape
14	Grundy Mining Co., #21 Mine	Yes (or very close); all 13 victims killed instantly
15	Adkins Mining Company, No. 11 Mine	Yes; all 8 victims killed instantly
16	Mid-Continent, Dutch Creek #1 Mine	Yes; all 15 victims killed instantly
17	Westmoreland Coal Co., Ferrell No. 17 Mine	No – distance from active faces unknown; 5 miners retrieving track in an abandoned area and all 5 victims killed instantly
18	R&D Coal Company, Inc. Mine	Yes; all 1 victim killed instantly
19	Plateau Mining Corp., Willow Creek Mine	Yes; all 2 victims killed instantly
20	A.A. & W Coals Inc. Elmo #5 Mine	No – one miner alone in old works died instantly or very soon after igniting methane; explosion was about 2,000 ft inby active section; only one miner on the active section was injured
21	Fire Creek Inc. #1 Mine	Yes (but no active mining in progress); all 2 victims killed instantly
22	Granny Rose Coal Company, No. 3 Mine	Yes; all 3 victims killed instantly
23	Double R Coal Co., #1Mine	Yes (or very close; victim alone in mine)
24	Mid Continent Inc., Dutch Creek #2 Mine	Yes; none killed instantly; all escaped and one died in hospital
25	Pyro No. 9, William Station Explosion (1986)	Yes; none killed instantly but 2 of 3 injured; one died one week later
26	M.S.W. Coal Company, No. 2 Slope Mine	Yes; 5 miners in area: 3 died; 2 killed instantly
27	Greenwich Collieries No. 1 Mine	Yes; all 3 victims killed instantly
28	Helen Mining Co., Homer City Mine (1983)	No – explosion occurred in a section inactive due to mine vacation; distance to faces unknown (without access to mine maps); victim alone conducting fire patrol ignited methane
29	P and P Coal Company, No. 2 Mine	No – all 4 miners retrieving equipment from old works died instantly; explosion occurred a considerable distance from active areas (data not provided); 16 miners in other areas escaped
30	Helen Mining Co., Homer City Mine (1970)	Yes; 5 miners in area: 3 injured and 1 killed
31	Clinchfield Coal Co., Compass #2 Mine	No – one miner died while traveling alone when his personnel carrier ignited methane; distance to active areas unknown (without access to mine maps); mine was idle at the time

* Note that this explosion occurred some time after a mine fire had developed. This disaster is also shown in the table below related to mine fires.

Table 2. Mine Fires/Inundations

	MINE	FIRE/INUNDATION AT FACE AREA?
32	Emery Mining Corp - Wilberg Mine Fire	No (about 2,200 ft outby longwall face); 27 victims of 28 miners in face area
33	Blacksville No. 1 Fire & Explosion (1972)**	No (1,900 ft and 3,500 ft outby two longwall working sections); 9 of 9 victims
34	Aracoma Coal Co., Inc, Alma Mine #1 Fire	No (about 3,500 outby working section); 2 victims of 12 miners escaping face area
35	Buckeye Coal Co., Nemacolin Mine Fire	Yes (3 crosscuts - about 300 ft outby faces); 9 of 10 miners in section escaped and 1 died; 2nd victim was found about 1,100 ft outby
36	Grays Knob Coal Company, No. 5 Mine	Yes (inundation of CO_2; 3 miners in face area died; others escaped)

** Note that this fire included an explosion that occurred some time after the fire had developed. This disaster is also shown in the table above related to mine explosions.

Table 3. Disasters Not Applicable to This Study

	MINE (not applicable to this study)	NATURE OF DISASTER
37	Black Wolf Coal Co., Quecreek #1 Mine	Inundation of water; no deaths; all 9 miners impacted were rescued
38	Consolidation Coal Co., Loveridge #22 mine	Suffocation in coal storage bin
39	Clinchfield Coal Co., Moss #3 Portal A Mine	CO_2 inundation 265 ft from surface of mine
40	Kocher Coal Corporation, Porter Tunnel Mine	Water inundation in multi-level anthracite mine
41	Jim Walters Resources, No. 4 Mine	CO asphyxiation in an outby area
42	R and R Coal Company, No 3 Mine	CO asphyxiation near mine surface following a production blast with explosives
43	Consolidation Coal Co., Blacksville #1 Mine (1992)	Above-ground explosion at production shaft

3.2.1 Analysis and Conclusions

For the 32 mine explosions reviewed (including two separate explosions at Scotia), 16 occurred at a working face area while the other 16 occurred some distance away from a face area or elsewhere in the mine. Of the 16 explosions occurring at the working face, all of the miners who perished were killed instantly in eight of them. In four others, some of the miners were killed instantly and others died some time later. In two other explosions, one miner in each explosion died in the mine but the time of death is unknown. In the remaining two explosions, one miner in each explosion died after being removed from the mine.

Of the 16 explosions *not* occurring at a working face, only six directly affected miners were working in face areas at the time of the explosion. Of these six explosions, three resulted in the deaths of face area miners but none were killed instantly; all were killed later while attempting to escape or awaiting rescue. In another two explosions, some or most of the face area miners *were* killed instantly due to the violence of the explosion. In one of the explosions, a face area worker was injured but not killed.

Of the remaining ten of the 16 explosions *not* occurring at a working face, seven events affected only the miners who were in the vicinity of the explosion. Miners in face areas were not affected. In all of these cases except one, all of the miners in the immediate vicinity of the explosion were either killed or injured. In only one case, a miner in the immediate vicinity of the explosion was able to escape uninjured. In two additional explosions (the second explosion at Scotia and the explosion at Jim Walter No. 5 Mine), miners some distance outby the point of origin of the explosion were killed (and most of them instantly) by the violence of the explosion. One explosion (Blacksville No. 1 Mine) was minor and had no effect on any of the miners.

Of the 4 mine fires that were reviewed, three originated a considerable distance from face areas. In the Wilberg fire, 27 of the 28 miners present in the longwall face area perished trying to escape the smoke and gasses from the outby fire. In the Blacksville fire, all 9 of the miners in two face areas perished trying to escape the smoke and gasses from the outby fire. In the Alma fire, 2 of 12 miners escaping the fire became separated from the rest of the group and perished. In the Nemacolin Mine fire, which did occur near the working faces, one of 10 miners escaping the fire left the group and perished while another miner attempting to escape separately was not successful.

One gas inundation was represented in the study, occurring right at the active face area. In the Grays Knob CO_2 inundation, all but three of the crewmembers were able to escape while three perished.

Generally, the above conclusions supported our expectations. Explosions occurring right at working faces killed all or some of the affected section miners instantly in most cases, while face area miners were *not* killed instantly in most cases of explosions occurring away from the face. In cases of particularly violent outby explosions (Scotia, Jim Walters and Finley, for example), face area miners still died instantly from the explosions.

In the case of the four fires studied, one of them (Nemacolin) originated close to the working faces, was discovered immediately by section personnel and most of the miners were able to escape quickly. The other three fires occurred well away from face areas and two of them resulted in significant loss of life because they were not communicated to face areas in a timely manner and escape routes were blocked.

The results of this study show that in nearly all cases, it is disasters that occur away from the face areas that provide the best opportunity for underground refuge stations to have an impact in saving miners lives. Unfortunately, face area explosions with sufficient forces to kill miners will kill most of them instantly, rendering stations irrelevant in most cases. Explosions away from face areas on the other hand allow surviving miners an opportunity to attempt escape or to seek refuge in stations if escape is not possible.

Stations are also very viable in saving miners lives in the cases of fires originating away from face areas where smoke, gasses and heat block the miners escape routes.

3.3 Detailed Analyses of Selected Mining Disasters

During our review in Phase I of the 38 applicable past disasters, we assessed whether a refuge station would have had a “positive”, a “neutral” or a “negative” impact on the miners affected by the disaster if a refuge station had been present in the mine at the time. We did this for two basic situations:

1. Situations in which the miners escaped successfully, did not escape but were rescued or barricaded and were rescued.

2. Situations in which the miners died attempting to escape, barricaded and perished, or were too injured to escape and were either rescued or perished.

Clearly the most important impact that refuge stations might have had on the outcomes of the disasters are those situations in which the stations might have saved miners lives, i.e., in which they would have had a “positive” impact on miners who died (Situation 2 above). There were twelve (12) such mine disasters in our original study and a key part of our Phase II effort has been to re-evaluate those twelve disasters in greater detail. It is notable that all but one of these 12 disasters originated well away from face areas, hence correlating well with the conclusions reached in the study of disaster locations discussed in the previous subsection.

The objective of this more extensive study of the 12 select disasters was to determine as accurately as possible, based on the specific situations of each disaster, where the affected miners were located when they died and what environmental or physical conditions to which they might have been subjected. The intent was to help determine where a refuge station might have best been located to provide the greatest chance of saving the miners lives and, to the extent possible based on the information available, the conditions that a station would have had to endure (i.e. fire, explosion forces, etc.).

The twelve mine disasters selected for further study were (in reverse chronological order):

1. Darby No. 1 Mine Explosion – May 20, 2006
2. Aracoma Alma No. 1 Mine Fire – January 19, 2006
3. Sago Mine Explosion – January 2, 2006
4. Pyro William Station Mine Explosion – September 13, 1989
5. Wilberg Mine Fire – December 19, 1984
6. Scotia Mine Explosion – March 9 and 11, 1976
7. Oakwood Red Ash No. 4 Mine Explosion – September 25, 1973
8. Itmann No. 3 Mine Explosion – December 16, 1972
9. Blacksville No. 1 Mine Fire – July 22, 1972

10. Nemacolin Mine Fire – March 26, 1971
11. Finley No. 15 and 16 Mine Coal Dust Explosions – December 30, 1970
12. Pyro No. 2 Mine Explosion – November 30, 1970

For each of these disasters, we attempted to answer a series of key questions:

- Where were the victims found within the mine? Were they at active working faces, at outby (or inby) areas during an escape from active faces or elsewhere in the mine (at work areas away from active faces, while traveling within the mine, etc.)?
- Where were the miners found with respect to the source of the explosion or fire?
- Where did the source of the explosion or fire occur with respect to working faces?
- If a station had been in place in the mine within 1,000 ft from the face (i.e. per West Virginia regulations [1]), would the affected miners have been able to reach it?
- If a station had been in place in the mine 2,000 ft from the face (i.e. coincident with MSHA's breathable air guidelines [2]), would the affected miners have been able to reach it?
- Would a station at 1,000 ft from the face have been a preferred location compared to a station at 2,000 ft from the face or vice versa?
- Would a station positioned at some location *other* than 1,000 ft or 2,000 ft from the face have been preferred?
- Would flame and/or explosion forces have impacted a station (at 1,000 ft from the face, 2,000 ft from the face or some other location if applicable)? To what range of explosive forces would a station at each location have been subjected (if such information is available)?
- How long would it have taken mine rescue personnel to reach the affected miners if they were located in a station at 1,000 ft from the face? At 2,000 ft from the face?
- Would additional outby stations beyond those relative to the face (i.e. at 1-hour travel distances, etc.) have been potentially applicable to the miners?

We focused the above questions on the locations of 1,000 ft from the face and 2,000 ft from the face (WV regulations and MSHA breathable air guidelines) because those criteria already exist and mines are already beginning to adhere to them. Unless there was a compelling reason to choose a station location different than 1,000 ft from the face or 2,000 ft from the face, we preferred to hold the study to a comparison between those two potential locations. In fact, the results of the twelve detailed studies showed that there was ***not*** a strong reason in any of the cases to choose an alternative station location.

Table 4 presents a summary of the results of the detailed study of the twelve select disasters and an assessment of the results and conclusions follows the table. Appendix A provides additional detail related to each of the twelve disasters including a mine map showing the location of the disaster within the mine, locations of the miners who perished, locations where refuge stations would have been positioned at 1,000 ft from the face or 2,000 ft from the face, etc.

Table 4. Summary of Detailed Analyses of Twelve Select Mine Disasters from 1970 to Present

		Darby Explosion May 20, 2006	Alma Mine Fire Jan 19, 2006	Sago Explosion Jan 2, 2006	Pyro Wm Station Explosion Sept 13, 1989	Wilberg Mine Fire Dec 19, 1984	Scotia Mine Explosion Mar 9-11, 1976	Oakwood Red Ash Explosion Sept 25, 1973	Itmann No. 3 Mine Explosion Dec 16, 1972	Blacksville No. 1 Fire & Explosion July 22, 1972	Nemacolin Mine Fire Mar 26, 1971	Finley 15 & 16 Mine Explosion Dec 30, 1970	Pyro No. 2 Mine Explosion Nov 30, 1970
1	Where were victims found with respect to working face?	3 at faces	At face	11 at face	4 at face	Various (to 1900' outby)	Mar 9: 13 at face	N/A	1000' outby	600-3000' outby	1 @ face; 1 outby	Various (most @ faces)	N/A
2	Were some victims in outby areas?	2 outby (at explosion)	No	1 outby (at explosion)	6 at 250' outby	Yes	Mar 11: 11 outby	2 in old works	Yes, on mantrip	Yes, escaping	1 @ 1100' outby	Yes	2 in old works
3	Where were victims found with respect to disaster point of origin?	3 at 1000'	3500' outby	2300' inby	450-1000' outby (?)	Nearby or inby	800' outby 2500' outby	At origin	At origin	500-1200' inby fire	1 inby; 1 outby	150-1500' away	At origin
4	Where did the event occur relative to face (or work area)?	1000' away	3500 ft outby	2300' outby	450' inby	2200 ft outby	800' inby; 2500' inby	6000' away	1000' outby	Inby fire; outby face	300 ft outby	150-1500' away	Away from face
5	Would victims have been able to reach a station 1,000 ft away?	Yes	Yes	Yes	Yes (?)	Yes	Yes (some)	Maybe, if present	Maybe, if nearby	Yes (A2&A3)	Yes	Unknown	Yes, if present but would not have used
6	Would victims have been able to reach a station 2,000 ft away?	Yes	Yes	Maybe	Maybe (?)	Yes	Yes (some)	Maybe, if present	No	No-A2 Yes-A3	Yes	N/A	
7	Which station location (1,000 ft or 2,000 ft away) would have been favored?	2,000 ft	Neither	1,000 ft	1,000 ft	1,000 ft	Cannot say	Cannot say	1,000 ft (by luck)	1000 ft-A2 2000 ft-A3	Neither	N/A	N/A
8	Would a station at a location other than 1,000 ft or 2,000 ft away have been better?	No	No	No	No	No	Yes (in section)	N/A	No	No	No	No	N/A
9	Would FLAME have affected a station at 1,000 ft away?	No	No	No	No	No	Yes	Yes, if present	Yes	Yes-A2 No-A3	No	Yes	No, if present
10	Would FLAME have affected a station at 2,000 ft away?	No	No	No	No	No (flame) Yes (heat)	No	No, if present	No	Yes-A2 Yes-A3	No	N/A	No, if present
11	Would FLAME have affected a station per OTHER guidelines?	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A
12	Would FORCES have affected a station per at 1,000 ft away?	Yes; 15-20 psi	N/A (fire)	Yes; 2-5 psi	No	N/A (fire)	Yes	Yes	Yes; 2-4 psi	Yes (low)	N/A (fire)	Yes	No, if present
13	Would FORCES have affected a station at 2,000 ft away?	Yes; 2-4 psi	N/A (fire)	Yes; 2-5 psi	No	N/A (fire)	Yes	Yes	Yes; <2 psi	Yes (both)	N/A (fire)	N/A	No, if present
14	Would FORCES have affected a station per OTHER guidelines?	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A	N/A	N/A	N/A
15	Time (in hrs) rescuers would have made contact with trapped miners	1000 ft: 8-10 2000 ft: 3	48 or less	1000 ft: 48 2000 ft: 40	3 or less	2-32 (?)	1000 ft: 10+ 2000 ft: <1	<21, if present	1000 ft: 5 2000 ft: 4.5	96?-with borehole	<5 (?)	6.5-21.5	N/A
16	Would additional outby stations have been beneficial?	No	No	No	No	No	No	Cannot say	No	No	No	N/A	No

3.3.1 Analysis and Conclusions

- Of the twelve disasters given further study, eight involved explosions, three involved fires and one involved a fire with an accompanying minor explosion.

- Of the nine disasters involving explosions, none occurred right at a working face. In the Finley disaster (involving two conjoined mines), the explosion occurred about 150 ft away from one of the working faces but about 1,500 ft away from the other. In the other eight disasters, the explosions ranged from 450 ft to 2,300 ft away from working faces.

- In nine of the disasters, some or all of the victims were originally located at their working faces when the disaster was first discovered. In the other three disasters (all explosions), miners at outby locations triggered the explosions and they were the only miners affected.

- In nine of the twelve disasters, some or all of the miners were sufficiently healthy to attempt escape for a considerable distance. In the other three disasters, miners were apparently injured severely or overcome quickly and traveled only a short distance. Two of these (Oakwood Red Ash and Itmann) involved cases where outby miners triggered the explosions. The third (Finley) involved a violent explosion that instantly killed 33 of the 38 miners affected and the other 5 were only able to travel 100 to 140 feet before perishing.

- *<u>Stations located at 1,000 ft from the face</u>*: in eight of the twelve disasters, the victims would likely have been able to reach a station located 1,000 ft from the faces. In another of the disasters (Finley), it is not know whether the victims initially surviving the explosion could have reached a station at 1,000 ft because data is not available on the extent of their injuries. In another two of the disasters (Oakwood Red Ash and Itmann), the victims would only have been able to reach a station at 1,000 ft if it were close by due to their injuries. In one of the disasters (Pyro No. 2, in abandoned works), the sole victim could have reached a station at 1,000 ft (if it still existed in the area) but would probably not have stayed because he would have been in fresh air.

- *<u>Stations located at 2,000 ft from the face</u>*: in six of the twelve disasters, all or some of the victims would likely have been able to reach a station located at 2,000 ft from the faces. In two of the disasters (Itmann and Blacksville), all or some of the victims would *<u>not</u>* have been able to reach a station at 2,000 ft due to their injuries or mine conditions. In two of the disasters (Sago and Pyro William Station), it can't be determined for sure if the victims would have been able to reach a station at 2,000 ft based on their injuries or mine conditions. In one of the disasters (Oakwood Red Ash), the sole victim would only have been able to reach a station at 2,000 ft if it were close by due to his injuries. In one of the disasters (Pyro No. 2, in abandoned works), the sole victim could have reached a station at 2,000 ft (if it still existed in the area) but he probably would not have stayed because he would have been in fresh air. In the Finley disaster, a station at 2,000 ft would not have been provided due to close proximity to the mine portals.

- ***Stations at 1,000 ft from faces versus stations at 2,000 ft from faces***: for five of the disasters, a station located at 1,000 ft would have been preferred over the 2,000 ft location. In two of the disasters, the station location at 2,000 ft would have been preferred and in another two, neither would have been preferred over the other. In two other disasters, it wasn't possible to say if one would have been preferred based on data available. Finally, in two of the disasters the question was not applicable because stations would not have been used in one of them and a station at 2,000 ft would not have been provided in the other.

- ***Alternate station locations***: in only one of the disasters could it be said that an alternate station location would have been preferred over the 1,000 ft or the 2,000 ft locations. In the Scotia disaster, miners within their working section off the main entries were trapped inside their section due to an explosion that occurred out in the main entries inby their location. In such cases, it would have been preferable to maintain a refuge station some distance inside the section away from the junction with the mains. Although it is not possible to predict ahead of time that a disaster of this nature might occur, it might be a sensible protocol to establish a station within a dead-ended working section just as soon as possible after the section has advanced deeply enough to accommodate it. The Sago disaster bears this out as well; a location within 1,000 ft from the working faces at Sago would have been inside the section away from the direct firing line of the explosion and an ideal location for a refuge station. Because the submain was less than 2000 ft long a station at 2,000 ft from the faces at Sago would have been in the main panel and closer to the explosion and much more difficult for the miners within the section to reach. Note, however, that a station would never have been placed close to a gob seal because of exactly what happened at Sago.

- ***Effects of flame on stations at 1,000 ft from faces***: in seven of the twelve disasters, flames ***would not*** have impacted a station located at 1,000 ft from the faces. In four of the disasters, flames ***would*** have impacted a station at 1,000 ft and in one disaster (Blacksville) flames would have impacted a station at 1,000 ft for one working section but not the other.

- ***Effects of flame on stations at 2,000 ft from faces***: in ten of the twelve disasters, flames ***would not*** have impacted a station located at 2,000 ft from the faces, although heat would have been a factor in the Wilberg disaster. In only one of the disasters (Blacksville), flames ***would*** have impacted a station at 2,000 ft. One disaster (Finley) is not applicable because a station at 2,000 ft would not have been provided due to close proximity to the mine portals.

- *Effects of forces on stations at 1,000 ft from faces*: in seven of the nine disasters involving explosions, forces ***would*** have impacted a station located at 1,000 ft from the faces. Little numerical data was available as to the extent of the forces but in one explosion (Darby), a station at 1,000 ft would have been subjected to forces of up to 15 to 20 psi. In the Sago and Itmann explosions, a station at 1,000 ft would have been subjected to forces of about 2 to 5 psi and 2 to 4 psi respectively. In the Pyro William Station and Pyro No. 2 explosions, forces ***would not*** have impacted a station at 1,000 ft (and a station may not have even been provided in the Pyro No. 2 case).

- *Effects of forces on stations at 2,000 ft from faces*: in six of the nine disasters involving explosions, forces ***would*** have impacted a station located at 2,000 ft from the faces. Again, little numerical data was available but in the Darby explosion we estimate that a station at 2,000 ft would have been subjected to forces of about 2 to 4 psi; in the Sago explosion we estimate it would have been subjected to forces of about 2 to 5 psi and in the Itmann explosion we estimate it would have been subjected to forces of less than 2 psi. In the Pyro William Station and Pyro No. 2 explosions, forces ***would not*** have impacted a station at 2,000 ft (and a station may not have even been provided in the Pyro No. 2 case). Also, a station at 2,000 ft would not have been provided in the Finley explosion due to close proximity to the mine portals.

In most cases (though not all), stations located at 2,000 ft from the faces would have had the advantage of being further from most of the fires and explosions than a station at 1,000 ft and so less likely to be affected by flame and explosion forces; however, miners would have been able to reach a station at 1,000 ft in more cases than a station at 2,000 ft due to injuries, disorientation, debris in their path and the greater distance to be traveled, so stations at 1,000 ft would have been preferred in more cases as noted above.

- *Time for rescuers to reach miners in stations*: the time that it would have taken rescuers to reach miners taking refuge in a station varied widely across the twelve disasters, ranging from about 2 hours to potentially up to 96 hours where drilling a borehole would be required (see details in the table). Generally, rescuers would reach a station at 2,000 ft from the faces quicker than a station at 1,000 ft due to its location 1,000 ft further outby. In some cases, they would have reached a station at 2,000 ft much sooner (as in the Darby and Scotia explosions) while in other cases there would have been little difference. Obviously it would have depended on the conditions that rescuers would have encountered in the 1,000 ft of advance between the 2,000 ft and the 1,000 ft stations.

- *Additional outby stations*: as to the possible benefits of additional stations located in outby areas (as at one-hour travel intervals to match MSHA's breathable air requirements), there was only one disaster (Oakwood Red Ash) where an outby station might have possibly helped. The two victims were working in an abandoned area of the mine, so an outby station could possibly have been their only recourse had one existed in the area and if the extent of their injuries had allowed them to travel to it. In all eleven of the other disasters, miners either would have used stations at 1,000 ft or 2,000 ft from the faces instead or would not have been able to reach an outby station or would have been in clean air before ever reaching one.

- *Additional recommendations for locating stations*: recommendations related to station positioning surfaced from this study as follows:

  - Both the Wilberg and Alma mine fires were associated with conveyor belt systems. Conveyor belt systems, especially belt drives, are potential friction hot spots and have been sources of mine fires in the past. Avoid locating stations within escapeway crosscuts that are close to belt drives or other potential fire hot spots. Past mine fires and explosions have also often destroyed ventilation overcasts so station locations near overcasts should also be avoided.

  - The Blacksville No. 1 mine fire occurred in the track entry on equipment being moved in the entry. Fires and explosions have occurred in track entries in the past due to the prevalence of equipment, supplies and moving electrical and mechanical systems along the track. Although MSHA regulations [3] preventing the movement of equipment while miners are located inby will prevent similar disasters in most cases, another suggestion for station positioning would be to avoid locating them within or off track entries when other options are available.

  - The Oakwood Ash and Pyro No. 2 mine explosions both suggest that it could be important to maintain stations at either 1,000 ft or 2,000 ft from abandoned or mined out areas of mines as long as there is likelihood that miners will still need to access those areas, even if only occasionally, particularly since they may not be as well ventilated as more active working sections. Only a single station would be required since the section would no longer be advancing and the 1,000 ft location would be preferred since the greatest likelihood of an ignition or explosion would be in or near the abandoned face areas.

  - Based on the Sago disaster and general mining engineering judgment, stations should not be placed near gob seals.

- *Questions regarding station use and deployment*. It appears that some mines in the country are opting for portable stations (chambers) that have to be deployed for use. MSHA currently requires material to build an airtight barrier and will require rapidly inflatable walls when they become commercially available for breathable locations [4]. The reasons for such concepts for stations are obvious: the stations would be much easier to move as mining advances; however, our analysis of the mining disasters from 1970 to the present have shown that many of the disasters involved injured miners, most involve poor visibility due to dust and smoke and many have miners donning self rescuers. In fact, many miners under the duress of a mine emergency have had trouble performing the simple task of opening and donning a self rescuer. This leads to key questions that need to be addressed regarding the use of stations that would need to be deployed by miners during a disaster:

- How difficult are such stations to deploy, how long does it take and how much training is required to deploy them?

- How are injured and disoriented miners going to deploy the refuge stations or the inflatable walls if they barely make it to the station and are in dense smoke or dust when they get there?

3.4 Recommendations for Placement of Refuge Stations in Underground Coal Mines

Based on the Phase II research conducted above, following is a summary of our final conclusions and recommendations on the placement of stations within underground coal mines:

- In the cases of many of the disasters studied, stations would have been most effectively located within 1,000 ft from the faces of mining sections while in other cases stations would have been more effective at the 2,000 ft locations, so there are two choices: place stations at both locations or provide one about 1500 ft. It is not possible to maintain consistent distances (e.g., 1000 ft) at all times because the working section is continually advancing as coal is produced. Hence, the station(s) should be situated in ***nominal*** locations. In the approach using only one station it would be located within a range of 1000 ft to 2,000 ft from the face. Similarly, in the two station option one would be located in range of 500 ft to 1500 ft and the other within 1,500 ft to 2,500 ft from the face.

- It will always be necessary to maintain at least one active station for a working section at all times. A portable chamber cannot be considered "in-service" when it is being moved because its location will be changing and miners will not necessarily know of its in-transit or new final location. In addition, it may be subject to significant damage should an event occur while unanchored or in transit and rendered useless. Therefore, if a one-station system is being used it would require being moved during non-working shifts. If a mine is maintaining a two-station system for a working section, one can be dismantled and moved while the other station remains in service. This would apply whether the stations were portable chambers or bulkhead-based stations. Two basic scenarios that could be employed for this:

1. ***Alternating stations***: as the inby station begins to reach a distance of 1,500 ft from the faces (and the outby station approaches 2,500 ft from the faces), the outby station would be relocated to a position approximately 500 ft from the faces and the previously inby station would then become the new outby station. This cycle repeats as mining advances. If both portable chambers and bulkhead type stations are used in this scenario, they would alternate in their positioning.

2. ***Series station advancement***: as the inby station begins to reach a distance of 1,500 ft from the faces (and the outby station approaches 2,500 ft from the faces), the inby station would be moved up to a position approximately 500 ft from the faces while the outby station remains in service. Once the inby has been relocated and is back in service, the outby station would then be moved up to a new position about 1,500 ft from the faces. This cycle also repeats as mining advances.

- The above recommendations would apply to retreat longwall and pillar mining as well as to forward development mining. In cases of retreat mining, the stations would simply be relocated in the outby direction rather than the inby direction as mining progresses. Retreat mining could allow the reuse of abandoned bulkhead type stations that had been set up during earlier development mining.

- Note that special consideration has not been given to very low coal seams in this recommendation. Mines may need to consider placement of refuge stations within ranges closer to the faces on a case by case basis depending on the height of their coal seams or on other mitigating factors that would make travel to a station particularly difficult during emergency conditions of poor visibility and potentially bad atmosphere.

- In sections such as longwall sections where miners are spread widely throughout the face area and alternate escape routes are provided (as in headgate and tailgate escapeways), stations should be provided within each of the main escapeway routes where feasible. In the case of longwall tailgate entries, this may not be possible given the caved entries from adjacent mined out panels and dense cribbing installed to provide support in those entries.

- Stations should obviously be located within crosscuts off standard designated intake escapeways. If necessary in some instances, they may be located off designated return escapeways.

- None of the disasters studied suggested a specific station location that would obviate the 1,000 ft , 1,500 ft or 2,000 ft options. Hence, we are not recommending any specific alternative locations; however, we recommend establishing an initial station within a dead-ended working section as soon as possible after the section has advanced deeply enough to accommodate it. This will provide refuge to miners who could become trapped within the dead-ended section by fires or explosions that might occur either inby or outby in the adjoining main entries.

- The likely timeframe required for mine rescuers to reach miners trapped in a refuge station varied widely in the disasters studied. In at least one disaster, it could have taken rescuers up to 96 hours to reach trapped miners through a borehole. In many other cases it took substantially less time to reach trapped and injured miners. We recommend that stations be equipped to handle stays of up to 96 hours to accommodate the outside range of the rescue timeline and to account for the potential for stations to be overloaded (over designed capacity).

- Our study has shown that additional outby stations would only rarely be helpful in sustaining miners escaping a mine disaster and we do not consider maintaining outby stations to be a necessary requirement. However, mines providing boreholes at regular intervals as mining progresses (typically under minimal cover with ready access to all surface areas) might consider maintaining stations at intervals within the mine based on the relative ease in doing so. In a severe disaster, they could certainly provide temporary refuge to escaping miners to regroup and rest as they continue their escape.

- Stations should not be located within escapeway crosscuts that are close to belt drives or other potential fire hot spots. Past mine fires and explosions have also often destroyed ventilation overcasts so station locations near overcasts should also be avoided.

- Fires and explosions have occurred in track entries in the past due to the prevalence of equipment, supplies and moving electrical and mechanical systems along the track. MSHA regulations (initiated based on the Blacksville No.1 fire and explosion) prevent the movement of equipment while miners are located inby. Nonetheless, stations should not be positioned within or off track entries when other options are available.

- Stations should be maintained at either 1,000 ft or 2,000 ft from abandoned or mined out areas of mines as long as there is likelihood that miners will still need to access those areas, even if only occasionally, particularly since they may not be as well ventilated as more active working sections. Because mining will not be occurring in such inactive areas, stations will obviously not need to be relocated within those areas.