MISSOURI S&T | Mining and Nuclear Engineering

2nd Solicitation for Single Investigator Research Grants (AFC215)

ALPHA FOUNDATION FOR THE IMPROVEMENT OF MINE SAFETY AND HEALTH

Final Technical Report

Project Title: Management with Bag Barriers of Dust Explosion Risks in Underground Coal Mines

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Organization: The Curators of the University of Missouri on behalf of Missouri University of Science and Technology

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1 Executive Summary

Problem Statement

A coal dust explosion is the most significant and powerful hazard in underground coal mines. Since 2001, coal dust explosions have claimed 59 lives in the United States (U.S.). Many controls have been developed and implemented world-wide to address this hazard. One of the most significant health and safety interventions currently in use internationally is the ‘Bag Barrier’ explosion barrier. Though explosion barriers have been in use in other countries for over 15 years, they have not been adopted in the United States. This project brought together the U.S. coal industry, researchers, and regulators to discuss the possible design, regulation, and implementation of explosion barriers as a final contingency against the propagation of coal dust explosions in U.S. mines.

Research Approach

The approach taken with this project is qualitative in nature. Extensive quantitative research has already been completed in other nations on the “Bag Barrier” passive explosion barrier. The primary obstacle to implementing such technology in the U.S. is to refine existing regulations or develop new guidelines for their design and installation in U.S. mines where there are systemic differences in ventilation and mining practices, as compared to other countries where they are currently in use. Therefore, this project orchestrated conversations between coal industry personnel, researchers, and regulators regarding this additional line of defense against deadly coal dust explosions. Additional tasks were to advance industry-wide knowledge regarding coal dust explosion hazards, install trails of the bag barrier system in coal mines in the U.S., and begin to develop guidelines for adapting the Bag Barrier system for use in underground U.S. coal mines.

Project Accomplishments

Significant accomplishments for the project include:

1. First version of a U.S. specific guideline document developed.
2. Bag Barrier video created and seen by over 1100 people on YouTube.
3. Successful Industry Day attended by MSHA, NIOSH, and the coal industry.
4. Long term moisture analysis study showed no significant moisture in the contained dust after one year.
5. Two, month long trials were carried out in operating longwall mines in the U.S.
6. Differences between current users of the bagged barrier and the U.S. established and solutions recognized.
7. Two papers presented at the 2017 SME Annual meeting, one was selected for ‘Mining Engineering’ magazine publication and other selected for a webinar dissemination.
8. Accommodations for shortened U.S. Seam heights established - Short bags
9. Alternative hanging mechanisms developed for mines without roof mesh.

Impact on Mining Health and Safety

This project has established guidelines for installing a passive barrier system, specifically the ‘bagged barrier’ system in the U.S. Other continents, including Africa, Europe and Australia already use this system. Since implementation, a coal dust explosion in Poland successfully triggered the passive barrier and all personnel outby of the barrier survived [1]. Coal dust explosions thankfully are not common, but can be deadly when they do occur; employing this last line of defense has the potential to save lives in the U.S coal mining industry.

2 Problem Statement and Objective

The most significant and powerful hazard that exists in an underground coal mine is a coal dust explosion. A coal dust explosion has the potential to propagate to every part of a mine resulting in massive damage to the mine and equipment, as well as tragic loss of life. Since 2001, disasters due to coal dust explosions in U.S. underground coal mines have caused 59 deaths, including 29 deaths in a single mine explosion at the West Virginia Upper Big Branch (UBB) mine in 2010. Many controls have been developed and implemented in different countries to reduce the impact of coal dust explosions. This project came under the ‘Health and Safety Interventions’ focus area. One of the most significant health and safety interventions in use internationally is the ‘Bag Barrier’ explosion barrier. Explosion barriers have not been adopted in the U.S. due to the belief that good housekeeping and other preventative strategies (such as the practice of ‘rock dusting’) will always be 100% effective. Following the UBB disaster, many have realized that additional defenses are needed to prevent the propagation of a methane ignition into a coal dust explosion. From a risk management viewpoint, the explosion barriers are a supplemental and final contingency control for the rare occasion when one or more of the employed prevention strategies fails. Research and revised guidelines specific to U.S. mines are needed to demonstrate the practical application of bag barriers as supplemental protection, in addition to generalized rock dusting, to prevent explosion propagations.

To work towards accomplishing this goal, significant effort was undertaken at U.S. mine sites performing trial bag barrier installations as part of a technology transfer effort. Additionally, the education of mine management and other industry authorities on the merits and importance of introducing explosion barriers to the U.S. was imperative. The knowledge and insight gained from the trial barrier installations, along with the views and input sought from these mining leaders, would be incorporated into the development of a preliminary set of guidelines for the use of ‘bag barrier’ explosion barriers in U.S. coal mines, including those with low seams.

3 Research Approach

The approach taken with this project is qualitative since extensive research has already been done on the use of the bag barrier type of explosion barrier. Additionally, the performance of this barrier system has been comprehensively tested and demonstrated by numerous mines in Australia, New Zealand, South Africa, Poland, and the United Kingdom. The primary challenge to the implementation of this technology in the United States is to refine existing regulations or develop new guidelines for their design and installation in U.S. mines where, for instance, the mining height may be low or the bleeder returns off the longwall face presents unique explosion suppression issues. To accomplish the goals of the project, the main tasks were divided into 3 main objectives and 23 sub-tasks. An overview of these objectives and tasks can be read in the following sections.

3.1 Objective 1 Research on Bag Barriers, Survey, Design, and Planning of Layouts

Objective 1 and its sub-tasks focus on an analytical study of existing foreign mines using explosion barrier systems (including mine layouts, ventilation practices, and barrier placements), along with the respective regulations and regulatory regimes overseeing their use in these mines. An extension of this objective was to research and visit several U.S. coal mines (in both the Eastern and Western U.S.) to understand the production methods used, the typical mine layout characteristics and seam heights, and ventilation practices. This was done to evaluate, compare, and understand the similarities and differences between foreign mines using explosion barriers and U.S. coal mines. The knowledge gained from these analytical studies was then utilized to design and perform the installation of a scaled length bag barrier explosion barrier system in the Missouri S&T Experimental Mine. This exercise allowed for the details involved in the setup of the bag barrier system to be experienced first-hand in a benign mine environment. The lessons learned during this exercise were then incorporated into the design, placement, and installation of scaled length bag barrier explosion barriers in two U.S. underground longwall coal mines. An added benefit of these activities and trial installations at operating mines was the building of relationships with management, and mine personnel. This also laid the foundation for the technology transfer and industry outreach efforts that were very important to the success of this project.

3.1.1 Literature Review and Survey

A thorough review of literature pertaining to: coal dust explosion history and research; explosion barrier history, testing, and development; bag barrier system history, testing, and development; coal mining regulations pertaining to explosion barriers or bag barriers in those countries that require them; and mining technology, production methods, layouts, seam heights, and ventilation practices of foreign and domestic coal mines was conducted. Three English-speaking coal-producing countries were identified that are known to regulate the use of explosion barriers; the United Kingdom (UK), the Republic of South Africa (RSA), and Australia’s New South Wales (NSW). While there were some minor differences in the regulations between those countries studied, overall they were fairly similar. The majority of differences related to the particulars of the bag spacing, the barrier distances, and the rock dust quantities. See Table 1 for a general comparison of the differences between the regulations in the different countries. Also see Figure 1 for a visual depiction of bag spacing according to these guidelines. This task gave project personnel the system background and knowledge base to draw from going forward.

Table 1: Comparison of Bag Barrier Specifications for the United Kingdom, Republic of South Africa, and New South Wales

General	**UK**	**RSA**	**NSW**
Minimum Bag Contents (kg)	6	5 (Low Seams) 6 (High Seams)	N/A
Stonedust Specs	Appropriate Type	*	**
Stonedust Amounts	1.2 (kg/m^3)	$100 kg/m^2$ or $1 kg/m^3$ whichever is greater	$\geq 200 kg/m^2$ within distance specs $\geq 400 kg/m^2$ outside specs
Bag Spacing (m)	0.4 - 1.0	0.4 - 1.0	N/A
Bag Space to Rib (m)	≤ 0.5	≤ 0.5	N/A
Row Spacing (m)	1.5 - 3.0	1.5 - 3.0	$\frac{Stonedust\ mass\ in\ row}{cross\ section\ area}$
# of Layers (< 3.5m Height)	1	1	N/A
Spacing from Roof (m)	≤ 0.5	≤ 0.5	
# of Layers (3.5-4.5m Height)	2	2	N/A
Spacing from Roof (Layer 1) (m)	< 0.5	4m from Floor	
Spacing from Roof (Layer 2) (m)	0.5 - 1.0	3m from Floor	
# of Layers (> 4.5m Height)	3	3	N/A
Spacing from Roof (Layer 1) (m)	< 0.5	5m from Floor	
Spacing from Roof (Layer 2) (m)	0.5 -1.0	4m from Floor	
Spacing from Roof (Layer 3) (m)	1.0 - 1.5	3m from Floor	

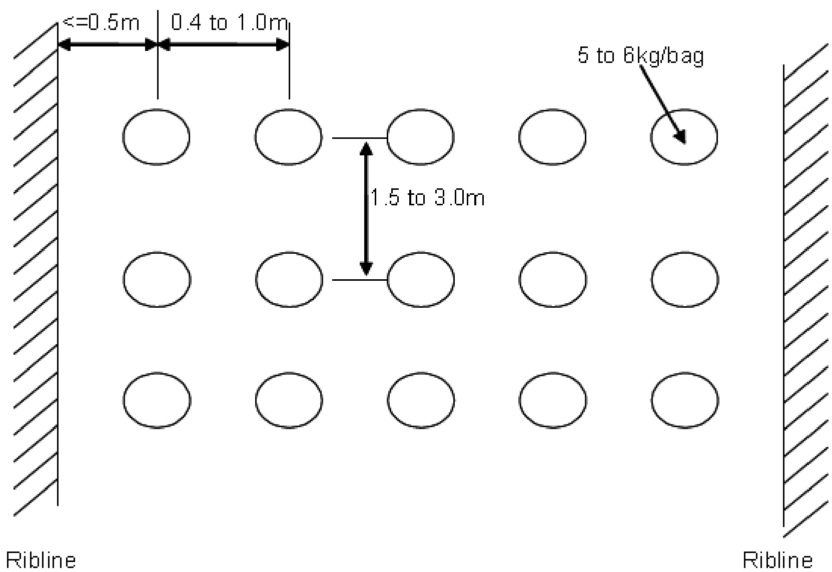


Figure 1: Spacing of Bags within a Barrier (No Significance of the Number of Bags per Row)

Image courtesy of SkillPro

3.1.2 Visit with Consultants to Two Eastern U.S. Coal Mines and Conduct Survey

Three underground coal mines in the Eastern U.S. were visited to perform a survey of mine and ventilation layouts. These three mines operated using Longwall mining, Room & Pillar mining, or both. The major differences noted between the Eastern U.S. mines and foreign mines are the coal extraction height differences, and the ventilation differences. The Eastern U.S. mines average a shorter extraction height than foreign mines; and the ventilation systems in U.S. Longwall mines are required to have a bleeder system for the gob areas, whereas the foreign mines use a traditional "airflow across the face" or "U" type of ventilation only.

The Alpha Natural Resources' Running Right Academy was also toured as an alternative site to an operating mine for later "Industry Day" demonstrations. The logistics of getting a large number of demonstration attendees to a mine, getting their site specific training completed, having the appropriate sized PPE for everyone, and getting them to and from the location within the mine would prove to be quite a difficult undertaking, and very time consuming for that mining operation.

These mine tours allowed for meetings to be held with mining company executives, site management, engineering staff, and miners. This provided the opportunity to identify key mine characteristics, build relationships, educate miners and mining companies about coal dust explosion hazards and mitigation measures, and garner support for the project and for bag barrier explosion barrier systems.

3.1.3 Visit with Consultants to Two Western U.S. Coal Mines and Conduct Survey

One Western U.S. coal mine was available to visit that fit the criteria for this project. During the site visit, a survey of the mine and ventilation layout was completed. The major difference noted between this mine and the Eastern U.S. mines previously visited is the greater extraction height; extraction heights noted in many foreign mines are also greater than that of the Eastern U.S. mines. This aspect will support the use of the bag barrier system in this western U.S. mine with no difficulties regarding clearance height.

3.1.4 Trial Layouts at Missouri S&T Mine

To complete an initial demonstration and setup of the bag barrier system at the University's Experimental Underground Mine, a method/device for quickly and consistently filling the bags with the appropriate amount of rock dust was developed. A bag/dust calculator spreadsheet was also developed, based on the UK regulations, to determine the amount of rock dust, the number of bags, and the layout required for the demonstration setup. Once both items were complete, the device was used to fill enough bags for a scaled length installation of a bag barrier system in the University's Experimental Underground Mine; see Figure 2. The bag spacing and dust density was kept consistent with current guidelines but the length was reduces from a typical coal mine environment to accommodate our smaller workings. This exercise gave valuable hands on experience working with the system, the spacing and height variables, and the required supplies.

Figure 2: Scaled Length Bag Barrier Installation at S&T Experimental Mine

This demonstration setup also allowed monitoring of the moisture content in the rock dust over time; a concern raised by mine site engineering staff and literature reviews. To address these concerns, samples were taken from the original supply of rock dust, in addition to periodic re-sampling of the dust contained in random bags (20% of those hung) over a one-year period. These dust samples were analyzed for free moisture content using ASTM specification C25-11. After 1 year hanging in the S&T Experimental Underground Mine facility, all bags were sampled and tested to conclude the trial. The overall moisture content of all 35 bags was 0.35% at the end of the one year trial, as opposed to 0.0428% at the beginning. This value was is expected to be even higher than during normal operation since we had repeated removal/reinstallation of the retaining rings for dust sampling; a process that would not occur during the normal installation and use of the bag barrier system.

3.1.5 Familiarity with Arch Coal #1 Mine

Familiarity with Arch Coal #1 mine was gained through two visits/tours, continued communications with site engineering staff, discussions with the labor force, and study of the mine maps (layout, sequencing, and ventilation).

3.1.6 Design Layout for Arch Coal #1 Mine

The design for the bag barrier layout in the #1 mine was developed using information gathered from the research of foreign regulations, previous mine visits and discussions with engineering staff, and in collaboration with the consultants. Due to Arch Coal not wanting competitors in their mines, longer term installations were performed to gain feedback from the mine workers after a month of operation with the bags in place.

3.1.7 Install Trial Barrier System and Mine #1

In preparation for the trial barrier setup at the #1 mine, bags were pre-filled with the required rock dust, loaded into pallet-mounted boxes, and shipped in advance to the mine. Some shipping damage was noted to the outer carton upon arrival at the mine site. Roof mesh was absent in most locations throughout the mine, and the bolt spacing was wider than conducive for recommended bag placement. Therefore, several alternative methods of hanging the bags from the roof bolt plates and/or the straps were employed. One such method used commercially available hooks, while the others employed materials and supplies readily available in the mine. The bags were hung by hand by the project team with help from two mine workers. This is common practice in mines where mine height enables workers to reach the roof. Installation was quick and easy.

The barrier was installed approximately 800 feet from the face in a location that experiences moderate equipment and personnel traffic. Following the barrier installation, a battery powered scoop car was positioned to check height clearance with the bags. Approximately 1 feet of clearance was observed above the scoop car cab (Figure 3) indicating that roof height in this mine would not be an issue for equipment interference with the bag barrier system.

Figure 3: Trial layout for #1 Mine

3.1.8 Familiarity with Arch Coal #2 Mine

Familiarity with Arch Coal #2 mine was gained through two visits/tours, continued communications with site engineering staff, discussions with the labor force, and study of the mine maps (layout, sequencing, and ventilation).

3.1.9 Design Layout for Arch Coal #2 Mine

The design for the bag barrier layout in the #2 mine was developed using information gathered from research of foreign regulations, previous mine visits and discussions with engineering staff, and in collaboration with the consultants.

3.1.10 Install Trial Barrier System and Mine #2

In preparation for the trial barrier setup at the #2 mine, bags were pre-filled with the required rock dust, loaded into pallet-mounted boxes, and shipped in advance to the mine. No shipping damage was noted to the outer carton upon arrival at the mine site. Unlike the #1 Mine, the #2 Mine uses roof mesh in most entries on development (Figure 4). This made barrier installation very straightforward. The only complication was the height of the mine roof (approximately 9 ft). A ladder was needed to hang the bags from the mesh directly but again the bags were hung by hand. The time to hang the bags was slightly longer than mine #1, but was still a simple task. In Australia where mine height exceeds what can be reached from the floor, a man lift attached to a front end loader is used. Due to the taller roof height, bag barrier interference with men or equipment was not expected to be an issue.

Figure 4: Trial layout for #2 Mine

3.2 Objective 2 Education of U.S. Mine Industry on Possible Applications in U.S. Mines

The focus of *Objective 2* was the education of the U.S. coal mining industry on the possible application of the explosion barrier technology in U.S. mines. This was completed in two main steps. An informational video was produced and distributed via the popular internet video sharing website YouTube.com. The purpose of the video was to inform, educate, build interest, and gain feedback. The title of the video is *Bag Barrier System – Coal Dust Explosion Mitigation*. There was a link in the video that also took viewers to a survey that offered the opportunity to ask questions and give feedback. Once the video was posted, a link (https://www.youtube.com/watch?v=VApk-oaeb-4) to the video was emailed to known industry contacts with a note that asked the viewer to pass the link on to their industry contacts, as well as discussing with coworkers. Since posting the video, it has received over 1,100 views. The insight gained from the video survey feedback was incorporated into the bag barrier installation guidelines, as well as the design of the bag barrier exhibit to be on display at the Industry Day to be held later.

In May 2017, the industry day was held at the Running Right Conference Center, and was attended by various personnel from MSHA, NIOSH, West Virginia Miner's Health and Safety (WVMHS), and numerous coal mines in the region. The itinerary included presentations by project personnel, discussions with a panel of subject matter experts and project personnel, and a tour of the facilities. The tour concluded in the simulated underground mine building where a scaled length bag barrier explosion barrier system was installed so that attendees could get the look and feel of a bag barrier system without the inherent hassles and risks of going into an active coal mine. Throughout the day, attendee feedback and questions were addressed and noted for consideration and implementation into the final recommendations and guidelines document.

3.2.1 Plan for Industry Days

Alternative sites for the Industry Days were tentatively selected. The two sites were: The Running Right Conference Center for the East, and Missouri University of Science and Technology's (S&T) Experimental Mine for the West. At both locations, there are ample lodging and services available as well as large conference room facilities. The S&T Experimental Mine has an underground working section for demonstration of the bag barrier that is safely and easily accessed by visitors. The Running Right Conference Center has a simulated mine building that would be used to setup a scaled length bag barrier. Neither facility requires specialized PPE, training, nor transportation, yet both sites still allow for the attendees to better experience a typical bag barrier system without the associated hazards and complications of entering an operating coal mine.

Support and interest for the Industry Day demonstrations was increased through project promotion at mine sites, mining conferences (International and Local SME), the Running Right Conference Center, and at MINExpo International in September of 2016.

3.2.2 Demo Mine 1

The first demonstration was changed to a presentation video that eliminated the incursion of travel related expenses for interested parties during tight economic times in the coal mining industry. The video was posted on YouTube.com with a link sent via email to a list of wide ranging coal industry related individuals, companies, and organizations. It was requested that the link be shared or forwarded to other colleagues and interested parties so the information reached a wider base of viewers than could/would attend an on-site demonstration. There was also an electronic survey and questionnaire attached to the video so that feedback and comments could be collected and incorporated into the design for the 2nd Industry Day Demonstration to be held in May 2017.

3.2.3 Feedback, Discussion, Suggestions

During mine site visits, meetings, installations, and follow-up visits, many individuals shared concerns, thoughts, and suggestions regarding the effective application and installation of the bag barrier system in U.S. mines. Some of this feedback was solicited via formal questionnaires, while some was obtained through verbal discussion. This was a continuous and ongoing process throughout the entire project period.

Feedback and comments were also collected in connection with the video presentation. This was done via an electronic survey/questionnaire that video viewers could participate in. Contact information for the project engineers was also provided in the video so that interested parties could reach them for more information or in depth discussions.

3.2.4 Incorporate Items Learned into Design of Industry Day 2

Feedback, suggestions, and other information received by survey, questionnaire, and discussion was used in the design of the entire experience for the second technical demonstration held at the Running Right Conference Center. Previously raised and experienced concerns were investigated and incorporated into the presentations and discussions to ensure the dissemination of this information.

3.2.5 Industry Day 2

In preparation for Industry Day 2, a pre-fabricated freestanding framework was designed and constructed to support the scaled length bag barrier exhibit. Additionally, over 120 barrier bags were filled using the previously designed and fabricated equipment, and assembled with their hooks. The freestanding framework was then disassembled, loaded onto a trailer, and transported to the conference center. The barrier bags were also boxed, palletized, and transported to the site. The project team arrived on site early to assemble the freestanding bag barrier exhibit, and to coordinate and finalize preparations and presentation materials. The second Industry Day was held on Tuesday May 23rd, 2017. Attendees included representatives from MSHA, NIOSH, the West Virginia Miner's Health and Safety organization, as well as individual mines from three major mining companies in the region. Attendees were invited through the YouTube video and emails that were sent to the contacts gained throughout the project. Additionally, letters were sent to all individual mines within 175 miles (approximately 3 hours driving time) from the Running Right Conference Center (Figure 5). Figure 6 shows the Missouri S&T project team in front of the pre-fabricated framework and scaled bag exhibit; project team members from left to right are Jeff Heniff - Technician, Jay Schafler – Graduate Student, Dr. Catherine Johnson – PI, and Jake Brinkman – graduate student.

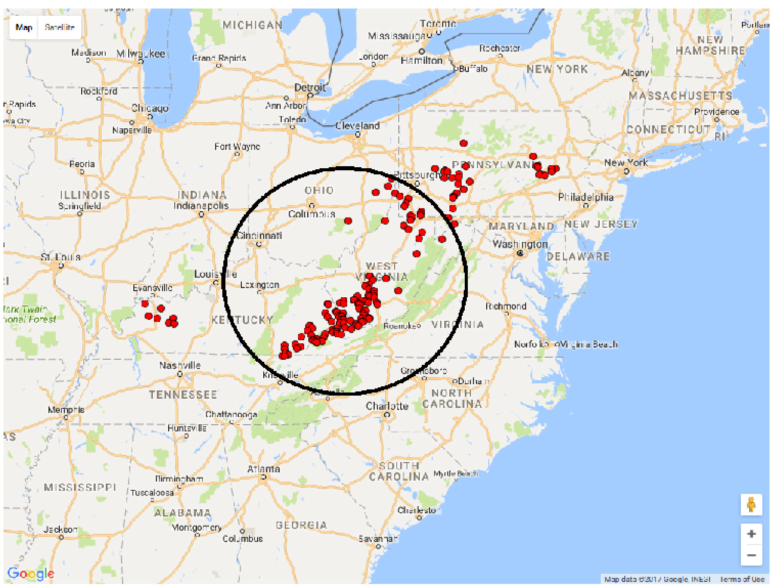


Figure 5: Map showing mines within 175 miles of industry day facility.

Figure 6: Missouri S&T project team and Industry day in front on pre-fabricated framework and scaled bag exhibit. Scoop provided for mine height reference

3.2.6 Feedback, Discussions, Suggestions

Survey responses and feedback were collected from the widely distributed video presentation, as well as during the Industry Day presentations and discussions. There were 56 respondents for the video presentation questionnaire. Additional information including questions and responses can be found in Section 4.

3.2.7 First Draft of Paper and Guidelines Written

Composition of the first drafts of the project paper and recommended guidelines is complete and can be found in the Appendix of this report. The working outline for the bag barrier guidelines is as follows:

- Disclaimer
- Introduction
- Description of Bag Barrier System Used for Project
- Common Design Parameters
- Types of Barriers
    - Advancing Distributed
    - Advancing Concentrated
    - Fixed Distributed
- Non-Typical Installations
    - Cribs
    - Conveyors
    - Roof Cavities
    - Suspended Pipelines
- Filling of Bags
- Broken Bag and Hook Issues
- Component Recycling

- Bag Barrier System/Component Audits
- Risk Assessment of Common System Concerns

The guidelines and paper include diagrams to better illustrate and facilitate barrier design and placement explanations along with technical specifications of the different barrier configurations. Additional diagrams are included to show correct and incorrect installation methods for various mine design scenarios.

3.2.8 First Draft Shared with Stakeholders (MSHA, WVMHS, Etc.)

The first draft of the recommendations and guidelines were distributed and presented during the May Industry Day. Those in attendance represented MSHA, NIOSH, West Virginia Miner's Health and Safety (WVMHS), and several large coal-mining companies.

3.3 Objective 3 Write-up and Sharing of Final Report, Presentations, and Papers

Objective 3 focused on reviewing and incorporating the knowledge gained over the project period into the final report and recommended guideline document, and the preparation and presentation of materials to industry and regulators alike. This was done through presentations given at the annual Society for Mining, Metallurgy, and Exploration (SME) conference and local SME meetings, papers written and distributed in support of the project, and meetings with MSHA officials, mining executives, and mine personnel.

3.3.1 Responses from First Draft Reviewed

Responses from the first draft were collected, tabulated, reviewed, and incorporated into the final draft of the project report as appropriate.

3.3.2 Final Report Written with Recommendations and Guidelines

This report along with recommendations and suggested guidelines were completed as planned. Updated installations as well as a U.S. specific guideline document can be found in the Appendix.

3.3.3 Prepare Presentations

Presentations regarding the information uncovered and compiled during this project have been prepared and were presented at the 2017 SME Annual Conference and Expo held February 19 – 22, 2017 at the Colorado Convention Center in Denver, Colorado. Two separate papers were accepted for presentation and inclusion in the Conference Proceedings. One discusses coal mining trends in the U.S., and the other discusses coal dust explosion risk management with the use of bag barriers. Additional papers and presentations are planned to aid in the widespread dissemination of project information to industry and regulatory stakeholders following completion of the guidelines.

3.3.4 Present to MSHA, NIOSH, WVMHS, Etc.

In October 2016 the PI met with representatives from the ventilation and dust divisions of MSHA. The aim of the meeting was to begin a relationship, present the goals of the project, and seek information relating to regulating barriers in the U.S. In May 2017, several representatives from MSHA, NIOSH, WHMHS, and regional coal mining companies attended the second Industry Day, which included presentations over the coal dust explosion problem, typical mitigation practices, variations in regulations worldwide, and the bag barrier solution. These presentations included recommendations and suggested guidelines for bag barrier use and system implementation.

3.3.5 Prepare and Publish Papers

To date, two papers have been prepared and accepted for presentation at the 2017 SME Annual Conference, and will be included in the published conference proceedings. The paper titles are: "A Study of U.S. Coal Mines Since 1994" and "Management of Explosion Risks with Bagged Barriers". Final versions of these papers can be found in the Appendix of this report. SME editors requested the first paper be adapted and placed in the October 2017 version of *Mining Engineering* magazine, the latter regarding the barriers in general will be presented again as a webinar through SME. These accomplishments demonstrate the importance of the work conducted throughout this project to the coal industry as a whole. Additional papers are planned for release including Recommendations and Guidelines for the Implementation and Use of Bagged Barriers in Underground U.S. Coal Mines.

4 Summary of Accomplishments

4.1 Literature Search on Bag Barrier Systems in Other Countries

A literature search into other countries that currently use the bagged barrier system was carried out as part of this project. An overview of the regulatory control, barrier design, and research into the system is outlines in the following subsections.

4.1.1 Regulatory Control

All passive barriers are to be used only as a contingency control. All nations that require barriers use them in addition to 50-85% (see Table 2) incombustible content. Barriers are not a replacement for wide-are rock dusting as the primary explosion suppression method. The purpose of passive barriers is solely to support any failures or limitations of the primary rock dusting system.

Table 2: Summary of Incombustible Content Requirements for Various Nations

Country	Requires Supplemental Protection Barriers	Total Incombustible Content (%)	Location	Volatile Matter (%)	Methane (%)	Comments
Queensland, Australia	No	80-85	return/belt	-	-	85% TIC ≤ 200 m from face
						80% > 200 m from face
		70-85	intake	-	-	85% TIC ≤ 200 m from face
						70% > 200 m from face
NSW, Australia	Yes	70-85	return/belt	-	-	85% TIC ≤ 200 m from face
						70% > 200 m from face
		70-80	intake	-	-	80% TIC ≤ 200 m from face
						70% > 200 m from face
Nova Scotia, Canada	No	75	intake	-	< 1	-
		80	return/belt	-	> 1	
Czech Republic	Yes	80	all entries	-	< 1	-
		85	all entries	-	> 1	
Slovakia	Yes	80	all entries	-	< 1	-
		85	all entries	-	> 1	
Germany	Yes	80	all entries	-	-	-
Poland	Yes	70	all entries	> 10	"non-gassy"	-
		80	all entries	> 10	"gassy"	
South Africa	Yes	65	intake	-	-	-
		65-80	return/belt	-	-	80% TIC for belt < 180 m from face
						65% for belt > 180 m from face
						80% TIC for return < 1000 m from face
						65% for return > 1000 m from face
United Kingdom	Yes	50	all entries	< 20	-	-
		65	all entries	20-27	-	
		72	all entries	27-35	-	
		75	all entries	> 35	-	
United States	No	80	all entries	-	-	Add 0.4% TIC per 0.1% methane

In Australia, the individual state governments regulate barriers. There are only two coal-producing states; NSW is the only state that currently requires barriers, and Queensland only requires whatever explosion suppression system is deemed necessary by a risk assessment, which occasionally includes barriers. NSW regulations specify the use of either rock dust shelf or water tub barriers, but mines may use any other system, including bag barriers, as long as the system is proven effective and the system is installed according to manufacturer recommendations. All underground coal mines in NSW use the bag barrier system because they have determined it to be the most economical barrier. NSW regulations do not cover specifics of bag barrier installation, only stipulating that the bags be installed according to manufacturers' recommendations, although the regulations do specify barriers must be installed in at least the return air entries and conveyor belt entries. As the manufacturer and primary distributor of bags, SkillPro has created installation guidelines.

The national government of the RSA regulates explosion protection strategies. They also allow any kind of barrier, and many of their mines have also chosen to use bag barriers. RSA regulations also do not cover specifics of bag installation. The South African national research company CSIR developed the bag barrier system, and they wrote the original guidelines in 1999, upon which the SkillPro guidelines were based. The national approach to explosion risk management in the RSA was updated in 2002.

In the UK, barriers are also regulated federally. The UK also allows three types of barriers, water tubs, Polish shelf barriers, or bag barriers, and of these they have also found bag barriers to be the most economical. However, the federal organization Health and Safety Executive has elected to create their own installation guidelines by combining and adapting the CSIR and SkillPro guidelines to their mine layouts.

The Mine Safety and Health Administration (MSHA) is the federal regulatory body over all mining activity in the U.S. MSHA, state, and local governments in the U.S. have the power to require barriers, though no governing bodies in the U.S. have made any recent comments for or against requiring any kind of barrier. Whether or not barriers are legally required, U.S. mines should contact MSHA before implementing a barrier, and MSHA will likely oversee any safety concerns regarding a barrier's installation and decide which guidelines are acceptable to use for installation.

4.1.2 Barrier Design

Since the guidelines for use of the bag barrier system in the different countries is based off the same sets of research, there are many similarities in basic barrier design parameters. The United Kingdom (UK) and Republic of South Africa (RSA) both specify minimum bag contents of 6 kilograms of rock dust (5kg minimum for bags in low coal seam headings in RSA). They also both specify 0.4 to 1.0 meter spacing between bags in the same row, less than 0.5 meter spacing between the rib and closest bag, and 1.5 to 3.0 meter spacing between rows of bags. However, New South Wales (NSW) does not specify such barrier dimensions as long as the total dust loading from the bag barrier (not including conventional rock dusting) of the area exceeds a criteria of 200 kg/m^2, which is approximately double the UK and RSA standards, which require 120 and 100 kg/m^2 respectively. Additionally, NSW row spacing is based on equal distribution of the density of dust contained in each row, instead of a specific measurement like the UK and RSA. Aside from the specifics of bag loading and bag and row spacing, there are also similarities in the configuration of the barrier components into different barrier types.

Bag barrier configurations successfully tested at the Kloppersbos, Tremonia, and Lake Lynn test sites consisted of a distributed barrier or a concentrated barrier. These barrier types can be configured in different ways to accommodate site-specific needs, as long as they still conform to their country's basic barrier design parameters shown in Tables 3, 4 and 5. The bag spacing within a barrier is illustrated in Figure 7. For example, in NSW and RSA, distributed barriers can be configured in one longer continuous formation, or broken up into four or five shorter discontinuous sub-barriers. The continuous distributed barrier formation adds additional bags to the front of the barrier during mining advance, and they are either recycled or left for waste as mining retreats, (Figure 8). These types of barriers are typically used where rapid advance or retreat requirements are prohibitive to relocating sub-barriers used in other barrier configurations. Additionally, these barrier types tend to cover long areas of roadway, minimum of 120 meters.

The discontinuous distributed formation (Figure 9) is comprised of four equal sub-barriers [2]. A fifth sub-barrier can be added that allows for the rear sub-barrier to be moved to the front as mining advances, and for the front sub-barrier to be moved to the rear upon retreat. This is done to maintain the required rock dust loading, and proper barrier spacing from the last crosscut, at all times. In common vernacular, it is said that the sub-barriers 'leap frog' to the front or rear to maintain the proper distance from the face or last cut through. This type of distributed barrier formation covers fairly long areas of roadway, generally less than 120 meters. Crosscuts that are outby of the start of either distributed barrier formation can be ignored.

Table 3: General Requirements for All Bagged Barrier Systems in the United Kingdom, Republic of South Africa, and New South Wales

General	**UK**	**RSA**	**NSW**
Minimum Bag Contents (kg)	6	5 (Low Seams) 6 (High Seams)	N/A
Stonedust Specs	Appropriate Type	*	**
Stonedust Amounts	1.2 (kg/m^3)	100kg/m^2 or 1kg/m^3 whichever is greater	≥200kg/m^2 within distance specs ≥400kg/m^2 outside specs
Bag Spacing (m)	0.4 - 1.0	0.4 - 1.0	N/A
Bag Space to Rib (m)	≤ 0.5	≤ 0.5	N/A
Row Spacing (m)	1.5 - 3.0	1.5 - 3.0	$\frac{Stonedust\ mass\ in\ row}{cross\ section\ area}$
# of Layers (< 3.5m Height)	1	1	N/A
Spacing from Roof (m)	≤ 0.5	≤ 0.5	
# of Layers (3.5-4.5m Height)	2	2	N/A
Spacing from Roof (Layer 1) (m)	< 0.5	4m from Floor	
Spacing from Roof (Layer 2) (m)	0.5 - 1.0	3m from Floor	
# of Layers (> 4.5m Height)	3	3	N/A
Spacing from Roof (Layer 1) (m)	< 0.5	5m from Floor	
Spacing from Roof (Layer 2) (m)	0.5 -1.0	4m from Floor	
Spacing from Roof (Layer 3) (m)	1.0 - 1.5	3m from Floor	

Table 4: Requirements for Concentrated Bagged Barrier Systems in the United Kingdom, Republic of South Africa, and New South Wales

Primary Barrier	**UK**	**SA**	**NSW**
# of Sub barriers	4	4	N/A
Span of Primary Barrier (m)	120	100 min	N/A
Distance 1st row to coal or heading face, or ignition source (m)	70 -120	60 - 120 (from last through road)	60 - 200
Middle Sub Barriers	equidistant	equidistant	N/A
Distance Between 1st and 4th Sub Barriers (m)	N/A	≤ 120	N/A
Max Distance Between Sub Barriers (m)	N/A	30	N/A
Extra Sub Barrier Required for Advance or Retreat	Yes	No	N/A
Secondary Barrier	**UK**	**SA**	**NSW**
# of Sub barriers	2	N/A	N/A
Span of Secondary Barrier (m)	120	N/A	N/A
Distance First Row to Last Row of Primary Barrier (m)	70 -120	N/A	N/A
Extra Sub Barrier Required for Advance or Retreat	Yes	N/A	N/A
Stonedust Density Required (kg/m^3)	2.4	N/A	N/A

Table 5: Requirements for Distributed Bagged Barrier Systems in the United Kingdom, Republic of South Africa, and New South Wales

Distributed Barrier	**UK**	**SA**	**NSW**
Distance First Row to Working Face (m)	70 - 120	N/A	< 100
Span of Distributed Barrier (m)	360	N/A	N/A
Stonedust Density Required (kg/m^3)	1.2	N/A	See "General" Above
Distance to Conveyor belt feeder, bootend, trickle duster, Aux. Fan, Last through Road (m)	N/A	N/A	< 30

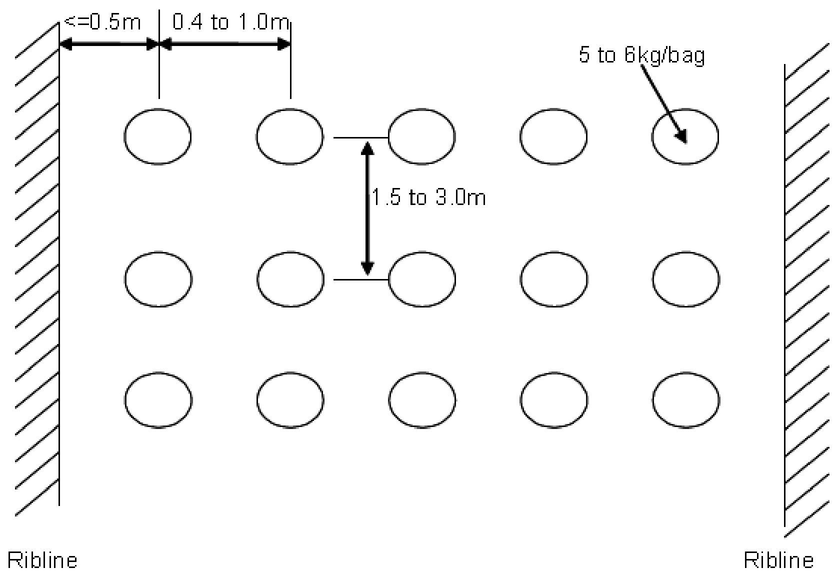


Figure 7: Spacing of Bags within a Barrier (No Significance of the Number of Bags per Row)

Image courtesy of SkillPro

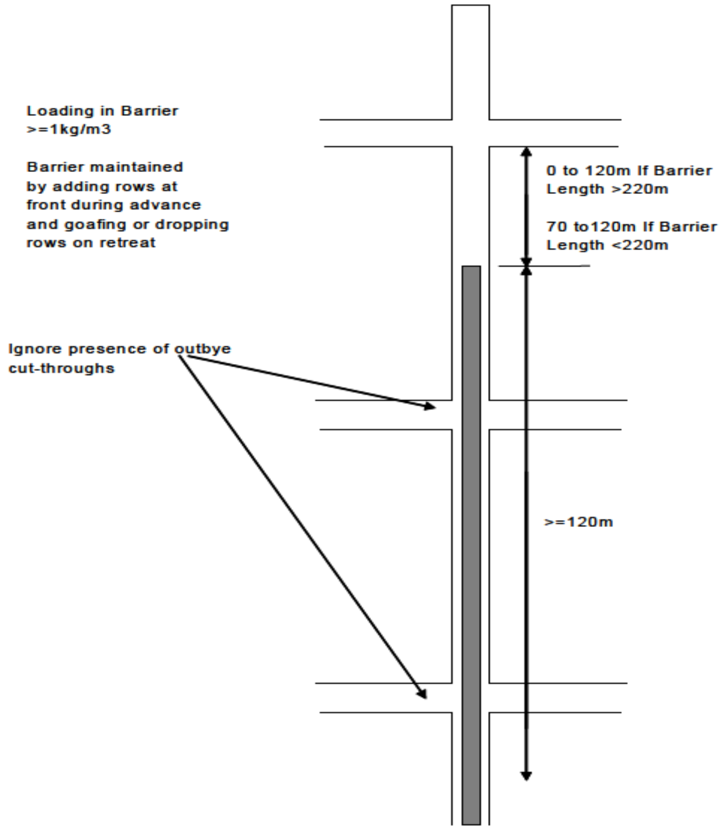


Figure 8: Example of Typical Continuous Distributed Barrier Arrangement [3]

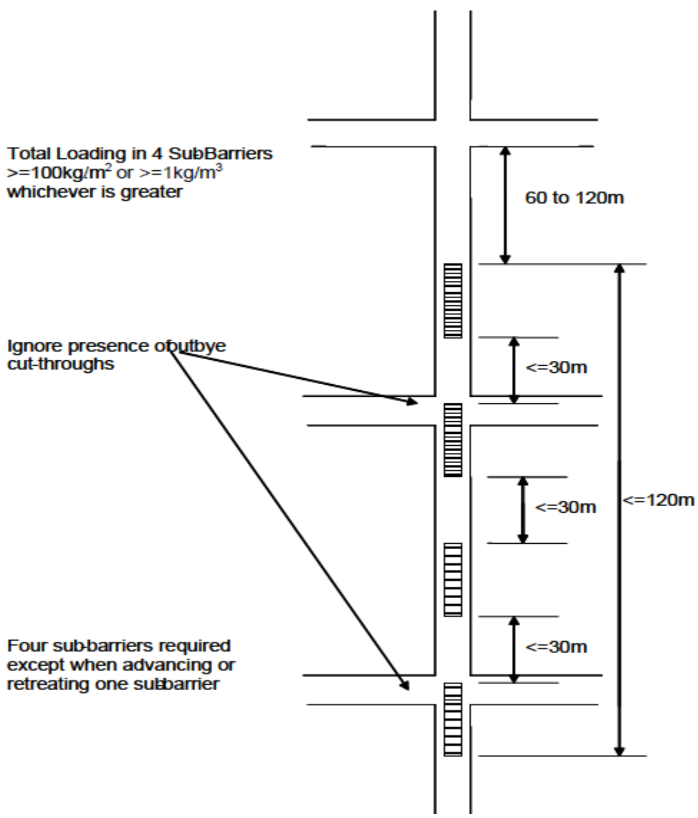


Figure 9: Example of Typical Discontinuous Distributed Barrier Arrangement [3]

A concentrated barrier contains the required amount of rock dust in one barrier that is only 20 to 40 meters long instead of approximately 120 meters. A second, equal barrier is needed for advancing or retreating so that the required rock dust loading, and proper barrier spacing from the last crosscut, is maintained at all times. Again, crosscut outby the start of the barrier can be ignored, see Figure 10 [2].

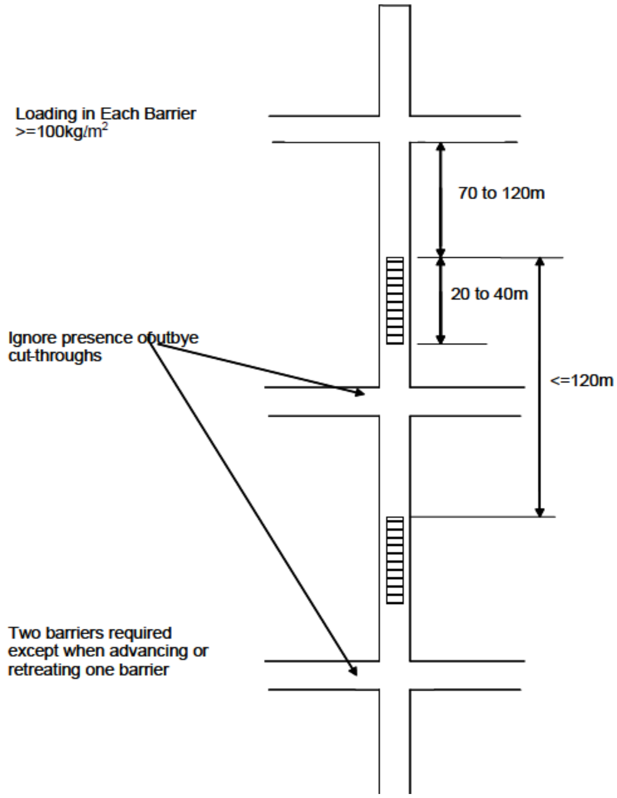


Figure 10: Example of Typical Concentrated Barrier Arrangement [3]

The UK however, mandates the use of a primary and secondary barrier system or a distributed barrier system in all longwall workings, headings in coal, and room-and-pillar workings. The primary barrier design is similar to that of the discontinuous distributed barrier described previously in that it is comprised of four sub-barriers; with a fifth added for advance or retreat. The secondary barrier design is similar to the concentrated barrier described previously, except that it requires two sub-barriers, with a third added for advance or retreat. The distributed barrier design is similar to that described earlier, except that the UK standards require minimum roadway coverage of 360 meters in length; see Figure 11-13 for typical arrangements of UK barriers [2].

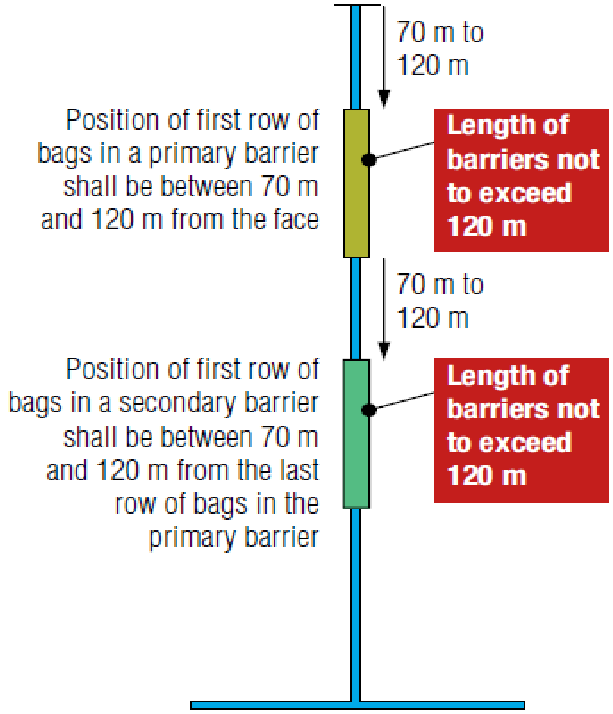


*Figure 11**:** Typical Primary/Secondary Barrier Arrangement for Coal Heading [2]*

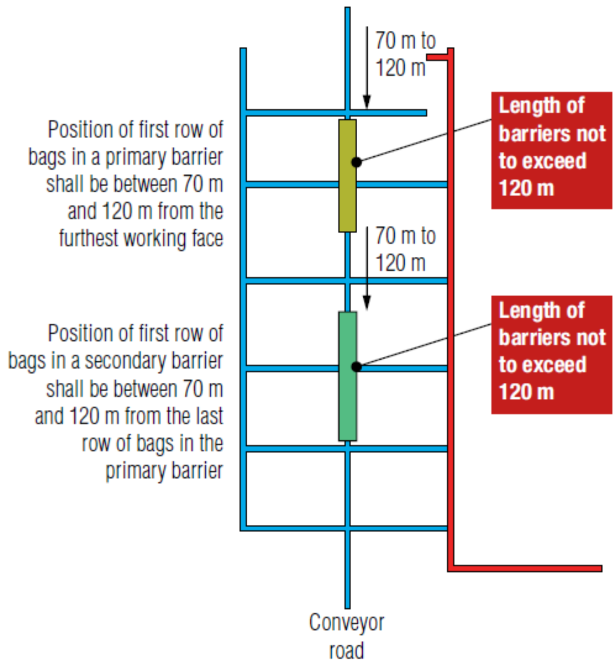


Figure 12: Typical Primary/Secondary Barrier Arrangement in Room-and-Pillar Mine [2]

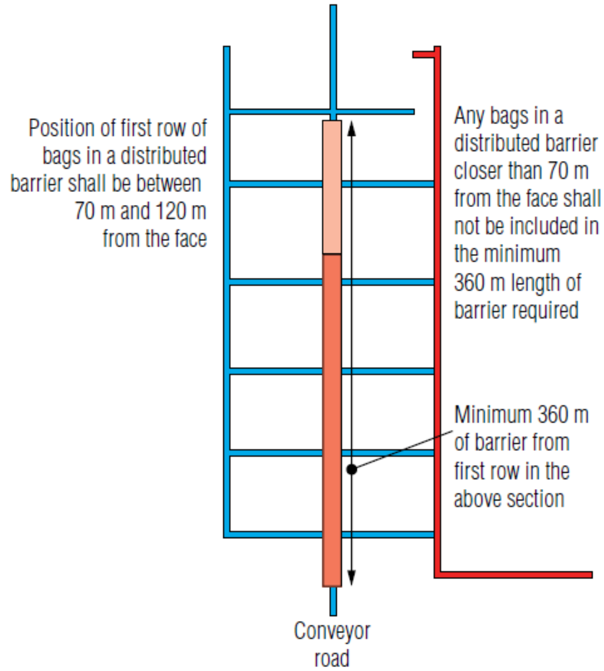


Figure 13: Typical Distributed Barrier Arrangement in Room-and-Pillar Mine [2]

All barrier design configurations must account for any voids in coverage due to conveyor systems, ventilation and other ducting or piping, and other overhead obstructions. These voids in rock dust coverage could allow the passage of flame beneath, between, or around them. Therefore, additional bags would need to be hung next to, between, and/or under those structures to prevent flame passage in the event of an explosion (Figure 14). Additionally, should a barrier installation encounter a beltway or roadway intersection before completion, the remaining distance (number of bags/amount of rock dust) required to complete the barrier must be installed in each and every direction leading away from that intersection so that all entries are equally protected (Figure 15).

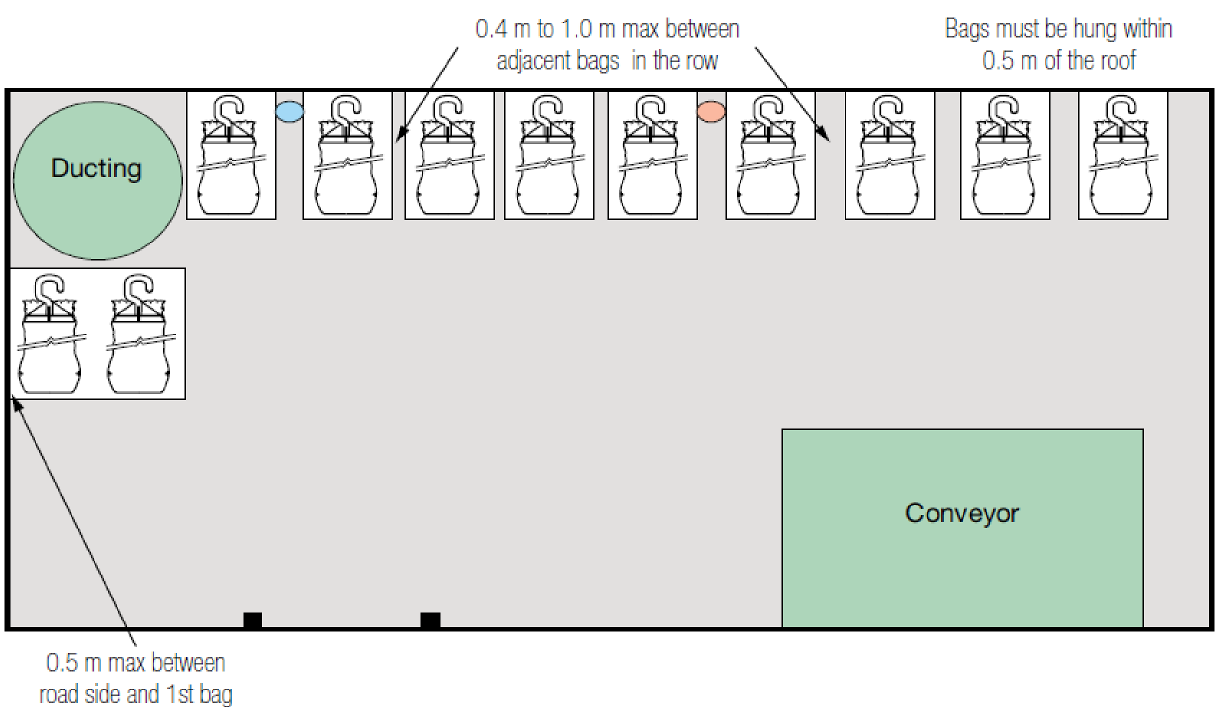


Figure 14: Typical Configuration of Bags Hung around a Suspended Obstacle [2]

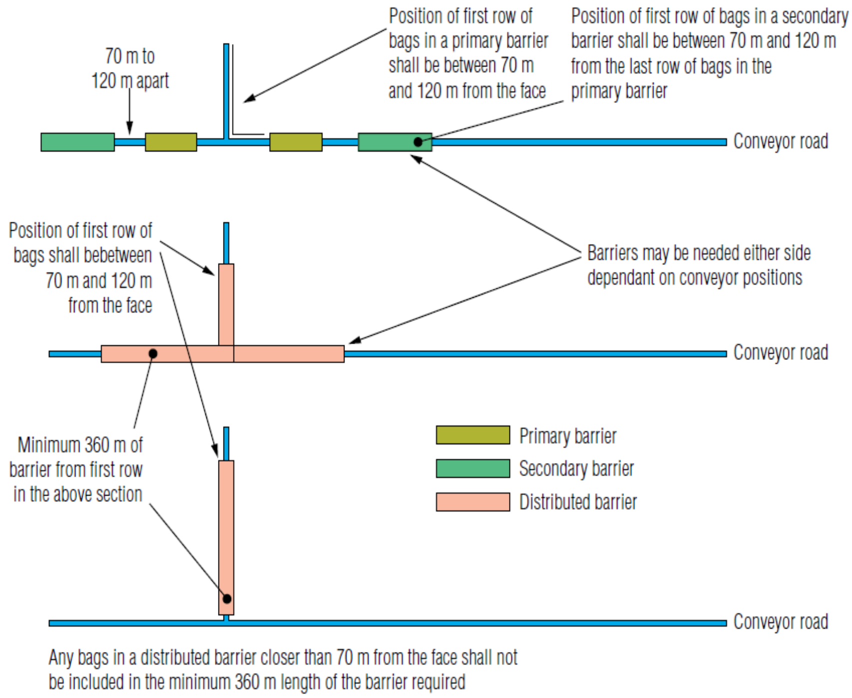


Figure 15: Typical Barrier Arrangements when Intersection is Encountered [2]

The bagged barriers are generally installed within certain distances of the working face or last crosscut (60 to 120 meters typically) and in all entries leading to that face/crosscut. Additional barriers are typically placed within 30 meters outby of conveyor belt feeder/breakers, any transfer points in the conveyor roadway, trickle dusters or auxiliary fans (if used), or the last line of crosscut (if auxiliary fans are not used) [4]. In general, the bagged rock dust barriers are installed as close to likely points of ignition as possible and in locations that are likely to accumulate methane or significant coal dust deposits [4].This means that every entrance to every production section, every development district, and every ventilation split must be protected by a barrier. There can be no pathway left unprotected for a flame to circumvent or bypass a system of barriers and propagate further into the mine.

4.1.3 Testing Performed in Other Countries

Rock dust explosion barriers were introduced in the 1920s and consisted of elevated shelves that upheld piles of rock dust on them. The basic design principle is that the pressure wave that moves ahead of an explosion flame front would disrupt or overturn the shelves causing the supported rock dust to become airborne and extinguish the flame front upon arrival due to the high levels of incombustible content. Their design did not change much over the next decades, except for slight variations in the construction of the shelves, the materials used for shelf construction, and the amount of rock dust supported on them. A variant of this basic design was also developed using troughs of water instead of rock dust [5]. Regardless, explosion barrier use was still limited even after research completed by Cybulski in 1975 clearly showed that rock dusting alone was not sufficient to prevent or suppress coal dust explosions, and that additional barriers were needed [6].

In the early 1990s, the Division of Mining Technology within the Council of Scientific and Industrial Research (CSIR) of South Africa began development and testing of a new system for the effective implementation and installation of rock dust barriers [3, 4]. This was done in response to recent mine explosion disasters and the need for a system that was effective, yet cheaper and easier to install and maintain. This new system was based on individual bags containing rock dust hung in an equal distance and spacing arrangement from the mine roof that would react to an explosion and disperse the contained rock dust. The bags themselves are designed with special anisotropic characteristics that support the weight of 6 kg of rock dust for an indefinite period of time without deteriorating or degrading, and still rupture at very low pressures (reported as low as 4.0 kPa) allowing dispersal of the enclosed rock dust. Furthermore, the bag and complimentary hook and ring closure system effectively encloses the rock dust, aiding in the prevention of moisture contamination and caking of the rock dust.

The bag and hook design underwent extensive testing and development over the next several years. The testing continued at Kloppersbos Research Facility in South Africa (Figure 16) and the Tremonia Experimental Mine Gallery in Germany (Figure 17). This testing proved the concept of the bag rock dust barriers and the effectiveness of these barriers at protecting long single entry mines during coal dust explosions of varying magnitude. However, most underground coal mines use multiple entry methods of mining progression.

Figure 16: Kloppersbos Test Tunnel – 5m^2 cross-sectional area

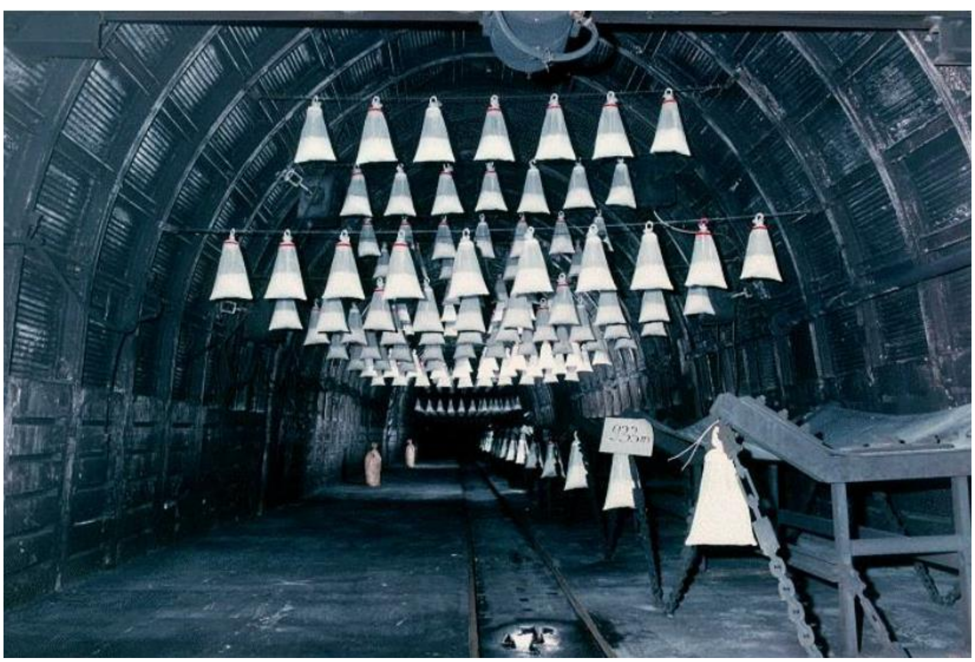


Figure 17: Tremonia Experimental Mine Gallery

To study bag barrier effectiveness in mines with multiple entries, further testing was performed at the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Research Laboratory's Lake Lynn Experimental Mine in Pennsylvania in the late 1990s. This facility was the only one worldwide that could accommodate such testing in multiple entry development. (Figure 18) The test facility was comprised of three entries with seven crosscuts located towards the inby end of the entries. This layout is similar to three entry headings currently used in many U.S. longwall coal mines. After several preliminary test explosions were performed to calibrate the equipment and explosion pressures, the bag rock dust barriers were tested in various configurations and under various explosion pressures.

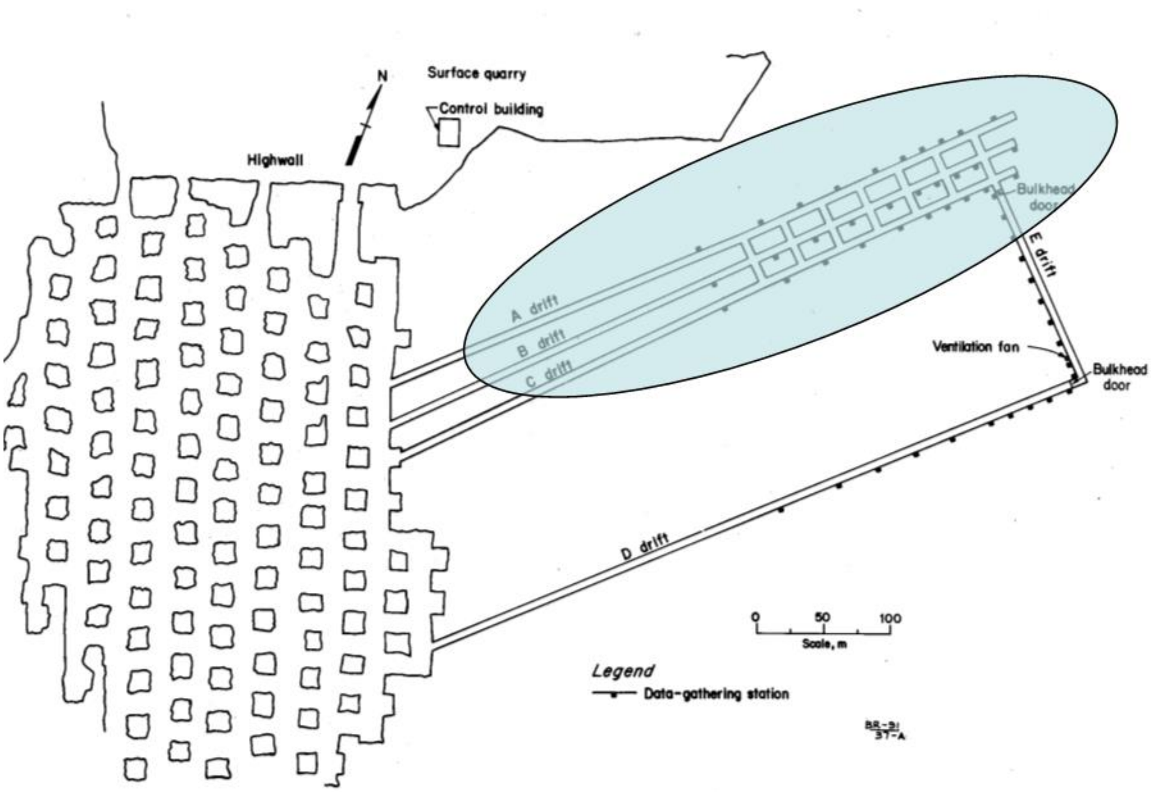


Figure 18: Lake Lynn Experimental Mine Testing Area

In these tests, the bagged rock dust barriers were proven to be successful, in the distributed barrier and concentrated barrier configurations, at stopping the flame propagation of a coal dust explosion within the barrier zones under different coal/rock dust loading amounts (69% and 82% TIC). This testing therefore proved the viability of using the bagged rock dust barriers in average height (5-8 ft), multiple entry mines under different dust loading and barrier configurations. Though the bag system operation is still dependent on the pressures developed by the explosion and the barrier's location in respect to the ignition point; bags located in crosscuts are less likely to rupture and disperse rock dust effectively due to pressure equalization between entries. Based on these findings, many countries started incorporating explosion barriers into their mining regulations in the early 2000s. Furthermore, many countries' principle barrier design features are based on the distance, spacing, and dust loading specified in these conclusive tests.

4.2 Stakeholder Feedback

4.2.1 MSHA and NIOSH Feedback Related to the Bag Barrier

Throughout the project, meetings and conference calls were held with both NIOSH and MSHA. Some comments and concerns that arose include; if finer dust in the bag is used, would they be more efficient whilst also containing respirable dust particles; can a hydrophobic dust be used to eliminate the possibility of caking; if float dust accumulates on the bags they would need to be dusted or cleaned regularly, this is of particular concern in the returns; and would ventilation need to be altered due to the bags. Finally, hanging methods would need to be looked at, currently in Australia they use a man basket on the front of a scoop on development to hang the bags efficiently. This would not be possible in the U.S. so an extended hook with workers standing on the ground, or similar, would be needed, this could slow progress and increase hours necessary to hang them. All concerns brought up by MSHA and NIOSH alike go beyond the scope of this project and cannot be answered without further investigation. All are associated with safety and cost associated with mines and miners. The Aim of the bagged barrier system is to help save lives, not impede production, or alter ventilation designs. These concerns have been collected and shared with project leaders at NIOSH in order to continue to look into these concerns.

4.2.2 Industry Feedback Related to the Bag Barrier

The project had several opportunities to gain feedback from industry representatives through site visits, an online survey, the Industry Day, and other meetings.

4.2.2.1 Site Survey Results

Surveys were used to gather feedback from mine employees regarding the bagged rock dust barriers, their installation, and working around them as mining progresses. Pre-installation, post-installation, and follow-up surveys were given. Each of the surveys were given to mine employees from a variety of job classifications, including engineer, production foreman, electrician, shuttle car operator, and safety foreman. The preliminary survey consisted of six questions designed to determine the employee's familiarity with methane and coal dust explosion hazards, and with the bag barrier system itself, the results are shown in Table 6. Seven employees were available to assist with the installations. Of these, all were familiar with recent mine disasters caused by methane and coal dust explosions and the potential for such explosions in coal mines. Five of the seven employees believe current explosion prevention standards are not sufficient, although two of these added that the prevention methods will never seem to be sufficient as long as ignitions still occur in U.S. mines. All of those surveyed believe more should be done to prevent/mitigate coal dust explosions, however most added the stipulation that the prevention methods could always be improved. Only two of these employees were familiar with the bag barrier system, although both had only briefly heard of it and did not know any specific details. Note that one employee declined to comment on question 5.

Table 6: Preliminary/Pre-Installation Survey Results

Question	Response	
	Yes	No
1. Are you familiar with the Upper Big Branch Disaster?	100%	0%
2. Are you familiar with the Sago Mine Disaster?	100%	0%
3. Are you familiar with methane/coal dust explosion risks related to coal mining?	100%	0%
4. Do you think current methane/dust explosion prevention methods/standards are sufficient?	29%	71%
5. Do you think more should be done to prevent/mitigate coal dust explosions?	100%	0%
6. Are you familiar with the rock dust bag barrier passive explosion mitigation system?	29%	71%

The post-installation survey consisted of ten questions designed to gain feedback from those who assisted with the partial barrier installation.

Table 7 contains the results of the survey. Questions 3, 5, 7, and 9 asked for further explanation of positive responses to the prior question, and question 10 asked for any additional comments. These questions are omitted in Table 7, but are discussed below.

Table 7: Post-Installation Survey Results

Question	Response	
1. How difficult were the barrier bags to hang/install, on a scale of 1 (easy) to 5 (hard)?	1.4	
-	Yes	No
2. Did you encounter any issues or difficulties during the barrier installation?	17%	83%
4. Do you have any suggestions for system/process improvements?	71%	29%
6. Do you forsee any short or long term problems with the bag barrier system?	57%	43%
8. If there were a full-scale barrier setup in the mine, would you have an improved sense of workplace safety?	86%	14%

Each of the employees felt the barrier was relatively easy to install. Only one reported installation difficulties; this employee worked in the mine that did not normally use roof mesh and reported issue with developing a method for hanging the bags at the appropriate spacing, which is discussed in more detail in section 3.1.7. Many had suggestions for system improvement, and the same concepts were heard from several different employees. The three concepts were: (1) adding a wide circle around the ring that clamps the bag to the hook to protect the bag from puncture by falling rocks, (2) a redesign of the hook so it does not hang so low, and (3) a redesign of the hook so it can be stronger than the current plastic. Four employees foresaw potential issues with the system. The three issues stated were: (1) damage to the bags during regular moving of power stations, belt conveyor systems, power cables, etc., (2) additional labor required for bag installation as mining progresses, and (3) damage to the bags from rock falls.

After the trial period, an 8-question survey was presented to all mine employees who were available to answer. A total of 14 employees and 1 MSHA inspector from both mine sites were surveyed, and the employees included the following positions: electrician, general laborer, mechanic, mine safety, production foreman, roof bolter, scoop operator, and shift foreman. Some of the results are shown in Table 8. Three of those surveyed had no interaction with the bag barrier system. One of those surveyed did not learn the purpose of the bag barrier system during the trial period. Of those who did understand the bag barriers function, three learned by speaking with project representatives during installation, and the remaining 11 learned by asking coworkers (Question 3). Questions 4 and 5 pertained to potential future issues with implementing a bag barrier system and issues encountered during the trial period. These issues included several topics that are discussed elsewhere in this project, including advancement of the barrier, installation costs, and hanging method. Other issues presented including the ease for bags to break on contact and that the bags can hang too low in some areas and block traffic or are damaged by moving equipment. Question 6 asked the surveyed employees to discuss potential improvements for the system. One improvement suggested is stronger bags, which is not possible if they are function properly during an explosion event. Other suggestions are discussed elsewhere in this report, including shorter bags and installation only in the returns to eliminate interference with the mining process. Two employees stated they were tempted to break bags as a prank, to get a bag out of their way, or for some other purpose. Finally, when asked if a full scale bag barrier system would improve employee sense of safety, 7 agreed, 5 disagreed, 1 said it might improve, and 2 elected not to respond.

Table 8: Results from Follow-Up Survey for Mine Employees

Question	Yes	No	Maybe	No Response
1. Did you encounter the bag barrier system at all over the past month?	80.0%	20.0%	0.0%	0.0%
2. Do you understand the purpose and function of the bag barrier system?	93.3%	6.7%	0.0%	0.0%
7. Were you ever tempted to intentionally break a bag (to prank a coworker, get the bag out of the way, etc.)?	13.3%	86.7%	0.0%	0.0%
8. Given a full scale bag barrier setup in the mine, would you have an improved sense of workplace safety with the barrier installed versus no barrier installed?	46.7%	33.3%	6.7%	13.3%

In addition to the 8-question follow-up survey, 5 more questions were presented to 11 employees in management positions. Question 1 asked if any hooks had been dislodged during the trial period. 6 thought that no hooks were dislodged, but the other 5 thought 1-3 may have been dislodged. Questions 2 and 3 pertained to bags broken during the trial period, which is discussed in the following paragraph. Questions 4 and 5 pertained to any kind of injuries directly caused by the bag barrier system or its installation, and all 11 employees said that no injuries were caused by the system.

During the trial period, the miners at the first mine attempted to remove and reinstall the bags in order to protect them when mining progressed and tracks were being laid to move supplies and equipment inby of the original barrier position. This was done contrary to explicit instructions to not move them. A majority of the bags were damaged when set down on the uneven floor covered in jagged coal particles; tiny holes were poked in the bags that lead to larger holes, tears, and complete bag failure when trying to re-hang them. Therefore, there were only a small percentage of bags left to inspect upon return to the first mine site. Upon return to the second mine site, the barrier was found intact in the original location with very few bags found damaged (approximately 3%). Since installation, mining had progressed and the power distribution centers, ventilation ducting, water piping, and other equipment that was originally outby the barrier location had been moved inby. This had been done without incident from, or damage to, the barrier bags. The lack of disturbance may be attributed to the additional 2 feet of mine entry height at this mine.

4.2.2.2 Online Survey Results

At the end of the YouTube video created for this project, the video requested the viewer to complete a survey that contained questions similar to those asked in Section 4.2.2.1. The survey had 56 respondents and consisted of 10 questions. Results for questions 2-9 are shown in Table 9. Question 10 asked for explanation of positive responses to Question 9, and results are discussed later in this section. Question 1 asked the respondent to share their relation to the mining industry, and the results are as follows: 1 corporate representative, 3 in mine management, 3 in safety and health, 19 engineers, 0 mine laborers, 5 regulatory agency employees, 9 research and university representatives, and 16 selected "other interested party/prefer not to share".

Table 9: YouTube Video Survey Results

Question		Response	
2	Are you familiar with any of the mine disasters that happened at the following mines: Upper Big Branch, Sago, Derby No. 1, or Jim Walters No. 5?	Yes	90%
		No	10%
3	Are you familiar with methane/coal dust explosion risks associated with coal mining?	Yes	98%
		No	2%
4	Do you think current methane/dust explosion prevention methods in the US are sufficient?	Yes	21%
		No	38%
		I do not know enough about current prevention methods to have an opinion	41%
5	Do you think more should be done to prevent/mitigate coal dust explosions?	Yes	75%
		No	5%
		I do not know enough about current prevention methods to have an opinion	20%
6	Before watching this video, were you aware of the bag barrier system?	Yes	52%
		I had heard of it, but I did not know details	15%
		No	33%
7	Would you feel safer if you worked in a mine that used a bag barrier system?	Yes	86%
		No	14%
8	Do you plan to attend the bag barrier presentation at the Running Right Conference Center in Julian, WV on May 23rd, 2017?	Definitely yes	2%
		Probably yes	0%
		Might or might not	15%
		Probably not	29%
		Definitely not	54%
9	Do you forsee any future problems with this system (safety, installation, maintenance, etc)?	Yes	63%
		No	37%

The YouTube video survey showed a greater number of respondents who had not heard of recent U.S. coal mine explosion disasters, and 1 respondent was not aware that coal mines had risk for explosions, both of which are probably attributed to the video's potential to attract viewers who are from foreign nations and/or are not familiar with the mining industry. Likewise, Question 4 and 5 showed a high percentage of respondents who were not knowledgeable enough about current prevention methods to be able to answer. Of those that did answer, the majority felt that current suppression methods are not sufficient and that more should be done to mitigate coal dust explosions. This result coincided with the mine site survey results, as did the response to Question 7 where the majority stated they would feel safer in a mine that used the bag barrier system. Contrary to mine site survey responses, the majority of online respondents was familiar with or had heard of the bag barrier system prior to watching the YouTube video. Only 65.0% of viewers were located in the U.S., and 20.3% were located in nations that currently use the bag barrier system, which is possibly why so many respondents had heard of the system. The potential for a large number of foreign respondents also raises uncertainty about the results from Questions 4 and 5; it is possible that persons from nations that already use the bag barrier system answered with bias when stating that the U.S. should implement this system. Unfortunately, the respondents were not asked to share their nationality, so this potential issue cannot be investigated further. Question 8 was included primarily to raise awareness for the upcoming Industry Day.

Finally, Questions 9 and 10 showed that 29 respondents foresaw potential issues with installing a bag barrier system in the U.S. The primary concerns presented were maintenance costs of replacing broken bags (10 respondents), difficulty to work and move equipment beneath hanging bags (9 respondents), and installation time and costs (8 respondents). Secondary concerns were convincing the mining industry and regulators that the system is necessary (5 respondents) and moisture intrusion (4 respondents). Other concerns submitted by 1 or 2 respondents include: coal dust adhering to the bag exteriors, rock dust compaction over time, bags blocking the view and access of escapeway markings, and damage to the bags from heat or shifting roof. Additionally, 1 respondent felt that active barrier systems sound similarly useful but with less cost, and another felt that installation would be of little use since mines who fail to rock dust properly are also more likely to fail at proper installation of a bag barrier system. Each of the primary and secondary concerns is addressed elsewhere in this report, though several of the minor concerns may require future research.

4.2.2.3 Industry Day Feedback

Industry Day attendees showed great interest in learning about the bag barrier system. The presentation, panel discussion, and demonstration answered all of the attendees' questions. The majority of questions presented during the Industry Day are answered elsewhere in this report, including those pertaining to installation requirements, cost, moisture intrusion, etc. The most novel questions and ideas mentioned by the attendees pertained to the shorter mining heights that are more common in U.S. mines. The guidelines recommend an ideal distance from the face for the first row of bags; one question asked if this distance also pertained to mines with very short seam heights since the pressure wave and flame front may behave differently. Another question asked if it were possible for short mines to concentrate bags towards the ribs with a large gap in the center to provide a roadway and limit damage to the bags from equipment; an alternative to this idea was to load bags with more rock dust near the rib and less in bags near the center, allowing shorter bags in the center. Another alternative presented was to load all bags with less dust and hang rows closer together, thereby reducing bag hanging height across the entire roadway. These ideas mentioned by attendees will require further research to ensure that the bag barrier system will still behave as needed after making these changes.

4.2.2.4 Feedback from Other Meetings

During the initial installation visit and the follow up visit, some additional questions and concerns raised by engineering staff during discussions were: the flammability of the bags themselves, MSHA approval for installing the bags in a U.S. coal mine, the need for dusting/maintaining dust on the outside of the bags, and the impedance to ventilation created by the installation of the barrier. A prominent concern was the added costs of the bags/hooks and the labor required to install and maintain the bag barriers. Additionally, MSHA strategies for program roll out, implementation, and fine structures for non-compliance were a concern should the system become mandated, regulated, and inspected in America.

Unfortunately the coal industry did not have a large presence at the 2016 and 2017 SME or ISEE annual conferences, though the project team was able to discuss with industry members that were in attendance. At the SME conferences, interest seemed high, though the primary purpose of these discussions was to raise interest in the Industry Day, so feedback was limited.

4.3 Bag Barrier Installation and Associated Costs

Nations that use bag barriers have differing systems in place for filling and installation. In most nations, the process begins at external third party sites that fill bags with rock dust, pack them into boxes of about 150 units (about 1 ton), and ship them to customer mines. However, the cost of labor in the RSA is low enough that several mines elect instead to purchase empty bags and rock dust separately and pay mine employees to fill them on site and attach the hanging hook. Since labor costs are higher in the U.S., it is more probable that the U.S. will develop a third party filling system in conjunction with existing rock dust suppliers. Such systems are not established in the U.S., which means initial costs will likely be higher due to additional costs required while developing a bag filling process. As the process is refined, this cost should decrease and level out. This final cost can be estimated by comparing with nations that currently use bag barriers, though accurate cost estimations cannot currently be determined due to a vast quantity of economic differences between these nations and the U.S.

The current price in NSW is approximately $4.80 USD per filled bag. This cost includes the bag, hook, and rock dust. It is typically estimated that the installed cost is roughly twice the purchase price, which includes the cost of the bag plus labor and other miscellaneous costs associated with installation, such as fuel for travel, etc. These costs bring the total to approximately $9.60 per bag, including materials and labor for installation. However, this value assumes that roof mesh will be installed in the mine regardless of bag barrier installation, thereby assuming roof mesh will not be an additional cost for bag barrier system installation. Mines that do not plan to install roof mesh must also consider additional costs for installing roof mesh or an alternative method for hanging the bags. Also, the estimated cost per bag can be subject to variation if a bag barrier system is implemented in the U.S. for the reasons described in the previous paragraph.

As an example using the $9.60 cost, a mine with a 6 ft opening and 20 ft entry width typically has three entries in the headgates and tailgates. All three entries must have a bag barrier system for reasons described in Section 4.5.2. Assuming the mine will be installing a distributed barrier and using the recommended spacing requirements in the SkillPro installation guidelines, each entry will require approximately 792 bags for a complete barrier. This means each barrier will cost approximately $22,800 for the entire gateroad, or $7,600 per entry, assuming the mine will install the bags with intention to leave in place (see Section 4.5.14.5.2). The barrier length is 1,180 ft, and the barrier will be extended as mining progresses and the original bags are left in place, so this cost can be broken down to roughly $19.33 per ft, or $6.44 per ft per entry. For purchasing costs and all costs related to installation, the total cost for each gateroad will be $22,800 per barrier location plus $19.33 per ft of advancement, and the total cost per entry will be $7,600 per barrier location plus $6.44 per ft of advancement. However, if the mine chooses to install advancing stands (see Section 4.5.1 of this paper), then this initial cost will be higher to obtain such stands; the cost of advancing will primarily only include labor, which depending on labor required may be higher or lower than the advancing cost of the "leave in place" method. A summary of these costs is found in Table 10, including costs for installing in mines without roof mesh and installing barriers to protect bleeder entries. Section 4.5.3 discusses bleeder entry barriers. For the "alternate hanging method" in Table 10, note that the presented method is only one of many possible options, and note that the costs may be drastically higher if additional roof bolts are used to install the roof strap (i.e. the roof bolt spacing required by the ground control plan is not at the same distance required for the bags).

Table 10 – Bag Barrier System Estimated Installation Costs

Cost Item (each)		Comment	Capital Cost	Operating Cost (per ft of Advance)
Bag		Includes bag, hook, and rock dust	$ 4.80	-
Bag (Installed)		Includes bag, hook, rock dust, labor, and other miscellaneous costs associated with installation	$ 9.60	-
Roof Mesh (sq. ft.)		Does not include installation costs	$ 0.66	-
Alternate Hanging Method	Hook	One per bag	$ 0.25	-
	Perforated Roof Strap (20 ft section)	One per row of bags; does not include installation costs	$ 17.12	-
Room-and-Pillar Entry or Longwall Development Entry	Roof Mesh Already Installed	Assuming opening dimensions are 6 ft thickness and 20 ft width	$ 7,603.20	$ 6.44
	With Additional Cost for Roof Mesh	Same as above	$ 23,084.80	$ 19.56
	With Additional Cost for Alternate Method	Same as above	$ 10,061.04	$ 8.53
Bleeder Barrier (all entries)	Roof Mesh Already Installed	Assuming: (1) opening dimensions are 6 ft thickness and 20 ft width, (2) panel width is 1200 ft, (3) pillar dimensions are 50 ft x 30 ft, (4) gateroads and bleeers have 3 entries	$ 30,541.67	-
	With Additional Cost for Roof Mesh	Same as above	$ 92,730.47	-
	With Additional Cost for Alternate Method	Same as above	$ 40,414.69	-

4.4 Risks Assessment Relative to Bag Barrier Application

Risk assessment will be used to determine exact locations within a mine where barriers must be installed. According to installation guidelines, barriers must always be installed near working faces since will always be potential sources for ignition. Other potential ignition sources requiring protection may include the gob, bleeder entries, specific equipment, or any other area that the mine’s risk assessment determines to be an explosion hazard. Installation guidelines also state that locations requiring bag barrier installation must install barriers in the return and belt entries. Mines should perform an additional risk assessment to evaluate the necessity of barrier installation in intake entries. Finally, mines should also perform a risk assessment of bag barrier maintenance in tailgates and bleeder entries to ensure protection of employees. This section discusses topics where risk assessment may be used to determine hanging locations within the mine. For potential risks inherent to the bag barrier system itself, including installation/operational hazards to mine employees, a detailed risk assessment is outlined in the Appendix section of the SkillPro-CSIR Bagged Barrier Suggested Installation Guidelines document, which is attached in the Appendix of this report.

4.5 Recommended Guidelines for the U.S. Market

The principles of coal dust explosions are similar in U.S. and foreign mines alike. Therefore, many of the design characteristics for bag barrier installation in the U.S. can be adapted from installation guidelines used in foreign nations. However, the U.S. does have unique mine layout and ventilations aspects that could cause changes in bag barrier system installation and design. The following subsections each discuss the areas in which this system may differ between installation in the U.S. and other countries, as well as providing predictions as to which aspects the U.S. is likely to copy from foreign nations.

4.5.1 Installation

It is recommended that installation be performed according to the guidelines in the Appendix document 'Suggested Installation Guideline – SkillPro-CSIR Bagged Barriers'. The foreign guidelines on which these are based are summarized in Section 4.1.2 for comparison. The remainder of this section addresses any installation techniques that may differ between the US and other nations using the bag barrier system.

There are two common methods for barrier installation in these nations. The first is to install a barrier by hanging each row on a separate movable stand and then move the stands and bags from one end of the barrier to the other as mining progresses. This method reduces cost by purchasing significantly fewer bags, though it is much more labor intensive. This method is more cost effective for use in RSA since labor costs are relatively low. The second method is to leave the bags hanging and install new bags on the advancing end as mining progresses, resulting in nearly an entire panel filled with bags despite the fact that bag barriers are only required across a shorter distance. This method requires purchasing a greater number of bags, but it is less labor intensive. NSW and the UK use this method since labor costs in these nations are relatively higher than in RSA. It is assumed that U.S. will likely use this method as well, though this prediction is subject to change if cost benefit evaluations are performed at U.S. mines.

Mine employees are used to hang the bags. These employees must be task trained on the proper method for hanging bags and the location/spacing according to each mine's specific barrier plan, though this task training is not lengthy. Installation typically is performed during non-production shifts, and the barrier is installed at the same time as advancing cables, power stations, etc. 1 or 2 members of this crew perform barrier installation during the advancing process, though it will depend on individual mine productivity to determine if additional workers must be hired or if the current crew is capable of performing the task along with their current duties.

Mines with tall opening heights purchase equipment called a man-basket that are mounted on a front-end loader, replacing the bucket, to assist with barrier installation. Use of these machines is faster and more efficient than using ladders, and it is safer than standing on other mobile machinery that is not designed for this purpose. If a tall U.S. mine installs a bag barrier system, they might be required to purchase equipment such as a man-basket. Mines with low seams where it is easy to reach the roof will not require this additional expense.

All mines in NSW install roof mesh in all portions of the mine, which allows for ease of bag barrier installation. On the contrary, mines in the RSA typically only install the roof support required for safety, which does not provide ease of bag barrier installation. Also, they have several mines over 11 ft opening height, requiring bags to be hung in 2 rows. Instead, they use fabricated stands that hold row(s) of bags. As mentioned previously, mine employees carry the stands from one end of the barrier to the other as mining progresses. The UK also only installs necessary roof support, but the cost of labor is too high to move stands like in the RSA. Instead, UK mines that do not already install roof mesh typically take one of two approaches: (1) install roof mesh wherever a bag barrier will be required, regardless of roof support requirements, or (2) use a system to hang bags from roof bolts or roof bolt plates, though this method may require additional roof bolts to be installed since bag spacing is typically slightly tighter than roof bolt spacing.

The U.S. only requires roof mesh where it is necessary and has high labor costs, so it is expected to follow a similar approach as the UK. U.S. mines that do not install roof mesh may have additional expenses to install roof mesh, install additional roof bolts, or develop an appropriate and more cost-effective alternative system for hanging the bags.

4.5.2 Mining Layout

Mining method is one of the primary differences between underground coal mines in the U.S. and the other nations that use bag barriers. In the U.S., room-and-pillar mines are similar in number to longwall mines. In the UK and NSW, room-and-pillar mines are virtually non-existent. In the RSA and the U.S., room-and-pillar mines are the majority; approximately 14% of U.S. coal mines use longwall mining methods [7] [8]. The room-and-pillar mining method results in a significantly larger area of open workings because there are a greater number of entries in each panel, submain, and main. The greater number of entries is necessary both for increased extraction and ventilation purposes. In longwall mining, much of the mined out area is immediately covered by the gob and open workings are reduced to a minimum. Room-and-pillar mines that wish to install bag barriers will have more entries to cover, meaning a greater number of bags must be purchased, and this number will be even greater if the mine decides to leave them hanging in place.

US mines have much lower average opening heights than mines in NSW, the UK, and the RSA. Since the required dust weight for a bag barrier is based on opening volume, U.S. mines may require fewer bags. However, the potential for these savings are limited since current SkillPro and UK guidelines have restrictions on the maximum spacing between bags and minimum weight of rock dust per bag. Potential also exists that low mine height may render bag barrier system installation impossible if heights are so low as to guarantee damage from moving equipment. It is possible that adjustments may be made to the design to accommodate mines with lower opening height. Some of these possibilities are described in Section 4.2.2.3 and are listed below, although research has not been performed to evaluate the effects of such changes on explosion mitigation performance, and none of these changes should be implemented until future research has proven the system to remain effective after making these adjustments.

1. It may be possible to concentrate bags towards the ribs with a large gap in the center to provide a roadway and limit damage to the bags from equipment.
2. Similar to #1, it may be possible to load bags with more rock dust near the rib and less in bags near the center, allowing shorter bags in the center.
3. It may be possible to load all bags with less dust and hang rows closer together, thereby reducing bag hanging height across the entire roadway.

In NSW, barrier installation is only mandated in returns and belt entries, though mines installing this system should use a risk-based approach to evaluate the necessity of placing barriers in all entries. Assume that a U.S. mine has decided to install a bag barrier on the pre-existing room-and-pillar panel shown in Figure 19. The blue shaded areas in the entries are the required bag barrier locations according to regulations and guidelines used in NSW. The start and end locations of the barriers must be within certain ranges of distance from the face, so additional bags will be installed inby as mining progresses inby. For this mine, entry A is the return, entry B has the belt, and entry C is the intake. According to NSW regulations, barriers are only required in entries A and B, not in the intake. In NSW, individual mines will decide if they want to put bags in the intake entries for other areas of the mine. Since barriers are not mandated in the U.S., individual mines may also make this decision for themselves. Additionally, note that mines using the “leave in place” installation method will have bags hanging further outby the blue locations in this diagram. However, the blue locations are the area of risk for explosion propagation, so those are the areas where bag barriers must be actively maintained. Bags left hanging in outby locations are no longer necessary for explosion prevention, and therefore do not need to be maintained.

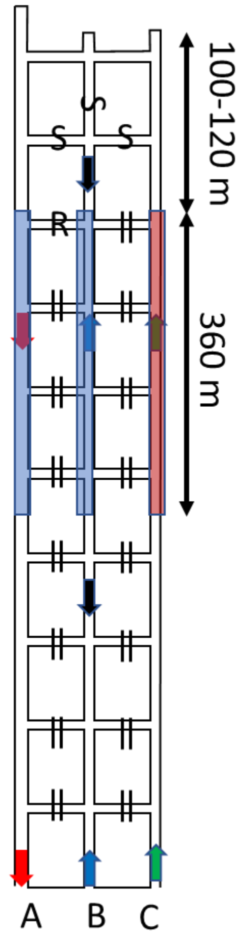


Figure 19: Required (Blue) and Optional (Red) Bag Barrier Locations for an Example Room-and-Pillar Panel

Image courtesy of SkillPro

Contrary to barriers in room-and-pillar entries, barriers are more likely to be placed in all longwall entries. Since a longwall panel's development section on the headgate side becomes the tailgate side for the next panel, it is generally easier to install the barrier in all panel development entries including intake air. Assume that a U.S. mine has decided to install a bag barrier on the pre-existing longwall panel with one bleeder, shown in Figure 20. The blue shaded areas in the entries are the required bag barrier locations according to regulations and guidelines used in NSW. The start and end locations of the barriers must be within certain ranges of distance from the face, so additional bags will be installed outby as mining progresses outby. For the development section on the headgate side at this mine, entry A is the return, entry B is the intake, and entry C has the belt. According to NSW regulations, barriers are only required in entry C, not in the intake. On the tailgate side however, entries A, B, and C are all returns, and each of these entries require barriers. However, if another longwall panel is created to the left side of this panel, then the headgate for this panel will become the tailgate for the next panel. Assuming U.S. mines will leave installed barriers in place, it is safer and more efficient to install barriers in A, B, and C during headgate development so that no additional work is required to install a barrier in the A and B entries of the tailgate development section. For all future panels, barriers must be installed during headgate development in all entries, aside from the very last panel which will not turn into a tailgate and therefore is not required to have a barrier in the intake. As mining progresses outby, the barrier will also progress outby. Once the furthest distance from the face exceeds the length of the panel, that length must be completed by continuing in all adjacent entries and crosscuts for the submain, although mines that have used bag barriers since the mine's opening will already have bags in the submains that were installed during development.

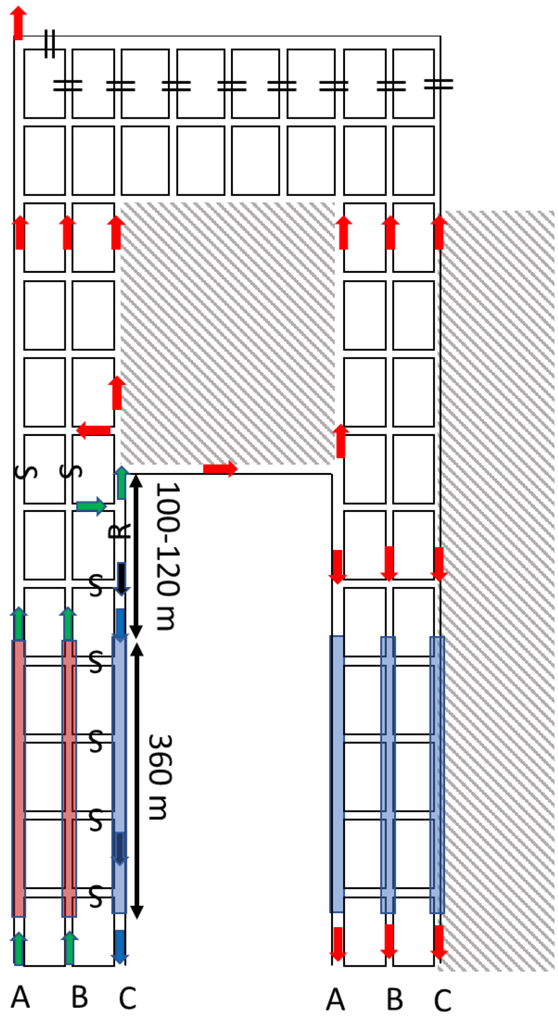


Figure 20: Required (Blue) and Optional (Red) Bag Barrier Locations for an Example Longwall Panel

Image courtesy of SkillPro

In summary for Figure 20, the blue locations are locations where bag barriers are required, and the red locations are optional. However, if panels will be placed adjacent to one another, is strongly recommended that bag barriers are also placed in the optional locations during development for every panel aside from the last panel. Doing so will prevent installation work in the tailgate once a headgate becomes the tailgate for the next adjacent panel. Also note that this diagram is only for the required placement of a barrier. A mine that uses the "leave in place" installation method will have bag barriers installed in nearly the entire panel for two reasons: (1) production will begin further inby, so the barrier will initially begin inby and (2) development will act as a "room-and-pillar" scenario that must be protected. Once again, the blue locations are simply the locations in which bag barriers must be actively maintained.

4.5.3 Ventilation

There are two primary differences between ventilation systems in the U.S. and those in NSW, the UK, and the RSA. The first regards longwall panel ventilation. In most U.S. longwall mines, bleeder systems are used which have entries at the inby end of the panel, behind the gob. NSW and UK mines almost exclusively use U-system ventilation, which does not have these additional entries. RSA mines use various ventilation systems, though bleeder systems are rare. It is possible that U.S. mines may be required to protect the bleeder entries in addition to areas normally protected, which may be an additional cost not seen in these other three nations. Figure 21 shows the scenario for Figure 20 if that mine had chosen to install bag barrier systems to protect the bleeder entries. Note that the working face is close to the bleeder entries, which does not allow ample distance to complete the required length for the barrier. Therefore, the barrier length is continued in each adjacent entry or crosscut for the panel. For future panels, production begins at the inby end of the panel, which means protecting the bleeder entries will require bags installed in all entries in the bleeder area and all crosscuts adjacent to the gateroads. Installing a bleeder protecting barrier on an existing mid-production panel will require work inby the working face, which is generally considered dangerous. In the interest of safety, this mine may decide instead to avoid barrier installation on this panel, and to hang bags for future panels throughout the headgate and bleeder entries/crosscuts during development.

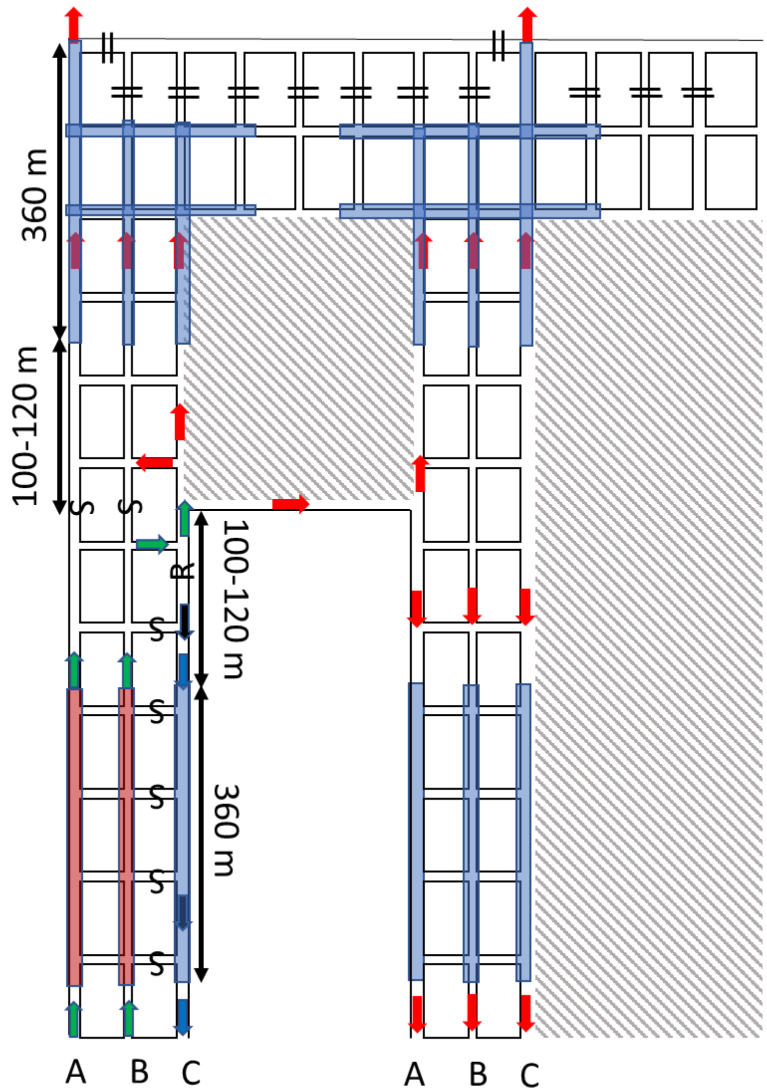


Figure 21: Bag Barrier Locations for an Example Longwall Panel, Including Bleeder Barriers

Image courtesy of SkillPro

The second difference between the U.S. and NSW, UK, and RSA mine ventilation is the neutral airway. In the U.S., the belt is required to be in neutral airways, but neutral airways are not required at all these other three nations. This means the U.S. will have at least one additional entry to install bags in longwall panels compared with these three other nations. For mains, submains, and room-and-pillar panels, barrier installation is only necessary in the returns according to current guidelines, though it is recommended to install barriers in all entries. If U.S. mines choose to install in all entries, U.S. mines will have at least one additional entry to install bags in all portions of the mine.

5 Dissemination Efforts and Highlights

The efforts to disseminate the information uncovered by the project was a very large part of the project itself; since the knowledge of the Bag Barrier explosion barrier technology is not used in coal mines in the United States. Therefore, even though this technology has been in use for over 15 years in other countries, it was brand new to nearly all U.S. coal mining companies. An additional concern was the common misconception among U.S. coal mines that having 80% rock dust content in their returns yields 100% certainty of extinguishing a coal dust explosion. To address this misconception and introduce the bag barrier system to the U.S. coal mining market, various approaches were utilized.

- Presentations
    - Local Presentations given at University level and local SME Chapter meetings
    - National Presentations given at 2017 SME Annual Conference and Expo
    - International Presentations given via YouTube website (over 1,100 views)
    - Industry Presentations given to coal mining executive officers, mine site engineering staff, and miners
    - Regulator Presentations given to MSHA, NIOSH, and WVMHS
- Demonstration
    - Industry Day open house event and scaled length bag barrier exhibit
- Documents
    - Conference Papers
        - Management of Explosion Risks with Bagged Barriers
        - Study of U.S. Coal Mines Since 1994
    - Guidelines
        - Bag Barrier Installation in U.S. Mines
        - SkillPro installation recommendations

6 Conclusions and Impact Assessment

The main goal of this project was to introduce a well-tested and widely utilized (internationally) explosion mitigation strategy to the U.S. coal mining industry, and to instigate conversations between coal industry researchers, regulators, and producers regarding the need for additional safety measures concerning explosion risks in U.S. underground coal mines. In the simplest context, these goals were accomplished through the industry outreach performed during this project. However, the introduction and implementation of explosion barriers is a very dynamic subject requiring multi-faceted analysis; not the least of which is the economic impacts of the implementation and regulation of such devices. These analyses must be continued beyond the scope of this project for the full impact of this project to be realized. In the absence of specific legislation regarding the implementation and required installation locations of explosion barriers in U.S. mines, a risk based approach is the only applicable method for interested mines to utilize the bag barrier system.

7 Recommendations for Future Work

To continue this work and further the understanding and implementation of explosion barriers in underground coal mines in the U.S., further research is recommended. The areas of this future research should include the appropriate location/placement of passive and active explosion barriers in U.S. mines based on disaster reports and coal dust fallout survey data, active explosion barrier alternatives, and active explosion barrier triggers, suppressants, and dispersion apparatus. Additionally, an investigation as to the applicability of incorporating an active explosion barrier system with the in-mine monitoring and communication systems should be performed.

In addition to this, questions and concerns from industry and regulatory centers can continue to be evaluated. Specific questions that arose during the course of this project that can be answered through further research are listed below, in no particular order:

- Do mines with shorter seam heights need the same distance to the first row of bags, since in shorter seam mines the pressure wave and flame front may behave differently?
- Can short seam height mines concentrate the bags towards the ribs to save space in the center of the roadway for equipment clearance?
- Can the bag height be reduced by having less contained dust and bag row and spacing closer together?
- Is there a concern with the flammability of the bags and is further testing required to satisfy MSHA?
- Are the bags an additional area for dust collection or ventilation impedance?
- Can finer dust be used to increase efficiency whilst containing respirable dust within the bags?

8 References

[1] S. P. Wing, "Safety Alert - Flamable Dust Explosions," Health and Safety Executive, [Online]. Available: http://www.hse.gov.uk/mining/alerts/sa_fldustexp.htm. [Accessed 22 Octoober 2016].

[2] H. a. S. Executive, "Bagged Stone Dust Barriers," Health and Safety Executive, UK, 2005.

[3] S. S. P. Ltd, "Suggested Installation Guidelines for the SkillPro-CSIR Bagged BArriers in Underground Coal Mines," SkillPro, Brisbane, 2017.

[4] M. S. O. Division, "Guidelines for Coal Dust Explosion Prevention and Suppression," New South Wales Departmnet of Primary Industries, NSW, 2001.

[5] D. H. Zou and S. Panawalage, "Passive and Triggered Explosion Barriers in Underground Coal Mines - A Literature Review of Recent Resaerch.," *Dalhouse University Department of Mining and Metallurgical ENgineering,* 2001.

[6] W. Cybilski, "Coal Dust Explosions and Their Suppression," U.S Bureau of Mines, Washington DC, 1975.

[7] S. Fiscor, "US Longwall Operators Ramp Up Production," Coal Age, 26 February 2015. [Online]. Available: http://www.coalage.com/features/4230-us-longwall-operators-ramp-up-production.html. [Accessed 7 Nov 2017].

[8] J. J. Du Plessis, E. S. Weiss and K. L. Cashdollar, "Bagged Stone Dust BArrier Evaluations in a Bord and Pillar Mine," Safety in Mines Advisory Committee, 2000.

[9] J. J. Du Plessis and P. S. Vassard, "Increase the Use of Stone Dust Bagged Barrier Enhancing Its Application for Differing Conditions," Safety in Mines Advisory Committee, 1999.

9 Appendices

Final Guidelines for the SkillPro Bag Barrier

Presentation from Industry Day

SkillPro Services Pty Ltd

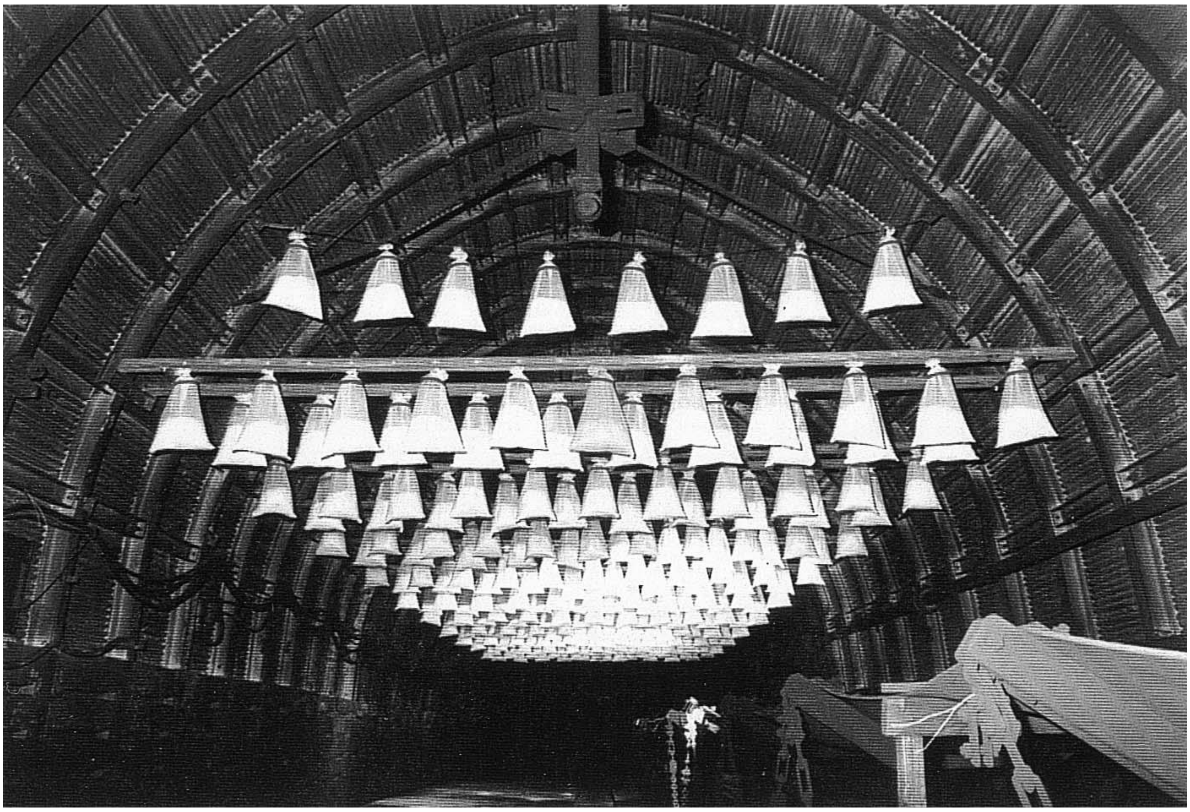
ABN 18 096 918 884

Suggested Installation Guideline

SkillPro-CSIR Bagged Barriers

Underground Coal Mines

August 2017



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Disclaimer

This guideline is intended to assist in the design, construction and installation of the SkillPro-CSIR bagged barrier system of rockdust explosion barriers. SkillPro, its distributors, agents and its employees will not be held responsible for damages arising from inappropriate use of the product or errors or omissions in this guideline. It is the responsibility of the customer to ensure that any explosion barriers are designed, constructed, installed and maintained in a satisfactory manner, by suitably competent persons.

If there is any doubt in relation to the application of these guidelines, independent professional advice should be sought. SkillPro may from time to time make amendments to these guidelines, in light of better knowledge of explosion protection from research it or others carries out, or in response to industry requirements. The responsibility rests solely with the mine to ensure that personnel who design, install and maintain explosion barriers have the necessary qualifications, training and experience to allow safe and compliant work practices to be followed.

These guidelines apply only to SkillPro barrier bags and hooks which carry the SkillPro Services logo as shown in this document and cannot be applied to any other explosion barrier product.

Introduction

The SkillPro-CSIR bagged barrier is an alternative type of passive coal dust explosion barrier to traditional explosion barriers made from rows of rockdust on shelves, or rows of suspended water tubs. Whilst the idea of suspending rock dust in bags goes back over 50 years, the current product was developed by CSIR of South Africa in the 1990's and is supplied in Australia and various overseas counties by SkillPro Services Pty Ltd, under license to CSIR.

This installation standard describes the components and various configurations of the bagged barrier as might be applied in US coal mines. It is based upon both the South African and Australia Guidelines.

The cover page photo shows a multi-layer barrier installed in the Tremonia test mine in Germany, prior to a full-scale coal dust explosion test. The bag-barrier system has been extensively tested in large scale facilities in South Africa, Germany and USA.

Description of the SkillPro-CSIR Bagged Barrier

The bagged barrier explosion suppression system consists of an array of specially made clear plastic bags containing rockdust, and matching suspension hook, arranged in rows across the width of a coal mine road and installed in accordance with the following chapters. In roadways over 3.5m height, the bags of rockdust are suspended in multiple horizontal layers. For lower height mines (about 2.5m), a shorter bag is used but containing the same mass of rockdust, however there are some caveats applied to its application (see later)

The actual distances between bags and rows of bags used in the layout of a barrier are determined by the requirement to achieve certain minimum levels of rockdust within the barrier, and by the roadway dimensions.

These guidelines have been specifically developed around the SkillPro-CSIR bagged barrier. Extensive large-scale explosion testing was undertaken in the development of the SkillPro-CSIR bagged barrier components and these resultant guidelines. Only bags clearly identifiable with the brand names SkillPro or SkillPro-CSIR, can be installed utilising these guidelines.

This guideline provides generic information that any coal mine can apply to their unique circumstances. It does not offer advice on exactly which roads or places might require barriers as this is driven by a combination of mine design, local risks and sometimes Legislation. For example, drawings in this document show a 2-roadway development for a longwall. This could easily be expanded to 3 or more roadway layouts using the same layouts for barrier placement to protect all required roadways. The design and layout for barriers can equally be applied to multiple main development or entry roads, to bleeder roads etc.

SkillPro
Services Pty Ltd

A Product of SkillPro and CSIR (South Africa)

SkillPro–CSIR Bagged Barrier Logo 1

Common Barrier Design Parameters

There are several common design parameters that apply to all types of barriers covered by this document. These define limits for the mass of dust needed, distance between individual bags, for separation from the ribs (sides) of the roadway and the requirements for bags to be distributed in layers in high workings. These parameters are given below:

1. Each plastic bag is marked with a horizontal line to indicate the approximate location of the hook's locking ring once it is filled with dust. It must contain dry rockdust complying with MSHA requirements and/or and local mining regulations. The actual quantity contained in each bag is not critical so long as it lies between 5 and 6 kg., and the number of bags in the barrier is designed upon the average mass per bag determined by some weighing scheme. The bag is not designed to carry more than 6kg. The worked examples provided later in this document, are all based on 6kg/bag as this is the default mass used.
2. The horizontal distance between the hooks of the bags in a row, must be not less than 0.4m and not greater than 1.0m, when measured across the roadway width (see Figure 1).
3. The distance between the bags and the side of the roadway must not be greater than 0.5m (see Figure 1).
4. For roadways up to 3.5m high, each row must have a single level of bags suspended with the hooks not more than 0.5m from the roof.

5. For roadways between 3.5m and 4.5m high, the bags must be distributed evenly amongst two layers, suspended with the hooks located at not more than 0.5m and 1.0m below the roof level.

6. For roadways between 4.5m and 6.0m high, the bags must be distributed evenly in three layers suspended with the hooks located at not more than 0.5m, 1.0m and 1.5m below the roof level.

7. The distance measured along the roadway between rows of bags must be not less than 1.5m and not more than 3.0m.

8. Most importantly, the minimum total mass of rockdust used in the barrier is based upon the values of either 100kg/m^2 of roadway cross-sectional area or 1kg/m^3 of roadway volume between the extremities of the barrier, whichever amount is greater. It should be noted that for any barrier longer than 100m, the rockdust mass will be calculated on the basis of roadway volume i.e. 1 kg per m^3.

9. Bags should be suspended from a rigid structure or device, e.g. steel roof mesh or a purpose made hanger of some sort that can withstand a 25kg static load. If a 2nd or 3rd layer of bags is needed due to the road height, then the lower layers of bags should be fixed onto the most rigid device or structure that can be arranged. A loose or un-tensioned chain or cable across the roadway is inadequate.

10. Bags should be suspended so the hook and bag can swing freely inbye/outbye, ideally with the open part of the hook facing inbye. The hook should never be attached so it faces across the roadway.

11. There are currently 2 different height (length) bags and 2 different height (length) suspension hooks with a total height variation of 200mm. Either hook can be mated to either bag. For the purpose of this Guideline document, any reference to ‘short bags” assumes the shorter bag will be mated with the shorter hook to maximize clearance in low height roads. Any reference to “long bags” refers only to the bag length, however it could be mated to either height hook depending on mine requirements**. Bags and hooks should be of the same design within any given barrier.**

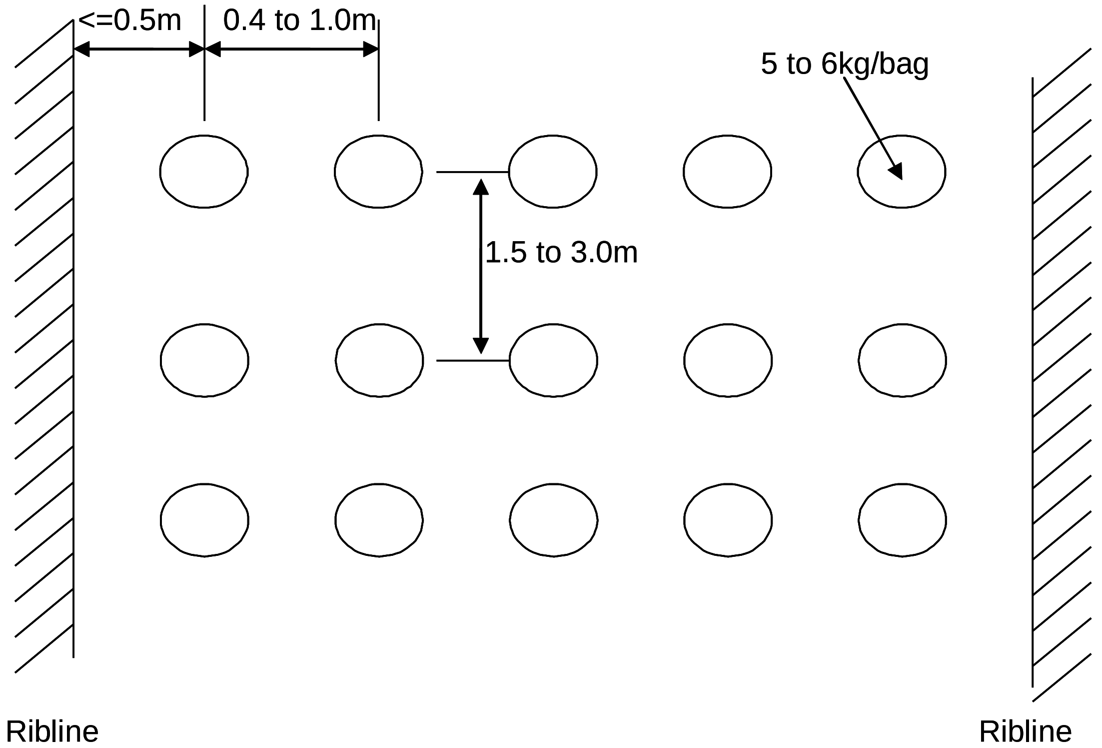

Figure 1 - Spacing of bags within a barrier – No significance should be placed on the number of bags shown across the roadway in this figure

Types of Barriers

The bagged barrier system can be configured in several different ways depending upon the application and the requirements of the mine. The four alternatives that can be applied are:-

1. an advancing distributed barrier after the original South African model,

2. an advancing concentrated barrier, or

3. a fixed distributed barrier, and,

4. a fixed concentrated barrier

All barriers must comply with the common barrier design parameters given above**.** A discussion on each type of barrier is given below.

(1) Advancing Distributed Barrier

An advancing distributed barrier consists of four sub-barriers, installed over a maximum distance of 120m of continuous roadway. Three complete sub-barriers must remain in position at all times, while the fourth sub-barrier is in the process of being moved ahead/back as the section advances/retreats. The original concept was that the fourth barrier would be moved only during non-production shifts when the probability of ignition is greatly reduced. If this is not the case, a fifth sub-barrier should be added, to have confidence that the barrier meets the required dust loading all times.

Historically, this layout has not been used outside of South Africa due to the relatively high labour costs, however it remains in the Guidelines for completeness.

The following distances must be maintained:

(a) the first row of the first sub-barrier, must not be installed closer than 60m and not further than 120m from the last cut-through, or face line of a producing longwall panel;

(b) the last row of the fourth sub-barrier, furthest from the last cut-through or face line, must be installed not more than 120m from the first row of first sub-barrier;

(c) the two intermediate sub-barriers must be equidistant between the first and fourth sub-barriers;

(d) the presence of cut-throughs other than the last completed cut-through is not a consideration in determining distances;

(e) the maximum distance between the end of one sub-barrier and the start of the next sub-barrier must not exceed 30m.

These dimensions are illustrated in Figure 2.

Some mines have found it is financially not worth advancing sub-barriers, but build a new one at the front of the full barrier when space is available. This does not alter the requirement to adhere to the design guidelines presented herein.

Example 1

A worked example of the required calculations will illustrate the design of an advancing distributed barrier.

Assume that a bagged rockdust barrier is to be installed in a bord-and-pillar section. Assume also that the first row of the first sub-barrier will be located 100m from the last cut-through and the last row of the fourth sub-barrier at 220m from the last cut-through. The belt road is 3.0m high and 6.5m wide.

The distance between the barrier extremities is 120m and the cross-sectional area is 19.5m^2. The volume between the extremities of the full barrier is therefore 2340m^3. Based on cross sectional area requirements of 100kg/m^2 and roadway volume requirements of 1kg/m^3, the barrier will require either 1950kg or 2340kg of rockdust, whichever is the greater, in this case being 2340kg.

If each bag contains 6kg of rockdust, a total of 2340/6 = 390 bags are needed. With four sub-barriers, there would be 390/4 = 98 bags per sub-barrier. (Obviously if it is decided to use only 5kg of rockdust in each bag, more bags will be required)

Each sub barrier needs 98 bags which is best arranged as 7 rows of 14 bags. If say only 12 or 13 bags can easily be hung across the road, then additional rows will be needed, possibly with additional bags in some rows to make up to 98 bags in the sub-barrier.

Assuming the 7 row x 14 bag arrangement, and if rows in sub-barriers are 2.0m apart, then each sub-barrier will extend over 12m. Taking the cut cut-through as zero, the sub-barriers will be located as follows:

Last cut-through		0m
1st sub-barrier	start	100m
	finish	112m
2nd sub-barrier	start	136m

	finish	148m
3rd sub-barrier	start	172m
	finish	184m
4th sub-barrier	start	208m
	finish	220m

The position of first sub-barrier must not be closer than 60m and not further than 120m from the last cut-through.

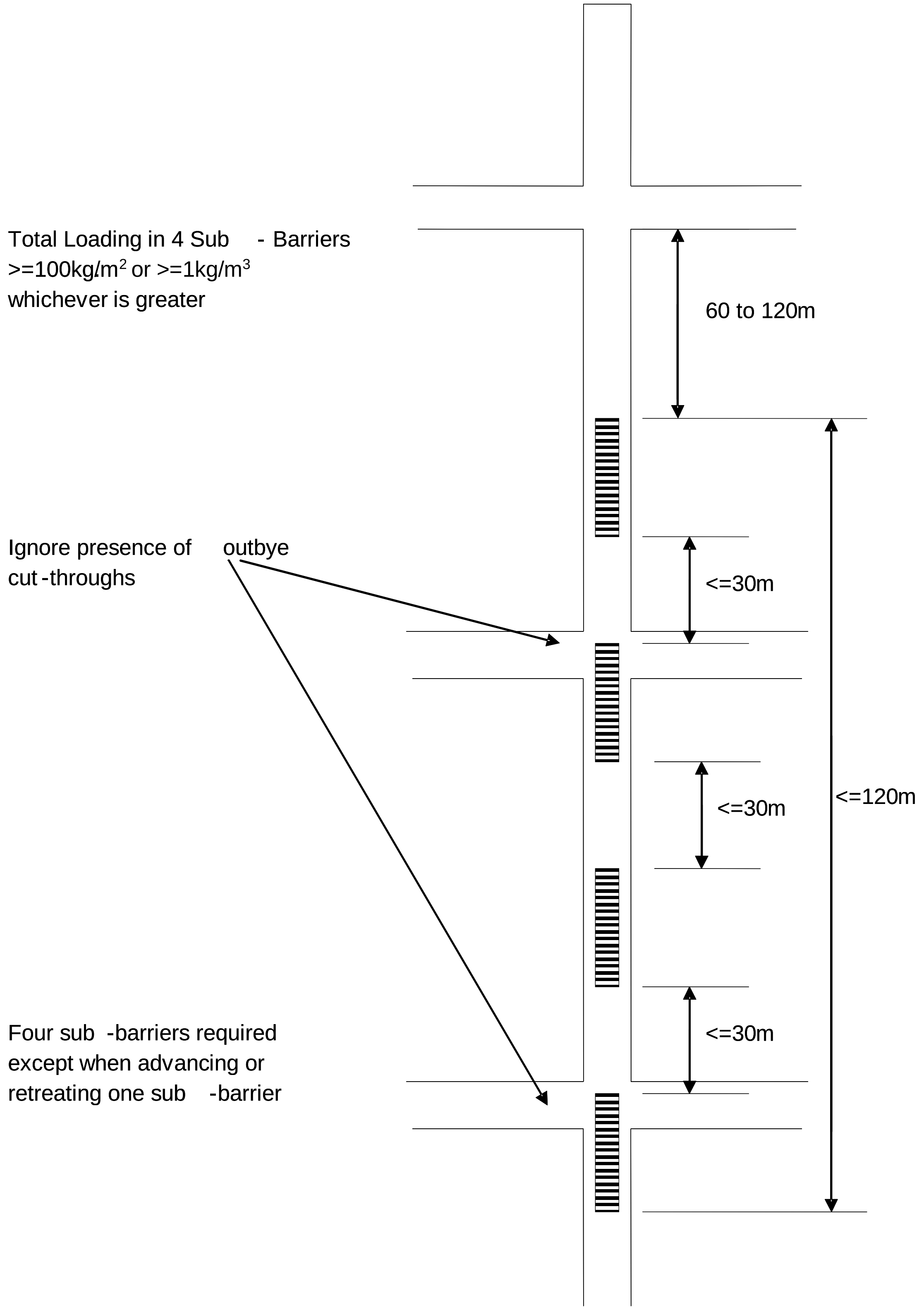

Figure 2 - Advancing Distributed Barrier (not to scale)

(2) Advancing Concentrated Barrier

An alternative to the advancing distributed barrier is the advancing concentrated barrier. Instead of the dust being distributed among four or five sub-barriers spread over about 120m of roadway, the rockdust is placed in one concentrated barrier 20 to 40m long. To facilitate panel advance/retreat, a second concentrated barrier is also installed and used to leap-frog the first barrier to maintain the correct distance from the last cut-through. Each of the individual barriers is designed on the basis of 100 kg/m^2 and therefore holds sufficient dust to act as a discrete explosion barrier. Two barriers are installed to allow removal of one for advancing or retracting as the face moves, without compromising the barrier dust loading.

Historically, this layout has not been used outside of South Africa due to the relatively high labour costs, however it remains in the Guidelines for completeness.

Despite the above comment, it is acceptable to advance a concentrated barrier by building a new barrier in front of an existing barrier when sufficient space is available, rather than leapfrogging barriers. This does not alter the requirements to adhere to the design guidelines presented herein.

The distance between the last cut-through or longwall face and the first row of bags must be greater than 70m but less than 120m at all times, both advancing and retreating.

The next barrier in the sequence must start no further than 120m from the inbye end of the first barrier, so the exact distance between them will be dependent on the barrier length chosen.

The rockdust requirement in each barrier is calculated on the basis of 100kg/m^2 of roadway cross-sectional roadway area.

The dimensions for an advancing concentrated barrier are illustrated in Figure 3 following

Example 2

An example of the calculations undertaken to design an advancing concentrated barrier follows.

Consider a roadway in which the barrier is to be installed and which has a height of 3.6m and width of 6.5m. The area of the roadway is 23.4m^2 and the amount of rockdust required in each barrier is 2340kg. With 6kg of rockdust in each bag, each barrier will consist of 390 bags. At 3.6m roadway height, there should be two layers of bags with the suspension hooks at not more than 0.5 and not more 1.0m below the roof. Allowing 0.5m between the ribs and the nearest bags and between adjacent bags, it is possible to install 12 bags in each row. The height of the roadway dictates the requirement for two layers of bags. Therefore, the final barrier consists of two layers of bags each of 17 rows and each row holding 12 bags (2*17*12 = 408 bags). Allowing a spacing of 2m between rows each barrier will be 32m long ((17-1)*2).

Two barriers are installed to allow removal of one barrier for advancing or retracting as the face moves without compromising the barrier dust loading. The design details of the second barrier will be the same as the first barrier. At least one of these barriers, each consisting of 390 bags in this example, must always be in place.

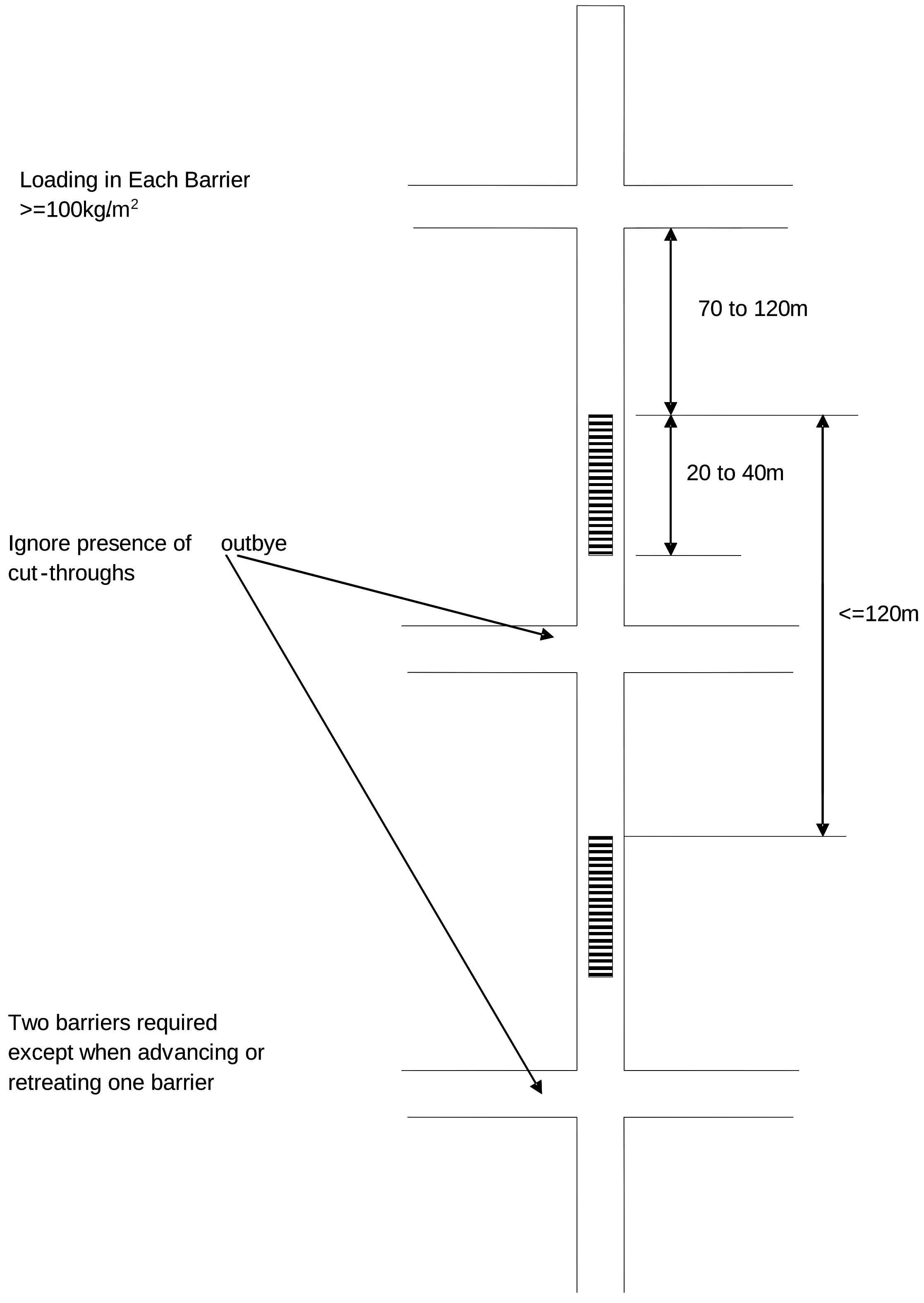

Figure 3 - Advancing Concentrated Barrier (not to scale)

(3) Fixed Distributed Barrier

For mining situations in which there is rapid advance or retreat, and/or where mining sequence, and/or pillar sizes make either of the previous choices difficult, then a fixed distributed barrier can be used. This variation is typically applied in the gateroads of longwall extraction panels, to avoid safety risks and production delays associated with relocating sub-barriers used in either of the advancing barrier systems described above.

The fixed distributed barrier places a continuous array of rockdust bags in a roadway, possibly over its whole length. These would usually be installed during development and left in place for the retreat phase of mining. By leaving the bags in place, there is no requirement to advance or retreat barriers as described above, while providing a very high degree of explosion protection for that roadway.

The distance between the start of the fixed distributed barrier and the last cut-through or longwall face must not exceed 120m. To be effective, the barrier must run for a minimum distance of 220m unless additional loading is used at this starting point.

It is not always possible to maintain the barrier length more than 220m as a longwall panel sets off or as a longwall face line approaches its end. For such cases, the mine can increase the density and convert the outbye end part of the barrier to the specifications given for an advancing concentrated barrier. Some part of this barrier may also have to project beyond the gateroad being protected, into the mains development roads, in which case the barrier may have to split and extend into a number of roadways to ensure the proper overall length.

The design of the fixed distributed barrier requires is based on a minimum rockdust density of 1kg/m^3 in the mine roadway (see Figure 4).

Whilst this arrangement is the most flexible, it is suggested that in cases of doubt, or circumstances not clearly covered by these guidelines, the mine should seek professional advice from SkillPro or other competent parties, on the configuration of such barriers.

Note well – Short (height) bags can only be used in a fixed distributed barrier or a fixed concentrated barrier. The original style "Long" bags can be used to construct any of the four types of barriers described above, but must not be mixed with short bags within a barrier.

Example 3

An example of the design calculations will illustrate the requirements for a fixed distributed barrier.

Consider a longwall gateroad that is 3.4m high and 5.2m wide. At a roadway height of 3.4m, each row of bags requires only one layer with suspension hooks within 0.5m of the roof. The roadway area is 17.7m^2 and the rockdust requirements will be 17.7kg/m of roadway length. At 6kg/bag this requires 2.95 bags/m. If the row separation is 2.5m each row will require 2.5*2.95 = 7.4 bags/row, which will be rounded up to 8 bags per row.

These can be installed immediately outbye of the face at a convenient position, but the first-row location should not be more than 120m outbye of the last cut-through or face line.

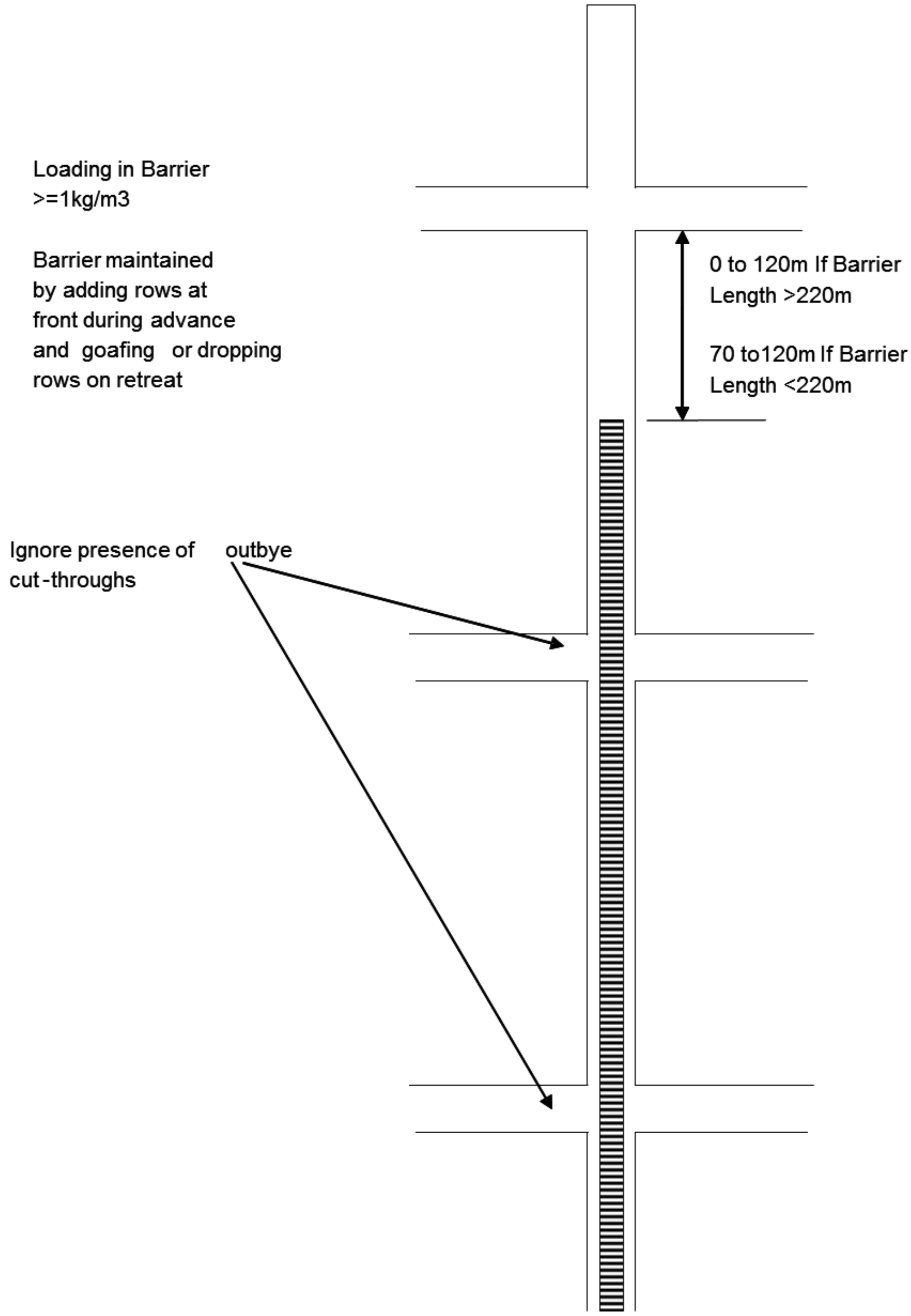

Figure 4 - Fixed Distributed Barrier (not to scale)

(4) Fixed Concentrated Barrier

The fixed distributed barrier is a variation on the advancing concentrated barrier in that instead of using only using two sub-barriers which leap-frogging during the advance, a series of sub-barriers is built in accordance with the requirements for the advancing barrier but left in place as mining progresses. In this way, the fixed concentrated barrier achieves the same degree of safety associated with the fixed distributed barrier while possibly better meeting local requirements for sequencing of installation and alignment with pillars. The fixed concentrated barrier developed from the use of barriers in Australia as the use of bagged barriers matured over the years.

The design parameters for a fixed concentrated barrier are the same as those for an advancing concentrated barrier as described above. The only change is that as each sub-barrier is built it is left in place so that ultimately there are many sub-barriers. In this way, the dust mass in the barrier increases and provides a high degree of protection.

Note well – Short (height) bags can only be used in a fixed distributed barrier or a fixed concentrated barrier. The original style "Long" bags can be used to construct any of the four types of barriers described above, but must not be mixed with short bags within a barrier.

Protection of Roadways with Obstructions

Where the bagged barrier is used to provide explosion protection in a conveyor belt roadway, **additional** rockdust bags must be suspended on the conveyor belt structure to provide **additional** protection against passage of an explosion under or between the belts, or between the belt and roadway side. This should take the form of one bag on either side of the belt structure for each row of bags suspended on the roof in the roadway. The hooks can be directly attached to the structure, but ideally, the bag should remain free-hanging and be incapable of touching any moving part of the conveyor belt, even if accidentally bumped. These additional bags do not necessarily have to exactly align with the roof mounted row.

For suspended belt structure, wherever there is clearance to do so, **additional** bags must also be hung underneath the belt structure. This should take the form of one bag per metre of belt width for each row of bags in the roadway. If there is insufficient clearance to suspend a bag, there can be no confidence in a bag simply placed on the road floor below the belt.

The same conditions apply whenever a ventilation duct or large pipe is suspended above the floor is used i.e. one **additional** bag is to be suspended under the vent duct/pipe for each row of bags in the roadway.

There is no conclusive research into the exact mounting arrangement for attaching to belts or other such structures. Conceptually, provided the hanging system prevents the hook from dislodging as it rotates under explosion pressure, but still allows it to move under explosion pressures, then any reasonable hanging arrangement should be acceptable. There is some limited evidence that vibrating belt structures may prematurely fatigue the plastic hook, so mines with this application, need to periodically inspect and rectify as needed.

There is no direct research data showing the need or otherwise for additional protection around a longwall monorail system or a single pipe, that penetrates the barrier, other than that noted above, but there should not be an unprotected "passage" between the rib and side of any large obstruction such as a suspended belt or ventilation duct.

Mines are alerted to research that indicated explosions can propagate in the narrow band of fine dust, commonly found under conveyor belts.

Appendix B provides some generic illustrations.

"Non-Compliant" or "Non-standard" Installations"

There will almost certainly be circumstances in a mine that are not adequately covered by these guidelines. It is impossible to anticipate every mine layout and configuration in which a bagged explosion barrier may be placed. The information provided with the four differing barrier layouts described above,, gives the most commonly seen arrangements only and should not be inferred as showing what roadways barriers should be installed in, nor should it be assumed that one of the 4 layouts will solve every possible explosion risk.

Special consideration may need to be given in circumstances such as :-

- when a longwall panel approaches completion and the take-off road is close to the main headings
- single entry development over about 100m
- An extraction panel that uses a system of bleed return behind the working place
- drivage of long face installation roads, eg over about 300m When a gate road or single entry drivage sets off, there will be times when it cannot easily comply with the guidelines in this document.

Increasing chain pillar lengths are making the use of either of the advancing systems more problematic, especially barrier separation distances, however the distributed barrier arrangement can usually rectify such issues For any unusual or apparently non-compliant circumstances, the mine should seek professional advice.

Hanging hooks and suspension systems

Two slightly different designs of hooks can be supplied, commonly referred to as short and long (Fig 5). The role of the hook is to securely hold the bag in place so the explosion pressure can shred the bag of dust. Testing has included both types of hook. Figure 1 also shows how the specially made bag shreds and frees its payload of dust, when subjected to pressure impulse testing. Figure 6 shows hooks recovered from test explosions and the remnants of the bag can still be seen fused onto the hook, demonstrating the hook has totally fulfilled its function.

Figure 5 SkillPro Short Hooks (left) and Long Hook (right)

Figure 6. Remnants of bag attached to hook post explosion

In mines with mesh against the roof, and limited roadway height, the short hook and short bag combination is generally favoured. The long hook can be more difficult to install when the mesh is tight against the roof, but is more adaptable on belts and other structures and may better suit some mines with loose mesh or other forms of support such as tensioned chains. The long bag is marginally easier to handle and secure the hook immediately post filling.

Experience shows some long hooks have failed due to continual abrasion between the hook and roof mesh in roadways with very high air velocity. The suppliers should be contacted if this appears to be a problem.

Hooks should be attached to fixings that run across the roadway so the hook can swing freely inbye and outbye. Hanging systems that unduly impede hook swinging, are unacceptable and this can be a challenge around belt structures etc. Ideally, the open part of the hook should face inbye, to lower the risk of it becoming dislodged when impacted by a pressure pulse which is assumed to originate inbye.

Testing has shown the minimum pressure at which bags rupture is may be related to the rigidity of the fixing system and all of the testing which generated the fundamental design guidelines, used rigid frames or other similar steel supports for the hooks, equivalent to mesh commonly found on the mine roof. In some cases, testing in very high roadways included suspension from tensioned cables. As such, this guideline recommends only rigid roof fixing systems such as mesh. In high workings where multiple layers of bags are needed, then a frame, taut cable or chain should be satisfactory for the lower layers, but the mine should seek advice if there is any doubt or concern.

Changes to the hook design, or adding additional straps, hangers etc. should not be undertaken without first contacting the suppliers or seeking professional advice.

Pre-filled bags

Pre-filled bags with appropriate hooks, are supplied to mines by specialist contractors. They can be supplied in palletised or pod mounted boxes, in some cases suitable for direct transport underground.

All prefilled bags sold in Australia and UK contain 6kg of dust mass unless special arrangements are made. Filling bags underground has historically been limited to South Africa due to the relatively low labor cost.

Figure 7 – Bulk Supply of pre-filled Bags

Neither the bag nor hook is ultra-violet (UV) protected and as such, should not be stored outdoors or exposed to sunlight except during filling operations. Boxes of pre-filled bags, covered with shrink-wrap plastic should not be left exposed including during transportation or storage, nor should they have additional loads placed on top of them i.e. top load only unless purpose made packing crates are used.

Filling of Bags

It should be noted that the bagged barrier system is in part, reliant upon the proper filling of the rockdust bags that together form an explosion barrier. The individual bags are intended to hold between 5 and 6 kg of rockdust, although the exact amount is not critical so long as due consideration is given to the exact mass, in calculating the final barrier design (See worked examples above). The bag and hook is not designed to hold more than 6kg.

All pre-filled bags sold in Australia contain 6kg unless special arrangements are made.

The horizontal line printed on the bag represents the approximate location of the hook locking ring and is a guide for those assembling them once filled.

Bag Closure

Once bags are filled with rockdust the hook is installed in the mouth of the bag and locked in place with the ring as shown in Figure 8(a) at about the position of the line on the bag. With both short and long bags, it is important that the excess plastic is folded over the outside of the lock ring, to prevent the bag pulling through the lock ring in an explosion, and also to prevent accidental water ingress (Figure 8(b)).

Figure 8(a) – Correctly fitted locking ring and position and (b) excess plastic folded over.

Broken or Defective Bags and Hooks

To preserve the integrity of the explosion barrier, the proportion of broken bags must not exceed 10% of the bags in any sub-barrier or in any 50m section of a continuous barrier. The proportion of broken bags must not be allowed to exceed this amount before steps are taken to replace them. This also applies to any additional bags hung under or around belts or other obstructions, as noted elsewhere in this guideline.

While in many situations, the life of the bagged barrier components may not be of significance, especially in an underground mine, it is expected that the component lives will be effectively indefinite. The safeguard against failing components in a barrier is regular inspection to ensure compliance with the 10% rule stated above.

Broken and/or defective hooks or bags should not be used and your supplier contacted

Re-Cycling Bagged Barrier Components

There is no research data to support or refute the re-use of apparently undamaged bags and/or hooks. SkillPro is aware that some mines cut bags to dump the dust and recycle some of the recovered hooks.

Auditing

SkillPro expect contract fillers of bags and mine end-users, to both have processes in place to ensure these guidelines are observed, and if they appear to have a non-compliant situation, to take steps to adequately assess, then manage, those risks. SkillPro and/or its distributors can assist with such circumstances.

Consumer Feedback

Comments on any aspect of this guideline should be submitted in writing to:-

The Managing Director

SkillPro Services Pty Ltd

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EMERALD QLD 4720

Australia Phone + (61) 7 4987 5999

Email: admin@skillpro.com.au

Appendix A Risk assessment

SkillPro bag barrier design risk assessment. To be expanded as needed by contract fillers, before going to mines				
Phase	**Problem, risk, Issue**	**Unwanted outcome**	**Current design controls**	**Additional controls needed by mine and/or contract fillers**
Filling	Under-filled	Inadequate dust density so the system does not work as intended in explosion	At 6kg, the dust is 135mm from the base of a bag that is 310mm wide, when the bag is suspended. Minor changes in bag width may occur The exact mass/bag is covered by SkillPro guidelines and worked examples of barrier designs in the guideline, are based on 6kg/bag	Mines need to order bags filled to the mass required by their design Contract fillers are expected to have an audited scheme to ensure bags are filled to 6kg, or between 5kg and 6kg, should the mine specially request any such value Bag filling mass and numbers are expected to be part of ongoing mine audits of major hazard management systems. Mine procedures should ensure any minor underfilling detected in service, is compensated for by hanging extra bags within the length of the barrier Contract bag fillers should ensure their staff are trained to visually detect gross non-conformance
	Over-filled	Minor economic loss only	The hook cannot be easily fitted in the marked location if it is drastically overfilled, so partially self- managed.	Contract bag fillers should ensure their staff are trained to visually detect gross non-conformance

			SkillPro guidelines deals with fill levels.	Bag fill level/weight is expected to be part of ongoing mine audits of major hazard management systems
	Non-conforming dust used	does not work as intended in explosion	All prior testing is with rockdust as used underground.	The mine/contract bag-fillers are expected to purchase dust that complies with the regulations of the Jurisdiction they are to be sold in. Mine purchasing systems should require proof of compliance with dust Standards. Correct dust usage/compliance is expected to be part of ongoing mine audits of major hazard management systems
	Bag or hook damaged in handling/packaging/freight/storage (The bags are deliberately fragile by special design of the plastic).	No impact on performance-Minor economic loss only	The load capacity of the hook is periodically tested by the suppliers. Hooks, rings and bags are all separately bulk packed and sealed in cardboard crates immediately upon production The dust packs into the bags and very minor bag damage does not always result in loss of all the dust.	It is expected that technicians filling bags quickly work out how to handle them to avoid damage and put in place any necessary procedures/equipment. As-received condition is expected to be part of ongoing mine audits of major hazard management systems. Contract fillers should ensure crates of pre-filled bags are "top-load" only Mines and contract fillers should ensure neither bags nor hooks, or filled units, are left

			Purpose made divided boxes can be supplied to hold/ship pre-filled bags, and reduce likelihood of transport damage.	exposed to sunlight (UV radiation) for any time except that essential for filling and/or handling operations
	Moisture/water gets into the dust or bag	1) Harder to fill 2) Does not work as intended in explosion	The bag is sealed against accidental water ingress provided the ring is correctly fitted and the top of the bag folded over it. The bag is made so that there is sufficient free material at the top to fold over the hook The ring on the hook is a tight fit to maximize sealing capability Wet dust will not flow easily through the hopper and into the bags.	It is expected that contract fillers will have a procedure to ensure bags are not filled with moist dust It is expected that contract fillers will have a procedure to ensure bags that are accidentally damaged (torn/penetrated) during filling are rejected and not supplied to mines It is expected that mines will have a procedure to ensure bags that are accidentally damaged (torn/penetrated) during hanging, or in-service are rejected and replaced Mine procedures should include a check for workers to visually identify significant moisture ingress by way of hard-caked dust and/or visible moisture beading inside the bag and take remedial action in conjunction with the suppliers and or/contract fillers and/or hanging crews Barrier/bag/dust condition is expected to be part of ongoing mine audits of major hazard management systems

	Wrong, different or sub-standard bag used	Explosion not quenched because the bag does not rupture and disperse the dust as intended	All bags sold by SkillPro have that name and company logs printed on them The installation designs and these guidelines are based are numerous large scale tests with these specific bags & hooks (note there are 2 sizes available and both have been large-scale tested in real coal dust explosions). SkillPro has a program and procedure to periodically re-test at large scale, a number of bags and hooks to confirm rupture conditions Test reports available to Mines Inspectorate & Customers on request. The plastic bags have very special anisotropic properties so they will rupture under credible explosion pressures SkillPro show contract fillers how to confirm the bags have intended properties SkillPro routinely subjects the plastic bags to impact tear testing and the results are linked to large scale testing	Contract fillers are expected to have a process to periodically check the bags have the intended properties Correct bag in use is expected to be part of ongoing mine audits of major hazard management systems

	Wrong, different or sub-standard hook	Explosion not quenched because the hook does not hold the bags or hold onto the mesh as intended	All hooks sold by SkillPro have that name printed on them and are specifically designed to retain the SkillPro bags until they shred and dislodge the dust, under explosion conditions The installation designs and these guidelines are based are numerous large scale tests with these specific bags & hooks (note there are 2 sizes available and both have been large-scale tested in real coal dust explosions). SkillPro has a program and procedure to periodically re-test at large scale, a number of bags and hooks to confirm rupture conditions Test reports available to Mines Inspectorate & Customers on request. SkillPro routinely subjects the hooks to static load tests as per SP-2016-001	Mines and/or contract fillers should ensure SkillPro bags and hooks are only used as "matched pairs" i.e. SkillPro bag with SkillPro hook and ring
	Hook wrongly placed post bag filling	May make hanging more difficult	There is an upper red line printed on the bags indicating hook placement to provide correct location with 6kg of dust in bag	Contract fillers are expected to have a process to check hook integrity as part of the packing process
	Hook locking ring not correctly secured post bag filling	Bag may slip out of hook when being handled or in an explosion.	The outer plastic ring on the hook is designed to have a positive lock when correctly fitted	Contract fillers are expected to have a process to check lock ring integrity as part of the packing process

		Minor economic loos to contract filler/mine	SkillPro instructs contract bag fillers on required processes	
Transport to mine & underground	Broken bags with dust falling out	Inadequate dust density so the system does not work as intended in explosion	The SkillPro guidelines have a small allowance for damage. SkillPro offers guidance to any mine buying product (via the retailer/bag filler if used)	Mines expected to use the SkillPro guidelines to design a compliant system Mine workers are expected to replace damaged bags/hooks on-job to maintain compliance with guidelines Barrier/bag condition is expected to be part of ongoing mine audits of major hazard management systems Mines are expected to train their staff in requirements and have multiple levels of technical management that should assess installations routinely.
	Accidentally encounter water once installed	Water gets into the dust and explosion not quenched because dust does not disperse as intended	The bags are effectively sealed using the locking ring as part of the purpose-made hook and should not uptake water unless deliberately hosed or submerged, or otherwise damaged	Barrier/bag condition is expected to be part of ongoing mine audits of major hazard systems. Mines should periodically take particular note of dust state in any installations associated with water coming from the roof

Installation	Inadequate number of bags hung	Inadequate dust density or layout so the system fails to work as intended in explosion	SkillPro guideless specify bag density for specific applications, all based on large-scale testing	Detailed Barrier design is expected to be part of ongoing mine audits of major hazard systems
	Excess bags hung	Economic loss only- Not a system problem	SkillPro Design guideless specify bag density for specific applications based on large-scale testing	Barrier/bag numbers are expected to be part of ongoing mine audits of major hazard management systems
	The hooks cannot easily be suspended from the roof line or around conveyors etc	Explosion not quenched because dust bags cannot burst as intended (note, quality suspension hook is critical to them working)	Two different hooks designs allow for use in most modern mine situations (refer to SkillPro for unusual situations including on or around belts---testing may be required) SkillPro guidelines suggest the hooks are optimally placed if they can swing inbye/outbye without jamming, so they should be placed on lines/mesh/rods etc running across the roadway, not longitudinally	Bag hanging arrangements are expected to be part of ongoing mine audits of major hazard management systems
	The barriers are wrongly placed	Explosion not quenched because dust bags cannot burst as intended (ie by pressure front ahead of flame front)	SkillPro Design guidelines specify barrier layouts and these should match Legislated requirements	Barrier location is expected to be part of ongoing mine audits of major hazard systems

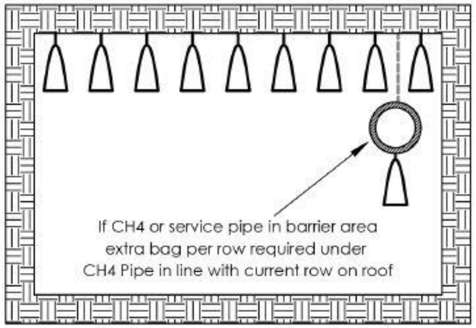
	Crates/boxes of filled bags are excessive mass for the work platform	Overturning or toppling of the work platform or associated machine	No controls offered by SkillPro	Mines buying cartons of pre-filled bags should work collaboratively with suppliers of filled bags to ensure all related mechanical risks are being appropriately considered and managed. Mines self-managing the bag filling operation should ensure all related mechanical risks are being appropriately considered and managed. It is expected that contract fillers note/advertise the gross mass of packages/crates they supply.
Operation	Bags fall down or are hit/damaged (Note, Bags not designed to be deliberately hit by passing machinery)	Inadequate dust density so the system does not work as intended in explosion	SkillPro guidelines require the mine to have some audit program to replace any damaged/missing bags. The SkillPro guidelines have an in-built safety factor of 10%, meaning up to 10% of the bags can be defective before the dust mass is inadequate for the application. SkillPro provide a short hook and short bag specifically for improving clearance.	Barrier/bag damage is expected to be part of ongoing mine audits of major hazard management systems
	Bags fall down due to premature hook failure (could be high	Personal injury Non-compliant installation	Hook testing is part of large-scale system testing (note, the design intent is the hook remains intact until the bag commences to	SkillPro guidelines require the mine to have some audit program to replace any damaged/missing bags/hook.

	ventilation speed causing swinging or vibration induced failure from belt structure)		shred under the influence of an explosion pressure pulse). SkillPro routinely subjects the hooks to static load tests as per SP-2016-001 SkillPro can investigate alternate hook designs on a case-by-case basis	Contract fillers are expected to have some scheme to periodically test samples of hooks using 20kg static load and report any deficiencies Abrasive wear can occur and needs to be part of ongoing mine inspections/ audits of system
	Sprayed by water		Refer filling	
	Insufficient bags/dust to prevent an explosion		A number of layouts have been designed based on full-scale explosion tests. Refer SkillPro installation guidelines.	Barrier design against guidelines is expected to be part of ongoing mine audits of major hazard management systems
	Barrier is penetrated by a fixed installation such as a conveyor	Explosion can pass through or around the conveyor	SkillPro guidelines refer to this	Barrier design against guidelines is expected to be part of ongoing mine audits of major hazard management systems
	Bags rubbed through by being hung too close to a conveyor	Inadequate dust density so the system does not work as intended in explosion	SkillPro guidelines require the mine to have some audit program to replace any damaged/missing bags.	Barrier design against guidelines is expected to be part of ongoing mine audits of major hazard management systems
	Static discharge from being placed in air-stream	Gas ignition by electrostatic discharge	The filled bags have been tested and assessed as not posing an electrostatic discharge hazard.	Mine Procedures should prohibit unfilled bags /hooks being stored underground

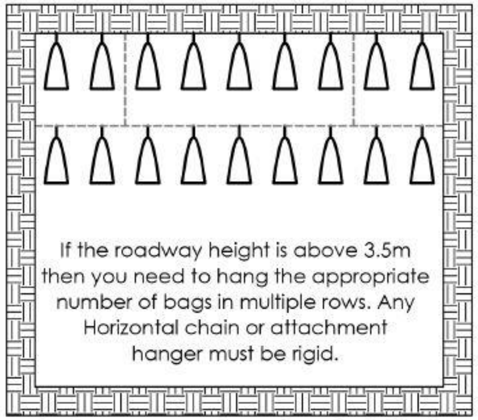
			IEC 613440-4-4-2005 as reported in DNMR report no. 08/367	Mine procedures control the absence of ignitable gas levels
	Incomplete protection as bags not correctly hung across the road	Inadequate dust density so the system does not work as intended in explosion	SkillPro guidelines cover the arrangements needed for most common scenarios	SkillPro guidelines advise the mine to have some audit program to ensure bags are hung as per guidelines SkillPro guidelines advise the mine to take special note of obstacles such as vent ducts, monorails, suspended belts etc.

Appendix B - Generic Drawings

Any of the following drawings can be supplied as JPEG or DWG files by SkillPro to assist customers create their own training program or work procedures.

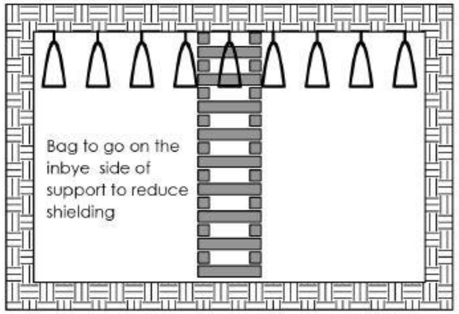


Typical arrangement for CH4 Pipe

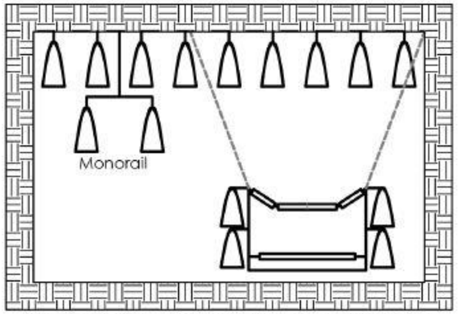


Typical arrangement roadway height >3.5m

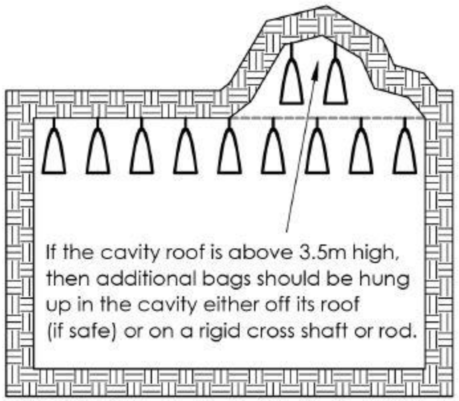
DRAWN	Z. Fleischmann	**SkillPro Services Pty Ltd**		
DATE	07/03/2017	TITLE	**Barrier Bag Guidlines**	
CHECKED	T. O'Beirne			
APPROVED	T. O'Beirne	SCALE N.T.S	DRAWING NO. 2017_002	A4



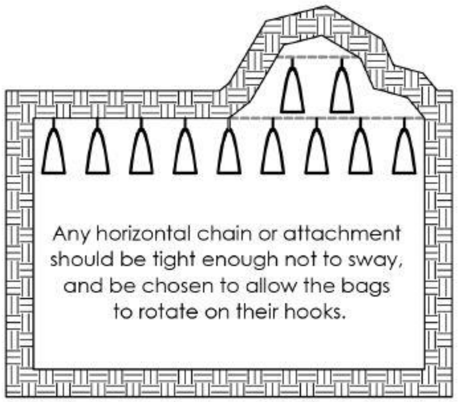
Typical arrangement around standing support



Typical arrangement for conveyors & monoroails

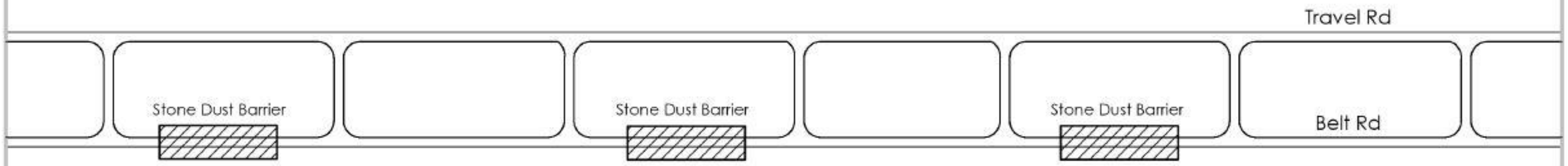


Typical arrangement for roof cavity

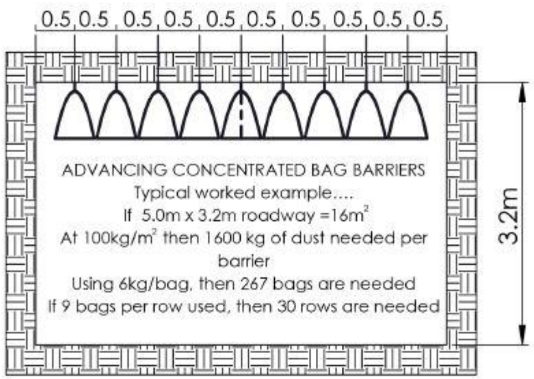


Alternative arrangement for roof cavity

DRAWN	Z. Fleischmann	**SkillPro Services Pty Ltd**			
DATE	06/03/2017	TITLE			
CHECKED	T. O'Beirne	**Barrier Bag Guidlines**			
APPROVED	T. O'Beirne	SCALE N.T.S	DRAWING NO. 2017_001	A4	



Example: Standard Roadway
(5m Wide x 3.2m High)
X-Section showing typical bag layout



ROADWAY HEIGHT / **ROADWAY WIDTH**

	3.0m	**3.1m**	**3.2m**	**3.3m**	**3.4m**
5.0m	250	259	267	275	284
5.1m	255	264	272	281	289
5.2m	260	269	278	286	295
5.3m	265	274	283	292	301
5.4m	270	279	288	297	306
5.5m	275	285	294	303	312

IMPORTANT NOTES FOR CONCENTRATED BARRIERS

- Concentrated barrier must be >20m <40m long
- Separation of barrier start to next barrier end, must be <120m
- Bag separation across the road >0.4m <1.0m
- Row separation along the road >1.0m <3.0m
- At least 2 completed barriers in place at any time
- Barrier and most inbye row in next barrier must be <120m
- Each barrier designed on 1kg/m2

Where not stated... Dimentions are in Metres

DRAWN	Z.FLEISCHMANN	**SkillPro Services Pty Ltd**	
DATE	28/02/2017	**TITLE** Typical Two Heading Long Wall Development Roadway - Concentrated Explosion Barriers	
CHECKED	T. O'Beirne		
APPROVED		**SCALE** N.T.S	**DRAWING NO.** 2017_003 A4

MANAGEMENT OF EXPLOSION RISKS IN UNDERGROUND COAL MINES WITH THE USE OF BAG BARRIERS

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Project Goals

- Based on recent coal dust explosion disasters that have taken 59 miners (Upper Big Branch, Darby No 1, Sago, Jim Walter No 5), questions arise as to whether additional explosion prevention strategies are necessary
- Bring together members of industry, research institutions, and regulatory agencies to discuss barrier systems
- Demonstrate the use of bag barrier systems that are currently used in other countries
- Identify potential issues and benefits for implementing bag barrier systems in the US
- Establish whether barrier system installation in US coal mines is the next step

Itinerary

10:00 – Welcome

10:15 – Presentation on Bag Barrier Systems

11:15 – Panel Discussion

11:45 – Lunch

12:30 – Facility Tour

1:00 – Exhibit of Simulated Barrier

Presentation Outline

- Explosion Mitigation Strategies
- Worldwide Comparisons
  - Coal Mine Design
  - Regulations
- Bag Barrier System
  - How It Works
  - Barrier Designs
  - Tests at Kloppersbos
- US Trials
  - Trial Installations in Two US Underground Coal Mines
  - Bag Barrier Moisture Study
- Conclusions

Explosion Mitigation Strategies

Four Sided Approach to Explosion Suppression

Explosion Mitigation Strategies

Four Sided Approach to Explosion Suppression

Removal of Coal Dust Accumulations

Explosion Mitigation Strategies

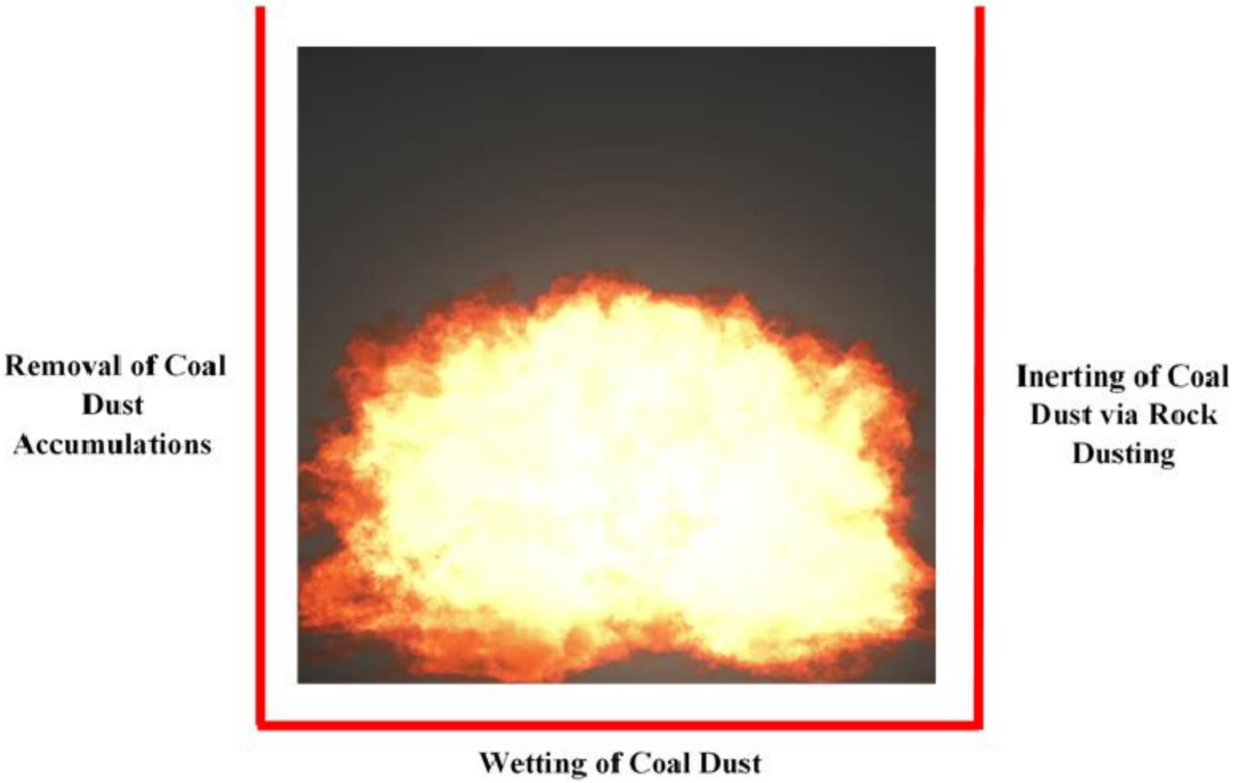
Four Sided Approach to Explosion Suppression

Removal of Coal Dust Accumulations

Wetting of Coal Dust

Explosion Mitigation Strategies

Four Sided Approach to Explosion Suppression



Explosion Mitigation Strategies

Four Sided Approach to Explosion Suppression

Install Explosion Activated Barriers

Removal of Coal Dust Accumulations

Inerting of Coal Dust via Rock Dusting

Wetting of Coal Dust

Other Coal Producing Countries Researched

- Countries Investigated
  - Australia, Canada, China, Germany, New Zealand, Poland, Republic of South Africa, Russia, United Kingdom, and more
- Countries that currently require barrier systems
  - Australia (New South Wales)
  - Republic of South Africa
  - United Kingdom
  - New Zealand
  - EU Nations

Main Differences in Foreign/U.S. Underground Coal Mines

- **Mining height**
  - U.S. Mines typically lower
- **Ventilation**
  - Bleeder type gob (goaf) ventilation not used in foreign mines
  - May require additional barrier installations
- **Most differences due to technical specifics of individual mines**
  - Can be carefully considered, organized, researched, accounted, and planned for with barrier design and placement
  - Similar process currently used in all foreign mines requiring barriers

Regulatory Comparisons Related to Rock Dust

- **Similarities**
  - Strategies for prevention/removal of coal dust accumulations
  - Strategies for wetting of coal dust
  - Rock dusting required to within 12 meters (approx. 40 feet) of face
  - Increasing rock dust due to high methane content

- **Differences**
  - U.S. CFR 30[1] does not require explosion barriers, others do
  - Location, design, approval, and regulatory oversight of explosion barriers
  - Varied rock dusting incombustible content requirements (65% - 80%)

Country	Total Incombustible Content	Regulates Barriers
United States	80%	No
Australia (NSW)	85%	Yes
Canada	65%-75%	No
Germany	80%	No
Republic of South Africa	80%	Yes
Russia	60%	No
United Kingdom	75%	Yes

How a Bag Barrier Works

- Coal dust explosions are generally caused by methane ignition, which causes coal dust to become airborne and propagate the explosion
- Explosion pressure wave travels faster than the flame front
- The pressure wave moves ahead of the flame front and ruptures the rock dust bags
- The rock dust is dispersed and inter-mixes with the airborne coal dust to make it inert
- The flame front is extinguished as it moves through due to higher incombustible content of the dust cloud

Rock Dust Bag and Hooks

How the Explosion Disperses Dust from Bags

- Static Pressure – pressure on the bag while it is hanging motionless
  - The bag plastic is designed to withstand the vertical force to support the static rock dust weight
- Dynamic Pressure – pressure that is applied rapidly and maintained for a period of time
  - The bag plastic is designed to tear open under horizontal dynamic pressure
- The bags are designed to rupture at 5 kpa (0.73 psi), but the length of time that the dynamic pressure is applied is important:

Brief Dynamic Pressure

Sustained Dynamic Pressure

Barrier Operation in a Tunnel

Tremonia test tunnel in Germany

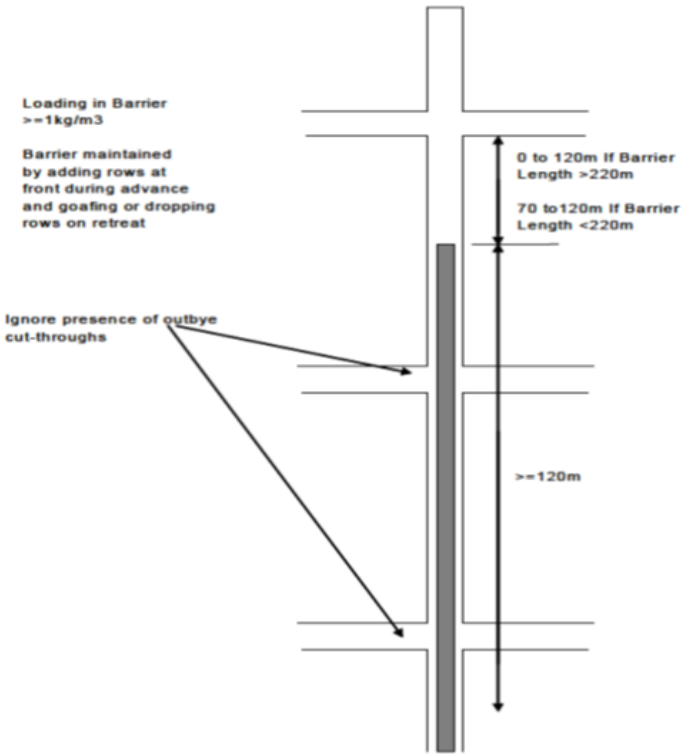
Comparison of General Guidelines for Bag Barrier Construction

General	UK	South Africa	Australia
Minimum Bag Contents (kg)	6	5 (Low Seams) 6 (High Seams)	N/A
Stonedust Amounts	1.2 (kg/m^3)	100kg/m^2 or 1kg/m^3 Whichever is Greater	≥200kg/m^2 within distance specs ≥400kg/m^2 outside specs
Bag Spacing	0.4 - 1.0	0.4 - 1.0	N/A
Bag Space to Rib	≤ 0.5	≤ 0.5	N/A
Row Spacing	1.5 - 3.0	1.5 - 3.0	$\frac{Stonedust\ mass\ in\ row}{cross\ section\ area}$
# of Layers (< 3.5m Height)	1	1	N/A
Spacing from Roof	≤ 0.5	≤ 0.5	
# of Layers (3.5-4.5m Height)	2	2	N/A
Spacing from Roof (Layer 1)	< 0.5	4m from Floor	
Spacing from Roof (Layer 2)	0.5 - 1.0	3m from Floor	
# of Layers (> 4.5m Height)	3	3	N/A
Spacing from Roof (Layer 1)	< 0.5	5m from Floor	
Spacing from Roof (Layer 2)	0.5 -1.0	4m from Floor	
Spacing from Roof (Layer 3)	1.0 - 1.5	3m from Floor	

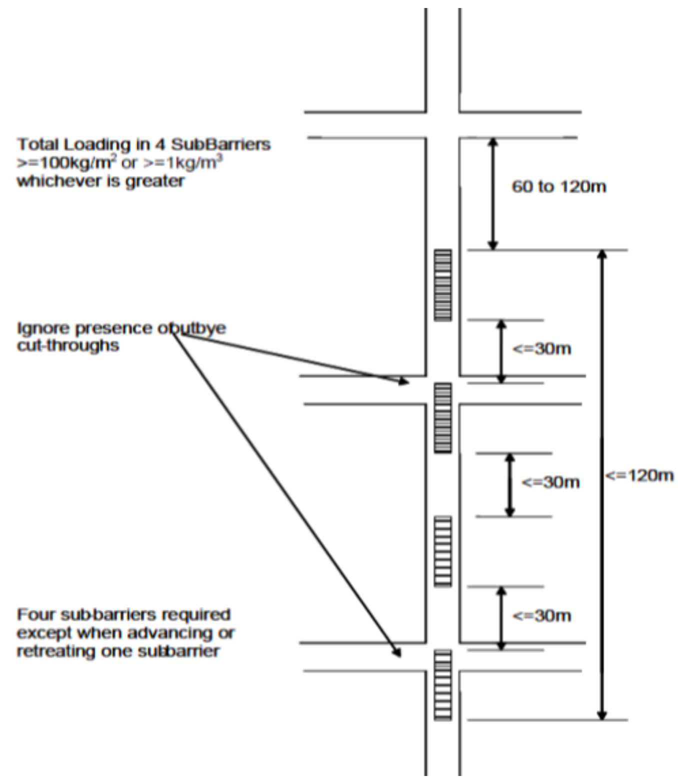
Distributed Barrier Designs

Distributed Barrier	UK	South Africa	Australia
Distance First Row to Working Face	70 - 120	N/A	< 100
Span of Distributed Barrier	360	N/A	N/A
Stonedust Density Required (kg/m^3)	1.2	N/A	See "General" Above
Distance to Conveyor belt feeder, bootend, trickle duster, Aux. Fan, Last through Road	N/A	N/A	< 30

Distributed Barrier Designs



Fixed Distributed Barrier [5]



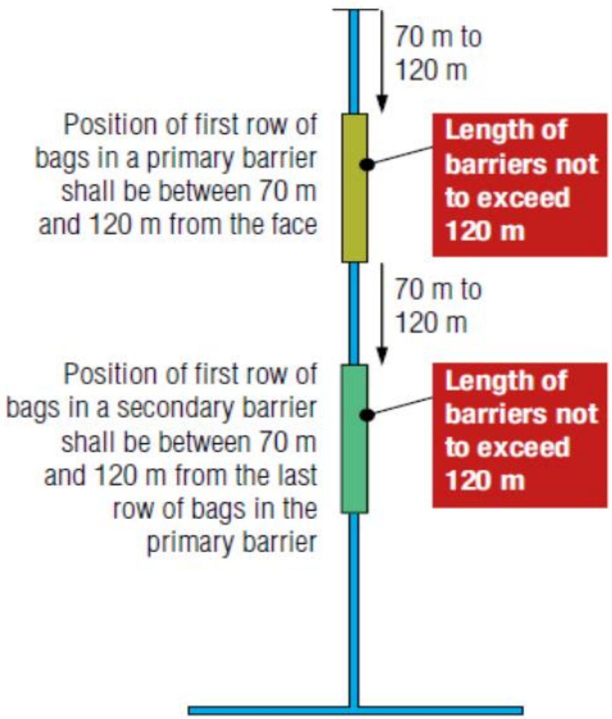
Distributed Barrier [5]

Primary/Secondary Barrier Design

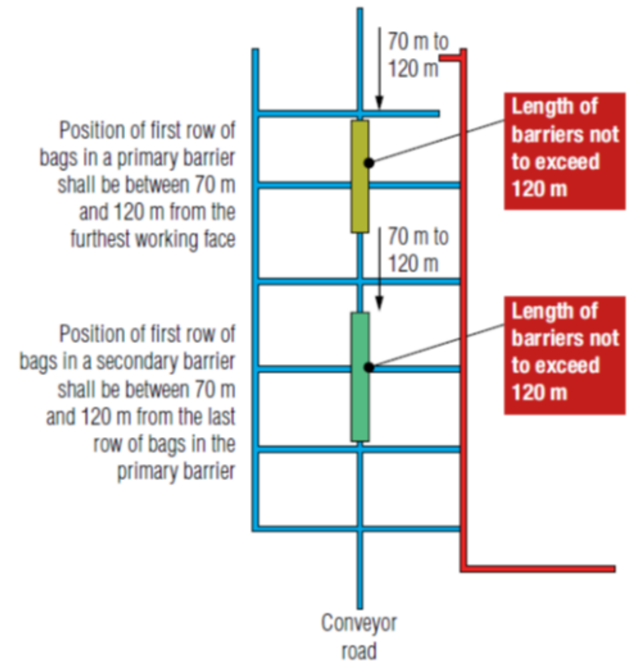
Primary Barrier	UK	South Africa	Australia
# of Sub barriers	4	4	N/A
Span of Primary Barrier	120	100 min	N/A
Distance 1st row to coal or heading face, or ignition source	70 -120	60 - 120 (from last through road)	60 - 200
Middle Sub Barriers	equidistant	equidistant	N/A
Distance Between 1st and 4th Sub Barriers	N/A	≤ 120	N/A
Max Distance Between Sub Barriers	N/A	30	N/A
Extra Sub Barrier Required for Advance or Retreat	Yes	No	N/A

Secondary Barrier	UK	South Africa	Australia
# of Sub barriers	2	N/A	N/A
Span of Secondary Barrier	120	N/A	N/A
Distance First Row to Last Row of Primary Barrier	70 -120	N/A	N/A
Extra Sub Barrier Required for Advance or Retreat	Yes	N/A	N/A
Stonedust Density Required (kg/m^3)	2.4	N/A	N/A

Primary/Secondary Barrier Design

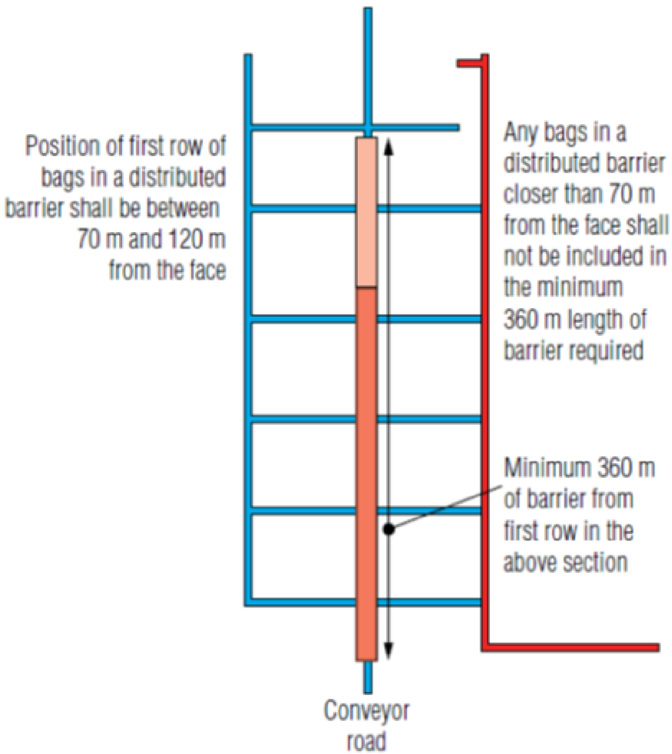


Coal Heading [2]

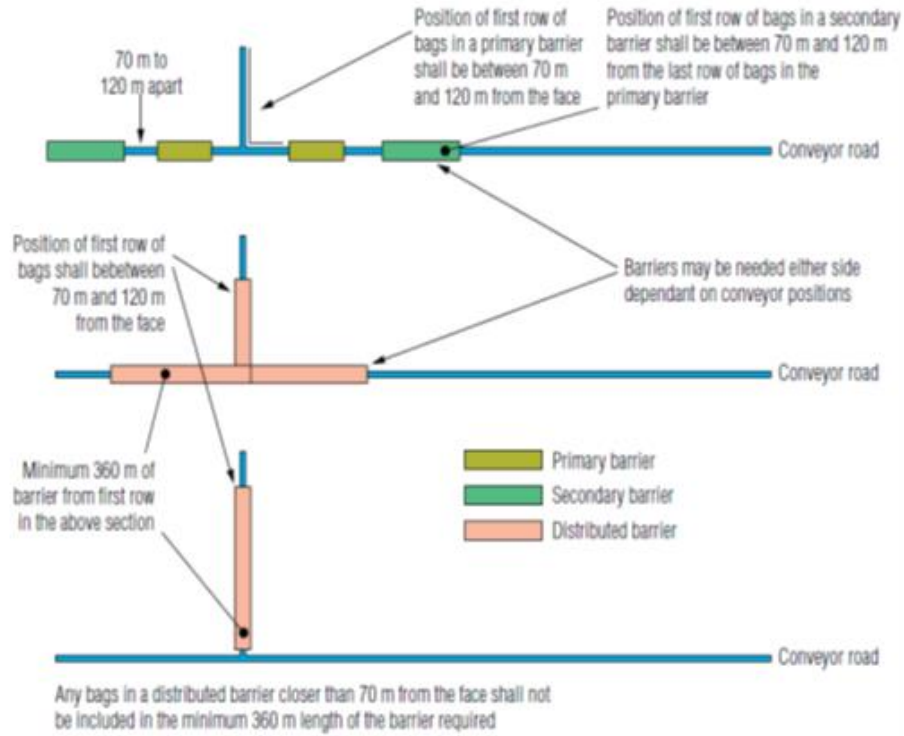


Room & Pillar [2]

Other Barrier Design Considerations



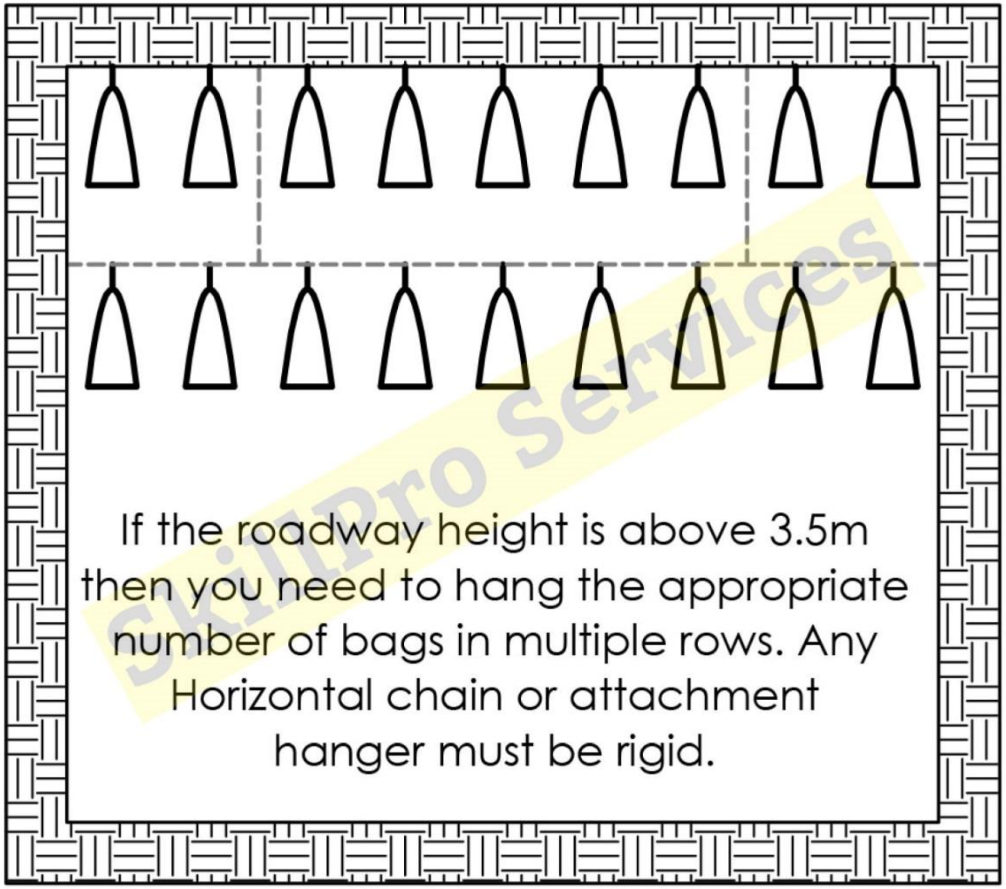
Distributed Barrier Design in Room & Pillar [2]



Typical Barrier Design when Intersection is Encountered [2]

Special Design Considerations

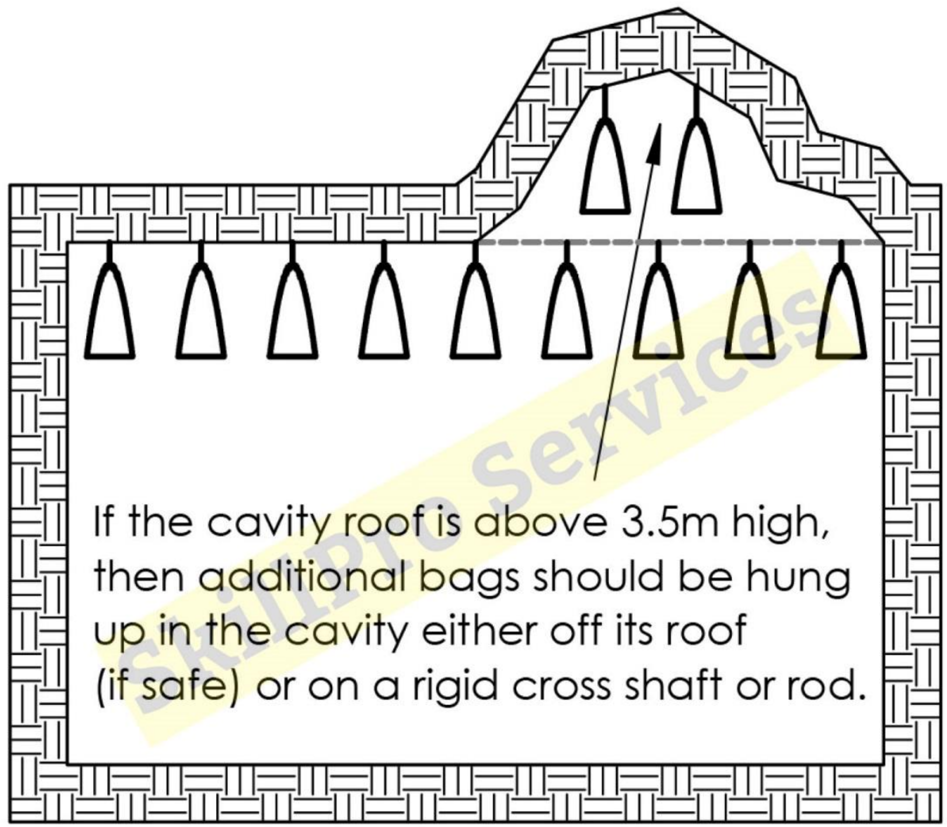
- **Tall Workings**



Typical arrangement roadway height >3.5m

Special Design Considerations

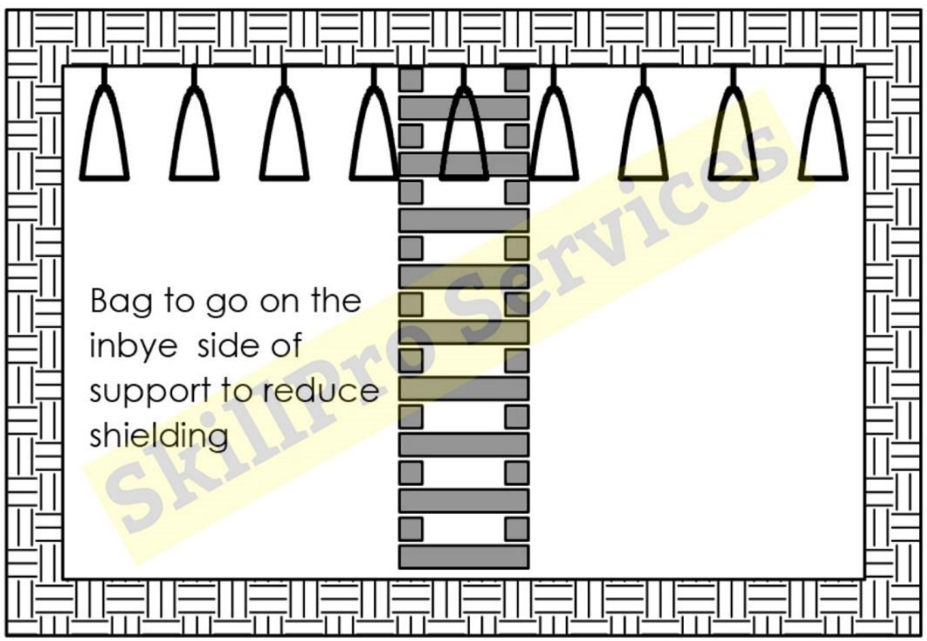
- **Roof Cavities**



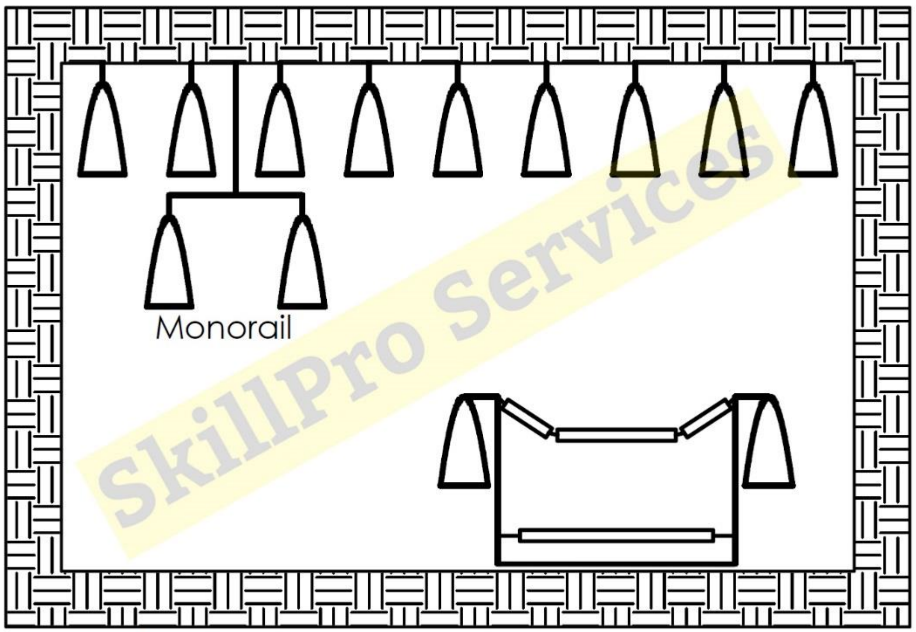
Typical arrangement for roof cavity

Special Design Considerations

- **Freestanding Obstacles**



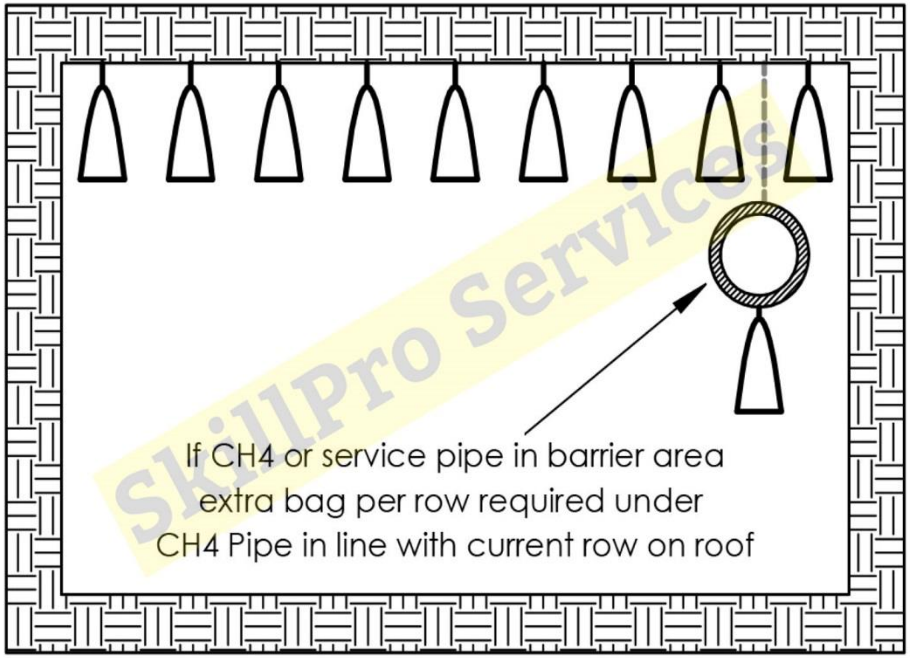
Typical arrangement around standing support



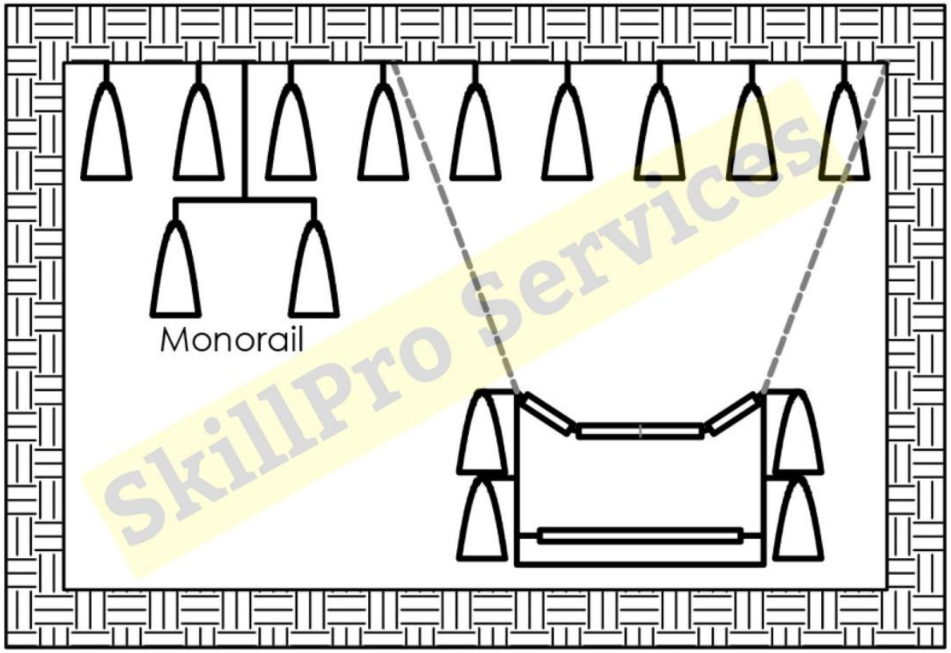
Typical arrangement for conveyors & monorails

Special Design Considerations

- **Suspended Obstacles**

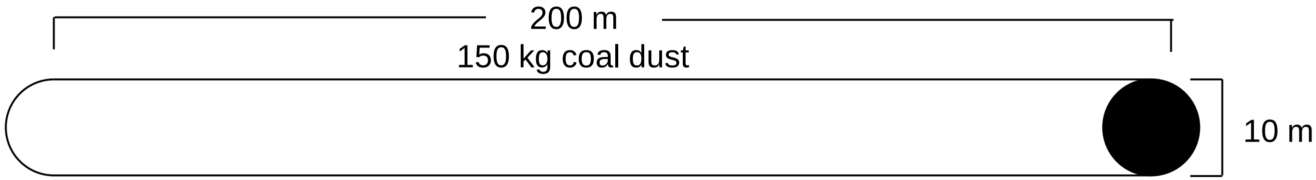


Typical arrangement for CH4 Pipe



Typical arrangement for conveyors & monoroails

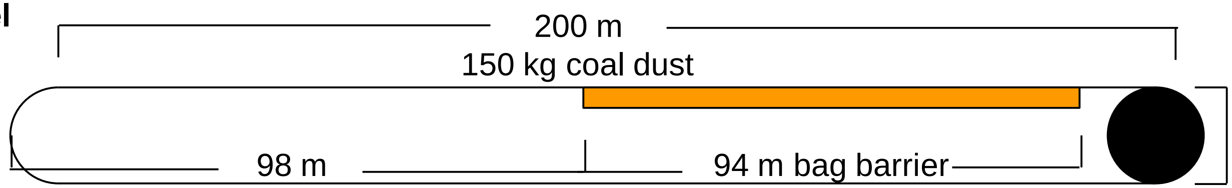
Coal Dust Explosion – No Barrier



Coal Dust Explosion – No Barrier

SkillPro

85 bags in the tunnel
- 510 kg
- Equivalent to 88% TIC in the yellow portion



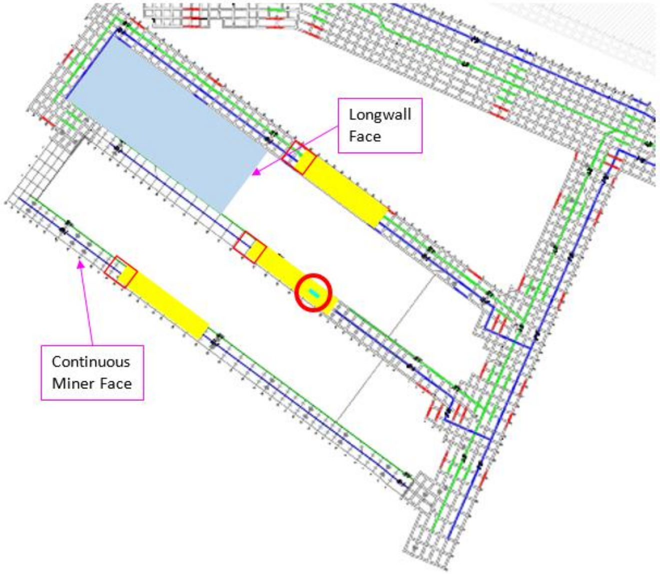
Bag Barrier Trials in U.S. Underground Coal Mines

- **5 Mine sites visited in different regions**
- **2 sites selected in Eastern U.S.**
- **Representative of multiple entry medium height coal mines**
- **Different roof support methods**
  - Roof mesh, bolts, straps, and plates
- **Different locations**
  - #2 (track) entry of 3 entry longwall section
  - #2 (power & piping) entry of 4 entry longwall section
- **Left in place for 5 weeks, returned for inspection and miner feedback**

Bag Barrier Trials in U.S. Underground Coal Mines

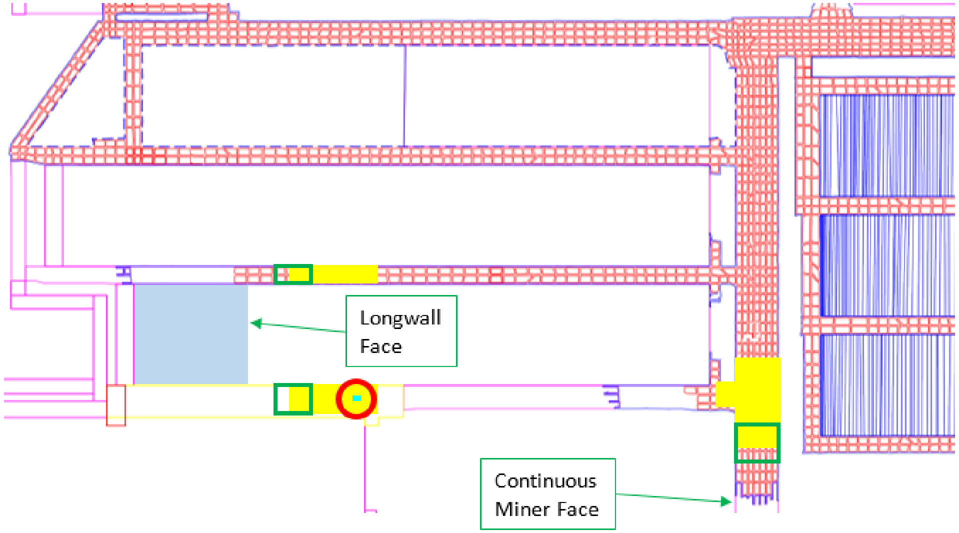
- **Mine 1: #2 (track) entry of 3 entry longwall section**
  - **No roof mesh, bags hung from bolt plates, straps etc.**
  - **6 bags per row across 19ft wide entry**





Bag Barrier Trials in U.S. Underground Coal Mines

- **Mine 2: #2 (power and piping) entry of 4 entry longwall section**
  - Bags hung from roof mesh
  - 6 bags per row across 19ft wide entry



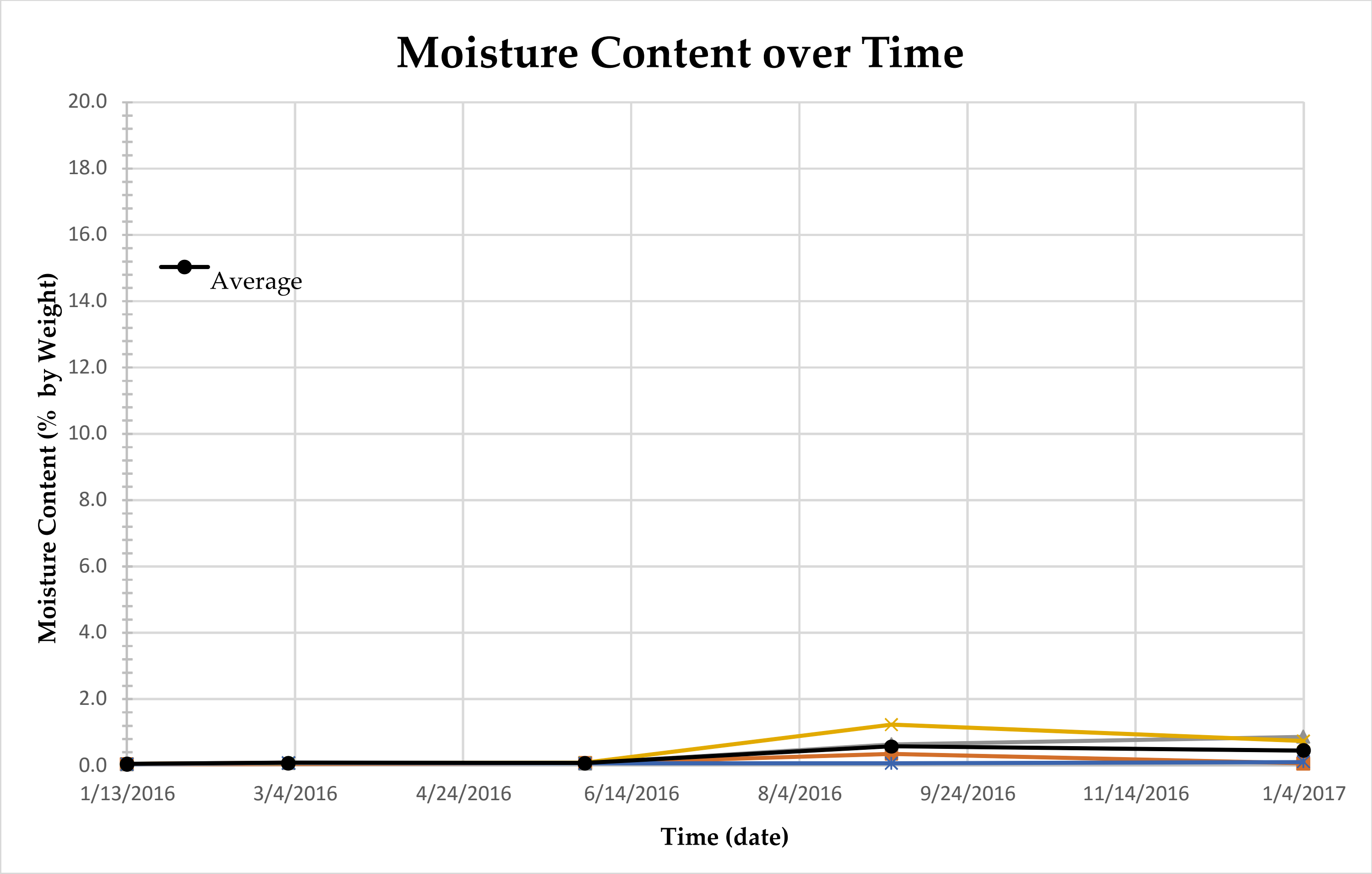
Feedback

On a scale of 1-5 where 1 is easy and 5 is difficult, mine employees rated barrier installation as 1.4.

Question	Response				
	Mine Employees		Video Survey		
	Yes	No	Yes	No	Not Sure
Are you familiar with any of the mine disasters that happened at the following mines: Upper Big Branch, Sago, Derby No. 1, or Jim Walters No. 5?	100%	0%	90%	10%	-
Are you familiar with methane/coal dust explosion risks associated with coal mining?	100%	0%	98%	2%	-
Do you think current methane/dust explosion prevention methods in the US are sufficient?	29%	71%	24%	41%	35%
Do you think more should be done to prevent/mitigate coal dust explosions?	100%	0%	82%	6%	12%
Before now, were you aware of the bag barrier system?	29%	71%	52%	15%	33%
Would you feel safer if you worked in a mine that used a bag barrier system?	86%	14%	86%	14%	-
Do you forsee any future problems with this system (safety, installation, maintenance, etc)?	57%	43%	63%	37%	-

Long Term Bag Moisture Intrusion Study

Long Term Bag Moisture Intrusion Study



Conclusions

- The US does not regulate a barrier system, whereas several other nations do
- Requirements for bag barriers around the world are similar
  - Mine design differences such as additional development and bleeder entries in the US means additional barrier bags would be required
  - All nations that regulate the use of barriers also require wide area rock dusting
- Shock tube tests at Kloppersbos demonstrate coal dust explosion suppression with bag barrier in place
  - Distributed barriers are the most common design currently in use
  - Considerations for cribs, belts, and other obstacles have been considered and guidelines are available
- Trial layouts were conducted in two US operating coal mines
  - Long bag hanging height was above all equipment
  - Carried out in areas with high equipment and foot traffic
  - Feedback from miners indicated a level of increased safety with a bag barrier in place

Panel Discussion

11:45 – Lunch
12:30 – Facility Tour
1:00 – Exhibit of Simulated Barrier

References

1. *ECFR — Code of Federal Regulations Title 30*. US Government Publishing Office, 31 Oct. 2016. Web. 02 Nov. 2016.
2. Health and Safety Executive. Bagged Stonedust Barriers. Tech. N.p.: United Kingdom, n.d. Print.
3. Health and Safety Executive. *The Prevention and Control of Fire and Explosion in Mines*. Tech. N.p.: United Kingdom, n.d. Print.
4. "Historical Data on Mine Disasters in the United States." *Mine Safety and Health Administration*. United States Department of Labor, n.d. Web. 2 Nov. 2016. <http://arlweb.msha.gov/mshainfo/factsheets/mshafct8.htm>.
5. SkillPro Services Pty Ltd. *Suggested Installation Guidelines for the SkillPro-CSIR Bagged Barriers in Underground Coal Mines*. Tech. N.p.: n.p., 2011. Print.

Full reference list available