Overview of NIOSH research on built-in-place refuge alternatives in underground coal mines

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Abstract

In a 2007 report to the U.S. Congress, the Office of Mine Safety and Health Research of the U.S. National Institute for Occupational Safety and Health (NIOSH OMSHR) stated that built-in-place refuge alternatives (BIP RAs) provide significant advantages over mobile refuge alternatives. At present, the requirement to locate refuge alternatives within 305 m (1,000 ft) of working faces makes BIP RAs impractical in most coal mines. BIP RAs would be practical if three issues are addressed: (1) allowing BIP RAs to be located at greater distances from the working face, (2) developing a reliable process for the design and approval of BIP RA stoppings that meet the 0.1-MPa (15-psi) design criteria, and (3) developing systems that reliably deliver breathable air to the refuge alternative. In 2015, NIOSH OMSHR conducted a study of these three issues and issued a report. In the report, justification was provided for allowing the placement of BIP RAs at greater distances from the working face than the currently mandated 305 m (1,000 ft), guidelines were developed that could be used by industry when submitting BIP RA stopping design applications for approval which are patterned after the Mine Safety and Health Administration guidelines for coal mine seal design applications, and insights were provided into options for providing a reliable supply of clean, breathable air to BIP RAs. This paper presents a summary of the study's findings and also addresses issues discovered during the building and designing of a BIP RA that OMSHR researchers constructed in NIOSH's Experimental Coal Mine in Pittsburgh to research the testing and improving of BIP RAs. These issues include several issues related to the delivery, distribution and exhaust of ventilation air to the BIP RA and some general construction issues that require further investigation.

Key words: Coal, Refuge alternatives, Built-in-place shelters

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Background

Three major coal mining disasters occurred in 2006. In all of these tragedies, miners survived the initial disaster but were unable either to escape or successfully isolate themselves from the poisonous gases present in the mine environment resulting from the disaster. These commonalities focused renewed attention on the subject of whether the availability of refuge alternatives (RAs) would have potentially saved the lives of these miners. Significant research has been conducted for decades on RAs as potential safe havens for miners while waiting for rescue crews to reach them in the event of an emergency (Maser, Kingery and Hoadley, 1975; McCoy, Berry and Mitchell, 1983; National Institute for Occupational Safety and Health, 2007a), but RAs have traditionally not been embraced by labor, industry or the government, with the primary focus being on methods and resources to help ensure

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successful escape rather than refuge.

In response to the 2006 mine disasters and the renewed interest in refuge alternatives, the U.S. Congress passed the Mine Improvement and New Emergency Response Act (MINER Act) of 2006, as Public Law 109-236. The MINER Act called for each underground coal mine operator to develop and adopt a written accident response plan to "provide for the maintenance of individuals trapped underground in the event that miners are not able to evacuate the mine." The MINER Act also charged the U.S. National Institute for Occupational Safety and Health's Office of Mine Safety and Health Research (NIOSH OMSHR) to "provide for the conduct of research, including field tests, concerning the utility, practicality, survivability, and cost of various refuge alternatives (RAs) in an underground coal mine environment." The term "refuge alternative" can be applied to either mobile chambers that are advanced as the mining face advances or to built-in-place refuge alternatives (BIP RAs) that are generally located permanently in outby areas of a mine.

In 2007, NIOSH OMSHR completed its initial mandated research into RAs and provided its findings in the form of a report to Congress (NIOSH, 2007b). In summary, this report found that RAs were practical for use in most underground coal mines to facilitate escape and to serve as a refuge of last resort, provided that mine operators develop comprehensive escape and rescue plans that incorporate RAs and training on their use. These findings applied to both mobile RAs and BIP RAs, with the BIP RAs emerging as generally being able to provide a superior environment if they could be provided with a reliable supply of clean, breathable air. This air could be provided from either a protected compressed air line or a borehole to surface. BIP RAs with a constant supply of breathable air offer numerous potential advantages over mobile RAs. These include minimizing or eliminating the need for purging, eliminating the need for carbon dioxide (CO_2) scrubbing, reducing thermal buildup issues, providing a higher likelihood of the communication system surviving a disaster, requiring fewer operating requirements, eliminating the 96-hour time clock for both refuged miners and rescuers, and because they are generally of significantly more volume they provide miners with an improved psychological and physiological environment, which can be greatly advantageous to their health and safety in the stress of an emergency.

Figure 1 — A built-in-place refuge alternative (BIP RA) in an outby location of a coal mine.

Figure 2 — Interior of a built-in-place refuge alternative (BIP RA).

Despite these advantages, BIP RAs cannot be moved frequently from a practical standpoint—with movement of the BIP RA location required to keep up with dynamic mining production—and as such it would be impossible to keep them within 305 m (1,000 ft) of the nearest working face, as prescribed in Title 30 Code of Federal Regulations, 30 CFR 75.1506(c) (Mine Safety and Health Administration, 2008a). Notwithstanding, OMSHR's 2007 report to Congress on refuge alternatives concluded that compared with mobile RAs, the strengths of BIP RAs "are so significant that consideration should be given to allowing extended distances, if in-place shelters are used to provide refuge for face workers" (NIOSH, 2007b). Figure 1 shows a BIP RA in an outby location of a mine while Fig. 2 shows the interior of a BIP RA.

Currently, there are approximately 20 approved BIP RAs in U.S. underground coal mines. However, all of these are located outby the face area and none are designed to be advanced with the working face. The use of BIP RAs that can be advanced with the working face will only be practical if three issues are addressed:

- Allowing BIP RAs to be located at greater distances from the working face.
- Developing a reliable process for the design and approval of BIP RA stoppings that meet the 0.1-MPa (15-psi) design criterion.
- Developing systems that reliably deliver breathable air to the BIP RA.

NIOSH OMSHR conducted a study related to these issues and issued a report on the study's findings in 2015 (Trackemas et al., 2015).

Summary of report findings

Distance from the face. To investigate the possibility of locating BIP RAs further from the face given the 120 minutes of breathing time provided by currently available self-contained self-rescuers (SCSRs), researchers developed three different approaches to determine how far from the face area miners could travel (Trackemas et al., 2015):

- *Approach 1* was based on mandated SCSR storage cache locations, and examined the Mine Safety and Health Administration (MSHA)-established crite-

Table 1 — Summary of allowable distances from RA to face based on mine entry height. (SCSR = self-contained self-rescuers, NIOSH = National Institute for Occupational Safety and Health, BOM = U.S. Bureau of Mines, BIP RA = built-in-place refuge alternative)

Entry height	Approach 1: Based on mandated SCSR storage cache locations	Approach 2: Based on worst-case SCSR usage times	Approach 3: Based on NIOSH and BOM-established travel times and escape probabilities	Maximum BIP RA distance from the face
<40 in.	2,200 ft	2,640 ft	NA	2,000 ft
>40 to <50 in.	3,300 ft	3,960 ft	NA	3,000 ft
>50 to <65 in.	4,400 ft	5,280 ft	6,000 ft	4,000 ft
>65 in.	5,700 ft	6,480 ft	6,500 to 7,000 ft	5,000 ft

ria for distances between SCSR storage caches as a method of determining acceptable distances from the face area for BIP RA locations.

- *Approach 2* was based on worst-case SCSR usage times, with researchers performing a timeline study of an assumed worst-case scenario for miners involved in a disaster, beginning with the time they first don their initial SCSR and including the times it would take to travel on the face area, assemble as a group, make decisions, perform a switchover to a new SCSR if needed, and activate and enter the BIP RA.
- *Approach 3* was based on established travel times and escape probabilities determined from research by NIOSH and the former U.S. Bureau of Mines, including research from 2011 (Harteis et al., 2011) involving travel in high coal where actual miners traveled in airways filled with dense smoke without lifelines, and research from 1990 (Kovac, Vaught and Brnich, 1990) that considered the probability of making a successful mine escape in high coal with a single SCSR.

Based on approaches 1 and 2, it was determined that the worst-case travel time required for non-escapeway travel activities would be 30 minutes. This 30-minute timeline included times for donning the initial SCSR, traveling to the assembly location on the face and deciding on a course of action, switching over to the second SCSR, and preparing and entering the RA. Maximum times were assigned to each of these actions. A detailed statistical analysis along with MSHA-established values of realistic travel distances to SCSRs in emergency situations were used to establish this travel time. In a worst-case scenario, miners would use 30 of their 120 minutes of SCSR time for non-escapeway travel activities, thus leaving 90 minutes for travel time from the face to the BIP RA.

Based on approach 3, which uses established travel times and escape probabilities from published research, and choosing the most conservative estimates of travel times needed, 90-minute travel distances were calculated in smoke-filled escapeways based on entry height. These worst-case scenarios combined three pieces of information: (1) the regulations in 30 CFR 75.1714-4(c)(2)(ii) for 30-minute travel distances in various entry heights (MSHA, 2015), (2) the fact that smoke-filled airways reduce travel times, and (3) the above-outlined discussion that escaping miners should have 90 minutes of SCSR breathing time available for travel from the face to a BIP RA. The resulting evidence clearly justifies the argument that BIP RAs can be located further from the face, and that greater maximum distances of the BIP RA from the face can be recommended in parallel with greater entry heights.

Table 1 presents a summary of these findings based on entry height. The maximum BIP RA distances were determined by rounding down the most conservative distances arrived at in the analysis.

Allowing mines to locate BIP RAs at distances of 610 m (2,000 ft) or more from the working face introduces a number of advantages: (1) a higher likelihood of the BIP RA avoiding damage from both primary and secondary explosions that occur at the face area, which also increases the likelihood that the communication system to the BIP RA survives a disaster, (2) a reduction in the number of BIP RA moves necessary, resulting in a lower likelihood of damage to the RA structure, air systems and communication systems, and (3) the introduction of a wider variety of BIP RA designs, which could improve the safety as well as the psychological and physiological comfort and mental well-being of confined miners.

Process for the design and approval of BIP RA stoppings. To address the issue of BIP RA stopping design and approval, NIOSH researchers analyzed the criteria that engineers should consider when submitting BIP RA stopping designs for approval under the requirements of MSHA's Refuge Alternatives for Underground Coal Mines Design (MSHA, 2008a). Using the MSHA coal mine seal design application guidelines (MSHA, 2008b) as a model, guidelines were developed for BIP RA stopping design applications as well as specifications for an example BIP RA stopping design (Trackemas et al., 2015) that could be used by industry when submitting stopping design applications for approval by MSHA.

The report (Trackemas et al., 2015) provided an example of a BIP RA stopping design consisting of a conventional rebar-reinforced, 30-cm (12-in.)-thick concrete wall that can withstand a 0.1-MPa (15-psi) explosion pressure. The complete design calculation for this example is included in the 2015 report. This design was presented to illustrate the application of the proposed design guidelines in preparing a design submittal to MSHA district managers for approval. Significantly different BIP RA stopping/door systems have already been approved for use by MSHA, and we believe that if BIP RAs become more commonly used in U.S. coal mines, then many more acceptable and economically viable stopping/door designs that meet the 0.1-MPa (15-psi) blast pressure criteria will be developed.

The design example presented was developed by adapting recognized protective structure design principles provided in the Unified Facilities Criteria UFC3-340-02: Structures to Resist the Effects of Accidental Explosions (U.S. Department of Defense, 2008). The design method follows three general stages: (1) design inputs, where the design load and material properties are specified, (2) foundation design, where an anchorage system for the stopping structure is designed, and (3) structure design, where the stopping structure itself is designed. In all cases, the design pressure-time curve is 0.1 MPa (15 psi) with 0.1s rise time, 0.1 s fall time and 0.2 s duration. The equivalent static design pressure is 0.1 MPa (15 psi), and the design remains in the linear elastic range under the design pressure. The entry dimensions for this example design are width of 6 m (20 ft) and height of 2.4 m (8 ft). The design example follows conservative protective design principles used by the military.

This 30-cm (12-in.)-thick concrete wall design is reinforced using #5 bar steel rebar with diameter of 1.6 cm (5/8 in.) located vertically and horizontally on 30-cm (12-in.) centers on both sides of the BIP RA stopping wall. Shear reinforcement consists of #4 bar stirrups with diameter of 1.3 cm (1/2 in.) at each intersection of vertical and horizontal reinforcement bars. The BIP RA stopping wall is anchored to the surrounding rock with #5 bar rock bolt anchors with diameter of 1.6 cm (5/8 in.) spaced every 0.5 m (1.5 ft) around the BIP RA stopping perimeter. The 1.5-m (5-ft)-long anchors have 0.9 m (3 ft) grouted into the surrounding rock and 0.6 m (2 ft) embedded in the BIP RA stopping structure. The total number of rock bolt anchors required is 40. The yield strength for reinforcement steel is 414 MPa (60,000 psi). The compressive strength of the concrete is 21 MPa (3,000 psi). Figure 3 shows this rebar-reinforced concrete BIP RA stopping design.

Development of reliable breathable air supplies. To explore the third critical issue of delivering a reliable supply of clean, breathable air to a BIP RA, NIOSH researchers considered existing available technologies for accomplishing this purpose. These included systems that deliver air to the BIP RA either through a borehole to the surface or a protected compressed air line.

To inform these approaches and gather relevant data for analysis, NIOSH researchers visited a number of underground coal mines to view BIP RAs and discuss with mine officials why they were used, gathering extensive information on their construction, location, capacity, air supply and provisioning. Several coal mines in Colorado, Kentucky, Montana and New Mexico were visited, with specific mines selected to obtain a cross section of the industry including high and low coal, and eastern, central and western coal mines. A summary of the findings of this effort is included in the Trackemas et al. (2015) report.

As noted previously, most of the advantages of a BIP RA disappear if the BIP RA is not guaranteed a constant and highly reliable supply of clean, breathable air. A borehole from the surface directly into the BIP RA is the most advantageous and reliable approach because it guarantees communication with refuged miners and can be used to provide occupants with additional food and water as well as needed medications. However, a borehole from the surface to the BIP RA is often impractical due to such factors as drilling costs and surface rights issues. Instead, using a protected compressed air line carrying clean, breathable air to a BIP RA is emerging as a potential practical and achievable goal. One such system already has MSHA approval. The Hubble Breathable Air Units, models HBA75, HBA 100 and HBA 250, have been approved by MSHA under Approval No. 07-LCA110001 (MSHA, 2011) for use in providing breathable air to a BIP RA through a protected compressed air line. These units deliver a continuous supply of breathable air to the BIP RA through a two-in pipeline that is either buried along the rib in soft floor or anchored along the rib and covered with waste material for hard floor. However, in-mine evaluation of this system has been very limited, especially in terms of its ability to survive a 0.1-MPa (15-psi) blast pressure. It is anticipated that other systems will be developed if BIP RA designs are advanced with the working face of coal mines. We believe that a constant supply of clean, breathable air can be provided to BIP RAs either from a borehole to the surface or through a protected compressed air line system. Several efforts to develop and test such systems are already being undertaken by private companies.

Other design issues associated with BIP RAs. As part of its ongoing research to test and improve BIP RAs, OMSHR researchers constructed a BIP RA in NIOSH's Experimental Coal Mine in Pittsburgh, PA (Fig. 4). In the building and designing of this BIP RA, several issues were discovered related to the delivery, distribution and exhaust of ventilation

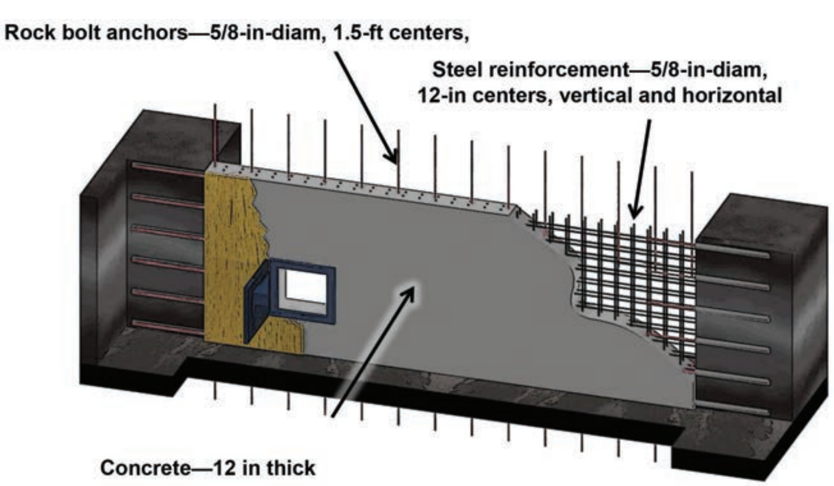

Figure 3 — Design example for a 15-psi built-in-place refuge alternative (BIP RA) stopping using conventional rebar-reinforced concrete.

air to the BIP RA along with some general construction issues that require further investigation:

Ventilation of BIP RAs in nonemergency day-to-day operation. BIP RAs need to be ventilated in normal day-to-day mining operations to protect against the buildup of explosive methane concentrations. At the same time, it is desirable to ensure the BIP RA does not fill up with potentially high contaminant concentrations in the event of a mine disaster, primarily an explosion that could produce high carbon monoxide (CO) levels in the mine ambient air. Coal mines around the United States that use BIP RAs are currently employing different methods for conducting this day-to-day ventilation in addition to conducting the required preshift fire-bossing of each BIP RA.

Some mines that use outby BIP RAs and operate with mine-wide blowing (positive pressure) ventilation systems are simply leaving the doors to a BIP RA open and using the BIP RA boreholes to act as exhaust vents for air out of the mine. In this way, mine ventilation air is pulled into the BIP RA through the door or doors, ventilates the BIP RA and is then exhausted up and out of the borehole. Those mines that have had this approach approved have had to demonstrate they could quickly ventilate the BIP RA to acceptable contaminant levels once the BIP RA doors were closed. Mines that do not have the BIP RA ventilation system—blower or compressed air system—permanently located at the borehole surface but that have to transport the ventilation system some distance to the borehole could have problems reducing contaminant levels in the BIP RA to safe levels in acceptable time frames.

Mines that have outby BIP RAs using mine-wide exhausting (negative pressure) ventilation systems are also leaving the doors open and allowing the mine ventilation system to pull fresh air down the borehole inside the BIP RA. Fresh air travels down the borehole, ventilates the BIP RA and is then exhausted (pulled) out the door of the BIP RA into the main ventilation system of the mine. However, in the event of a mine explosion that produces high CO levels and has an impact on the mine ventilation system, unacceptable CO levels could result in the BIP RA and would need to be quickly cleared by the BIP RA ventilation system. Properly designed relief valves could be used to exhaust the air from the BIP RA in day-to-day operation and allow the BIP RA door to remain closed, thereby preventing contaminant entry in the event of a mine explosion.

Another option is to have a permanent blower or fan attached to the BIP RA borehole on the surface and to use this system to constantly push air down the borehole into the BIP RA. Air from the borehole would ventilate the BIP RA and leave either through an open door or through relief valves in the stopping walls. For mines using postive-pressure blowing ventilation systems, the borehole flow would have to be at an adequate pressure to overcome the mine ventilation pressure. One mine that uses BIP RAs plans to have two boreholes in each BIP RA with a small blower on one that will create a ventilation flow into and out of the BIP RA, with one borehole as an intake and the other as an exhaust.

There is uncertainty as to the amount of contaminants, primarily CO, that could enter a BIP RA following an explosion in the mine using an open door for day-to-day ventilation. Equally important is the need to determine how quickly and efficiently the CO could be reduced to acceptable levels once the primary BIP RA ventilation system is established to provide air down the borehole or through a protected compressed air line.

Figure 4 — The built-in-place refuge alternative (BIP RA) in in the Pittsburgh Experimental Coal Mine.

Ventilation of BIP RAs in emergency operations. In the event of a mine emergency where miners start occupying the BIP RA, fresh air is provided to the BIP RA either through a borehole to the surface or through a protected compressed air line. The air introduced into the BIP RA creates a positive air pressure in the room, and this pressure opens relief valves that release air from the room at a rate equal to the flow rate entering the room. The equilibrium air pressure established in the room is determined by the relief pressure of the relief valve or valves. Regardless of the air supply source, 30 CFR 7.506(a) (MSHA, 2008a) mandates that a minimum air flow rate of 0.4 m^3/min (12.5 cfm) of breathable air is required for each RA occupant. A BIP RA designed to handle a maximum of 30 miners would need an available air supply of no less than 11 m^3/min (375 cfm). However, in many cases simply providing the minimum air flow requirement of 0.4 m^3/min (12.5 cfm) will not be adequate due to the potential need to purge the BIP RA of CO immediately following an explosion or the need to provide adequate air flow to maintain a safe and comfortable environment throughout the BIP RA occupation. Accordingly, BIP RA ventilation systems must be designed to provide enough air supply to dilute any possible CO concentrations to safe levels in a timely manner regardless of the number of miners in the BIP RA. Some mines that have BIP RAs are using airlocks immediately inside of the BIP RA entrance to help minimize the amount of contaminant entering the BIP RA with miner entry. If the BIP RA ventilation system is established prior to miner entry, then it will be easier to purge the smaller airlock of contaminant than to purge the entire BIP RA. If the ventilation system is not established prior to miner entry, the smaller volume of the airlock may help minimize the amount of contaminant miners introduce into the BIP RA during entry.

In addition to providing the mandated quantity of breathable air, the air must be able to effectively ventilate the entire BIP RA volume. This requires the design of an effective air distribution system from the point where the air enters the BIP RA to the point where it exits the BIP RA through a relief valve or valves in the BIP RA stopping wall. There are several general ventilation guidelines that should be applied to ensure the available ventilation air is distributed as uniformly as possible throughout the BIP RA:

- If the ventilation air enters the BIP RA in the corner of one end of the BIP RA, it should exit through a relief valve or valves in the corner at the other end of the BIP RA so that it is forced to sweep the entire space. Short-circuiting of the ventilation air from its entry point to a relief valve or valves nearby should be avoided.
- At the point where the ventilation air enters the BIP RA it should be designed to distribute in a uniform manner. Air coming from a borehole could be more evenly distributed by means of a deflector plate directly in line with the borehole flow. Another option would be for the borehole flow to be tied to a duct system that carries the flow to different areas of the BIP RA. Air from a compressed air line in the BIP RA could be distributed throughout the BIP RA by means of a manifold system.
- If the ventilation air enters the BIP RA at a high elevation, it should be designed to exit the BIP RA through a relief valve or valves located at a lower elevation in the BIP RA stopping or vice versa. The ideal situation would be for the air to enter at a low elevation and exhaust at a higher elevation, thus making use of the buoyancy effects of the heat generated by miners who will generally be near the floor.
- The use of multiple relief valves at different locations can assist ventilation air distribution depending on the overall system design, but there may be cases where a single relief valve may be advantageous.

BIP RA ventilation relief valve design. Relief valves are a critical part of both BIP and mobile RAs. Any air supply used to ventilate or purge refuge chambers or airlocks must exhaust into the mine in a controlled manner and prevent contaminated air from entering the airlock or chamber during a mine disaster. The MSHA specification for relief valves in 30 CFR 7.506(c) (1) (MSHA, 2008a) is 1.2 kPa (0.18 psi) or less, or as specified by the manufacturer. BIP RAs may have one or more relief valves in the BIP RA stopping wall or walls. There are several aspects to relief valves that are critical to the successful operation of a BIP RA in the event of a mine disaster. Primary among these are:

- The relief valve must operate at a pressure that meets the MSHA specification listed above, but steps must be taken to ensure that the relief pressure at which it operates does not create a problematic pressure on the BIP RA door, as discussed in the following section on stopping/door design issues.
- The relief valve may be required to operate in an open condition to allow flow out of the BIP RA during the day-to-day operation of the mine in order to create a constant ventilation flow through the BIP RA, while having the ability in the event of a mine disaster to operate effectively once the BIP RA ventilation system starts to provide ventilation air.
- The relief valve must be properly designed to handle the maximum air flow that will be provided to the BIP RA when it is occupied by miners without providing excessive backpressure to the air delivery system.
- The relief valve must be designed to survive a 0.1-MPa (15-psi) blast pressure and remain operational.

NIOSH researchers have been testing various relief valves typically used in BIP RAs and mobile RAs as well as off-the-shelf products including a polyvinyl chloride (PVC) check valve and a cast iron/brass butterfly check valve. Field visits to mines had revealed the use of PVC check valves in BIP RAs. One commercially available BIP RA relief valve was also tested. The testing consisted of measuring relief pressures while maintaining adequate flow through a 10- to 13-cm (4- to 5-in.) duct. Further testing is planned to determine if the check valves can survive the 0.1-MPa (15-psi) blast pressure, or if modifications are required.

Stopping/door design issues. The Trackemas et al. (2015) BIP RA report provided thorough details on the design and approval of BIP RA stopping/door systems in terms of structural design criteria, foundation design, location, leakage and quality control. However, some issues specific to the doors used in BIP RA stoppings emerged in the construction of the BIP RA in the Pittsburgh Experimental Coal Mine:

- Steps must be taken to ensure that the door will not be exposed to excessive pressure once the ventilation air supply to the BIP RA is established. The 30 CFR 7.506(c)(1) regulation (MSHA, 2008a) requires that fans or compressors "provide positive pressure and an automatic means to assure that the pressure is relieved at 0.18 psi, or as specified by the manufacturer, above mine atmospheric pressure in the refuge alternative." A BIP RA door that is 0.9 m (3 ft) wide and 1.2 m (4 ft) high and is subjected to 5.5 kPa (0.18 psi) of pressure would have 1.4 kN (311 pound force) of force acting on the door, calculated by 3 ft × 4 ft × 144 in^2/ft^2 × 0.18 pounds/in^2. This pressure could result in difficulty operating the door latch mechanism. For an inswing door, the miner opening the door would have a difficult time opening it, and for an outswing door, the door could open very rapidly when the latch is released, possibly causing injury.
- All components of the door, including frame, door, hinges, latch, seals and the system for anchoring the door to the BIP RA stopping, must meet the requirement to survive a 0.1-MPa (15-psi) blast pressure. Any door system designed for use in a BIP RA must have a complete set of calculations showing that it meets the pressure-time curve requirements and remains linear elastic, or in the case of a commercially available door, it must meet ASTM F2247-11 Standard Test Method for Metal Doors Used in Blast Resistant Applications (Equivalent Static Load Method) (ASTM International, 2011). While regulations (MSHA, 2008a) require the physical testing of mobile RAs for 2018 approval, this is not the case for BIP RAs. A mine must submit a design that is certified as meeting the 0.1-MPa (15-psi) criterion over 0.2 s from a reputable structural design engineering firm to a district manager who has authority to give approval. However, in most cases, the district manager then submits the design to MSHA Tech Support for its review. No physical testing is required. However, physical testing of stopping/door systems, where possible, would provide an increased degree of safety.
- The seal material around the perimeter of the door and/or on the door frame must be able to withstand both heat and moisture over extended periods of time without degradation. Fire endurance properties must, at a minimum, be consistent with the criteria codified

in 30 CFR 75.333(D) (MSHA, 2015) for the design of mine ventilation controls.

- The door latch system must be easy to operate, while still being capable of creating a tight seal around the door perimeter.

Summary

The 2007 NIOSH OMSHR report to the U.S. Congress on refuge alternatives concluded that BIP RAs offer substantial advantages over mobile RAs. However, the use of BIP RAs that can be advanced with the working face will only be practical if three issues can be addressed:

1. Allowing BIP RAs to be located at greater distances from the working face.
2. Developing a reliable process for the design and approval of BIP RA stoppings that meet the 0.1-MPa (15-psi) design criteria.
3. Developing systems that reliably deliver breathable air to the BIP RA.

NIOSH OMSHR conducted a significant study of these issues and issued a report on the findings (Trackemas et al., 2015). In this report, NIOSH OMSHR provided justification for allowing the placement of BIP RAs at greater distances from the working face than the currently mandated 305 m (1,000 ft). Using the MSHA guidelines for coal mine seal design applications as a model, NIOSH OMSHR developed guidelines that could be used by industry when submitting stopping design applications for approval by MSHA, and provided insight into options for providing a reliable supply of clean, breathable air to BIP RAs.

As part of ongoing research to test and improve BIP RAs, OMSHR researchers constructed a BIP RA in NIOSH's Experimental Coal Mine in Pittsburgh. In building and designing the BIP RA, several issues emerged that were related to the delivery, distribution and exhaust of ventilation air to the BIP RA along with some general construction issues that require further investigation to ensure the safe and efficient operation of BIP RAs. NIOSH researchers are currently undertaking research to address these issues.

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