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SUBJECT: Assessing Coal Burst Hazards in Deep Cover Underground Coal Mines

Scope
This Program Information Bulletin (PIB) applies to operators of underground bituminous coal mines, miners’ representatives, Mine Safety and Health Administration (MSHA) enforcement personnel, and other interested parties.

Purpose
The purpose of this PIB is to provide information on factors that can be used to assess the risk of coal bursts occurring in underground mines, particularly those deep cover mines operating at depths exceeding 1,000 feet. This PIB also provides information operators can use to conduct a risk assessment to identify the potential for coal bursts. In addition, this PIB provides information on control techniques that are available to mitigate the burst risk. Where appropriate, MSHA will consider coal burst risk assessments, including mitigation strategies, when evaluating roof control plans.

Information
Coal bursts involve the sudden, violent ejection of coal or rock into the mine workings. They are almost always accompanied by a loud noise, like an explosion, and ground vibration. Bursts are a particular hazard for miners because they typically occur without warning. Despite decades of research, the sources and mechanics of bursts are not well understood, and therefore are difficult to predict and control. Experience has shown, however, that certain risk factors are associated with an increased likelihood of a coal burst. In addition, some control techniques are effective in reducing the likelihood of coal bursts or protecting miners from their effects. A coal burst risk assessment consists of evaluating the degree to which these risk factors are present and identifying control measures that can be implemented to mitigate the risk.

Because of their complicated nature, burst risk assessments should be conducted by experienced ground control professionals. Site-specific assessments should be
conducted at deep cover mines as mining conditions or experience warrant, but at least on an annual basis.

**Factors contributing to the risk of coal bursts**

The universal characteristic of burst prone environments is the presence of highly stressed coal. The overburden depth is responsible for the overall level of stress, but pillar design or multiple seam interactions can concentrate stresses in distinct locations. Geology is also important. Strong roof and floor are characteristic of most, but not all, burst prone environments. Geologic features including sandstone channels, faults, and seam dips have also been associated with coal bursts. Certain mining layouts and practices also increase the burst risk, as does a past history of bursts. Each of these factors is discussed in more detail below.

**Depth of cover:** Very few bursts have occurred at depths less than 1000 feet, although there were two incidents during pillar recovery under 750 feet of cover during the early 1980’s. Experience shows that the burst risk increases with depth.

**Pillar design:** Pillars become highly stressed when they are too small to properly distribute the loads that they carry, but too large to yield. Barrier pillars are particularly important in room and pillar mining because they protect each new panel from the abutment loads arising from previously mined areas. In longwall mining, two-entry yield pillar layouts have been effective in reducing the hazard of pillar bursts, but they can result in higher stresses near the tailgate corner of the longwall face.

**Multiple seam interactions:** The severity of a multiple seam stress concentration typically depends on two factors:

- The thickness of the interburden between the active seam and the previously-mined seams. In general, the thicker the interburden, the less likely that the interaction will result in a severe stress concentration.
- The type of remnant structure present in the previous seam. Isolated remnants, with worked out areas on two or more sides, are the most hazardous.

Remnant structures are typically created when coal is left in place adjacent to areas of full extraction. However, bursts have occurred above and beneath large remnants adjacent to smaller developed pillars that transferred much of their load to the larger pillar.

Interactions between all previously mined seams should be considered in the assessment. Mine workings in several seams may overlap, creating very high stress zones, particularly if the interburdens separating the older workings from the active seam are thin.
Empirical or numerical computer models should be a part of a thorough burst risk assessment. Models such as the Analysis of Multiple Seam Stability (AMSS) or LaModel can identify potentially high stress zones due to multiple seam mining. However, these programs are designed to prevent pillar squeezes or roof instability, and may require special adjustments for burst risk evaluation. Specialized analysis techniques, such as Energy Release Rate (ERR), may be useful in some applications.

Accurate identification of remnant structures requires reliable maps of older workings. The burst risk assessment should also include an evaluation of the adequacy of the available maps. If mapping detail does not exist or is incomplete, then consider the likelihood of encountering unexpected remnants.

Not all multiple seam mining increases the risk of coal bursts. The risk can actually be reduced when mining is conducted in de-stressed ground above or below an area that has been mined out.

**Geology:** Strong sandstone or siltstone roof and floor have been associated with coal bursts, particularly in the eastern US and in Utah. In evaluating whether the roof or floor geology may contribute to the burst risk, it is important to consider:

- The thickness of the strong sandstone or siltstone unit. Thicker units are more likely to be associated with bursts.
- The distance between the strong unit and the coal seam. Strong units close to the seam pose the greatest risk of coal bursts.
- The strength of the rock. Surrounding rock units associated with coal bursts typically have uniaxial compressive strengths of at least 10,000 pounds per square inch (psi) but can exceed 15,000 psi.
- The characteristics of the rock. Massive units with minimal bedding, jointing, or other discontinuities are more likely to be associated with coal bursts.

While there is no proven definition of burst-prone geology, the following are two examples developed from experience in different regions:

- A 15-foot thick unit of strong sandstone in the first 30 feet above the mining horizon, or a 6-foot thick unit of strong sandstone within the first 15 feet of the floor.
- A massive sandstone unit at least 5 feet thick is found within 4.25 feet above the coal seam.

Core logs, combined with rock mechanics testing, may be used to identify when burst-prone geology might be present. However, since surface core holes are generally
spaced too far apart to identify all zones of burst prone ground, supplemental underground test holes may be necessary.

*Sandstone channels* may simply be a special case of the strong sandstone described above. Because sandstone channels may be limited in extent, they may be particularly difficult to identify in widely spaced surface boreholes.

*Faults or joint systems* have been associated with increased burst risk. When mining approaches a highly-stressed fault or joint system, the ground may suddenly shift, releasing seismic energy that results in a burst. Faults or joints may also partition the overburden, resulting in an unexpected concentration of overburden load.

The presence of steep *seam dips* has been observed at a number of burst sites, and rapid changes in the depth of cover due to steep topography have also been associated with bursts.

*Coal strength* is one factor that does not seem to play a significant role in the burst risk. Bursts have occurred in at least 25 different U.S. coalbeds, varying from strong, blocky seams to the very friable Pocahontas No. 3 and No. 4 seams. Laboratory studies have also shown that most bituminous coals can be made to burst if they are highly stressed and the confinement is suddenly released.

*Mining layouts and practices*: Historically, more than 80% of bursts have been reported during retreat mining, with less than 20% occurring on development. *Retreat mining* increases the likelihood of bursts because it concentrates abutment loads on the pillar line, gate pillars, or longwall face, and caving overburden releases seismic energy as it breaks. Of the two widely used retreat mining methods, pillar recovery is significantly more burst prone than longwall mining.

*Wider panels* are a factor that increases the burst risk during pillar recovery. A wider panel results in a greater front abutment load, and mobilizes more overburden. ERR modeling indicates that the risk may increase in proportion to the square of the panel width.

Certain pillar recovery practices can increase the burst risk. In particular, many bursts have occurred during *barrier pillar extraction*, a practice that was once wide-spread but is now seldom employed. *Pillar splitting*, during which coal is mined from the most highly stressed part of the pillar core, has been another high risk procedure. MSHA Handbook PH13-V-4, “Roof Control Plan Approval and Review Procedures,” (MSHA Roof Control Handbook) states that “at depths exceeding 1,000 feet, pillar splitting should not be conducted on the pillar line.” Mining in *pillar points*, where pillars are surrounded on two or more sides by extracted pillars, also adds to the risk of bursts.
Pillar points can be created when the center pillars in a row are mined last, as occurs with some cut sequences used with continuous haulage.

A past history of bursts: Major bursts have often been preceded by smaller ones. These precursors have occurred at the same stage in the mining process as the subsequent large event (i.e., in the same pillar in the row and pillar lift). Also, once a mine has experienced bursts, future mining operations with similar geology and mining methods should also be considered high risk.

Conducting the risk assessment

Based on the evaluation of the burst risk factors listed above, an overall risk level can be assigned to future mining areas. For example, those areas with negligible burst risk might be considered green zones, areas with slightly higher risk could be yellow zones, and the areas of greatest risk might be orange zones.

The initial risk assessment should be conducted before an area is developed, using available borehole logs and maps of previous mining in overlying and underlying seams. During development, underground test hole drilling may be employed to provide more detailed information on the geologic conditions. Underground mapping should be conducted prior to any retreat mining (see Appendix H of MSHA’s Roof Control Handbook). The mapping should attempt to use rib conditions to identify the locations of significant multiple seam interactions. At each step, as new data becomes available, burst potential zones should be re-evaluated and updated.

The matrices shown in the Attachment may be used to assist with the risk assessment. Each of the significant known risk factors can be rated as low, moderate, or high. Note that it is the level of the factor that is being rated, not the burst risk associated with it. While all the factors should be considered when assessing overall burst risk, there is no standard method for combining the individual factor ratings into an overall burst risk rating. The matrix is intended as a generic guide that can be tailored for each site-specific burst assessment. The assessment should clearly state the assumptions made in the process, including any ratings and weightings of individual factors, and the procedure used to estimate the overall burst risk. An experienced ground control professional can use the matrix to evaluate the overall burst risk.

Control techniques that can reduce the risk of coal bursts

Once zones at elevated risk of bursts are identified, appropriate control techniques should be used within each zone. The most effective way to reduce a risk is to eliminate the hazard. In the context of burst control, this would be achieved by not mining in the areas of greatest risk.
Where avoidance is not possible, mining may be limited to development only. For example, within a pillar recovery panel, a few pillars or rows of pillars might be left in place beneath a remnant structure that was considered to be at an orange level of risk.

**Pillar design** is the primary engineering control for minimizing the risk of pillar failures and coal bursts during retreat mining under deep cover. Engineered barrier pillars that isolate each new panel from the abutment loads arising from previously mined ones are a critical design element for pillar recovery. In longwall mines, inter-panel barriers have successfully reduced the burst risk under the deepest cover (greater than 2,000 feet). Appendix E of MSHA’s Roof Control Handbook provides guidance on the use of NIOSH software for pillar design. Other aspects of pillar design are discussed in Appendices D, F, and G.

**Keeping panels narrow** is another design technique that can reduce the burst risk during pillar recovery. The extraction front also may be narrowed by leaving pillars in place.

Several operational techniques may be used to reduce the burst risk during the process of pillar extraction:

- **Narrow lifts:** The risk of extracting highly stressed coal is reduced by taking lifts that are just one-half the width of the continuous mining machine cutting head, and the remaining pillar is given more time to yield and redistribute the load.

- **Avoid mining directly into the core of a highly stressed pillar:** Start pillar recovery at the most inby portion of the pillar and progressively work in the outby direction.

- **Don’t “close out” in the center of the panel:** When continuous haulage is used to recover pillars, the most convenient cut sequence closes out in the belt entry in the center of the panel. This cut sequence should not be used in burst prone ground because it creates a highly stressed “pillar point.” Instead, the pillars should be extracted in sequence from left-to-right or right-to-left.

Some mines have employed bump cuts that are taken from pillars that are one or even two rows outby the pillar line. Only thin, yielded fenders are left to be recovered on the pillar line as the pillar recovery progresses. The technique was judged to be successful in controlling bursts, but was difficult to implement because it required mining operations to be sequenced over two or three rows of pillars at a time.

Operational techniques used by longwall mines include reducing the depth of the web, reducing the speed of the shearer, unidirectional cutting, and avoiding double cuts at the gate ends.
Underground observations and monitoring are critical components of a burst risk management program. Mining crews should be trained to observe coal burst warning signs, particularly the occurrence of small bursts, which are often the best indication that an area is becoming more burst prone. A record-keeping system should be maintained, and management processes developed to ensure that warning signs receive appropriate responses.

Background
During the years 2012-2014, serious coal bursts occurred at three different room and pillar mines. These events resulted in three fatalities and two permanently disabling injuries. In all three instances, the bursts occurred during pillar recovery at depths exceeding 1,000 feet. None of these three mines had previously reported a burst. Coal bursts also occurred at three longwall mines during this same time period.

In its 2010 report to Congress on coal pillar recovery under deep cover, NIOSH recommended that “deep cover room-and-pillar retreat coal mines conduct regular burst hazard assessments for any areas where retreat mining is proposed and the depth of cover exceeds 1,000 ft.” ¹ This recommendation was subsequently accepted by MSHA.²

Authority
The Federal Mine Safety and Health Act of 1977, as amended, 30 USC § 801 et seq., and 30 CFR §§ 75.202, 75.203, 75.220, and 75.223.

Internet Availability
This information bulletin may be viewed on the Internet by accessing MSHA's homepage at http://www.MSHA.gov under MSHA's Major Laws, Regulations and Policies select Compliance Information (PIBs, PILs, the PPM and More) and then select Program Information Bulletins.

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Distribution
MSHA Program Policy Manual Holders
Underground Coal Mine Operators
Coal Special Interest Groups
Miners' Representatives
Table 1. Coal Burst Risk Analysis Matrix for Pillar Recovery

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Level of Factor</th>
<th>Level of Factor</th>
<th>Level of Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td><strong>Depth of Cover</strong></td>
<td>&lt;1200 feet (365 m)</td>
<td>1200 – 1500 feet (365 – 450 m)</td>
<td>&gt;1500 feet (450 m)</td>
</tr>
<tr>
<td><strong>Pillar Design</strong></td>
<td>Meets NIOSH or other criteria, including barrier pillars</td>
<td>Does not meet NIOSH or other criteria</td>
<td></td>
</tr>
<tr>
<td><strong>Multiple Seam Interaction</strong></td>
<td>Stress shadow or AMSS Condition = “Green”</td>
<td>AMSS Condition = “Yellow”</td>
<td>Inadequate maps or remnant surrounded by gob (AMSS Condition = “Red”)</td>
</tr>
<tr>
<td><strong>Roof Condition</strong></td>
<td>Weak shale or similar, no massive strata within 50 feet</td>
<td>Typical Western U.S. or Central Appalachian stratigraphy</td>
<td>Strong, thick, and massive strata near the seam</td>
</tr>
<tr>
<td><strong>Floor Condition</strong></td>
<td>Claystone or similar, no massive strata within 50 feet</td>
<td>Typical Western U.S. or Central Appalachian stratigraphy</td>
<td>Strong, thick, and massive strata near the seam</td>
</tr>
<tr>
<td><strong>Other Geologic Factors</strong></td>
<td></td>
<td></td>
<td>Sandstone channels, faults or fracture zones, seam dips, rapid topographic changes</td>
</tr>
<tr>
<td><strong>Pillar Recovery Method</strong></td>
<td>Development Only, or Partial Pillar Recovery</td>
<td>Typical Christmas Tree or Outside Lift Pillar Recovery</td>
<td>Closing in center (continuous haulage), barrier pillar extraction, split-and-fender pillar recovery</td>
</tr>
<tr>
<td><strong>Panel Width</strong></td>
<td>&lt;350 feet (110 m)</td>
<td>350 – 500 feet (110 – 150 m)</td>
<td>&gt;500 feet (150 m)</td>
</tr>
<tr>
<td><strong>Past History of Bursts</strong></td>
<td>No burst history in the seam</td>
<td>Burst history in the seam</td>
<td>Burst history in the mine</td>
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Table 2. Coal Burst Risk Analysis Matrix for Longwall Mining

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<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of Cover</td>
<td>&lt;1200 feet (365 m)</td>
<td>1200 – 2000 feet (365 – 600 m)</td>
<td>&gt;2000 feet (600 m)</td>
</tr>
<tr>
<td>Pillar Design</td>
<td>Development only, meets NIOSH or other criteria</td>
<td>Longwall mines should use yield, abutment-yield, or interpanel barrier pillars as appropriate for depth and geology</td>
<td></td>
</tr>
<tr>
<td>Multiple Seam Interaction</td>
<td>AMSS Condition = “Green”</td>
<td>AMSS Condition = “Yellow”</td>
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