DEVELOPMENT MINING NEAR CHARTED OIL AND GAS WELLS

TECHNICAL SUPPORT WHITE PAPER

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ABSTRACT

Title 30 Code of Federal Regulations (30 CFR) 75.1700, requires coal mine operators to take reasonable measures to locate oil and gas wells penetrating coalbeds or any underground area of a coal mine. Mine operators must establish and maintain a coal barrier of at least 300 feet in diameter (150-foot setback distance) around these wells unless they obtain approval from the District Manager for a lesser setback distance. This standard also allows the District Manager to require a greater barrier based on the depth of the mine, other geologic conditions, or other factors.

Historically, the primary technical document addressing interactions between gas wells and mining in the United States has been the "Pennsylvania Joint Oil and Gas Well Gas Well Pillar Study" published in 1957 (1957 Study). Many MSHA Districts and state regulatory agencies have incorporated at least some aspects of the 1957 Study into their processes for granting approval to mine within 150 feet of a gas well. Although the 1957 Study was primarily concerned with pillar recovery, the mining industry now commonly uses it to establish setback distances during development mining where no retreat mining is taking place. Various adaptations of the guidelines have led to varying applications of the 1957 Study's recommendations. Moreover, mining methods have changed significantly during the past 60 years, and many mines now operate at greater depths and under more complex geologic conditions than mines in the past. For these reasons, the 1957 Study may not be appropriate in all cases to establish an appropriate setback distance from oil and gas wells for development mining.

This report examines relevant theory, experience, and past practices relating to development mining near gas or oil wells. This study also involved review of accident reports involving well interceptions, records of citations involving violations of 30 CFR 75.1700, and downhole well surveys. It provides technical considerations for decisions regarding safe setback distances for development mining throughout the United States' coalfields. The study's scope is limited to active or inactive (i.e. non-producing, abandoned or inadequately plugged) wells with known surface locations.

BACKGROUND

30 CFR 75.1700 states:

> **Oil and gas wells**: Each operator of a coal mine shall take reasonable measures to locate oil and gas wells penetrating coalbeds or any underground area of a coal mine. When located, such operator shall establish and maintain barriers around such oil and gas wells in accordance with State laws and regulations, except that such barriers shall not be less than 300 feet in diameter, unless the Secretary or his authorized representative permits a lesser barrier consistent with the applicable State laws and regulations where such lesser barrier will be adequate to protect against hazards from such wells to the miners in such mine, or unless the Secretary or his authorized representative requires a greater barrier where the depth of the mine, other geologic conditions, or other factors warrant such a greater barrier.

The standard is based on a statutory provision originally contained in the Federal Coal Mine Health and Safety Act of 1969[1]. One purpose of 30 CFR 75.1700 is to prevent mine development from inadvertently intersecting oil and gas wells. If the mine operator knows a well's surface location, the likelihood of an underground mine unintentionally intersecting it depends on the cumulative result of three kinds of errors: well deviation, surveying errors, and mining errors.

Many sources use different terms to describe the lateral distance from a well to mine workings. The term "setback distance" in this report refers to the distance between a well and the closest point of development mining (i.e., the rib-to-well distance). The term "barrier distance" is the distance between a well and the nearest full-extraction mining. This report only addresses development mining and does not include recommendations for barrier distances.

APPROVALS, CITATIONS, AND ACCIDENTS ASSOCIATED WITH MINING NEAR GAS WELLS

To assess the current nationwide practices for establishing oil and gas well protective pillars, Technical Support requested information from all MSHA Mine Safety and Health Enforcement Districts with responsibility for underground coal mines. Every District responded with information regarding the establishment of setback distances. Technical Support also reviewed the accident records and citations pertaining to oil and gas wells.

Pursuant to §75.1700, mine operators usually submit requests to the District Manager when they intend to conduct development mining within 150 feet of a well. However in some states, such as West Virginia, Mine Safety and Health Enforcement Districts receive requests when mining is planned within 200 feet of a well, since this is the minimum barrier that state regulations require. Of the nearly 1,000 requests that MSHA receives annually, approximately 40 percent are from the Northern Appalachian coalfields, and another 40 percent are from the Illinois Basin (Appendix A).

Guidelines for protective pillar approvals vary by District, depending in large part on state regulations and guidelines. For example, in some Districts the mine operator may be required to perform downhole deviation surveys of the well when the setback distance is less than 100 feet, while in others the mine operator may have to conduct closed-loop surveys between the underground entry and the surface location of the well. The setback distance guidelines for wells may also vary depending upon whether a well is active or inactive.

MSHA cited mine operators 152 times for violations of 30 CFR 75.1700 between 2010 and 2020 (Table 1). Approximately 50 percent of these citations were for mining within a 150-foot-radius of an oil or gas well without an approval from MSHA. Another 15 percent were for not complying with either a 101(c) mine-through "Petition for Modification" or an approval to mine past a well. For example, several citations were issued when mine operators failed to notify miners, as required under a petition, that they would encounter a well during their shift or because miners who were not directly involved in the mining process were present when a well

[1] Pub. L. 91-173, sec. 317 (a) (1969).

was intersected. The remaining 35 percent of citations were issued because the mine operator intersected wells that they had neither located nor plugged prior to the cut-through. Seven of these cases resulted in inundations of gas, oil, or water. In one case, the water inundation knocked down a continuous mining machine operator and caused debris to strike a shuttle car operator. Two other cases cited methane concentrations in the working place ranging from 2.0 to 8.9 percent after intersecting a well. The seven inundations occurred in the Northern Appalachian, Central Appalachian, and Illinois Coal Basins.

TABLE 1.—30 CFR 75.1700 Citations between January 1, 2010, and January 1, 2020.

District	**75.1700 Citations**
Barbourville	4
Beckley	9
Lakewood	1
Madisonville	17
Morgantown	54
Mt. Pleasant	24
Norton	30
Pineville	5
Vincennes	8
Total	**152**

30 CFR Part 50 *(Notification, Investigation, Reports and Records of Accidents, Injuries, Illnesses, Employment, and Coal Production in Mines)* requires mine operators to investigate mine accidents and report them to MSHA using Form 7000–1 (Mine Accident, Injury, and Illness Report Form). The accident reports provide information that helps identify risks associated with inadvertently intersecting an abandoned well (Table 2). Technical Support reviewed accidents classified as inundations, ignitions, or explosions from 2006 to 2020 and then considered only those with narratives that included words such as “well” or “uncharted.” Of the resulting 32 accidents:

- Approximately half did not result in any injury, and the narratives do not suggest that an inundation of gas or water occurred.
- Nine resulted in gas inundations, with the narratives often specifying that the methane concentrations exceeded 1 percent after intersecting a well.
- Three resulted in water inundations.
- One involved a miner who was struck by flying debris after the continuous mining machine intersected a pressurized uncharted well, but the accident report did not indicate whether gas or water was present.

TABLE 2.—30 CFR 50 Reported Accidents Classified as Inundations, Ignitions or Explosions, and Associated with Wells between January 1, 2006, and January 1, 2020.

TYPE OF ACCIDENT	OCCURRENCES
UNDERGROUND MINING INTERSECTED WELL, *WITH METHANE INUNDATION*	9
UNDERGROUND MINING INTERSECTED WELL, *WITH WATER INUNDATION*	3
UNDERGROUND MINING INTERSECTED WELL, NO INUNDATION REPORTED	17
OTHER UNCHARTED HOLE INTERSECTED (I.E., WATER WELL OR POWER BOREHOLE)	3
TOTAL	**32**

THE PENNSYLVANIA 1957 STUDY

Historically, the primary technical document addressing interactions between gas wells and mining in the United States has been the "Pennsylvania Joint Oil and Gas Well Gas Well Pillar Study" published in 1957 (Commonwealth of Pennsylvania, 1957). This report is more commonly referred to as the "1957 Study." Many MSHA Districts and state regulators have incorporated at least some aspects of the 1957 Study into their protective pillar approval processes.

The 1957 Study was conducted by the Joint Coal and Gas Committee (Committee), which included members from both the coal and gas industries. The Committee solicited information on mining-related well failures from the oil and gas companies, and obtained valuable mining data on each failure from the associated coal companies. The data set initially consisted of 77 case histories of gas well failures. The Committee considered five of the cases "not useable;" three because they involved a gob well or mining into the well, and two because they did not have sufficient data for analysis. The definition of "failure" for the remaining wells was that it stopped producing gas because they were "sheared or pinched off." The well blockages were apparently confirmed by attempts to re-enter the well, because the location (depth in the well) of the failure is recorded in each case. The 1957 Study does not make any mention of gas inundations of the mine atmosphere associated with any of the well failures.

The mining in the case histories occurred between 1918 and 1956, before continuous miners were widely used. Nearly all southwestern Pennsylvanian mines of that era recovered pillars, with reported extraction ratios averaging 90 percent. Figure 1 is a portion of a 1930s mine map that shows three gas wells and the protective pillars left around them. The protective pillars are essentially islands surrounded by caved gob. A large majority of the 1957 case histories involved full extraction mining of this nature.

FIGURE 1.—A portion of a mine map from southwestern Pennsylvania during the hand-loading era, showing three gas well protective pillars surrounded by pillar recovery.

The 1957 Study's authors noted that they originally expected to find that the failures would have "occurred above the coal horizon, [caused] by the action of the draw" (subsidence). However, of the 54 full extraction failures for which data were available, only 10 actually occurred above the seam, compared with 24 in the seam and 20 below the seam. The Study's authors therefore concluded that "pillar failure was the cause of the damage" since the great majority of the failures occurred within or below the seam. All failures in the overburden occurred within 100 feet of the seam, while the deepest floor failure was 34 feet below the seam. Approximately half of the failures occurred during mining or within 2 years of mining. Surprisingly, nearly 40 percent of the failures occurred more than 5 years after mining (Figure 2).

The width of the protective pillar was less than 100 feet in almost all case histories. The setback distance averaged 38 feet, and only exceeded 50 feet in a couple of cases (Figure 3). Notably, there were only two cases where the depth of cover exceeded 700 feet, which is shallower than many modern underground coal mines.

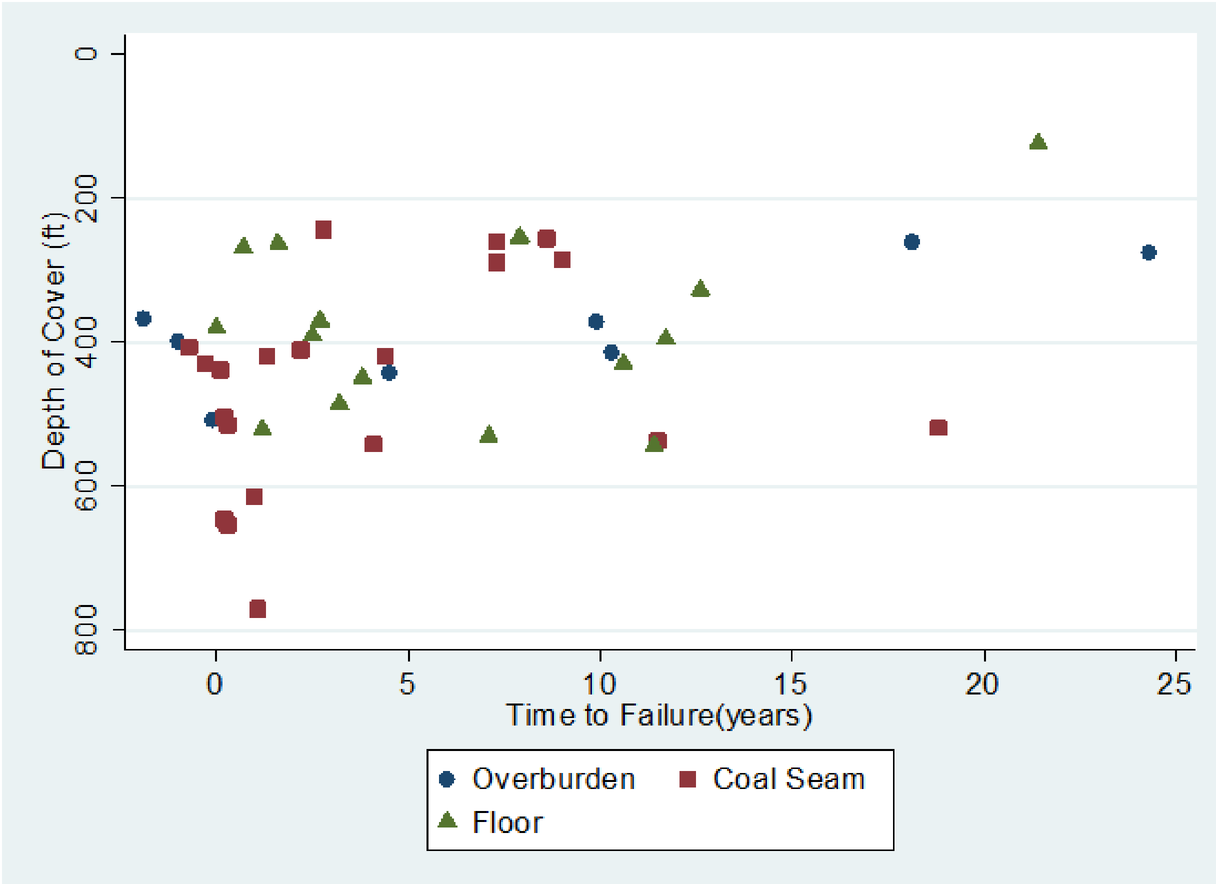

FIGURE 2.—Plot of the full extraction case histories from the 1957 Study, showing the depth of cover and the time elapsed between the end of mining and the well failure. The cases are grouped by failure location (overburden, coal seam, or floor).

The Committee drew the following key conclusions:

1. Well failures were rare when the mining radius (barrier distance) exceeded the tangent of 8 degrees (tan(8°)) multiplied by the depth of cover (Figure 3).
2. The minimum suggested setback distance from *development mining* is 50 feet (the center of a 100- by 100-foot pillar) for all cover depths in excess of 250 feet.
3. The maximum suggested barrier distance from *retreat mining* is 100 feet (the center of a 200- by 200-foot bearing area). The retreat mining barrier distance approximately follows the tangent of 8 degrees envelope (Figure 4). Multiple pillars may comprise the intact coal barrier surrounding a well.
4. Whenever the depth of cover exceeds 250 feet, the study suggests 100-foot square pillars centered on the gas well. However, it also proposed 60-foot square pillars (a setback distance of 30 feet) when the depth of cover is less than 150 feet. Notably, there is no mention of risks associated with surveying errors or well deviations. The discussion in the document implies that the 100-foot square pillar size is the largest size that mine operators could conveniently develop at the time.

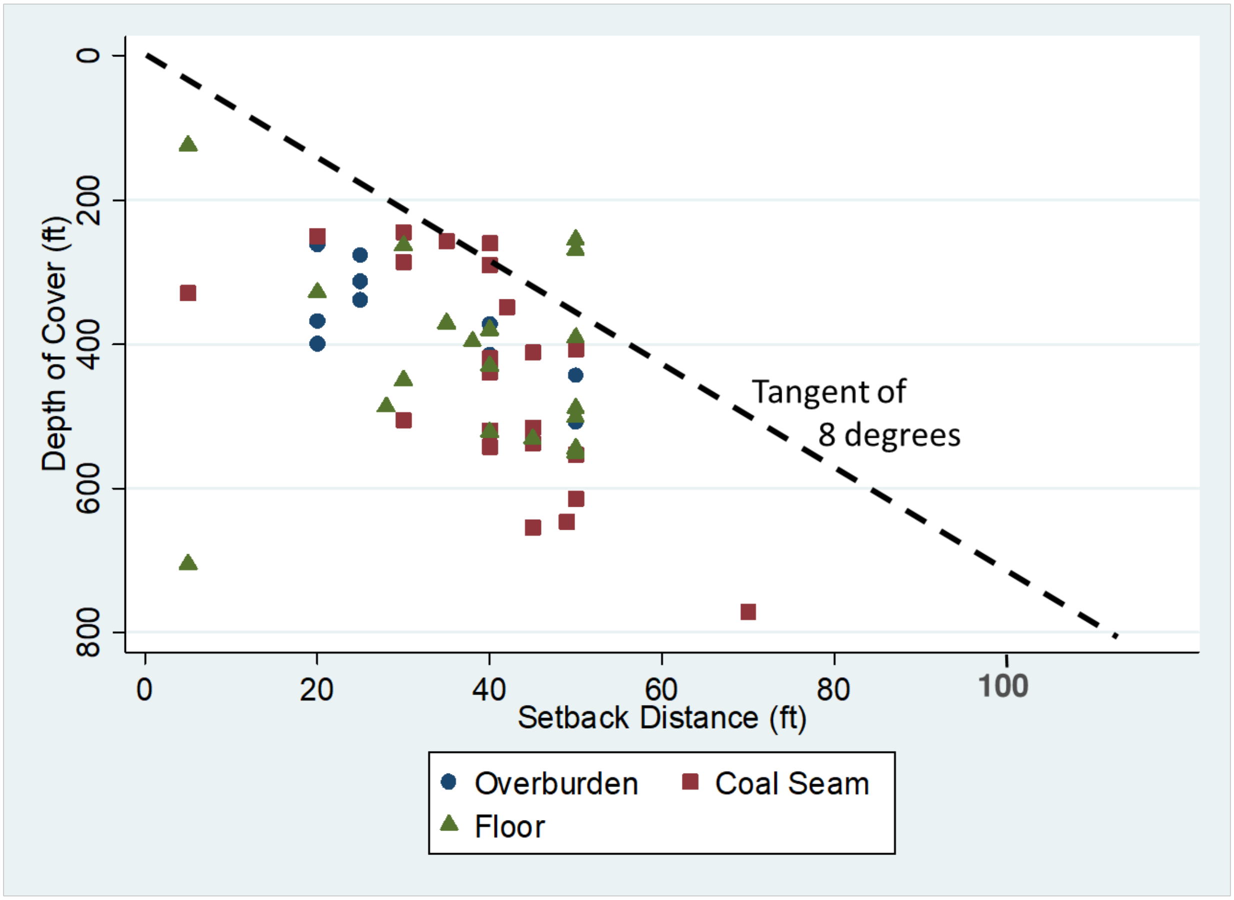

FIGURE 3.—Full extraction case histories from the 1957 Study, illustrating the tangent of 8 degrees failure envelope.

The 1957 Study serves as the basis of many oil and gas well protective pillar guidelines used throughout the United States. However, the application of the 1957 Study is by no means uniform and the guidelines generally are applied in one of four ways:

1. Under very shallow cover, approvals have been granted for setback distances that were less than 50 feet.
2. Approvals have been granted for setback distances of 50 feet, even in regions where the mining depths now are considerably greater than they were prior to 1957.
3. Guidelines for protective pillar sizes can vary between active and inactive wells. For example, active wells may require a minimum setback distance of 50 feet or tan(8°) times the depth of cover, up to a maximum of 100 feet. For inactive wells, the minimum setback distance may be reduced to 10 feet plus tan(4°) times the depth of cover, up to a maximum of 100 feet.
4. In many circumstances, the setback distances are to the "nearest mining," with no distinction made between development and retreat mining.

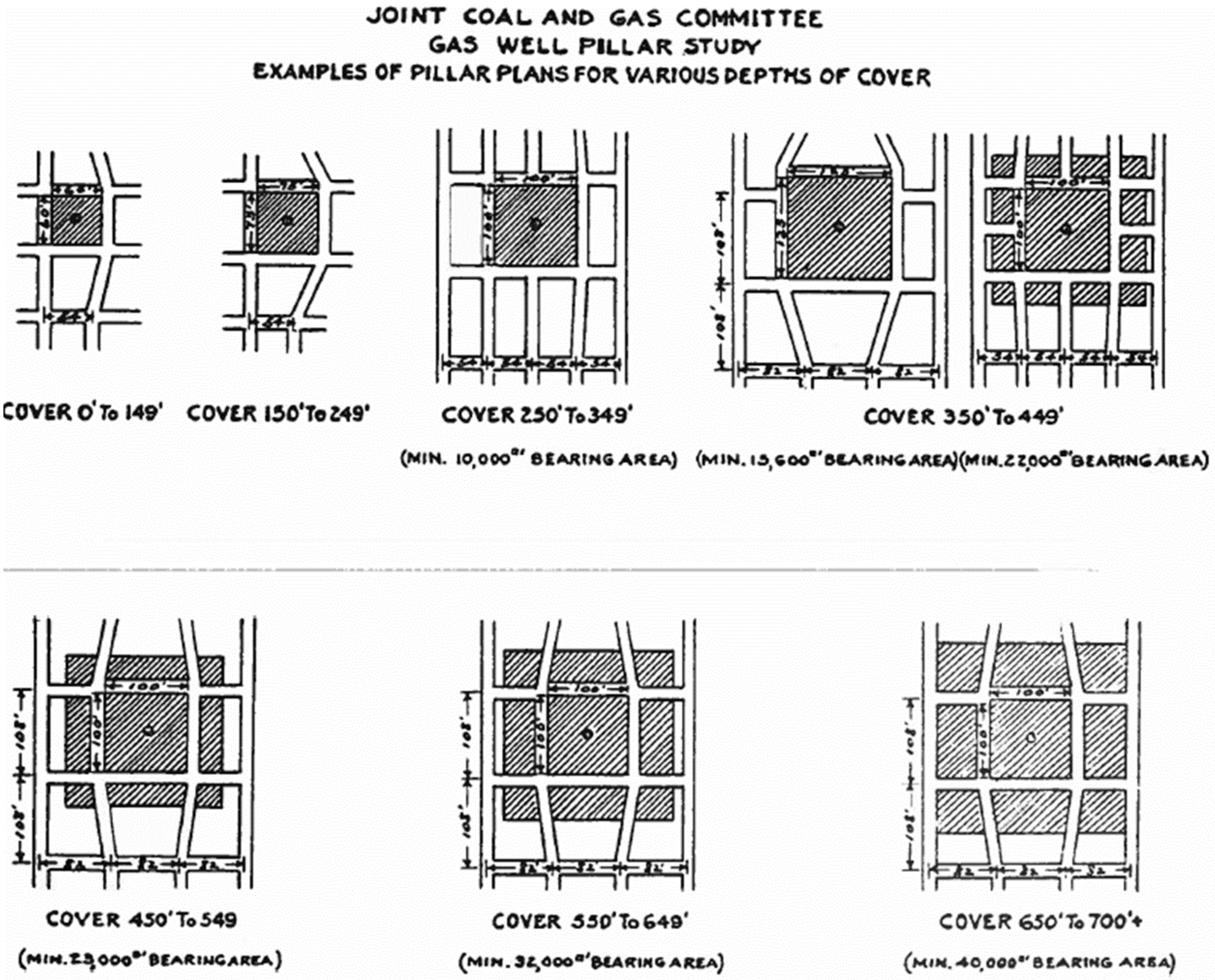

FIGURE 4.—Examples of pillar plans from the 1957 Study.

STABILITY OF OIL AND GAS WELL PROTECTIVE PILLARS

Pillar and floor stability are two design considerations determining the size of oil and gas well protective pillars. Addressing these two components mitigates risks associated with overburden movement and the associated conventional subsidence and nonconventional subsidence (bedding plane slip).

Today, engineers use methods like those in the "Analysis of Coal Pillar Stability" (ACPS) software to evaluate pillar stability (Mark and Agioutantis, 2018). ACPS provides a stability factor (SF) for the pillar system, which may consist of one or more pillars depending on the mining configuration. The developers of the methods used in the software recommend a SF of 1.5 for typical pillar systems. However, greater values may be more appropriate for long-term and high-consequence applications. For example, the Pennsylvania Interim Final Technical Guidance Document (PA TGD), titled "Guidelines for Chain Pillar Development and Longwall Mining Adjacent to Unconventional Wells," released by the Commonwealth of Pennsylvania (2017), suggests a SF of 2.0 for longwall chain pillars that are protecting unconventional gas wells.

While the stability of the pillar system is important, so is the protective pillar's potential post-failure behavior. The pillar's width-to-height ratio (w/h) is often a good predictor of the pillar's likely post-failure behavior. Slender pillars, when overloaded, can undergo large deformations that might damage well structures, whereas the strain-hardening behavior of squat pillars is more likely to limit those deformations. Unfortunately, the precise w/h beyond which pillars transition to strain hardening behavior is unknown. In laboratory studies, the transition occurs at a w/h of 8 to 10 (Das, 1986). However, geologic structure can significantly influence actual mine pillars, and their transition to strain-hardening may occur when the width-to-height ratio is greater than 12. Pillars whose w/h is greater than 20 are very likely to exhibit strain hardening behavior under load.

The ribs of a coal pillar can also deteriorate over time due to exposure to the mine atmosphere. Studies have shown that this weathering can reduce the strength of parting materials in the Pittsburgh Coal Seam, but the effects only extend about 6.5 feet into the rib after 50 years (Biswas et al., 1999). The limited depth of weathering helps explain why few apparent long-term pillar failures occur when a pillar system stability factor exceeds 2.0. Floor failures are more common under these conditions.

When mining creates coal pillars, a "yield zone" forms around the pillar's perimeter (Figure 5). Significant deformations may occur within this yield zone. The yield zone expands and the peak stress migrates towards the core as additional load is applied. Even in high-stress environments, experience has indicated that the yield zone typically extends no more than about 10 to 20 feet into a stable coal pillar. The peak stress in the coal pillar occurs just inside the edge of the yield zone. These high-stress levels and rapidly changing stress gradient may also generate significant deformations near the peak stress (Wilson, 1972; Mark and Iannacchione, 1992; Gale, 1999; Su, 2010). However, a substantial core zone subjected to relatively little deformation should exist in squat pillars within pillar systems having a SF of 2.0. The PA TGD also suggests, based on pillar mechanics considerations, that a well located at least 40 feet from the rib should be in the relatively stable central core of the pillar.

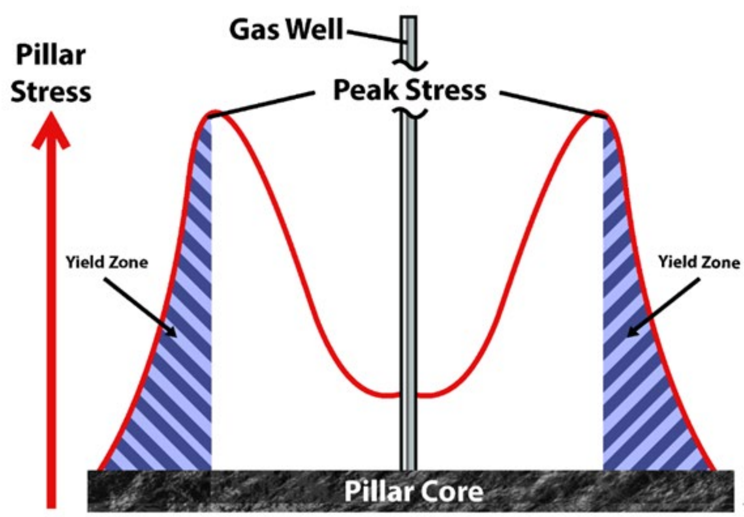

FIGURE 5.—Conceptual view of the distribution of vertical stress within a coal pillar.

Floor failure is often associated with long-term subsidence events. Groundwater infiltration into the mine can exacerbate floor failures. The floor failure risk level depends on the floor composition and material properties. The thickness of soft claystone in the immediate floor is the most significant factor (Hasenfus and Su, 2005). Floor failure is most likely to occur soon after mine waters pool and interact with the mine-floor substrate. Pillar systems with high stability factors and larger w/h inherently produce larger bearing areas for the pillars to distribute the load to the mine substrate, mitigating the risks associated with floor failure.

WELL LOCATION INACCURACIES

When the mine operator has a surveyed surface location for a well, the likelihood of unintentionally mining into it depends on the cumulative result of:

- ***Well deviation*** from the vertical between the surface and the seam.
- ***Surveying error,*** which includes errors in the surface location, errors in the underground location, and errors in matching surface and underground surveys.
- ***Mining error*** (mining development off sights).

WELL DEVIATION

Well deviation causes variation between the surface location of the well and the location where the well penetrates the coal seam. Well deviation occurs due to factors associated with drilling methods, equipment, and geology. Even when well records contain such information, it can be hard to predict their cumulative impact on the wellbore location at the coal seam elevation. MSHA Districts have obtained a large number of conventional gas and oil well deviation surveys conducted to meet the requirements of 101(c) Petitions for Modification for mining-through wells located in longwall panels. These data are from mines located primarily in Northern Appalachia, but they also include some from Central Appalachia (Appendix B: Well Deviation Database).

Figure 6 shows the deviation survey data encompasses depths of coal from 427 feet to 1,280 feet. The measured deviation ranges from 0.5 feet to a maximum of 44.3 feet. The relationship between depth and deviation is not linear. As wells penetrate deeper seams, their deviation potential increases at a higher rate. For example, the maximum deviation at a shallow cover of 600 feet is 11.9 feet, or a deviation to depth ratio of approximately 0.02. At approximately twice the depth, the maximum deviation is 44 feet, or a ratio of 0.04. Another method to evaluate the relationship between depth and well deviation is to look at the deviation values that occur within a certain envelope of mining depths (Figure 7). The deviation angle, or inverse tangent function of the deviation-to-depth ratio, can present this data in a way familiar to personnel evaluating requests to mine near gas wells. At less than 1,000 feet of depth, no wells had deviations with an angle greater than 2 degrees. At depths of cover greater than 1,000 feet, the maximum deviation angle remained below 2.5 degrees.

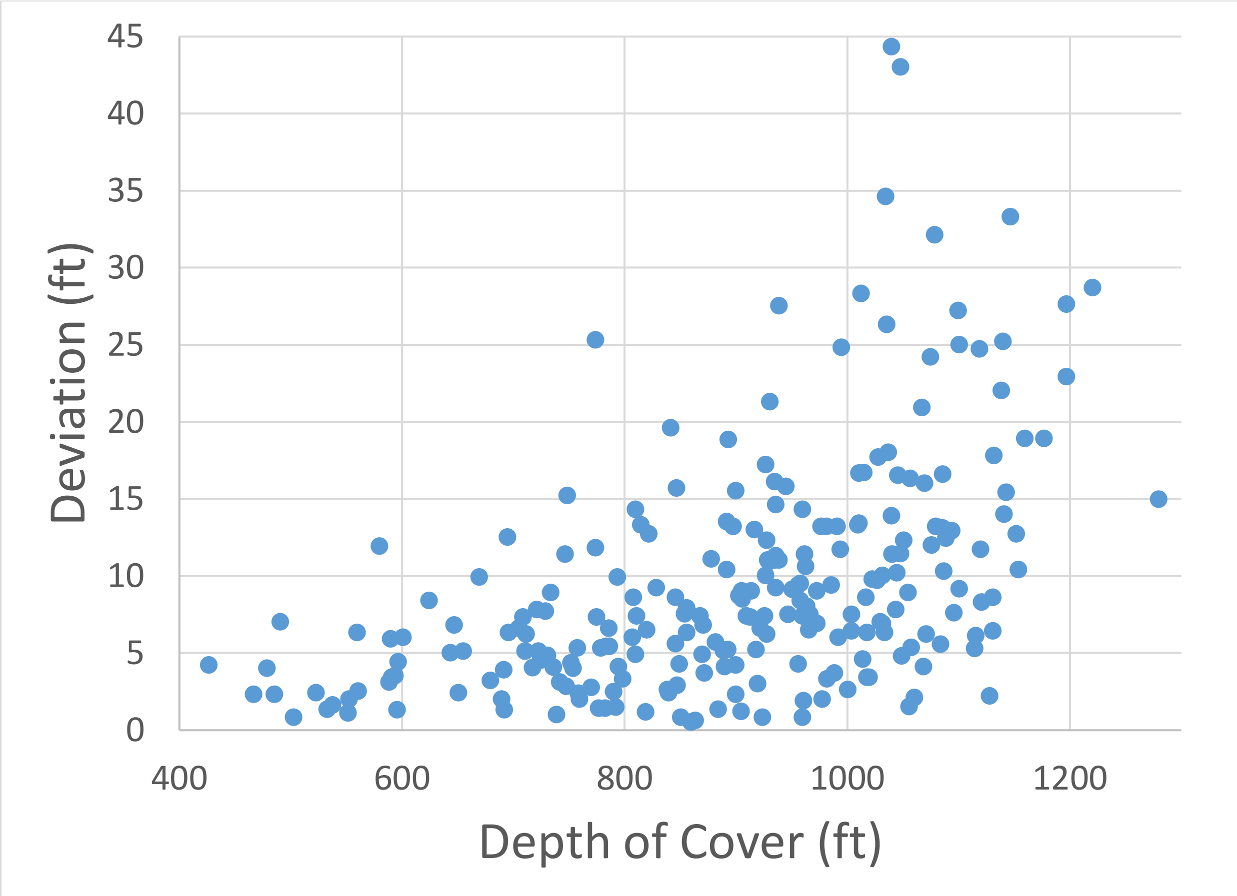

FIGURE 6.—Conventional oil and gas well deviation at coal seam level (n=244).

A well deviation survey that is conducted with a downhole gyro provides much greater certainty regarding the well location. Re-entering and examining the wellbore to conduct the survey may also help characterize the risks associated with the specific well. Recognizing the value of a deviation survey, the PA TGD reduced the minimum suggested setback distance from 50 feet to 40 feet when one is available (Commonwealth of PA, 2017).

Downhole deviation surveys do have inherent accuracy errors, however. While the greatest gyro tool errors are in the vertical direction, some errors can affect the accuracy of the location of the point where the well penetrates the horizontal plane of the coal seam. One independent source cited a gyro instrument error of 6.99 feet at 3,000 feet of depth, while a second observed 5.41 feet at 1,500 feet of depth (Olsen, 2019; Saunders, 2019). Generalizing these results gives errors of about 0.2°.

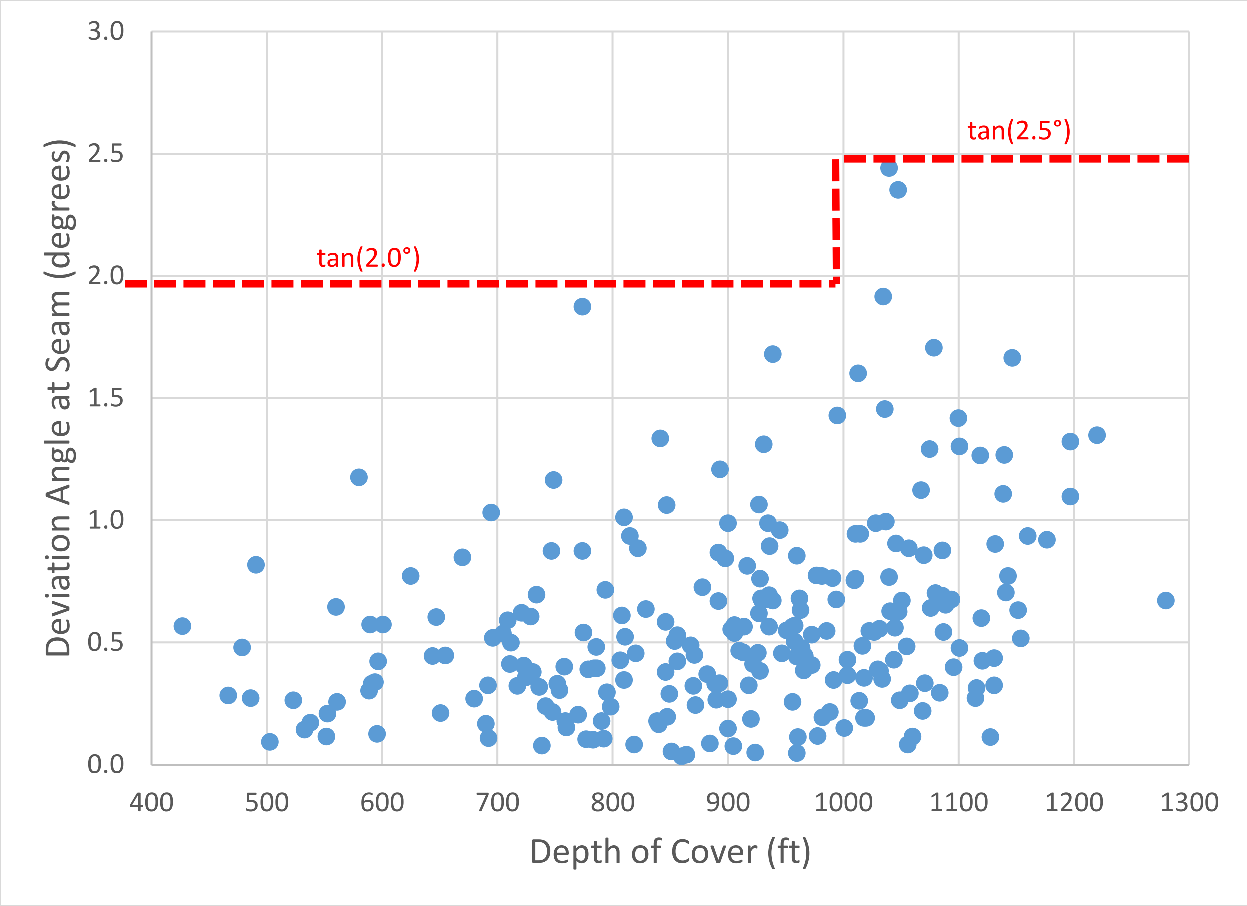

FIGURE 7.—Conventional oil and gas well deviation angles at coal seam level (n=244) with suggested error envelopes (dotted red line).

SURVEYING ERROR

The registered engineer or registered land surveyor who certifies mine maps pursuant to §§75.372(a)(1) and 75.1201 is responsible for accurately locating producing or abandoned oil and gas wells within 500 feet of underground mine workings. This process begins with an accurate survey and mapping of the wellhead on the surface, and transference of the location of the well to the underground survey. Many states have specific regulations regarding the accuracy of underground surveys. A few states require that oil and gas well protective pillar plans include the surveying accuracy on their application.

The mine operator should use a check survey (closed-loop traverse) to establish and verify accuracy as mine development advances towards a well (See Appendix C: Best Practices for Development of a Well Protective Pillar). In Pennsylvania[2], for example, the allowable closure ratio in an underground coal mine is 1:10,000. The surveyor can calculate the potential error associated with the underground mapping from the actual closure ratio. For example, one large coal operator recently evaluated the potential surveying error for wells located adjacent to their

[2] Pennsylvania Bituminous Coal Mine Safety Act, Pub. L. 654, No. 55, sec. 224 (b) (2) (2008).

gate roads. Their assessment, based on shafts up to 10,000 feet from the mouth of the gate road and gate road lengths of up 12,000 feet, found that the maximum potential surveying error is ((1/10,000)*(2)*(10,000+12,000)), or 4.4 feet (Saunders, 2019). This error is independent of the depth of cover, unlike well deviation.

MINING ERROR

The setback distance should consider errors which occur due to mining off-sights due to inadequate survey control at the face, regardless of the depth of cover. Frequently establishing sight spads and conducting check surveys mitigates risk associated with mining off-sights. However, there are cases where mining errors have resulted in entry development tens of feet from the projected orientation.

To minimize mining error, many mine operators require that sight spads be established in those entries and crosscuts nearest the well as they are being developed. To further mitigate risks associated with mining error, the mine operator should review the protective pillar safety precautions with the mining crews to emphasize the importance of maintaining the development projections (See Appendix C: Best Practices for Development of a Well Protective Pillar).

CASE STUDY

In November 2019, a longwall mine in Pennsylvania mined through a plugged well that was located within a gate road entry with a continuous miner (Figure 8). Prior to plugging, the well served as an injection and recovery well for an underground gas storage field. At the coal seam elevation, the well structure included three casings, which were 8.625”, 7”, and 5.5” in diameter. Attempts to remove the 8.625” and 7” casing from the surface were unsuccessful. The casings were cut at 29 locations and grout was squeezed into the annulus and outside of the well structure. The continuous mining machine subsequently mined-through the cut dual-casing well structure relatively easily. The continuous mining machine cut sections of the well structure into pieces ranging from 12 to 22 inches long. These pieces indicated that the well structure was fully grouted prior to the mine-through (Figure 9).

A deviation survey conducted prior to the mine-through indicated that the well deviated 13.6 feet from the surface to the coal seam elevation (Figure 8, blue). The mine operator surveyed the underground location after the mine-through occurred. The actual intersection point underground was 2.3 feet from the anticipated location (Saunders, 2019). This distance represents the total error introduced through mine surveying and the gyro instrument. For reference, the mine operator stated that their underground survey closure was within 1:30,000, and that strict precautions were in place by the mine operator to mitigate the risk of mining off-sights.

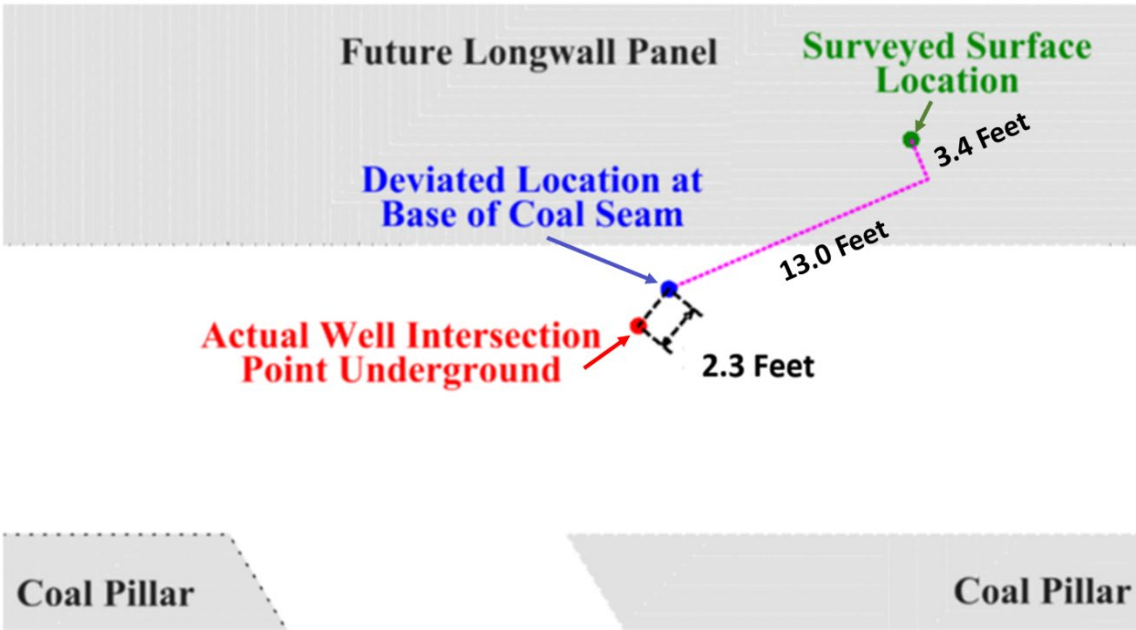

FIGURE 8.—Cut-through location (modified from Saunders, 2019).

FIGURE 9.—A portion of well structure recovered after cut-through.

SUGGESTED GUIDELINES

The purpose of the 1957 Study was to address wells that stopped producing gas because they were "sheared or pinched off." The authors of the 1957 Study concluded that the predominant cause of the observed well damage was failure of the pillars. The Study's guidelines regarding pillar size and setback distance have served for over 60 years to both maintain miner safety and to preserve the viability of simultaneous extraction of coal and gas in close proximity.

Modern coal mining often occurs at depths far greater than the cases in the 1957 Study database. The science of pillar design has also advanced considerably since 1957. Coal mine operators should consider the following factors when evaluating the stability of the protective pillar:

1. The pillar system stability factor should exceed 2.0, using programs such as the "Analysis of Coal Pillar Stability."
2. The minimum w/h for the protective pillar should exceed 12.
3. In cases where extremely soft floor is present beneath the protective pillar and may be exposed to water, its stability should be assessed to determine whether the pillar design is adequate for the site conditions.

One important provision from the 1957 Study is the 50-foot setback distance. Technical Support's evaluation of reported accidents and citations did not reveal any recent cases where a mine operator intersected a well when there was a 50-foot setback distance. Therefore, the guidelines also begin with a minimum setback distance of 50 feet when a deviation survey is not available. However, the well deviation data shown in Figures 6 and 7 reveal that wells penetrating seams at deep cover may warrant greater setback distances. The setback distance should be large enough to mitigate risks associated with the cumulative impact of the following four factors:

1. Well Deviation (WD):
    a. H*tan(2°), where H is the depth of cover. This equations applies when the depth of cover is less than 1,000 feet and no deviation survey is available.
    b. H*tan(2.5°), for depths of cover 1,000 feet and greater with no deviation survey.
    c. H*tan(0.2°) for all depths when there is a deviation survey, to account for inaccuracies in well deviation surveys. The mine operator may replace this value with a known, tool-specific error value.

2. Surveying Error (SE): Site-specific criteria based on the operator's survey methods.

3. Mining Error (ME): The establishment of safety precautions addressing mining error should mitigate most risks associated with mining error (Appendix C). If the mine operator uses such precautions, then 5 feet may serve as a reasonable approximation of this error.

4. Pillar Rib Weathering and Peak Stress Avoidance Setback (SA): The "SA" distance addresses risks associated with a well penetrating the zone of the pillar where weathering of the rib or high pillar deformations (yield zone) occur. This setback also should prevent

the well from penetrating within the region where the peak pillar stress occurs, and closer to the lower-stress, more stable core. Thirteen feet is generally an appropriate distance to prevent a well from encountering high-deformation zones of a pillar.

Two examples illustrate the use of these guidelines. The first is the case where the well's surface location is known, but no deviation survey has been conducted:

Example 1: A conventional gas well extends through a coal seam with 1,000 feet of cover. The surveying closure is within 3 feet, and safety precautions are in place to reduce the magnitude of mining errors. No deviation survey is available for the well. Therefore, the minimum setback distance SD_{MIN} is:

SD_{MIN} = 50' or (WD + SE + ME + SA), whichever is greater.
SD_{MIN} = 50' or (44' + 3' +5'+13'), whichever is greater.
SD_{MIN} = 50' or 65', whichever is greater.
SD_{MIN} = 65'

The second example illustrates the case where a downhole deviation survey is available:

Example 2: The location of a unconventional gas well at the mining horizon is known from a deviation survey. The depth of cover is 900 feet, the surveying closure is within 3 feet, and safety precautions are in place to reduce the magnitude of mining errors.

SD_{MIN} = 40' or (WD + SE + ME + SA), whichever is greater.
SD_{MIN} = 40' or (3' + 3' + 5' + 13'), whichever is greater.
SD_{MIN} = 40' or 24', whichever is greater.
SD_{MIN} = 40'

CONCLUSIONS

When a mine operator develops entries or crosscuts near a well, an appropriate setback distance serves to protect miners from risks associated with inadvertently intersecting the well. The mine operator should design the protective pillar to maintain stability and to account for setback errors inherent to surveying, mining practices, and well deviations. This review of accidents and citation records associated with wells revealed that accidents involving inundations of gas and water, and injuries to miners due to pressures within the wells, have all occurred when mines inadvertently intersected wells during mine development.

These data provide a solid technical foundation for new setback distance guidelines for development mining. These new guidelines distinguish between wells with a downhole deviation survey and those where only the surface location is known. They also provide for more conservative setback distances in deeper coal seams. The new setback distance guidelines intentionally do not differentiate between active oil and gas wells, inactive wells, abandoned wells, non-producing, or inadequately plugged wells. Abandoned wells producing from depleted gas reservoirs may recharge over time, either due to gas migration through the producing horizon or through nearby well drilling activities. In addition, while methane gas inundating a mining section from an active well presents a clear hazard to miners, flooded and abandoned wells have caused injuries by forcibly ejecting material surrounding the wellbore or inundating the mining sections with water.

These suggested setback distance guidelines do not address interactions with wells associated with retreat mining, such as pillar recovery or longwall mining, where caving-related ground deformations may affect the integrity of the wells.

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APPENDIX A: RESPONSES FROM MINE SAFETY AND HEALTH ENFORCEMENT DISTRICTS

<table>
<tr><th>District</th><th>Active Well Mine-Bys per Year</th><th>Inactive Well Mine-Bys per Year</th></tr>
<tr><td>Barbourville</td><td>20</td><td>5</td></tr>
<tr><td>Beckley</td><td>20</td><td>30</td></tr>
<tr><td>Lakewood</td><td><2</td><td><2</td></tr>
<tr><td>Madisonville</td><td colspan="2">125</td></tr>
<tr><td>Morgantown</td><td colspan="2">175</td></tr>
<tr><td>Mt. Pleasant</td><td colspan="2">200</td></tr>
<tr><td>Norton</td><td colspan="2">50</td></tr>
<tr><td>Pineville</td><td>15</td><td>3</td></tr>
<tr><td>Vincennes</td><td>30</td><td>270</td></tr>
</table>

APPENDIX B: WELL DEVIATION DATABASE

Well API No.	Well Type	Depth of Plug or Total Depth (ft.)	Seam Depth (ft.)	Deviation (ft.)	Azimuth (deg.)	Coal Seam
47-49-02263	Gas	1701	860	0.5	119.4	Pittsburgh
47-049-02273	Gas	1094	864	0.6	39.1	Pittsburgh
47-049-02355	Gas	1247	851	0.8	63.7	Pittsburgh
47-049-01866	Gas	1270	924	0.8	159.3	Pittsburgh
47-049-02277	Gas	1236	960	0.8	34.9	Pittsburgh
37-125-02191	Gas	1225	503	0.82	177.9	Pittsburgh
47-051-01016	Gas	2636	739	1	57.9	Pittsburgh
37-125-01837	Oil	2536	552	1.1	62.7	Pittsburgh
47-049-02357	Gas	1249	819	1.16	77.4	Pittsburgh
37-059-27725	Gas	1966	905	1.2	285.5	Pittsburgh
37-125-00093	Gas	1067	596	1.3	282.2	Pittsburgh
47-91-00507	Gas	5100	692.4	1.3	139.9	Pittsburgh
37-125-27383	Gas	2370	533	1.33	20.2	Pittsburgh
47-049-02371	Gas	2009	884.5	1.33	55.11	Pittsburgh
47-049-00697	Gas	2830	777	1.4	79.2	Pittsburgh
47-049-02233	Gas	1084	783	1.4	208.4	Pittsburgh
47-049-02415	Gas	1774	792.5	1.46	292.53	Pittsburgh
47-049-01581	Gas	1424	1056	1.5	335	Pittsburgh
37-125-28678	Gas	1606	538	1.6	326.5	Pittsburgh
47-051-00934	Gas	1457	961	1.9	246.1	Pittsburgh
37-125-01830	Gas	2757	553	2	137.9	Pittsburgh
37-125-28265	Gas	2788	690	2	4.6	Pittsburgh
47-049-01952	Gas	1165	760	2	318.6	Pittsburgh
47-049-01831	Gas	2269	978	2	85.8	Pittsburgh
47-049-01728	Gas	1571	1060.5	2.1	287.4	Pittsburgh
37-059-26418	Gas	1456	1128	2.2	3.9	Pittsburgh
47-005-01602	Oil	2685	467	2.3	228.8	Eagle
37-125-20763	Gas	1160	486	2.3	80	Pittsburgh
47-049-01905	Gas	1130	900	2.3	306.7	Pittsburgh
47-049-02395	Gas	1205	759	2.36	46.03	Pittsburgh
37-125-28207	Oil	2609	523	2.4	315.7	Pittsburgh
47-091-00515	Gas	2032	651	2.4	170.4	Lower Kittanning
47-049-01933	Gas	1236	840	2.4	56.4	Pittsburgh
47-49-02323	Gas	1650	790.5	2.46	209.17	Pittsburgh
37-125-01828	Gas	2727	561	2.5	258.5	Pittsburgh
47-049-01004	Gas	1520	838.7	2.6	180.6	Pittsburgh
37-059-26773	Gas	2265	1001	2.6	207.6	Pittsburgh
47-049-02470	Gas	2005	770.3	2.74	94.82	Pittsburgh

47-049-02370	Gas	2064	748	2.81	141.5	Pittsburgh
47-049-01771	Gas	1235	847.4	2.9	316.8	Pittsburgh
47-049-01867	Gas	1195	920	3	184.7	Pittsburgh
37-125-20838	Gas	2419	589	3.1	69.7	Pittsburgh
37-125-90122	Gas	2963	742	3.1	331.2	Pittsburgh
47-051-00414	Gas	1820	680	3.2	123.8	Pittsburgh
47-049-02376	Gas	1411	798.5	3.3	318.1	Pittsburgh
47-51-00982	Gas	2071	982	3.3	52.7	Pittsburgh
47-091-00636	Gas	5703	591	3.4	275.8	Lower Kittanning
47-051-00781	Gas	2350	1018	3.4	45.4	Pittsburgh
47-049-01772	Gas	1500	1020	3.4	181.9	Pittsburgh
37-125-92107	Gas	825	594	3.5	156.8	Pittsburgh
47-049-02298	Gas	1554	988.7	3.69	356.11	Pittsburgh
37-059-27726	Gas	1148	872	3.7	121.9	Pittsburgh
47-091-00517	Gas	1149	692	3.9	109.2	Lower Kittanning
37-125-01886	Gas	2670	479	4	310.9	Pittsburgh
47-049-02045	Gas	1230	754	4	14.2	Pittsburgh
47-049-02307	Gas	1788	717.6	4.02	116.7	Pittsburgh
47-049-02411	Gas	1355	736.3	4.08	46.99	Pittsburgh
47-049-01214	Gas	1208	890	4.1	129.2	Pittsburgh
47-051-00969	Gas	1926	1069	4.1	74.4	Pittsburgh
47-049-02449	Gas	1935	795	4.11	239.63	Pittsburgh
47-049-00595	Gas	3174	900	4.2	91.3	Pittsburgh
34-013-61593	Gas	652	427	4.21	293.5	Pittsburgh
47-049-02418	Gas	1480	849.4	4.28	303.47	Pittsburgh
47-049-02448	Gas	1567	956	4.28	205.01	Pittsburgh
47-049-02454	Gas	1741	752.2	4.34	133.6	Pittsburgh
37-125-91905	Gas	2649	597	4.4	214.7	Pittsburgh
47-49-02300	Gas	1188	725	4.5	270	Pittsburgh
37-059-27265	Gas	1592	1014	4.6	339.1	Pittsburgh
47-51-00916	Gas	2281	1049	4.8	113.2	Pittsburgh
47-49-02382	Gas	1120	731	4.83	2.13	Pittsburgh
47-049-00073	Gas	1236	810	4.9	351.3	Pittsburgh
47-049-01734	Gas	1394	870	4.9	156.9	Pittsburgh
47-091-00519	Gas	5184	644	5	320.9	Lower Kittanning
47-051-00415	Gas	1845	655.14	5.1	88.3	Pittsburgh
47-049-02036	Gas	964	711	5.1	272	Pittsburgh
47-051-00541	Gas	1461	723	5.1	177.8	Pittsburgh
37-059-27397	Gas	1396	889	5.14	177.66	Pittsburgh
47-051-00914	Gas	Unknown	893	5.2	242.2	Pittsburgh
47-051-00631	Gas	2800	918.4	5.2	76.5	Pittsburgh
47-049-02414	Gas	1533	1115	5.29	210.93	Pittsburgh
47-049-02383	Gas	1490	758	5.3	143.7	Pittsburgh
37-059-2733	Gas	1036	779	5.3	80.3	Pittsburgh

47-049-02417	Gas	1644	1058	5.36	320.52	Pittsburgh
47-049-01976	Gas	1261	784	5.4	226.8	Pittsburgh
47-051-00622	Gas	1860	786.6	5.4	24.4	Pittsburgh
37-059-01758	Gas	3169	1084	5.55	133.68	Pittsburgh
47-049-01958	Gas	1098	846	5.6	226.7	Pittsburgh
47-049-01747	Gas	1365	882	5.7	150.4	Pittsburgh
37-125-20770	Gas	1709	590	5.9	183.3	Pittsburgh
47-005-00174	Oil	2953	601	6	223.5	Eagle
47-051-00938	Gas	1135	807	6	171.9	Pittsburgh
37-059-27742	Gas	2496	992	6	12.1	Pittsburgh
47-049-01967	Gas	1460	1116	6.1	120.7	Pittsburgh
47-051-00413	Gas	1899	712	6.2	174.6	Pittsburgh
47-061-01681	Gas	1140	928	6.2	109.3	Pittsburgh
47-005-00872	Oil	3337	1071	6.2	26.6	Eagle
37-125-28604	Gas	1411	560	6.3	64	Pittsburgh
47-051-00646	Gas	1861	696	6.3	79.5	Pittsburgh
47-049-01196	Gas	1868	1018	6.3	103.7	Pittsburgh
47-049-01829	Gas	2191	1034	6.3	122	Pittsburgh
47-049-02297	Gas	1142	856.2	6.31	167.92	Pittsburgh
47-051-00968	Gas	1995	1004	6.4	296.6	Pittsburgh
37-059-26936	Gas	2331	1131	6.4	68.4	Pittsburgh
37-059-27299	Gas	1685	966	6.48	28.26	Pittsburgh
37-059-02273	Gas	2072	820	6.5	47.2	Pittsburgh
47-091-00810	Gas	5187	705	6.6	53	Pittsburgh
47-049-01957	Gas	1127	786	6.6	314.2	Pittsburgh
47-049-01735	Gas	2128	922	6.6	201.4	Pittsburgh
37-125-28150	Gas	1575	647	6.8	55.3	Pittsburgh
37-059-27727	Gas	1900	871	6.8	77.1	Pittsburgh
47-51-01032	Gas	1972	973	6.9	240.3	Pittsburgh
47-051-00992	Gas	2156	1032	6.9	359.2	Pittsburgh
47-51-00593	Gas	1866	491	7	252.4	Pittsburgh
47-049-01828	Gas	1530	1030	7	248.3	Pittsburgh
47-051-00392	Gas	1889	709	7.3	70.8	Pittsburgh
47-049-01956	Gas	1281	775	7.3	268.5	Pittsburgh
47-049-02255	Gas	1414	913	7.3	129.4	Pittsburgh
47-051-00192	Gas	1962	811	7.4	98.8	Pittsburgh
47-049-01906	Gas	1294	868	7.4	173.7	Pittsburgh
47-49-02295	Gas	1156	910	7.4	162.1	Pittsburgh
47-51-00935	Gas	1021	926	7.4	191	Pittsburgh
47-049-01936	Gas	1335	960	7.4	248.8	Pittsburgh
37-059-27752	Gas	2107	947	7.5	55.6	Pittsburgh
37-059-26850	Gas	1596	967	7.5	294.2	Pittsburgh
37-059-27242	Gas	2075	1004	7.5	78.3	Pittsburgh
47-049-02358	Gas	1973	854	7.51	133.17	Pittsburgh

37-059-27363	Gas	2195	1096	7.6	41.3	Pittsburgh
37-059-27734	Gas	1250	729	7.7	333.2	Pittsburgh
47-051-00344	Gas	1941	721.3	7.8	113.6	Pittsburgh
47-049-01961	Gas	1515	1044	7.8	265.9	Pittsburgh
47-49-02293	Gas	1230	856.1	7.9	118.6	Pittsburgh
47-051-00957	Gas	1313	964	8	117.6	Pittsburgh
37-059-27678	Gas	3240	1121	8.3	113.9	Pittsburgh
47-051-00470	Gas	1747	624.92	8.4	115.2	Pittsburgh
47-051-00959	Gas	1502	958	8.4	142.6	Pittsburgh
47-049-01903	Gas	1300	906	8.5	129.5	Pittsburgh
47-051-01598	Gas	1355	808	8.6	216.1	Pittsburgh
47-049-01023	Gas	1585	846.2	8.6	353.3	Pittsburgh
47-51-00978	Gas	1856	1017	8.6	195.3	Pittsburgh
37-059-27364	Gas	1951	1131	8.6	75.2	Pittsburgh
37-059-27398	Gas		903	8.7	322.3	Pittsburgh
47-005-00105	Oil	2968	734	8.9	175.4	Eagle
37-059-27396	Gas	2237	1055	8.9	99.8	Pittsburgh
47-049-02297	Gas	1762	905.6	9	87.2	Pittsburgh
47-049-00078	Gas	1788	914	9	65.8	Pittsburgh
37-059-26774	Gas	1564	973	9	47.4	Pittsburgh
37-059-01759	Gas	3009	951	9.1	331.2	Pittsburgh
37-059-26665	Gas	1746	1101	9.16	29.22	Pittsburgh
47-051-00937	Gas	1064	829	9.2	99.4	Pittsburgh
47-049-01937	Gas	1255	936	9.2	180.3	Pittsburgh
47-049-01932	Gas	1610	956.4	9.4	144.7	Pittsburgh
47-049-01964	Gas	1468	986	9.4	90.5	Pittsburgh
47-049-02069	Gas	2743	958	9.5	245.62	Pittsburgh
37-059-27693	Gas	1411	1027	9.7	85.2	Pittsburgh
47-049-02286	Gas	2120	1022.7	9.76	185.3	Pittsburgh
47-051-00476	Gas	1819	669.9	9.9	41.3	Pittsburgh
47-049-00153	Gas	1379	794	9.9	308.3	Pittsburgh
37-059-01827	Gas	2847	927	10	272.3	Pittsburgh
47-049-01807	Gas	1297	1031.7	10	235.3	Pittsburgh
37-059-27215	Gas	1245	1045	10.2	243.6	Pittsburgh
37-059-27346	Gas	2512	1087	10.3	34.9	Pittsburgh
47-049-01955	Gas	1158	892	10.4	249.5	Pittsburgh
37-059-27421	Gas	2098	1154	10.4	252	Pittsburgh
37-059-27695	Gas	1238	963	10.6	275.7	Pittsburgh
47-051-00919	Gas		930	10.9	244.7	Pittsburgh
37-059-27741	Gas	2800	929	11	90	Pittsburgh
47-51-00630	Gas	1158	935	11	264.8	Pittsburgh
47-051-00411	Gas	2066	939	11	164.4	Pittsburgh
47-049-01904	Gas	1258	878	11.1	171.3	Pittsburgh
37-059-27068	Gas	2018	936	11.3	320	Pittsburgh

47-049-02113	Gas	1197	747	11.4	25.6	Pittsburgh
37-059-27420	Gas	1987	962	11.4	29.4	Pittsburgh
47-051-00619	Gas	2400	1040.7	11.4	75.3	Pittsburgh
47-049-02455	Gas	1924	1048.3	11.44	262.01	Pittsburgh
47-051-00933	Gas	1355	994	11.7	20.5	Pittsburgh
37-059-27679	Gas	2300	1120	11.7	46.9	Pittsburgh
47-091-0462	Gas	5560	774	11.8	284.5	Lower Kittanning
47-049-01902	Gas	1410	580	11.9	240.2	Pittsburgh
47-005-02139	Oil	3390	1076	12	173.9	Eagle
47-049-02218	Gas	2524	928	12.3	274	Pittsburgh
47-051-00981	Gas	2239	1051	12.3	313.8	Pittsburgh
47-049-01992	Gas	2290	1089	12.43	167.3	Pittsburgh
47-051-00549	Gas	1600	695	12.5	323.6	Pittsburgh
47-049-00811	Gas	2997	822	12.7	97.4	Pittsburgh
47-049-01830	Gas	1619	1152	12.7	65.4	Pittsburgh
47-051-01000	Gas	2120	1094	12.9	9.2	Pittsburgh
47-049-02045	Gas	1965	917	13	130	Pittsburgh
37-059-26608	Gas	2482	1086	13.1	52.4	Pittsburgh
47-051-00945	Gas		898	13.2	314.2	Pittsburgh
47-051-00980	Gas	2138	977	13.2	273.5	Pittsburgh
47-049-02088	Gas	1468	981.5	13.2	67.6	Pittsburgh
47-51-00637	Gas	1216	991	13.2	92.4	Pittsburgh
37-059-27473	Gas	1326	1080	13.2	234	Pittsburgh
47-051-00450	Gas	1906	815	13.3	178.9	Pittsburgh
47-049-02072	Gas	1349	1010	13.3	177.6	Pittsburgh
47-049-02086	Gas	2551	1011	13.4	112.5	Pittsburgh
47-049-01987	Gas	1187	892	13.5	244.1	Pittsburgh
47-049-011729	Gas	1501	1040	13.9	240.2	Pittsburgh
37-059-21212	Gas	3134	1141	14	209.1	Pittsburgh
47-061-01721	Gas	1011	810	14.3	248.3	Pittsburgh
47-049-01926	Gas	2090	960	14.3	180.4	Pittsburgh
47-051-00633	Gas	2830	936.2	14.6	145.4	Pittsburgh
47-103-03013	Gas	1903	1280.1	14.97	208.1	Pittsburgh
47-051-00197	Gas	1280	749	15.2	237.2	Pittsburgh
47-51-00599	Gas	2188	1143.17	15.4	92.4	Pittsburgh
47-049-02039	Gas	1403	900	15.5	27.2	Pittsburgh
47-051-00426	Gas	1072	847	15.7	181.3	Pittsburgh
47-049-02349	Gas	1815	945	15.8	277.6	Pittsburgh
47-051-00628	Gas	3027	1070	16	44.7	Pittsburgh
47-051-00974	Gas	1194	935	16.1	29.4	Pittsburgh
47-103-03178	Gas	1662	1056.83	16.3	271.3	Pittsburgh
47-51-00944	Gas	1509	1046	16.5	277.4	Pittsburgh
37-059-01801	Gas	3136	1086	16.6	131.9	Pittsburgh

37-059-01472	Gas	3066	1011	16.64	60.2	Pittsburgh
47-051-01011	Gas	2272	1015	16.7	206.1	Pittsburgh
47-51-00953	Gas	1280	927	17.2	175.5	Pittsburgh
47-51-00918	Gas	1640	1028.22	17.7	192.2	Pittsburgh
37-059-26288	Gas	2323	1132	17.8	54.6	Pittsburgh
47-51-00617	Gas	2115	1037	18	133.9	Pittsburgh
47-049-02431	Gas	1987	893.5	18.82	231.86	Pittsburgh
47-051-00920	Gas		1160	18.9	165	Pittsburgh
37-059-27694	Gas	2027	1177	18.9	264	Pittsburgh
37-125-01087	Gas		841.7	19.6	73.1	Pittsburgh
47-051-00973	Gas	2143	1067.6	20.9	199.8	Pittsburgh
37-059-02207	Gas	1752	931	21.3	167.9	Pittsburgh
47-051-00966	Gas	1453	1139	22	253.5	Pittsburgh
47-51-00984	Gas	1665	1197	22.9	176.4	Pittsburgh
37-059-27675	Gas	2382	1075	24.2	213.1	Pittsburgh
37-059-01657	Gas	3360	1119	24.7	353	Pittsburgh
47-051-00939	Gas	1520	995	24.8	163	Pittsburgh
47-051-00960	Gas	1538	1101	25	229.9	Pittsburgh
47-051-00956	Gas	1862	1140	25.2	325	Pittsburgh
47-049-01887	Gas	1070	774	25.3	92.6	Pittsburgh
47-051-00958	Gas	1813	1036	26.3	283.4	Pittsburgh
47-051-00961	Gas	1401	1100	27.2	235.9	Pittsburgh
47-051-00613	Gas	2907	939	27.5	101.3	Pittsburgh
47-51-0093	Gas	1871	1197	27.6	43.4	Pittsburgh
37-059-27036	Gas	1977	1013	28.3	85.2	Pittsburgh
47-103-03179	Gas	1630	1220.5	28.7	269.7	Pittsburgh
37-059-01575	Gas	3143	1079	32.1	46.1	Pittsburgh
37-059-26287	Gas	2645	1147	33.3	221.9	Pittsburgh
47-051-00979	Gas	1648	1035	34.6	53.7	Pittsburgh
37-059-01089	Gas	2257	1048	43	90.4	Pittsburgh
47-051-00612	Gas	2298	1040	44.3	95.8	Pittsburgh

APPENDIX C: BEST PRACTICES FOR DEVELOPMENT OF A GAS WELL PROTECTIVE PILLAR

1. Prior to development, a "special precaution zone" should be defined around the gas or oil well as shown in Figure C1. When mining occurs within the precaution zone, miners should test for methane with a hand-held methane detector and a probe at least every 10 minutes. The precaution zone should also be free from accumulations of coal dust and coal spillage, and the mine operator should place rock dust on the roof, rib, and floor to within 20 feet of the face.

2. Firefighting equipment, including fire extinguishers, rock dust, and enough fire hose to reach the working face from the nearest fire tap should be available near the precaution zone while mining is conducted there.

3. Sufficient supplies of roof support and ventilation materials should be available near the precaution zone while mining is conducted there.

4. The mine operator should check the permissibility of and service equipment, including the section fan, on the shift prior to when mining begins in the precaution zone.

5. The mine operator should calibrate the methane monitor on the continuous mining machine on the shift prior to when mining begins in the precaution zone. The mine operator may check the calibration during the first half of the shift if they anticipate mining into the precaution zone during the second half of the shift.

6. The mine operator should advance check survey stations to within at least 300 feet of the precaution zone prior to development near the gas well.

7. The mine operator should install sight spads at the last open crosscut prior to development adjacent to the gas well. The mine operator should also use sight spads to establish crosscuts forming the protective pillar. Laser or additional sights should establish that the sight line for the entry or crosscut that they are mining is not more than 50 feet from the projected well location.

8. The mine operator should review safety precautions and a drawing of the area with all personnel involved in the mining operation near the well. They should do this prior to approaching the well and throughout all shifts while they are developing the protective gas well pillar.

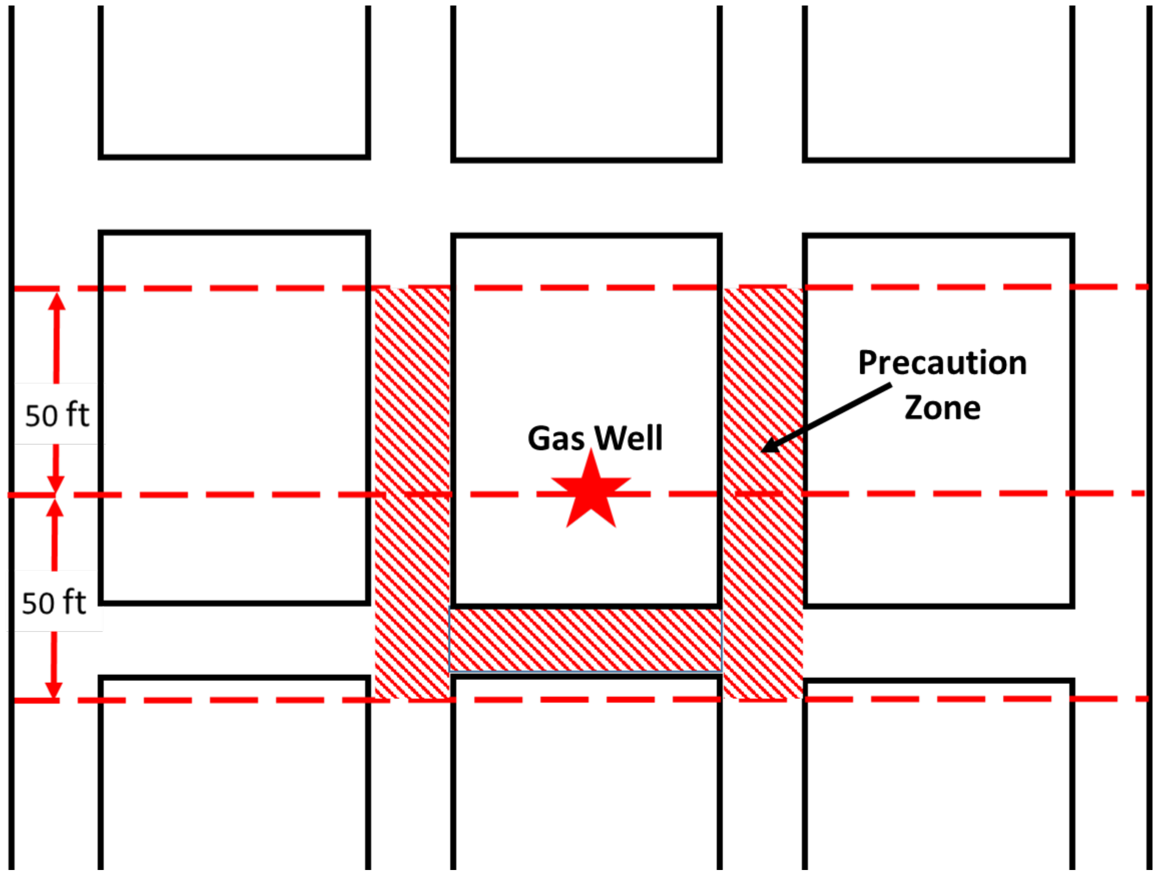

Figure C1. Special precaution zone around an oil or gas well.